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PROCEEDINGS OF THE INFORMAL MEETING
ON FILM-LESS SPARK CHAMBER TECHNIQUES
AND ASSOCIATED COMPUTER USE

Edited by
G.R. Macleod
B. Maglić

GENEVA
1964
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A few explanatory remarks are necessary about the preparation of these proceedings. The contributions have been copied from the typescripts as provided by the authors during the meetings. The texts of the discussions were taken verbatim from the tape recordings of the sessions, and some editing done in the interest of clarity. Where speakers submitted a written contribution to the discussion, this was used in preference to the verbatim text. In most cases the Scientific Secretaries checked the complete text of the discussion of each session with the contributors before the end of the meeting.

We consider it of the utmost importance that the proceedings be published as soon as possible after the meeting. Consequently we have not sent proofs either of papers or discussions to contributors, and any typographical errors or omissions in the final text of these proceedings are our responsibility.

We would like to thank the Scientific Secretaries for their work in compiling the text of the sessions and in checking the stencils and figures.

We are indebted to Mrs. G. Andréossi, who has been responsible for all the secretarial work associated with the proceedings; to Mrs. M. Nagy for typing the stencils, to Mrs. O. Marais for assistance with the drawings, to Mr. E. Bissi for the recordings of the sessions and to the Document Reproduction Services of CERN for the reproduction of the proceedings.

As organizers of the conference we would like to add our thanks to those expressed by Professor Roberts in his closing remarks; in particular we are very grateful to Miss E.W.D. Steel and Miss Y. Henry of the Scientific Conference Secretariat for all their preparatory work and the arrangements they made which assured the smooth running of the conference itself.

G.R. Macleod and B. Maglić
0. MORNING SESSION

OPERATING SYSTEMS OF DETECTORS WITH ON-LINE COMPUTERS

Chairman: A.E. Taylor,
Rutherford Laboratory

Secretaries: P. Blackall, CERN
D. Wiskott, CERN
INTRODUCTION

P. PREISWURK
CERN, Geneva

We are happy at CERN that the response to the invitation to this meeting on Film-less Spark Chamber Techniques and associated Computer Use has been so spontaneous and encouraging and we thank you for your coming.

This informal meeting has been organized jointly by the Data Handling Division and the Nuclear Physics Division of CERN. The initiators, Dr. Macleod and Dr. Naglić, originally planned this meeting as a small colloquium for 20 persons with the object to learn what others are doing in this field and to arrive at an orientation in which direction CERN should proceed. As these wishes coincided with similar wishes of others, the result has been that there are now more than 200 physicists assembled in this room to-day and that many laboratories are represented.

The seeds of ideas on film-less spark chambers which have fallen in the laboratories over the last years have germed and some of these have already found an application in experiments. The high density of human beings present in this room might, through the exchange of ideas and experiments, originate an acceleration of this development and may be an indication that the physicists will one day fully exploit the potentialities contained in these new techniques. On the other hand it is obvious and natural that the already grown-up techniques as normal counter techniques, film spark chambers, and bubble chambers are in many respects still superior at present. These more conventional types are also still open for further development and will therefore continue to play an important and even dominant role in the high energy physics experiments.

From the new systems and methods, of which we will discuss the merits, we expect a higher degree of automation of the experiments. We expect that the range of questions which can be put to the nature of physics can be widened by this automation, that answers can be received faster and that we can therefore also learn faster about what we are wondering about in nature, faster than in previous times.

The fact, that with computers-on-line the physicist will receive certain answers during the running of the experiment in the experimental
halls, might give him back the pleasure of being an experimenter and not only an operator, who is able to act and to put new questions on the grounds of this information during the running of the experiment.

The high cost of the new techniques might damp the speed of the development you have initiated, but not withhold it.
ON-LINE COMPUTERS IN DATA ANALYSIS SYSTEMS
FOR HIGH-ENERGY PHYSICS EXPERIMENTS

G.R. MACLEOD
CERN, Geneva

The two techniques which we are going to discuss during this meet-
ing - spark chambers and on-line computers - first became news in high-energy
physics, in quite separate contexts, at the Berkeley Instrumentation Con-
ference in 1960\(^1\)). At that time, all the spark chambers which people were getting
excited about were exceedingly photogenic, and the on-line use of computers
in high-energy physics was foreseen specifically for the analysis of bubble
chamber data. The on-line use was envisaged in the sense that one would
build a special purpose box-of-tricks, which at that time was the Hough-Powell
flying-spot digitizer, and that this device would run on-line with the com-
puter to analyze bubble chamber film; that is to do the analysis after the
experimental run at the accelerator.

Since then a large number of experiments have been done using spark
chambers and the vast majority have used photography. The particular problems
associated with the analysis of large numbers of spark chamber pictures are
now on their way to being solved, also by the use of on-line computers. For
instance, at CERN during the last fortnight or so the Hough-Powell flying-spot
digitizer on-line with the IBM 7090 has processed completely automatically a
hundred-thousand spark chamber pictures from an elastic scattering experiment
at the rate of a thousand pictures per hour\(^3\)). The kind of programming techniques
which have been used for this automatic processing are quite valid for data
from other kinds of spark chambers in the sense that once the digitizings are
in the computer memory, then the programme does not really care whether they
came off film or from some other device. In particular, very similar program-
ming techniques to the ones used for the flying-spot digitizer here could, for
instance, be applied to vidicon systems.

At the Instrumentation Conference held at CERN in 1962\(^2\)), there
were first reports of efforts to bring spark chambers and computers together,
doing away with the intermediate stage of film. Spark chamber techniques
have been developed which digitize spark positions directly and provide these
digitizings in a form which is suitable either to be recorded on magnetic tape,
or to be fed directly to a computer. The on-line idea has also evolved; now
one envisions "building a special purpose box-of-tricks, which in this case is
counter or spark chamber equipment in an accelerator beam, and this equipment
is used on-line with the computer to analyze the recorded experimental data;
that is to do the analysis during the accelerator run.
The use of on-line computers is a fairly widely used technique now in such fields as telemetry and guidance work with missiles and satellites, advanced radar systems, the oil and chemical industries and the communications industry. Getting nearer to our own field of activity, they are also being used now in low-energy nuclear physics where they masquerade under the name of multi-parametric analysers\(^3\). As it is only comparatively recently that high-energy physics has begun to profit from the use of on-line computers in experiments, I thought it might be useful at the start of this meeting to make a few introductory remarks illustrating the main characteristics of this kind of experimentation for those of you who are not yet familiar with it.

One can distinguish four functions which an on-line computer in an high-energy physics experiment can fulfil. These are data acquisition, checking and control, sample computation and data display. All of these things are very much interlinked and, although for the purposes of this talk I will discuss them separately, in any particular experiment it will be very difficult to draw clear dividing lines between them.

By data acquisition I mean the process whereby, on receipt of a signal from the counter trigger system, the computer reads into its memory certain numbers defining the event which has caused the trigger. Typically these would be some binary numbers from scalers or from some external buffer memory. The kind of data rates which one can reach now with available small computers are typically to transfer 18 or 24 bits in parallel in a time of the order of 2 to 5 \(\mu\)sec. The technique most convenient for this is to use a so-called interrupt feature of a computer. This is a property of the computer whereby the presence of an external signal, in this case the trigger signal, causes the computer to stop doing whatever it was doing and, in a time which may typically a few tens of \(\mu\)sec, to give its entire attention to handling the data which is presented. The mode of operation might be that during the accelerator burst, the computer records information from successive events and then in the interval between accelerator bursts, or when sufficient information has been collected, this raw data is read out on to some permanent storage, such as magnetic tape. With the present data rates experimenters are speaking of and using, it is quite feasible to store the raw data as it comes from the experimental equipment. When, as will surely happen in the next few years, the volume of raw data increases, it may well be necessary to do some kind of pre-processing before storing the experimental data simply to reduce the volume of magnetic tape and so on. On the other hand, it is, I think, most important that one should make a permanent storage as early in the data analysis chain as possible, simply to give oneself an insurance against later troubles in the analysis where one may want to get back as near as possible to the original experimental data; this also to some extent protects one against failures in the equipment in the later stages of the analysis.
Under the heading of "Checking and Control" the computer can do two things. Firstly it can do simple checking on the format and internal consistency of the data. It is important in designing these experiments to make sure that the data describing the event has sufficient redundancy in it that the computer can, in fact, carry out these kind of format checks on the data as it is read in. It is then possible to have a continuous check on what is going on and the computer can signal gross errors in malfunctioning of the equipment as soon as this occurs. The other kind of checking and control which has not been, I think, sufficiently emphasized in previous discussions on this subject, is that the computer can rather easily monitor all sorts of experimental parameters such as magnet currents, counting rates, voltage levels, beam intensities and so on. Taking this automatization one stage further, if these parameters are in any case susceptible to measurement they are equally susceptible to control, and it is quite practicable to think in terms of computer programmes together with analogue-to-digital and digital-to-analogue converters on the input/output of the computer, such that the computer could, following the instructions of the experimentalist, maintain the values of certain experimental parameters, within certain preset limits. This could be done quite automatically and checked at rather frequent intervals. The computer, having this kind of information available, could also prepare automatically a rather detailed log of the experiment; the sort of things which nowadays tend to be written (or worse, not written) in note books in illegible pencil writing at three o'clock in the morning by harassed physicists, could in fact be done automatically by the computer with rather more consistency and reliability.

The sample computations which the computer may carry out are essentially concerned with analysing in a more fundamental way the data as it is recorded. Ideally one would like to analyse all the events as soon as they are recorded; restrictions on the amount of computing capacity which one can have available, the data rates involved and the sophistication of the computations one may like to make etc., all act to limit the possibilities of full computation on-line. However, one might take a sample of the events as they are recorded and, for instance, choose one in ten or one in five of the events for a rather more thorough investigation than the preliminary checking which I mentioned above. The kind of computing one would do for these samples might be geometrical calculations for instance with sonic chambers to compute the spatial coordinates of sperks, or simple kinematic calculations estimating momenta of particles, or they might be quite complicated kinematic calculations even going as far as kinematic least squares fitting. The choice in any specific case will depend very much on the computer available and the experiment one is trying to do. But this leads, I think, to one of the most important features of this kind of experimentation, which is that on the basis of these sample calculations the computer itself can act as a variable logic element in the overall detecting system of the experiment. One could, for example, run an experiment with a reduced stringency in the triggering system, thus increasing the counting rate, and then use the computer (for which one can write one or several programmes to vary the kind of selection made) to
analyse the data and make the final selection of the events one wants. The computer programme could sort out the events recorded into various classes "good" or "bad", "elastic" or "inelastic", and could classify them according to criteria such as range or scattering angle, or scattered momentum, etc. All this kind of thing can be built into an overall system which includes, via the computer and its programme, this element of variable logic in the selection.

Under the function of data display, I mean the ability of the computer to feed back information to the experimentalist. A very simple sort of display is, I suppose, an electric typewriter, which is all right for printing short messages but is rather hopeless when you want to see rapidly what is going on with a lot of data. The kind of device which is most suitable at the moment for this kind of display is the cathode ray tube whereby the computer can display not only information for a given event but also histograms etc., summarising information from whole series of classes of events which have been recorded previously. It is equally important that associated with the display device there should be means by which the experimenter can communicate back to the computer. This is conventionally done through a console with switches and buttons and lights. This is a rather laborious way and requires very often some cool thinking about which button to press next; if one presses the wrong one an awful lot of information may be lost. A much more flexible way of talking back to the computer is to use a light-pen with a cathode ray tube; this kind of display enables the physicist to communicate also through a visual technique with the computer. I think this interaction between computer and the physicist is the second really fundamental gain which experimentation using an on-line computer offers - the physicist can get at information concerning events which have been computed just a few minutes or so after the events have been recorded. One can see rather rapidly the effect of changing experimental parameters; one can make the setting up on an experiment a rather less laborious and less random affair; one can actually see that the data being recorded is the data one wants to record; and one can plan the experiment on the basis of analysed data rather than having to make intuitive guesses based on what we did last time. All this I think makes for the physicist having a much better control over what is going on and gives him the information on which to base considered decisions on changes to be made during the experiment.

For all this, of course, one has to pay something and the main load which falls on the experimentalist is that he has to spend a lot of his time doing computer programming. The sample computations can in fact be handled quite readily with some automatic language of the FORTRAN type, but unfortunately the programming concerned with the input/output, with the control operations and handling interrupt situations has to be done in the basic language of the machine. About ten years ago any self respecting nuclear physicist spent a lot of his time building his own fancy coincidence circuits,
and I think now we have reached a time where computer programming is a more or less essential skill for experimental physicists. This is not a terrible price to have to pay for what the experimental physicist can gain in recording and analysing a large amount of data during the course of the experiment. The other cost which does not worry the physicist so much is that one has to buy small computers. The kind of small computer ideally suited to this sort of work has as fast a memory as possible with perhaps 2000 to 4000 words of 18 to 24 bits, fixed point arithmetic and 1 or 2 magnetic tape units. For an outlay of something like half a million to a million Swiss Francs one has a fair choice of these machines. There is a very good selection of machines available in the United States; the European computer market is sadly lacking in this kind of computer and it would certainly help us if computer manufacturers, in planning their next products, would think about making available more of this kind of computer in Europe.

There are several kinds of development work which need doing to aid this kind of experimentation. Firstly, I think the most important thing is to be able to have some kind of cheap visual display. If one is prepared to pay two hundred thousand or three hundred thousand francs there are some very fancy cathode ray tube display consoles available and with which one can do all sorts of nice things, but they are a bit on the expensive side to be handed out to every experimental group. However, this kind of experimentation does require a means of displaying either locally or remotely from the computer, a large amount of data in visual form and a comparatively cheap means of doing this is one thing which is lacking at the moment. Naturally one wants smaller, faster computers and one wants them to cost less. So far this tendency of increased speed and reduced price has been born out and one hopes it will continue to be so. The emphasis in computer design, I think, has to go very much in the direction of very flexible input/output, multi-channel computers with buffered input/output and with rather sophisticated interrupt facilities. Another point on which I think development would be rather useful would be for computer manufacturers to produce the equivalent of the FORTRAN language to handle all these control functions and input/output operations simply, in order to ease the programming load which must necessarily fall on the experimentalist using this kind of technique.

There is a conflict between the requirements of a computer to be used on-line to do the data acquisition and the control functions, and the kind of computer one ideally would like to do the sample computations. The kind of small computer I described a few moments ago is ideal for the data acquisition and control, but for the sample computations one would like to do more general calculations, for example, least squares fits, for which floating point arithmetic and a larger memory are desirable. It would be very useful to have the more powerful order code of a machine like the IBM 7090 available. All these things tend to imply that for the sample computations one does not want a small computer but one wants a large computer. In the course of the next few years, I am sure that in high-energy physics the requests for small on-line computers will certainly grow (and this is a phenomena which has been observed already in other fields) as the advantages of this kind of
experimentation are seen. As the amount of data experimentalists want to process increases then the requests will come for more computing capacity on-line and there will be a definite pressure to make small computers become middle-size computers become big computers. Just from the economics of this game there is some limit - a laboratory working on a fixed budget cannot afford to provide a 7090 for each experimental group. The direction which we intend to go in CERN to try and resolve this problem is to have a number of small computers on the experimental floors to carry out the data acquisition and control functions and to back these up by a large central computer which must obviously have time sharing properties. This will be connected by a data-link network to the small computers on the experimental floor. The small computers when they have enough data accumulated for the sort of computations which they themselves cannot do, can then signal this to the central computer which can take the data, do the computation and send information back to the small machine after computing. We are hoping to take delivery of a CDC 6600 towards the end of this year and we are already planning to use it in this kind of way. The communications industry regards it more or less as routine work to hook sizeable chunks of electronics together over distances of thousands of miles, so I hope that we can benefit from some of their experience and that it will not prove terribly difficult to bring some kind of scheme like this into operation.

In conclusion there are two points I would like to emphasize about experimentation with on-line computers. Firstly, it is very important that the whole experimental set-up including the detection equipment, the beam equipment, the computer and its programmes should be regarded as an entire system. One can no longer afford, as has regrettably been the case in the past, for an experimental group first to set up a beam, then to set up some spark chambers, then to fill a room with half a million pictures and only then to worry what to do about them. The whole advantage of using an on-line computer implies that one must see from the very early stages of planning an experiment that the data recording and the data analysis aspects are intimately related and must be planned together. Essentially this means, in rather crude terms, that one has to do an awful lot of planning and programming before one gets near an accelerator. Secondly, I would like to disarm one criticism which I have heard made on several occasions against using on-line computers in experimental physics of this kind. The criticism is that when you use a computer you make a completely automatic experiment which is perfectly well defined from the time you start. This is about as different as it possibly could be from the real situation. In using an on-line computer as part of his experimental equipment the physicist's role of decision making during an experiment is enhanced by having the possibility to make judgements on the basis of real live information, not just on intuition. He is in a much better position to be really aware of what is going on at any given time, what has gone on, and what he should do in the future in running his experiment.
I can perhaps finish with a somewhat outrageous remark which may contain a grain of truth. I think it is clear that counter and spark chamber experiments in the last few years have been rather limited by their inadequate data handling facilities. The well known fact that all elementary particle physics in the last few years has been done in bubble chambers may not be unconnected with the fact that the bubble chamber physicists have had well developed data handling facilities. Now we should listen to the reports from four experimental groups who have been working very hard to try and change this lamentable situation. Thank you.

References


A COUNTER HODOSCOPE DIGITAL DATA AND ON-LINE COMPUTER SYSTEM USED IN HIGH-ENERGY SCATTERING EXPERIMENTS

K.J. FOLEY, S.J. LINDENBAUM, W.A. LOVE, S. OZAKI, J.J. RUSSELL
and L.C.L. YUAN
Brookhaven National Laboratory, Upton L.I.

(presented by S.J. Lindenbaum)

1. INTRODUCTION

In this paper we shall describe a counter hodoscope system with automatic data handling and on-line computer analysis with immediate feedback of analysed results to the experimenters. This system was used recently at the Brookhaven 35 GeV Alternate Gradient Synchrotron (AGS) to investigate the differential cross-sections for elastic scattering of high energy protons, antiprotons, kaons and pions from protons. Due to the new techniques employed, up to two orders of magnitude increase in data accumulation rate accompanied by a higher systematic accuracy than previously attained in this type of experiment were possible and for the first time a wide survey of the field was practical in one experimental run. Two different methods were used to select elastic events. Experiment I used a high resolution magnetic spectrometer to separate elastically scattered particles in the range of scattering angle 10 mr to 50 mr, while Experiment II used the space correlations between scattered particle and recoil proton to separate elastically scattered particles. The latter technique was used for recoil moments in the region 450 MeV/c to 1 GeV/c generally involving larger angles (up to ~150 mr) than Experiment I.

In each experiment, more than a hundred scintillation hodoscope counters were used in plane arrays with accompanying crossed (rotated 90°) arrays arranged to locate particles by their intersection so that the effective number of counters was several hundred. Trigger counters selected likely elastic events and then fast (30 ns) gates interrogated all hodoscope counters and the information on which counters were struck was transferred to a buffer memory. After 32 such events were stored, or after the AGS beam

*) Work performed under the auspices of the U.S. Atomic Energy Commission
pulse ended, the whole memory was read to the Merlin computer for immediate on-line analysis and was also recorded on magnetic tape. The computer then analysed the events and returned oscilloscope displays to the AOS, thus permitting continuous monitoring of the experiment. At the end of each run, differential cross-sections were calculated by the computer.

2. EXPERIMENTAL ARRANGEMENT

Figure 1 shows a diagram of the experimental arrangement. The measured angular divergence of the 4.5° secondary beam used was ± 1.5 mr and the measured momentum spread was approximately 1.25%. A differential Cerenkov counter using Cu$_2$ gas, placed in coincidence with the beam telescope, separated the various types of particle in the incident beam. The liquid hydrogen target was 48" long and 4" in diameter. Hodoscopes H1 and H2 measured the horizontal projection of the scattering angle. The scattered particles were then deflected by two 72" long magnets. The angle of deflection was measured with Hodoscope H3, a two dimensional hodoscope screen which thus also measured the vertical projection of the scattering angle. The trigger counters, L, in front of Hodoscope H2 made it possible to select the range of scattering angle included.

H1 was made up of 28 scintillation counters, each 1/4" wide × 4" high × 0.30" thick, while H2 was constructed from 80 counters, each 1/4" wide × 6" high × 0.30" thick. The photomultipliers used for the hodoscopes were RCA Type 6199, which had sufficient gain to produce more than 4 m.a. from the passage of a minimum ionising particle. The relatively low cost of this tube, together with its small size (1.5" diameter) and fast rise time, made it a suitable tube for our purposes. Since Hodoscopes H1 and H2 were made up of 28 and 80 counters, respectively, while the total number of inputs to the data handler was only 96, an input coding system was used to reduce the number of outputs of H1 and H2 while retaining the necessary information.

The five trigger counters, L, were all 5.5" high, which was enough to shadow the effective counter height in Hodoscope H2, and their widths were, respectively 3", 2", 5", 5" and 5" starting from the beam side. Hodoscope H3 was made up of four screens, each being a 12 × 12 hodoscope containing 24 plastic scintillators each 30" long, 2.5" wide and 0.5" thick, coupled via lucite light pipes to 6199 photomultiplier tubes. The outputs were added with cables in groups of four counters defining the same horizontal plane in order to reduce the number of signals while preserving the information, effectively forming a hodoscope of 48 × 12 counters. The above system defined the scattering angle to ± 1.3 mr relative to the mean incident beam line, and the momentum resolution was ± 1.25% (half width at half height.)
The momentum of the beam was accurately determined by centering the unscattered beam (with the hydrogen target empty) on three counters D1, D2, D3 alongside the Hodoscope H3. The momentum distribution of the incident beam at each momentum and the angular dependence of beam intensity were measured magnetically by deflecting the unscattered beam into Hodoscope H3.

2.1 Description of Arrangement of Experiment II

Figure 2 shows a drawing of the arrangement of Experiment II. The beam telescope and Čerenkov counter were identical to those described in Experiment I, but the liquid hydrogen target was 20" long and 4" in diameter. The two-dimensional Hodoscope HS detected the forward scattered particle and the Hodoscope HT (vertical counters) and the two-dimensional Hodoscope HR measured the direction of the recoil particle. The Hodoscope HO served to locate the incident particle in the directions transverse to the beam.

The Hodoscope HS was 24" wide x 12" high. The 12 vertical counters were 12" high, 2" wide and 0.5" thick, while the 12 horizontal counters were 24" long, 1" high and 0.5" thick. Since this experiment was designed to cover a fixed region of four momentum transfer, independent of incident energy, HS was mounted on a lift table which could be moved on V-grooved wheels along a rail parallel to the beam. After each move, the position of the hodoscope was measured with a surveying telescope. The Hodoscope HT was made up of 12 vertical counters, each 10" high, 2.5" wide x 0.25" thick. The Hodoscope HR comprised 96 counters, each 30" long, 2.5" wide x 0.5" thick. Pairs of counters were butted together end to end and the outputs were connected together, effectively forming 60" long counters which were used to construct a two-dimensional 60" x 60" hodoscope. The Hodoscope HO was a two dimensional counter array, each array of which contained four counters 2.5" long, 0.5" wide and 0.25" thick.

The polar scattering angle resolution varied from \( \pm 2 \) mr at 20 GeV/c incident momentum to \( \pm 5 \) mr at 7 GeV/c incident momentum and the recoil polar angle resolution was \( \pm 15 \) mr. The azimuthal angles were measured to \( \pm 10 \) mr on the recoil side and, for the scattered particle, varied from \( \pm 30 \) mr at the smallest scattering angle to \( \pm 15 \) mr at the largest.

3. FAST ELECTRONICS

A block diagram of the most important parts of the electronic set-up is shown in Figure 3. The pulses from scintillation counters S1, S2, S3 and the differential Čerenkov counter C were placed in a fast \( (\tau \sim 3 \text{ ns}) \) coincidence circuit with the anticoincidence \( A \) from the Čerenkov counter, which improves the rejection efficiency of the counter by inhibiting the
system whenever particles of lighter mass than those selected pass through the telescope. A coincidence was then made between the beam particle defined by the above logic and several trigger counters. In Experiment I signals from trigger counters, L, were added, as were the Y plane counters of Hodoscope H3, using a twelve-fold adding circuit designed for this purpose. Thus, fast (τ ~ 10 ns) three-fold coincidence was required between the beam particle, trigger counters L and Hodoscope H3. In Experiment II, the trigger signals were obtained by summing independently the outputs of Hodoscopes HT, the vertical counters of HR and the vertical counters of HS, then requiring a four-fold coincidence between these three signals and the beam particle. Upon such a signal all counters were interrogated as described in section 4.1.

Since the data handler (see section 4.3) was capable of storing only 32 events per AGS burst, in some parts of the experiment only a fraction of the available several hundred events could be accepted for analysis. An anticoincidence from the gate control circuit prevented the trigger coincidence circuit from firing more than 32 times a pulse (see section 4.2). By recording the event rate with and without this anticoincidence, the fraction of the offered events which was actually analysed was known.

The accidental rate in the beam telescope was never allowed to exceed 1.5% of the beam rate. Accidental coincidence between each hodoscope and the beam were measured to be < 0.5%.

4. DATA HANDLING SYSTEM

4.1 Gates

The data handling system is shown schematically in Figure 4. The fast (~ 30 ns full width) gates are opened by blocking oscillators triggered by a suitable pulse from a coincidence circuit (see section 3). When a signal greater than 2 mV arrives at the gate during the "gate open" time, a tunnel diode is "set". A later pulse from the gate control circuit resets the tunnel diodes, generating a signal to be fed to the input stage of the buffer memory, if a tunnel diode has been previously set.

4.2 Gate Control Circuit

An input signal to the gate control circuit from the trigger generator (i.e., coincidence circuit) indicates that an event has occurred and that the gates have been triggered. This signal switches an input flip-flop in the gate control circuit, causing an anticoincidence signal which switches off the coincidence circuit controlling the hodoscope gate generator, thus avoiding an additional triggering of the control circuit. If the data handler is not busy, the control circuit resets the gate tunnel diodes after 0.5 μsec, generating signals which are fed to the input flip-flops of the Digital Data Handler (i.e. the X-chassis, see
section 4.3), and after a further .5 μsec sends a "store" command pulse to the data handler, causing the information in the input flip-flops to be transferred to the buffer memory, and also resetting the Data Control Circuit. In order that a second event should not be sent to the data handler while it is busy storing an event, an inhibit circuit introduces a minimum 5 μsec delay between consecutive "reset and store" operations. On the other hand, an inhibit signal from the data handler itself prevents the resetting of the tunnel diodes and generation of store pulses during the "read out memory" cycle. As soon as the inhibit signal is removed, the "reset and store" cycle proceeds as normal.

4.3 Digital Data Handler

A diagram of the digital data handler is shown in Figure 5. The electronic design of this unit was by W. Higinbotham and D. Potter and the unit was originally built for us in the Instrumentation Division of BNL. The unit contains the necessary circuitry to store sequentially 32 words, each of 96 bits, in a fast (5 μsec) ferrite core memory ("write" mode) and subsequently to transfer this information to magnetic tape ("read" mode). Information from the fast gates, transmitted on the command of gate control circuit, is received via gating transistors at the 96 inputs (henceforth called the "X-chassis") setting the relevant input flip-flops. When a "store" pulse is received by the data handler, the information in the X-chassis is transferred, using a coincidence current write, to one 96 bit word of the memory and the word number is increased by one. At the end of an accelerator burst, a clock circuit signal from the AGS starts the read mode. The read mode also starts automatically if the memory is filled with 32 events. The "Y" word is read out first, its bits information being transferred to the same flip-flops used as the input register. In order to prevent spurious pulses at the input from destroying the event, the input transistors are gated off during the read mode. The output format and speed are determined by the magnetic tape recording equipment, a tape character consisting of six information bits in parallel together with sprocket and parity check bits. The first six "X" bits are transferred to drivers which record them on magnetic tape, and also to drivers which transmit them on-line to the Merlin computer as described in the next section. This read-out and shift process is repeated 16 times until the whole word has been read out. Then the flip-flops are reset and the next "Y" word is transferred to the output register. This process is repeated until all information is transferred from the data handler, which is then ready to receive more events. The whole read-out process takes approximately one second.

All the electronics described in sections 4 and 5 were located in a data trailer on the AGS floor, an interior view of which is shown in Figure 6.
5. **ON-LINE COMPUTER - DATA TRANSMISSION**

In order to allow on-line data transmission to the Merlin computer*) the output of the Digital Data Handler was modified to include, in parallel with the magnetic tape drivers, an additional set of drivers which sent pulses to the Merlin computer (located about one mile away) via commercially leased telephone lines. Figure 7 is a photograph showing the Merlin computer.

6. **ON-LINE COMPUTER PROGRAM AND DATA PROCESSING**

A flow chart of the computer program is shown in Figure 8.

The sequence commences in the lower left-hand corner with the computer operator typing in information received from the experimenters at the AGS. The computer calculates the necessary kinematic quantities, clears out the resultant storage locations and transfers to the display loop. As an event arrives over the telephone lines, it is assembled into two Merlin words by a 48 bit shift register. The two words are transferred to two rapid access 48 bit registers on the computer console. Then the computer is interrupted (trapped), i.e. the instruction in process is completed and then control is transferred to the instruction stored at location 0000 (the asterisk on the flow chart), where the routine for processing the event commences. The counters which were struck (corresponding to "1" in the data) are identified and counted. The run identification number is compared to a number stored in the computer and a warning light is lit if these numbers are not identical. Then the "multiplicity" of the event is determined, i.e. the number of counters in each screen of each hodoscope which sent a signal. If one and only one bit appears in each screen, the event is classified as "single" and further analysis ensues. Otherwise, a "fault" is counted and this analysis bypassed. The distribution of the single events among the various counters (the profile) is constructed to enable the experimenter to check for uniformity of counter response in the hodoscopes. Then the single event is reconstructed in space (the computer has previously been supplied the dimensions and locations of all the hodoscopes) and the "elasticity" determined.

*) A 8,192 word of 48 bit length computer constructed several years ago by the Brookhaven Instrumentation Division, the computer is similar to the Los Alamos Maniac II, and has about 1/7 the speed of the IBM 7090.
In Experiment I the events were grouped in ten bins of roughly
5 mr angular width and the cross-sections were normalized by dividing
the number of counter combinations which correspond to each bin. In Ex-
periment II, the 12 bins were determined by the vertical counter struck
in Hodoscope HS. This gave bins which overlapped in scattering angle
somewhat but took advantage of the solid angle being well determined by
the area of each HS counter.

Spectra (10 for Experiment I, 12 for Experiment II) of the number
of events versus elasticity were made up and stored in memory. At this
point, control returned to the display loop. During the read out of data,
this served merely to use the few milliseconds remaining (of the thirty
milliseconds between events) before the arrival of the next event and the
next trap to the processing routine. After the data handler was empty,
however, there were 0.5 to 2 seconds available for display of the results
before the next AGS burst and the next trap during which the experimenter
at the AGS could watch the events accumulate and the elastic peak grow
on a pulse-by-pulse basis. For Experiment II, the spectra for both the copla-
nar and non-coplanar events were displayed, a peak at the kinematically
expected location always being found in the former and not in the latter.
Photographs of typical displays are shown in Figures 9 (a) and (b). When
sufficient data was accumulated, the experimenter turned off the scalers
and the data handler "store" pulses and pushed a button, setting a sense
light to inform the computer that the run ended. Control then passed to
the output routine which turned off the interrupt feature to prevent any
accidental data traps and asked for scaler information by typing requests
on the console typewriter. This information being typed in, the computer
calculates a normalization factor for the cross-sections. Then it prints
out the total number of pulses, events, faults, single events, processed
events and blanks on the high speed printer. The double loop in the pro-
gram indicates the search through the spectra for the peaks due to elas-
tic events. The peaks are then integrated, a background measured from
the regions on either side of the peaks is subtracted, and the cross-
sections and momentum transfer values corresponding to each peak are
calculated and printed. Finally, the profile, the parameters used, multi-
plicity distribution and all the spectra are printed. The whole output
routine takes about two minutes. The internal run identification number
is increased by one and the program returns to the start where the stored
value of the particle and momentum are typed out and the computer pauses
to allow changes to be made.

7. RESULTS

Differential elastic scattering cross-sections were calculated
as a function of the square of the four-momentum transfer, t, the usual
variable in high-energy scattering theory, and typical results are shown
in Figures 10 (a) to (c).
The ordinate factor:

\[
\left[ \frac{\sigma_{\text{tot}}(p)}{\sigma_{\text{tot}}(20)} \right]^2
\]

is inversely proportional to the value of \( \frac{d\sigma}{dt} \) predicted by the optical theorem assuming an imaginary, spin independent scattering amplitude. This factor serves to remove from \( \frac{d\sigma}{dt} \) any variation due to variations in the total cross-section. One of the most striking features of the data shown in the Figure 10 (a) is the dependence of differential cross-section on incident momentum for \( p - p \) scattering, i.e. shrinkage of the diffraction scattering with increasing energy. However, neither \( \pi^+ - p \) nor \( \pi^- - p \) scattering shows this behaviour (see Figures 10 (b) and (c)). For a more detailed discussion of the characteristics of elastic scattering, see reference 1.

8. DISCUSSION

The counter hodoscope digital data system with on-line computer technique described was run for several hundred hours at the Brookhaven AGS during our experiment and the system was capable of accumulating useful data virtually without interruption. We estimate that the data taking duty cycle of this system was well over 95%.

Several months before the AGS experiment, the original version of the equipment was de-bugged in a series of parasitic beam runs at the Brookhaven Cosmotron. Some modifications were made in the data handler, gates and other parts of the system at that time to ensure a cleanly operating highly reliable system. However, once we were set up at the Brookhaven AGS, everything worked well and the first time that we tried on-line data transmission to the Merlin computer in the Fall of 1963, meaningful results were obtained.

We found that the immediate processing of data with an on-line computer greatly reduces the test time and trouble-shooting prior to and during the experimental run. Furthermore, in those few cases where a counter or other component malfunctioned or failed during a run, we were able to detect it almost immediately, repair the fault and go back into operation in less than an hour.

The availability of large effective numbers of scintillation counters, each of small area, allowed us to cover large solid angles while maintaining high resolution. These advantages allowed one for the first time to make a reasonable survey of high-energy elastic scattering by protons of all known long lived (greater than \( 10^{-8} \) sec) strongly interesting charged particles.

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These data handling and on-line programmed computer analysis
techniques are also ideal for experiments using sonic, wire and other
digital spark or discharge chamber arrays. We are planning to apply them
soon, not only to elastic scattering but to multi-particle inelastic events.
Since our needs for computer speed and capacity, and the consequent cost,
increase with the complexity of the experiment, we are considering on-line
operation on a faster computer with a short period fractional duty cycle
so that others can use the computer in between.

We believe that the above described system and techniques will
allow us to exploit more fully the characteristics of high data taking
rate and automatic fast logic inherent in the counter and digitized spark
chamber techniques, which previously have been utilized to only a small
degree.

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Brookhaven National Laboratory for their generous and valuable cooperation
in electronic problems and operation of the Merlin computer. We also wish
to thank the members of the Brookhaven Accelerator Department for their
valuable cooperation in providing desired beam characteristics, magnetic
measurements, etc, throughout this project.

Reference

Figure captions

Fig. 1 Arrangement for Experiment I - elastic scattering identified by a counter hodoscope magnetic spectrometer.

Fig. 2 The arrangement of Experiment II which used the space correlation between scattered particle and recoil proton to identify elastically scattered particles.

Fig. 3 Fast electronics block diagram. For clarity, only the most important circuits are shown.

Fig. 4 Block diagram of the data handling system.

Fig. 5 A diagram of the Digital Data Handler.

Fig. 6 A photograph of the interior of the data trailer. The data handler is in the left foreground, the fast gates to the rear of it, and the computer driven oscilloscope at the right.

Fig. 7 A photograph of the Merlin computer.

Fig. 8 Flow chart of the on-line computer programme.

Fig. 9 a) Typical CRT display during Experiment I.

b) Typical CRT display during Experiment II. The lower curve shows the spectrum of non-coplanar events.

Fig. 10 Differential elastic scattering cross-sections as a function of the square of the four momentum transfer - t.

a) p - p scattering results of Experiment II.

b) Some of the π⁺ - p scattering results from both experiments.

c) Some of the K⁺ - p scattering results from both experiments.
Fig. 3

Fig. 4

TRIGGER FOR BLOCKING OSCILLATORS

ANTICOINCIDENCE

GATE CONTROL CIRCUIT

INHIBIT

READ MODE

INPUT-OUTPUT FLIP FLOPS

32 WORD x 96 BIT FERRITE CORE MEMORY

TELEPHONE LINES

DATA TAPE RECORDER

TELEPHONE LINES

DATA DISPLAY AT A.G.S.
A HIGH CAPACITY DIGITAL DATA HANDLING SYSTEM FOR USE WITH COUNTER
HODOSCOPIES AND DIGITIZED SPARK CHAMBERS IN ON-LINE COMPUTER AGS EXPERIMENTS*)

K.J. FOLEY, W. HIGINBOTHAM, S.J. LINDENBAUM, W.A. LOVE,
S. OZAKI, D. POTTER and L.C.L. YUAN

Brookhaven National Laboratory, Upton, L.I., N.Y.

(presented by S.J. Lindenbaum)

The previous talk described our use of a counter hodoscope system
with a digital data handler and on-line computer for AGS experiments on
elastic scattering of elementary particles at high energy. As was indicated
there, even in this first and conceptually simplest of the new breed of
counter experiments generated by this technique, the size of the digital
data handler was a severe limit on the performance of the experiment. The
96 input bits were fewer than the number of counters used; and we had to
resort to coding to reduce the number of bits required to describe an event.
Furthermore, in many cases where the incident beam rate was high, we could
have gathered more events than the 32 per pulse allowed by the depth of the
memory. This means that although with the first unit **) we were handling
more than 50,000 events/hour, we could have obtained sometimes ~ 500,000
to 1,000,000 events per hour, had we had sufficient memory capacity. As a
matter of fact, we were aware of these limitations for a considerable
period before beginning the previously described series of experiments, and
had already planned for an expanded digital data handling system. We con-
ceived a system with about two orders of magnitude greater capacity than
that just described, expanded both in depth and in number of bits per event.
Since it is considerably cheaper to expand the memory depth than it is to
expand the word length, we decided on a basic unit with 48 input bits and a
memory depth of 4096 words. The necessary expansion in inputs per event is
achieved by breaking an event too large to store in one memory word into an
ordered series of words and then stacking them in the memory in sequence
(up to 15 times) until the entire event is stored. Of course, this results
in a loss of speed, but with the short cycle time of 3.5 μsecs attained, this
is not an important limitation.

*) Work performed under the auspices of the U.S. Atomic Energy Commission

**) See preceding paper and Foley, Lindenbaum, Love, Ozaki, Russell and Yuan,
One might here raise the question — why bother with the digital data handling system at all? — why not go on-line directly to the computer input? While this certainly could be done in principle, a separate data handling system gives us several major advantages. First, it provides for a magnetic tape record of the experiment and allows the experiment to proceed independent of the condition of the direct data link or of the computer. Second, no major hardware change is necessary to change to another computer. Third, the system provides for buffering in future applications which may involve time sharing of a computer.

In the first part of this paper, we describe the new digital data handling system and in the second part its application to experiments planned shortly for the Brookhaven AGS.

The new data handling system at present consists of 200 fast gates, two of the 48 x 4096 bit memory units with associated electronics, two high speed magnetic tape transports and a direct data link to the Merlin computer. Fig. 1 shows a block diagram of the system. Figs. 2, 3 and 4 show photographs of the system in the data trailer.

I. THE FAST GATES

The scintillation hodoscope counter signals must be gated in fast coincidence with the signal identifying the event of interest in order to reduce the accidental rates to manageable levels. The fast gate circuit has a 2 ms input threshold. The gating pulse is provided by cascaded four-fold fan-out circuits driven by a discriminator whose output pulse width can be easily adjusted. Delay cables may be inserted to alter the timing of the gates (in groups of 4). The minimum available gate width is 6.5 μsec. A coincidence signal sets a tunnel diode in the gate circuit which stores the information temporarily until it can be transferred to the memory.

II. THE DATA STACKER

The Words per Event Decoder output is controlled by a front panel switch to provide for storage of up to 15 words per event in memory.

The Input Word Commutator is driven by the Words per Event Decoder and provides signals to drive the input word mixer, stepping through the successive word inputs.

The Input Word Mixer consists of 48 cards, one corresponding to each bit of a word, each containing 6 AND gates. One input of each AND gate is brought out to an input word connector, the other input of each AND circuit is enabled by the input word commutator at that time chosen to write the associated word. Tr. provides inputs for six words, the first four being used up by the fast gates (192 bits). By repeated loading of the sixth input, up to ten words can be stored through this channel which, along with the fifth word input, provides for 11-48 bit words of sonic chamber scaler information, for example.
III. THE MEMORY UNIT

The Memory is a Computer Control Corporation model TCM-30, 4096 word x 48 bit random access, coincidence current unit. Full cycle time is 6 μsec. Split cycle operation (read only, or write only) takes only 3.5 μsec, and this mode is used in this system. The memory consists of a 64 x 64 core plane for each of the 48 bits (see Fig. 5). During the write time a half write current in one x and one y wire sets the core at the intersection of these wires to the "1" state. If a "0" is to be written in the core selected, an "inhibit" wire which threads all the cores in the plane is pulsed with a half write current in the opposite sense, reducing the net current below the "1" writing level. Reading is accomplished by driving one x and one y wire with half write currents in a direction opposite to that during the write cycle. This resets to the "0" state those cores set to "1" during the write cycle, inducing a current in the corresponding sense lines. The read cycle is destructive, essentially clearing the memory to "0" as it proceeds.

The Input-Output Information Register is composed of 48 flip-flops which control the inhibit drives during writing and which during reading receive the memory information from the sense lines.

During the write cycle the output of the Input Word Mixer is transferred to the information register, setting the flip-flops to the "0" or "1" condition. During the read cycle, the output of the sense amplifiers delivers the information from the memory in parallel into this 48 bit register. The flip-flops are also wired as six 8 bit shift registers. During the read cycle the output word is shifted 8 times to provide eight 6 bit characters for transmission to tape and to the computer.

The Address Register holds a 12 bit address which determines which x and y wires are to be driven during the read and write operations. This information is provided by a 12 bit up-down scaler in the system control logic.

IV. SYSTEM CONTROL LOGIC

This control circuit switches and resets the input circuitry, controls and addresses the memory, starts and stops the magnetic tape transport, controls the writing of tape and drives the data link. It contains the Address Scaler, Special Word Input Gating, Write and Read Control, the Parity Generator and Output Driver.

The Up-Down Address Scaler is a 12 bit binary scaler which provides the information for the Address Register. The scaler is increased by one as each word is stored during the write cycle. When the memory readout is initiated by a readout command the scaler is not reset but addresses the last word written, then scales down one at a time until the entire memory is read out.
It should be noted that when a read-out command is given, before read-out is begun, two special words are written in the memory automatically. The last 12 bits of the second word contains the number of words that are stored in the memory. The remaining 84 bits may be used to record identifying information and other information such as the scaler numbers representing beam rate, etc.

**Write and Read Control** Events are sequentially written into the memory until either the memory is full or an external read-out mode command is supplied. This command usually comes from a predetermined timer signalling the end of an AGS pulse. There is also an adjustable minimum address flag which allows one to select a minimum number of words to be written in the memory before a read-out can occur, regardless of read-out command.

The system control logic automatically provides inhibit signals and disables input circuits as required when it is not ready to accept data.

V. **THE MAGNETIC TAPE TRANSPORTS**

These are Potter Model MT 120 operated at a speed of 112.5 inches per second. Packing densities available are 200, 555.5 or 800 characters per inch. Output is written in the IBM binary format, each character consisting of 6 data bits and a parity check bit. The contents of the memory is written as a single IBM "Record" end is followed by a longitudinal parity check character.

The Dual Transport Control Circuit permits one data handling system to use two magnetic tape transports alternately to avoid time losses due to tape changing. In a typical case, one transport will write experimental data until it senses a low tape situation. After that, one more block of information is written on the same tape, an end-of-file mark is written and the tape automatically rewinds.

The next block of information will be written by the second transport. A system of interlocks is provided to help avoid accidental writing over already recorded data.

VI. **PARALLEL OPERATION**

The two 48 bit word units can be connected by a tie line cable to operate as one 96 bit - 4096 word unit. During the read mode the units act as one "master" and one "slave", the master providing all control signals and driving the tape transports and data link.

VII. **EXPERIMENTS PLANNED WITH THIS SYSTEM**

1. Elastic Scattering of 11-30 GeV/c $\pi^\pm$ p, $\bar{p}$ and K $\pm$ by Protons

This is one of the first experiments planned to be done this year with the new data handling system. The experimental arrangement is given in
Fig. 6. The angular range measured will be ~1.5 mrad to ~25 mrad, corresponding to \(|t|\) ranging from 0.001 to 0.5 (GeV/c)^2 spread over 20 t bins in each measurement.

Taking full advantage of the new data system, we expect, in some high beam rate cases, to record up to 1,000,000 events/hour, of which about a quarter are expected to be elastic. The polar scattering angle measurement will be good to 0.7 mrad and the momentum of the forward scattered particle will be measured to within 0.8%.

2. **Elastic Scattering of 11-21 GeV/c \(\pi^\pm, p, \bar{p} \) and \(K^\pm\) by Protons in the \(|t|\) Range 0.7 to 3 (GeV/c)^2**

We will utilize sonic spark chambers of up to 1 metre in size with four probes per gap. These chambers will have up to three gaps per unit and will allow automatic computer measurements of the position of the tracks with a resolution estimated to be a fraction of a millimetre. The sonic time-of-flight will be measured by scaling a five Mc clock. The binary bits from the scalers will be read into our new data handling system and transmitted to the Heron computer for immediate on-line data processing. The planned arrangement of the experiment is given in Fig. 7. Two sonic spark chambers after the hydrogen target will accurately measure the direction of the forward scattered particle. Then a magnet followed by a third sonic chamber will determine its momentum to ~0.6%. Other sonic chambers will simultaneously measure the recoil \(\Theta\) angle to ~0.7 mrad, which is a gain in \(\Theta\) resolution of an order of magnitude compared to our previous work, and the recoil \(\phi\) angle will be determined to 12 mrad which is a gain over our previous \(\phi\) resolution by greater than a factor of 3. This, together with the high magnetic resolution for the forward scattered particle which was not used at all previously, should give us essentially a negligible background error out to the highest \(|t|\) measured.

The system contains hodoscope arrays behind sonic chambers to allow logic selection and also in cases where the higher resolution of the sonic chamber is not needed, the higher data rates obtained with the scintillators can be utilized.

3. **Other Experiments with this Data System**

It is obvious that other digitized chambers such as wire, etc., can be used with this system. Furthermore, multi-particle inelastic interactions can be investigated with techniques of this type. We already have planned for a series of multi-particle inelastic experiments detecting up to four final state particles. Furthermore, it turns out that inelastic scattering is studied as a by-product in our small angle scattering using a magnetic spectrometer.
Figure Captions

Fig. 1  A block diagram of the new Digital Data Handling System
Fig. 2  The Data Handling System Trailer
Fig. 3  The Data Handling System - Front View
Fig. 4  The Tape Transports - Front View
Fig. 5  Simplified Schematic of 48 Bit 4096 Magnetic Core Memory
Fig. 6  Small Angle Elastic Scattering AGS Experimental Set-up
Fig. 7  Elastic Scattering AGS Experimental Set-up using Sonic Spark Chambers and Counter Hodoscopes.
Fig. 1

Fig. 2
CORE PLANE WIRING SCHEMATIC DIAGRAM

Fig. 5

H_0'S (BEAM HODOSCOPE)
EACH 4 COUNTERS 1/4" WIDE x 1/8" HIGH
AND 4 COUNTERS 1" WIDE x 1/4" HIGH

H_2: 120 COUNTERS 1/2" WIDE x 1/2" HIGH
24 COUNTERS 1/2" HIGH X 20" WIDE

FROM BEAM COUNTERS
ELECTRONICS FOR PARTICLE IDENTIFICATION

FROM TRIGGER COUNTERS
HODOSCOPE FAST GATE TRIGGER GENERATOR

FROM HODOSCOPE COUNTERS H_0'S, H_1, AND H_2
FAST GATE 4B INPUT
FAST GATE 4B INPUT
FAST GATE 4B INPUT
FAST GATE 4B INPUT

DATA INPUT STACKER

BUFFER MEMORY
4B BITS WIDE
4096 WORDS DEEP

DATA TAPE RECORDER

DATA DISPLAY

MERLIN COMPUTER

SMALL ANGLE SCATTERING SET-UP

Fig. 6
Fig. 7
DISCUSSION

ROBERTS: Why do you need to collect $10^6$ events per hour?

LINDENBAUM: As to why we want $10^6$ events an hour recorded where possible, the answer is the following: In inelastic scattering there are a good deal of momenta in which one can record a million events of which about a quarter of a million are elastic. Now these elastic events are spread over 20 bins of 't' ranges, so in a sense we are aiming for a kind of 1% statistics in each 't' bin that we measure. This is about the most reasonable that one could do. To do much worse would limit the precision appreciably, to do better would not be very fruitful in view of systematic uncertainties. By emphasising the gathering of the data where possible at a high rate, I believe that we have been able, for the first time, to plan a broad survey or programme to cover a field which is indicated as reasonable to do at the Brookhaven AGS, for example 7-30 GeV/c incident particles over the 't' range 0 to 1-3. Now this programme certainly seems desirable, however, if we stick to the old fashioned techniques or limit ourselves to lower event rates it would take many years to do. By utilizing these new high rate techniques we can now foresee doing this programme in one year if we had a place on the floor of the machine, and we could do most of it using only a fraction of the beam parasitically. Therefore it means that we could then go on next year and do another programme. We could then perhaps spend the year after this on inelastic investigations of multi-particle final states (up to 4) and perhaps look at associated production, spins, and parities of particles. Here, although the final sought after events occur at lower rates, the higher rate handling capacity of the apparatus will allow these lower cross-section events to be selected and still obtained at a comfortable data accumulation rate. We feel that this kind of programme approach is for the first time made possible on a short time scale by techniques like this and will have a great impact on the future of this kind of counter and digitized chamber physics.

HINE: Could I ask the questions which Professor Preiswerk said I was going to ask? I expect I shall be asking them regularly of everybody. How much did it cost, how much programming effort did you have to put into this and who did it?

LINDENBAUM: The total cost of the first 4096 word data handling system unit (including indirect costs, salary overhead etc.) was several hundred thousand dollars, but I think you could do a double unit for under $200,000 and a single unit for $100,000 or less. This is not the major cost by the way. We spent more money on magnetic tapes and computing cost. The bulk of the programming was done by Bill Love, a member of our experimental group. As a check the problem was programmed for the IBM 7094 by Calkin's
Data Handling Group. We ran a tape through both programmes and the results agreed, event by event, except where the tape starts and stops. Bill Love took about 3 months to write the basic on-line programme with a further month debugging it on-line. That is a total of 4 man-months, a good deal of which involve 16 hour days.

LIPMAN: At a rate of $10^6$ events per hour, will the setting up procedure take a major portion of the experiment?

LINDENBAUM: You are asking: what percentage of the time did we actually take data on-line that ended up in a publication, and what percentage of time did we just tune up or calibrate the apparatus. That number was not larger than that of any other experiment that I have done. It was smaller surprisingly enough. I don't know the exact number but it was 10% or less. We spent 5 or 6 months over at the Cosmotron using a parasite beam to make the system do exactly what we wanted. When we transferred it to the AGS we spent a further couple of weeks on continuous tune up.

TOLLESTRUP: Would you just go over this system slightly and give the speeds for the various components in it - how wide are the gates and how long does it take to read the words?

LINDENBAUM: In the first system (32 word memory) already used in the published experiments, the gate widths were chosen to be between 20 and 30 nsec wide. They could have been squeezed down to about 5–10 nsec, but they were that wide so that we were not critical on timing. For the forward counters, the only time we were squeezed a little was on the recoil screen. We had to watch that because of the time of flight spread. The counter telescope timing was typically about 3 nsec. The cycle time was 3 μsec for an event to pass through the data handler. In other words you trigger a gate, you put an event in the fast store and you finally deposit it in memory within 5 μsec. The data handler has then finished and is ready for the next one. The new system (4096 word memory) is faster, it has a cycle time of 3.5 μsec. The readout time in the first system was limited by the fact that we used a relatively slow tape. It could read out in a second which was more than adequate. In the new system of course, we have a much more severe problem because there we have 96 input bits (the same as the old), but instead of a depth of 32 we have a depth of 4096, so in this system we need really high speed tape drives. We use a Potter MT 120 which reads out the contents of one memory in about half a second. The packing densities are 200, 555.5 and 800 bits per inch and are selectable. We are using the IBM format of 6 bits. We break the 48 bit words up into 6 bit characters and shift 8 times. We add one parity bit for each character, and we add a longitudinal parity character after the contents of the memory is written as a single IBM record. That gives a longitudinal parity check for each group. We have also other checks which can be checked automatically back at the computer.
STARK: Do you have troubles with the data transmission via the telephone lines, and do you provide any data for error correcting or detecting codes and if so to what extent?

LINDENBAUM: The telephone lines are adequate for transmitting the data but are inadequate for transmitting the 4096 word data from the new unit memory. We now have co-axial cables (50 ohm), 4000 feet long, but we also use telephone lines nevertheless as they are good for communications. For checking we have a permanent tape record here all the time that we can run through on an IBM 7094 if necessary.
CONNECTION OF A SMALL COMPUTER
TO A PHOTOPRODUCTION EXPERIMENT

R. ALVAREZ, Z. BAR-YAN, D. GARELICK, W. KERN, D. LUCKEY, L.S. OSBORNE,
and S. TAZZARI
Massachusetts Institute of Technology, Cambridge, Mass.

and R. FESSEL

(presented by R. FESSEL)

We wish to describe the projected use of a small digital computer
on-line with photoproduction experiments at the CBA. Since the function of
this computer will be to service the experiment, a discussion of the entire
system should begin with a description of the experimental apparatus.

The heart of the experiment is a large magnetic spectrometer system
which rests on a 40 foot long pivoted table for angular distribution measure-
ments (see Fig. 1). The magnetic system consists of a quadrupole doublet which
images the particles leaving a hydrogen target into a nearly parallel beam. This
parallel beam then goes through two deflecting magnets in tandem which serve
to measure the momentum of the particles. The velocity of the particles may
be measured in either one of two ways: Between the doublet and the deflec-
ting magnets, a differential gas Čerenkov counter may be inserted, or time
of flight of the particles may be measured between two of the triggering
counters.

Distributed along the trajectory of the particles are scintillation
counter hodoscopes which measure either the vertical or horizontal coordinate
of the trajectory. In particular, the vertical hodoscope in the middle of
the doublet is used to measure the azimuthal angle of the trajectory at the
target. The horizontal hodoscope between the doublet and the deflecting
magnets serves a twofold purpose: Firstly, it is used to measure the polar
angle of the particle at the target; secondly, since the beam at this hodo-
scope is parallel, this hodoscope in conjunction with the 9 (redundant)
double horizontal hodoscope behind the deflecting magnets, gives a rather
direct measure of the momentum.
On the other side of the beam is another, smaller, pivoted table. On this rests a total absorption Cerenkov counter which is used for detecting decay gamma rays from $\nu^c$ and $\bar{\nu}^c$. This Cerenkov counter is being replaced by a hodoscope of 48 lead glass blocks, each 3" x 3" x 27", arranged in a 6 x 8 array (see Fig. 2).

A photoproduction event is signalled by a triple coincidence of three trigger counters located on the large table. The general logic for processing an event is shown in Figure 3. A trigger opens the gates on the hodoscope discriminators and enables the digitizers for the total absorption counter pulse height, the time of flight pulse height, etc. The binary number of which counter in each hodoscope fired is encoded and all the bits of the event are stored in a 48 bit flip flop register (this temporary memory is currently being expanded to 96 bits).

The information in the buffer register is then sent to two places. All the bits in the buffer are punched on paper tape. Ten of the bits are used to select an address in a pulse height analyzer memory (Fig. 4). The information available during the collection of data is the contents of several scalers. The only information available to the experimenter immediately after the collection of data is the contents of the pulse height analyzer memory which is only a fraction of the total information. It is also in such a form that it can only be interpreted crudely on the spot. This method of collecting data has proven inadequate for monitoring the behaviour of the entire system during an experiment.

In view of the limitations of the present system as discussed above, it was felt that the best solution to the problem would be to connect a general purpose digital computer to the apparatus. The choice of which computer to use was governed both by price and availability. The computer chosen was a copy of the prototype of the LINCS computer (see Fig. 5). This computer was originally designed by the Digital Computer group of the MIT Lincoln Laboratory and further developed by the same group as the MIT Center Development Office for Computer Technology in the Biomedical Sciences; it will be commercially available in the near future at a price of $\$35,000 to $\$40,000. It was originally designed for use in biological experiments; however, it is sufficiently flexible that it can be adapted to the present use. The prototype is a transistorized machine with a 1024 word magnetic core memory. The word length is 12 bits and the memory access time is 10 microseconds. It has a rather large set of order codes obtained by using two words for many of the instructions (Fig. 6). The only standard input-output hardware is a keyboard, two separately addressable oscilloscope displays, and the magnetic tape system. The only really novel feature of the machine is the use of small reels of magnetic tape driven by a simple mechanical arrangement with storage on the tape in fixed length, addressable blocks. The use of a fairly rapidly accessible mass storage medium makes this a much more powerful machine than it would otherwise seem, (see Figs. 7 and 8).
Acceptance: $\frac{\Delta p}{p} = \pm 0.06$ and $3.2 \times 10^{-5}$ steradians
Resolution: $\frac{\Delta p}{p} = \pm 0.007$

CEA PHOTOPRODUCTION APPARATUS

Fig. 1

$$I = \text{Hodoscope Array}$$

$$\text{UP SUM} \rightarrow \text{GATE} \rightarrow \text{Analog to Digital Conv} \rightarrow U$$

$$\text{DOWN SUM} \rightarrow \text{GATE} \rightarrow \text{Analog to Digital Conv} \rightarrow D$$

COLUMN SUM = \sum_{i=1}^{6} \frac{1}{2} I_j = C_j$$
LEFT SUM = \frac{7}{9} C_1 + \frac{2}{9} C_2 + \frac{7}{9} C_3 + \frac{9}{9} C_4 + * * * *$$(\text{RIGHT SUM})

TOTAL \rightarrow \text{GATE} \rightarrow \text{Analog to Digital Conv} \rightarrow R$$
TOTAL \rightarrow \text{GATE} \rightarrow \text{Analog to Digital Conv} \rightarrow L$$

HORIZONTAL POSITION = \frac{R - L}{R + L}$$
VERTICAL POSITION = \frac{U - D}{U + D}$

Fig. 2
LOGIC FOR CEA PHOTOPRODUCTION EXPERIMENT

Fig. 3

Fig. 4
CENTRAL MACHINE

12-BIT BINARY, PARALLEL
1024 WORDS OF CORE STORAGE
10 µsec. CYCLE

INPUT OUTPUT

KEYBOARD
2 CRT DISPLAYS
8 MULTIPLEXED ANALOG INPUT CHANNELS
MISCELLANEOUS DIGITAL INPUTS AND OUTPUTS

INSTRUCTIONS

35 INSTRUCTIONS
SINGLE ADDRESS
16 INDEX REGISTERS
HALF WORD OPERATIONS
MULTIPLE-LENGTH PROVISIONS

MAGNETIC TAPE

2 UNITS
1024 BLOCKS PER UNIT
256 WORDS PER BLOCK
AUTOMATIC SEARCHING & BLOCK TRANSFER
20 BLOCKS PER SECOND

Fig. 5

| 2 | 10 |

| JMP | X |
| ADD | X |
| STC | X |

| 5 | 1 | 4 |

| LDA | i | β |
| ADA | i | β |

(32 possible)

LINC INSTRUCTION FORMATS

Fig. 6
DISCUSSION

BLUM: Do you control the beam elements with the computer?

FESSEL: No, we do not. We might at some future date, but it is not a completely straightforward addition. We run the system at momenta from about 0.7 GeV/c up to about 3.5 GeV/c and to get that wide a range with our system, you have to go and manually change taps, transformers etc. Consequently we have not really thought about it too hard.
PRELIMINARY RESULTS OF PHOTO-PRODUCTION EXPERIMENTS FROM 1-4 GEV

R. ALVAREZ, Z. BAR-YAM, W. KEVN, D. LUCKEY, L.S. OSBORNE and S. TAZZARI,
Massachusetts Institute of Technology, Cambridge, Massachusetts

R. FESSEL

(presented by R. Fessel)

SUMMARY

Results are presented from data collected with the system described in the previous paper with punched paper tape recording. The energy dependence of elastic $\pi^0$ photo-production was measured from 1 to 4 GeV at 90° and 60° in the centre of mass system. There is evidence for all the previously known pion-nucleon resonances. The general behaviour of the cross-sections is a monotonic decrease with increasing energy. There is some evidence for a resonant behaviour of the cross-section at a bombarding energy of 2.9 GeV. In addition, there is better evidence for a resonance at a gamma ray energy of 3.5 GeV. This system seems to show a large branching ratio for decay into a proton and an $\eta^0$. 

8446/mn
DISCUSSION

SALVINI: Your result on the $\eta$ cross-section is very interesting. The ratio of $\pi$ photo-production to $\eta$ photo-production at about 1 GeV is of the order of 10. The ratio of $\pi$ to $\eta$ reactions initiated by $\pi$'s also seems to be of the order of 5. In your case at 3.5 GeV, on the contrary, you have 10 times more $\eta$'s than $\pi$'s. This is a big increase, much more I believe, than any possible contribution of the phase space. Do you know the ratio $\frac{\sigma(\eta)}{\sigma(\pi)}$ at other energies of the $\gamma$ beam?

FESSEL: Yes, I may also add that we have looked at an experiment which has been discussed here around 2.5 GeV for $\eta$ and in fact found the ratio about a 10th, or less. So this number here is really quite remarkable, and this is a number which applies right at that mass value.

ROBERTS: It isn't clear to me that you have any evidence that these necessarily come from the same channel, couldn't it be more than one channel?

FESSEL: They go at the same mass.

ROBERTS: You can always pick a mass. Why do you assume that it has to come from a particle at a given mass?

FESSEL: This occurs at only one gamma bombarding energy.

ROBERTS: Does it always occur at the same invariant mass of the two products?

FESSEL: Yes, this is an invariant mass of the system.
SONIC SPARK CHAMBER SYSTEM WITH ON-LINE COMPUTER
FOR PRECISION MEASUREMENT OF MUON DECAY SPECTRUM

M. BARDON, J. LEE, P. NORTON, J. PEOPLES and A.M. SACHS
Columbia University, New York, N.Y.

(presented by M. Bardon)

We have been using a sonic spark chamber system in a magnetic
spectrometer for a precision determination of the momentum spectrum of
positrons in muon decay. For the accuracy we seek, we need to analyse
\sim 10^7 events, each consisting of single tracks in four single gap spark
chambers. In such an experiment with a very large number of simple events,
the use of sonic spark chambers, with the digitized information going
directly onto magnetic tape, is particularly suitable.

The experimental set-up consists of four single gap thin spark
chambers placed inside a 1-metre diameter magnet, with beam stopping target
and trigger counters. A sketch of the layout is shown in Fig. 1. The 7
kG magnetic field points out of the figure. A \pi^+ beam is incident along
the field and is stopped in the 3 mm thick target counter. The system is
triggered by a stopping \pi followed by a positron emerging as shown in the
figure, curving through the four sonic spark chambers and giving a count
in the pair of counters following chamber IV. The momentum distribution
of positrons from the \pi \rightarrow \mu + e decays is measured by this modified 180°
spectrometer. The momentum is essentially given by the separation of the
sparks along the line through chambers I and II, corrected by the cosine
of the angle at which the track crosses that line. Chamber III is used
to measure this angle, and chamber IV permits the exclusion of tracks that
may have scattered from surrounding materials, so that slits or collimators
that may degrade the spectrum are avoided.

Each spark chamber is made of two thin aluminium foils (.025 mm)
stretched on stainless steel frames, forming a single 6 mm gap. The sensitive
areas of the chambers are 15 x 15 cm for chamber I, and about 30 x 30 cm
for the others. A piezoelectric probe is mounted near each of the four
corners inside the brass frames of the spark chambers. The signals are
brought out through coaxial feed-throughs in the walls. A photograph of a
chamber, with the thin mylar windows removed, is shown in Fig. 2.

The probes are lead zirconate cylindrical shells (Clevite Corp.
No. 2020-5), 12 mm long, 3 mm outer diameter. Figure 3 shows a photograph of
a probe mounted on a coaxial cable. The inner and outer conductors are
soldered to the silver plated inner and outer surfaces of the cylindrical shell. This coaxial mounting reduced the electrical noise picked up from the spark discharges by a large factor. The brass fittings soldered at each end hold an O-ring used for shock-absorbent mount in brass brackets, as shown in Fig. 4. These are attached to the inside brass walls of the chambers through insulators. It was found necessary to take care in mounting the sonic probes and coaxial cables to prevent the occurrence of early pulses from shock waves propagating through the frames or along the cables.

The response of the probes to the shock wave produced by the spark in the gap is a pulse of several millivolts for spark energies $\sim 0.04$ J. The probe output signal is shown in Fig. 5. It has a rise time $\sim 1\mu$sec and is followed by ringing for a few milliseconds. Only the leading edge of the pulse is used to determine the distance from the spark. The pulse height is found to fall off approximately as the $3/2$ power of the distance from probe to spark.

The time intervals for the shock wave to reach the probes are digitized by scaling a 5 MC oscillator in a gate opened after a fixed delay from the spark trigger and closed by the leading edge of the sonic pulse. The counts in four-decade binary coded decimal scalers are transferred sequentially, one digit at a time, into an IBM 1401 computer. Checks and tests are carried out on-line with this computer. In actual data taking, however, the information is put on magnetic tape for later analysis in an IBM 7094. A general block diagram is shown in Fig. 6.

The "Main Pulse Generator" provides timing gate pulses, reset pulses, and a fan-out of the 5 MC oscillator clock pulses. A precision delay of 60 $\mu$sec is timed by counting 700 oscillator pulses. This provides a fixed time delay which allows electrical noise from the spark chambers to disappear. During that time a pulse is generated to reset all univibrators, scalers, etc. This circuit also forms the gate pulse, opened after the 60 $\mu$sec delay, for digitizing the transit time information. This gate remains open 2 msec if it is not closed by a sonic probe pulse.

The "Main Control Chassis" provides the logic for sequencing 4 digits from each of 32 channels. The pulses for the corresponding digits from all the channels are mixed through diode gate circuits, which are opened sequentially. Similarly, the 4 digits are then sequenced until the original 128 digits have been put onto the 4 lines needed to represent 1 digit in binary coded decimal.

The "1401 Control Chassis" contains the logic for generating the sequencing pulses, an "end of transmission" pulse, and a parity bit, and has the drivers for 5 lines to the IBM 1401. The logic is initiated by an I/O "Read Call" signal generated in the computer. Then a pulse (made from the closing of the gate in which probe time intervals were digitized) is used to start the digit sequencing and to signal the computer to read the data.
lines into the memory. After the predetermined amount of data has been read, the "end of transmission" pulse is sent to the IBM 1401 which then computes, stores, or writes tape as programmed, and then sends an I/O "Read Call" again when ready.

The circuit which accepts the signals directly from the sonic probes, and converts the time intervals to digital form is shown in Fig. 7. There are 32 input channels: that is the number of probes which this system can accept. (In the present form of the experiment, 16 are used.) The millivolt signals are amplified 1000 times in a narrow-band amplifier set for the 1 μsec rise time of the leading part of the pulse. Following the amplifier is a mixing circuit in which is set a threshold decreasing with time compensating for small amplitude of the pulses which correspond to greater distances from spark to probe and thus arrive later. In this way the timing is done always at about the same point on the rise of the sonic pulse. The number of clock pulses in the gate closed by the arrival of the sonic pulse is scaled in 4-decade Binary coded decimal scalers. The digitizer system is separated into 8 chassis containing 4 channels each. One such chassis is shown in Fig. 8.

The "Main Pulse Generator" was assembled from existing standard logic modules built and used at this laboratory. The other components were made up of transistorized printed circuit cards, designed and manufactured here also. The cost and availability of commercial 5 NC logic at the time (late 1962) made this preferable.

With the probe labelling and the coordinate system shown in Fig. 9, the time intervals measured with the sonic probes yield the spark coordinates x and y:

\[
x = \frac{v^2}{4a} \left[ (t_1 + T)^2 - (t_3 + T)^2 \right] = \frac{v^2}{4a} \left[ (t_2 + T)^2 - (t_4 + T)^2 \right]
\]

\[
y = \frac{v^2}{4b} \left[ (t_1 + T)^2 - (t_2 + T)^2 \right] = \frac{v^2}{4b} \left[ (t_3 + T)^2 - (t_4 + T)^2 \right]
\]

where

- \( t_i \) are the actual numbers recorded by the timing scalers.
- \( T = t_0 + \frac{k}{v} \)
- \( t_0 \) is the initial delay introduced, 60 μsec, as described with the "Main Pulse Generator",
\( v \) is the usual sound velocity in the gas of the chamber,

\( k \) is introduced to take into account the fact that the wave travels initially as a shock wave with a time dependent velocity. It can be defined by the equation:

\[
\text{distance} = k + vt.
\]

The quantity \( \frac{k}{v} \) is measured by:

\[
\frac{k}{v} = \frac{1}{2} \left( \frac{(t_4^2 - t_3^2) - (t_1^2 - t_2^2)}{(t_1 - t_2) - (t_4 - t_3)} \right) \approx 20 \mu\text{sec} \text{ for our sparks.}
\]

The quantities \( \frac{v^2}{4a} \) and \( \frac{v^2}{15} \) are obtained by photographic calibration: x coordinates as measured from photographs are plotted against the corresponding \( [(t_3 + T)^2 - (t_1 + T)^2] \) obtained from the computer. A straight line is fitted to the points. The slope gives \( \frac{v^2}{4a} \) directly. Similarly, photographs of the y coordinates give \( \frac{v^2}{15} \).

The system is overdetermined so that there are two sets of equations for \( x \) and for \( y \), each using only two probes at a time as given above. (The average value is used for the actual calculated coordinate.) The discrepancies between the numbers given by the two equations are used as a consistency check. It is found that under normal conditions they differ by \( \lesssim 0.1 \text{ mm} \). Abnormal inconsistencies indicate the presence of more than one spark, and are used to reject such events.

The velocity of sound in the gas varies with temperature and with gas composition. A mixture of 90% neon and 10% helium, where \( v \approx 5 \text{ mm/\mu sec} \), is used in the chambers. The concentration may change, for example by the helium leaking out through the thin mylar windows. Therefore, a "test spark" is used to monitor the sound velocity. It is formed at a pair of tungsten needles placed at distances \( d_1 \) and \( d_3 \) from probes no. 1 and no. 3. Then the velocity is given by

\[
v = \frac{(d_3 - d_1)}{(t_3 - t_1)}.
\]

This spark is triggered periodically and the digitized times, and special identification as "test spark", are sent to the computer which then corrects the value of the velocity being used for that part of the data.

Since \( k \) is constant for a given voltage on single-gap spark chambers, and \( v \) is only slowly varying and is measured independently, we find it sufficient and far simpler to obtain coordinates by using two probes at a time.
Therefore, we use this method rather than obtaining $k$, $v$, $x$ and $y$ by the solution of four simultaneous quadratic equations using the data from the four probes at once.

The accuracy with which spark positions are determined with this sonic spark chamber system was investigated by using high energy cosmic rays passing through a stack of three chambers. The measured r.m.s. deviations from a straight line were ± 0.3 mm. (Comparison with photographic measurements, made with one chamber tilted at 20° to the other two, shows that this is still true if it is assumed that the negative high voltage end of the spark defines the particle position, as is expected.) The uncertainty due to the inherent error of one clock pulse in the digitizing gate and in the initial delay is ± 0.15 mm.

In actual use during a run, it was found that on-line calculations with the IBM 1401 computer provided a very valuable feature. For checking and testing the system, the computer was programmed to have different calculations available by sense-switch selections. Spark positions, inconsistencies between pair of probes, distributions of missing sparks in various combinations among the four chambers, (punched card or printer outputs) all could be obtained on-line at about 1 event per second, and summaries of these after a preselected number of events could be displayed on the on-line printer. The punched cards could be loaded on an IBM 1620, which we have adjacent to the IBM 1401, and there used to reconstruct the trajectories in space. This was particularly useful in investigating background tracks by placing shielding in the magnet. The location of a track in space was given by the computer within 15 seconds of the event.

For the actual muon decay spectrum data, however, the IBM 1401 was used to transfer the digitized time intervals to magnetic tape for later analysis of events on an IBM 7094. About $5 \times 10^5$ events at 50 events/records can be written onto a 2500 ft reel of high density magnetic tape. The process is much faster than the repetition rate of our spark chambers which are limited to sparking at $\sim 20$/sec to retain efficiencies > 98%. The complete reconstruction in the IBM 7094 of a trajectory in space, with the effects of magnetic field non-uniformities, takes about 60 msec. Most of that time is spent reconstructing in a non-uniform field. The calculation of coordinates from sonic data, checks of inconsistencies, multiple sparks, and missing sparks, transformation into magnet coordinate system, fit of circle to observed points, check in chamber IV that no scatter occurred in track, and calculation of momentum and direction at decay, take about 10 msec.

The system gave complete reliability in a 3-week run in November 1963, during which tests and checks were made, and a sample of $\sim 10^6$ events was obtained.
Figure captions

Fig. 1 Layout of spark chambers and trigger counters inside 1 metre I.D. Helmholtz coil 7 Kgauss magnetic field.

Fig. 2 Spark chamber with mylar window removed, showing piezoelectric probes in brackets near corners. Probes are centered on plane in middle of 6 mm gap between the two thin plates, with the axes of the cylindrical shells perpendicular to that plane.

Fig. 3 Cylindrical skull sonic probe, 12 mm long, 3 mm O.D., with coaxial signal cable, and O-rings for shock mounting.

Fig. 4 Probe mounted in brass bracket which attaches to inside walls of chamber.

Fig. 5 Typical output signal from sonic probe, $\sim 2$ mV with $1 \mu$sec rise, on $10 \mu$sec/cm sweep.

Fig. 6 General block diagram of interface electronics.

Fig. 7 Detailed block diagram of digitizer chassis.

Fig. 8 Photo of digitizer chassis, showing four sets of amplifier transistorized printed circuit cards, followed by four sets of double cards for the binary coded decimal scalers. Amplifier cards are $8 \times 13$ cm; scaler cards are $10 \times 23$ cm. The chassis shown contains four independent channels.

Fig. 9 Sketch of layout of sonic probe within a spark chamber frame, outside of the plates, showing probe labelling and coordinate system.
DISCUSSION

MANNING: Have you any momentum distributions or any special distributions which you can give us to indicate the performance?

BARON: The momentum distribution looks fine, but it does not mean a thing unless I give you a very precise answer. I am not going to give you a very precise answer without having more data. I forgot to mention one thing, it is possible to have a computer "controlling" this system and we made use of this in the following way. If the spark chambers are warped so that the probes are no longer on a rectangle we get the wrong answers. However, it is possible by looking at a printer, after a few minutes of practice, to find out exactly which way the spark chamber is twisted. I could adjust set-screws which relocate the spark chamber on instruction from someone looking at the output from the printer, and see immediately when the twist was reduced to zero.

ANDERSON: In following the trajectory of the positron, is there gas between the chambers?

BARON: During the run that we made last November we had a helium path from one chamber to another. In the next run we will have vacuum. The multiple scattering then becomes essentially momentum independent because of the focusing effect in this 180 degrees spectrometer.

ANDERSON: How do you keep the sides of the spark chambers parallel?

BARON: The spark chambers are entirely separate from the vacuum chamber. They are mounted so that they are in a frame and float in the magnetic field, very precisely related to each other with 0.05 mm accuracy, much better than they have to be.

LIPMAN: I understand that you had pairs of gaps from the fact that you had 32 scalers.

BARON: No, we have used 16 so far. We have 32 channels and we send all kinds of identifying information to keep track of various parameters.

LIPMAN: I wanted to get some idea of the failure rate. How often does the gap fail to fire when it ought to have fired?

BARON: We are limited, as I said, to about 20 per second in order to maintain 98% efficiency. We could go faster but then the efficiency goes bad.
LIPMAN: How does this limit come about?

BARDON: Someone mentioned something about poisoning a chamber at these high rates, perhaps that is what it is. What we see, apart from misses, is a lot of sparks all over the chamber at the same time when we go too fast. We call that inefficiency also.

NEUMANN: How many events did you have to reject because of double sparks?

BARDON: Less than 10%.
SYSTEM CONSISTING OF SONIC SPARK CHAMBERS, TIME-OF-FLIGHT
AND PULSE-HEIGHT COUNTERS ("MISSING-MASS SPECTROMETER")
WITH ON-LINE COMPUTER

H. BLIEDEN, D. FREYTAG, F. ISELIN, P. LEFEBVRES,
B. MAGLIC, H. SLETENHAAR, S. ALMEIDA and A. LANG
CERN, Geneva

(presented by B. Maglić)

1. **INTRODUCTION**

We have built a system consisting of sonic spark chambers, time-
of-flight, pulse-height and hodoscope counters (see Fig. 2). Such an
instrument was proposed recently under the name of "missing-mass spectro-
meter"), for the search of new unstable particles, X. (X can be boson,
nucleon isobar or excited hyperon, depending on the type of the bombarding
particle.)

We have in mind an investigation of the reaction

\[ \pi^- + p \rightarrow p + X^- \]  \hspace{1cm} (1)

particle index: \(1\ 2\ 3\ 4\)

with \(X = \) unstable boson.

In Fig. 2 we have listed the measurements which are supposed to
be done by the MM-spectrometer. According to its function, the instrument
can be divided into two parts:

Part i) : "Pion line". It contains:
- hodoscopes \(H_1, H_2, H_3, H_4\)
- "vertex" counter, \(V\).

Part ii) : "Proton line". It contains:
- sonic chambers \(S_1, S_2, S_3, S_4\)
- hodoscopes for recoil proton \(R_1, R_2, R_3\)
- aluminium degraders \(D_1, D_2, D_3\), of variable thickness.
Part ii), the "Proton line", has been tested in a proton beam (with a 20% pion admixture) from the CERN Synchro-cyclotron. In Fig. 1, we show the diagram of this tested part of the system.

2. QUANTITIES INVOLVED IN THE MEASUREMENT OF MISSING-MASS

Mass of particle 4, \( m_4 \), in Reaction (1) is equal to the missing-mass of particle 3, \( m_3 \). In general, \( (\text{miss. mass})^2 = (\text{miss. energy})^2 - (\text{miss. momentum})^2 \), which, for the case of Reaction (1), \( (m_2 = m_3) \) becomes:

\[
m_3^2 = m_4^2 = m_1^2 - 2 \left[ \left( \frac{p_1^2 + m_1^2}{2} \right)^{\frac{1}{2}} + m_1 \right] \left[ \left( \frac{p_3^2 + m_3^2}{2} \right)^{\frac{1}{2}} - m_3 \right] + 2 p_1 p_3 \cos \theta_3. \tag{2}
\]

All quantities in Eq. (2) are in the laboratory system. Knowledge of \( m_3 \) requires simultaneous measurement of six quantities; they are listed in Table 1, together with the description of the measuring technique used.

All measured quantities listed in Table 1 are first digitized and then registered in scalers. The existing CERN scaler readout logic is used to transfer the information from the scalers, either onto magnetic tape or to the Mercury computer.

In the following text we describe only the essential facts about the operation of our system. Overall description of the interconnections and parts of the instrument will not be given. Apart from the descriptive figures 1 and 2, the reader is referred to talks presented by P. Iselin in Session IV and by H. Slettenhaer in Session V.

3. DATA STORAGE

All raw data without any pre-selection or pre-computation, are stored from the scalers onto the magnetic tape. We use the IBM unit, placed in an air-conditioned trailer. The tape speed is 36"/sec with a density of 200 characters per inch. A 2,500 ft reel can store \( 3 \times 10^4 \) events (from 30 scalers).

Assuming a 100% running efficiency and 100 msec for the recording of an event, one expects, on the average, 2 events per 300 msec/burst of the Proton-Synchrotron, or 3,600 events/hour. Our estimate is a 30% efficiency; thus, the expected data getting rate is \( 1,000 \) events/hour or \( 2.4 \times 10^4 \) events/day.
4. **ROLE OF THE ON-LINE COMPUTER**

Due to the slowness of the Ferranti "Mercury" computer used, only one out of three to four events can be processed to the point of computing \( N_2, \) Eq. (1). This makes the computer a sampling facility. The importance of sampling is two-fold:

i) It makes it possible to test the goodness of the physics result (missing-mass distributions) by applying certain prescribed checks on the \( \Theta_3 \) vs \( P_3 \) dot density distributions. The proposed method of "particle hunting" depends on these tests (described in paragraph 5). The \( \Theta \) vs \( P \) display is done by the mechanical x-y plotter.

ii) It constantly checks the functioning of the whole instrument: whenever an event cannot be "fitted", the reason for the failure (type of error) is displayed (see paragraph 6) on the typewriter on-line.

5. **ON-LINE CHECKS AGAINST FALSE PEAKS**

We know, today, only of two \( X^+ \) resonances (\( I = 1 \)): \( p \) and \( B \), whose masses are 750 and 1,220 MeV, respectively, and width \( \Gamma = 100 \) MeV. If there are no new resonances, the \( N \) vs \( M \) distribution would show a continuum (phase space), with only these two peaks superimposed on it. A new heavy boson would show as another peak on the continuum.

However, in the past bubble-chamber work, peaks in \( N \) vs \( MM \) distribution frequently turned out to be false ones. (All unstable bosons were found in the effective mass, rather than \( MM \) distributions.)

The proposed method prescribes definite tests, to be made in the course of the experiment, which should be capable of revealing if the peak is false or not.

\[ \Theta_3 \] vs \( P_3 \) scatter diagram

In this technique, the result is not displayed in the usual \( N \) vs \( MM \) histogram. Since, at fixed \( P_1 \), \( MM \) is a function of only two variables, \( MM = f(\Theta_3, P_3) \), each event can be represented by a dot in a \( \Theta_3 \)-\( P_3 \) plane. This gives more information than \( N \) vs \( MM \) histogram. First, it shows, simultaneously, cross-section as a function of the momentum transfer \( \Delta^2 (\approx P_3^2) \). Secondly, the scatter diagram provides two independent tests:
Test 1: If there is a discreet mass in X, the dots should lie along one mass-line whose shape is well known at any incident \( P_1 = \text{fixed} \). (See, for example, \( \Theta_3-P_3 \) mass lines for \( P_1 = 6 \text{ GeV/c} \) in Fig. 3.) An increase of dot-density, if the effect is real, is expected along a given line. If this condition appears to be satisfied in the course of the run, the physicist proceeds to

Test 2: The mass-lines shift in a known manner with the change of the incident momentum \( P_1 \); the increase (decrease) of \( P_1 \) by 1 GeV/c, typically increases (decreases) the maximum angle by about 30°. At any beam setting, the variation of the beam momentum of \( \pm 1 \text{ GeV/c} \) is possible without changes in the beam design.

Therefore, the second test consists of repeating the run at \( P_1 + 1 \text{ GeV/c} \) and \( P_1 - 1 \text{ GeV/c} \), and seeing if the density distribution follows the scale prescribed by kinematics. For example, the dotted line in Fig. 3 shows the shift of the 1.5 GeV mass line for \( P_1 = 8 \text{ GeV/c} \), in respect to the one at \( P_1 = 6 \text{ GeV/c} \) (solid line), i.e., it shows the effect of \( \Delta P = + 2 \text{ GeV/c} \).

6. OPERATION OF THE "PROTON LINE"

Here, we shall describe the procedure of identifying the proton and computing its \( \Theta_3 \) and \( P_3 \) in its time sequence:

From the sonic information obtained from 24 transducers in chambers \( S_1, S_2, S_3 \) and \( S_4 \), the spark co-ordinates \((x,y)\) in each of the six gaps are fitted; then a straight line (proton direction) is fitted through the points:

- The straight line is extrapolated into the \( R_1 \) hodoscope; the programme computes which of the three counters should have been hit by the particle; on the other hand, the programme checks the information stored in the pattern unit and sees if the observed counter number, \( R_1^{\text{obs}} \) is equal to \( R_1^{\text{expected}} \). If yes, the position of the particle in the plane of the \( R_1 \) counter is computed; then, the time of propagation of the light signal from this point to the photo-multiplier is subtracted from the observed time-of-flight, \((\text{TOF})^{\text{obs}}\). This gives "first-corrected TOF".

- The straight line is then extrapolated forward to the target to find the intersection with the incident pion direction. [This is the vertex of Reaction (1)]; then the time-of-flight taken for the pion to travel from \( R_4 \) to the vertex is subtracted from the first corrected TOF. This gives the real time-of-flight, \((\text{TOF})^{\text{real}}\).
- Check is made on the counter number R_{24} which is hit by the proton.

- Using the \((\text{TOP})_{\text{real}}\) and the information on the thickness of degrader \(D_{2}\), the expected pulse height, \((\text{PH})_{\text{EXP}}\), in hodoscope \(R_{2}\) is computed, on the assumption that the particle is proton; then, the information on the \((\text{PH})_{\text{observed}}\) is compared, and if they agree to 20\%, proton is identified.

- Similar procedure is repeated for the hodoscope \(R_{3}\); then,

- \(P_{3}\) is computed.

- \(\Theta_{3}\) is computed.

7. **USE OF TYPEWRITER ON-LINE**

The typewriter is in the experimental area, on-line with the computer output; it gives the evidence on the functioning of every instrument of the system at any time:

1) whenever an event cannot be "fitted" by the missing-mass programme, the reason for the failure is typed. This can be illustrated by the following examples:

- If the pion line operates properly only one counter in each of the hodoscopes \(H_{1} - H_{4}\) should go off. If, in one hodoscope, (say \(H_{3}\)), two counters, (say 2 and 4), give signals, the event will not be fitted.

  Error \(H_{3}24\) will be typed.

- There were two sparks in \(S_{2}\). This will give too short sonic times.

  Error type: \(6S2\)

- One transducer, say No. 1 in \(S_{2}\), has become insensitive or disconnected. This gives too long sonic time.

  Error type: \(5S31\)

- One spark chamber gap became inefficient. This would result in the absence of the stop signals in any of the four microphones in that gap.

  Error type: \(2\).
An event does not satisfy the PH criterion for proton of given TOF.

Error type: 2.

ii) The repetition of any of these errors draws the experimentalist's attention to the specific part of the apparatus. He requests the computer operator to output the quantities related to the part of the system which is malfunctioning. He can plot the distribution of each of the quantities.

An example of this is given in Figs. 4 and 5. Distribution has revealed that the spark chamber $S_1$ was inclined by $10^\circ$ to the vertical.

**ACKNOWLEDGEMENTS**

Thanks are due to G.R. Macleod for suggesting and helping to organize the use of the Mercury computer; to D. Harting for his help in the planning of the system; to B. Levret* for his help in the later stages; J. Tischhauser for his constructions; J.W. Beck, L. Dubal*, F. Marciano and G. Genova for their invaluable assistance.


* University of Geneva.
### Table 1

Physical quantities involved in measuring "missing-mass spectrum"

<table>
<thead>
<tr>
<th>Observable</th>
<th>Method of measuring</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mass of incident pion, (M_1)</td>
<td>Not measured. Beam is presumed to contain 99.3% pions.</td>
<td></td>
</tr>
<tr>
<td>2. Momentum of incident pion, (P_1)</td>
<td>Magnet 120 mrad, with 4 counter hodoscopes (H_1, H_2, H_3, H_4)</td>
<td>(\pm 1%)</td>
</tr>
<tr>
<td>3. Direction of incident pion, (\hat{P}_1)</td>
<td>2 counter hodoscopes (H_3 - H_4)</td>
<td>(\pm 1) mrad</td>
</tr>
<tr>
<td>4. Mass of recoil proton, (M_2)</td>
<td>Differential pulse-height (3 hodoscopes (R_1 - R_2 - R_3) and time-of-flight)</td>
<td>(\pm 20%)</td>
</tr>
<tr>
<td>5. Momentum of recoil proton, (P_2)</td>
<td>Time-of-flight</td>
<td>(\pm 0.5) nsec</td>
</tr>
<tr>
<td>6. Direction of recoil proton, (\hat{P}_3) (measurements 3 and 6 give angle (\theta_3))</td>
<td>2 three-gap sonic spark chambers</td>
<td>(\pm 1) mrad</td>
</tr>
<tr>
<td>7. Number of charged particles, (N), into which X-boson decays (not directly related to the measurement of (M_3) but essential to our method of eliminating background.</td>
<td>Pulse-height counter</td>
<td></td>
</tr>
</tbody>
</table>

In 5% cases one more particle will be counted due to Landau tail.
Figure captions

Fig. 1 Simplified version of missing-mass spectrometer, tested 19-20 December, 1963. Results of the test are given in Figs. 4-11. See also Fig. 2.

Fig. 2 Complete diagram of the data reduction system for MM-spectrometer. The "proton line" was tested (see Fig. 1).

Fig. 3 Kinematic "mass-lines" in the $\theta_2$ vs $p_3$ plane at incident pion momentum of $p_1 = 6$ GeV/c. An example for the shift of the mass-line is shown for $p_1 = 8$ GeV/c (dotted line). See paragraph 4 of the text.

Fig. 4 and Fig. 5 Distribution of the differences of the spark positions in two gaps in the sonic chamber of active area of 40 x 80 cm$^2$, for the x and y coordinates, respectively. The systematic shift of 1 mm in the y coordinate helped us in finding out that the chamber was inclined 10$^0$ to the vertical.

Fig. 6 Distribution of the differences of the shock-wave parameter $\Delta t$ in two gaps. $\Delta t$ is proportional to the square root of the spark energy (see Lillethun et al., Operation of a sonic spark-chamber system, CERN report 1963).

Fig. 7 Angular distribution of the collimated proton beam, as measured by two sonic spark-chamber gaps, 150 cm apart. This measurement gives our angular resolution to be $\pm 0.05^0$.

Fig. 8 Pulse-height distribution in a scintillator 50 x 30 cm$^2$, 1 cm thick, obtained with protons of 0.9 GeV/c. This gives our pulse-height distribution, which is $\pm 25\%$.

Fig. 9 Momentum resolution, obtained by time-of-flight measurements.

Fig. 10 Flow diagram of the MM-programme used in the test of "proton line". The set-up is shown in Fig. 1.

Fig. 11 Missing-mass resolution, obtained with the proton line set-up, described in Fig. 1.

Fig. 12 Layout of the cable connecting four experimental areas on the CERN site to Mercury computer (M). Details of the link are described by Slettenhaar, Session V.
IN REACTION:
\[ \pi^- + \beta \rightarrow \beta + X^- \]
WE MEASURE:
(1) INCIDENT R
(2) INCIDENT DIRECTION
(3) RECOIL ANGLE \( \theta \)
(4) TOP IN CEM
(5) DIFFERENTIAL PH.
(6) NUMBER OF CHARGED MESONS, N
1 VERTEX SCINT. COUNTER

\[ \text{NIA,} \ N_2 \]
\[ \text{N}_2 \text{N}_2 \text{K}_R \text{N}_2 \text{N}_2 \]

TRIGGER LOGICS (A-OUTPUTS) ARE NOT SHOWN

Fig. 2

MM-SPECTROMETER
GENERAL DIAGRAM OF B-OUTPUTS (DATA REDUCTION)

Fig. 3

Experiment mass “kinematic splitting” of the mass lines: angular resolution needed for \( \Delta M = 2.0 \text{ GeV} \Delta \theta = 0.5 \) 
Momentum resolution needed for the same mass resolution is typically 3% to 4%. 

Dotted line is the line corresponding to mass of 1.5 GeV at incident momentum of 8 GeV/c. All solid lines correspond to incident momentum of 6 GeV/c. The mass line shifts = 4 per 1 GeV/c. This property provides a check of the effect in W-distribution, if mass observed.
Sonic chamber 126x76 cm²

$x_{GAP1} - x_{GAP2}$

Space resolution is:

± 0.30 mm

in horiz. plane

Fig. 4

Sonic chamber
126 x 76 cm²

$y_{GAP1} - y_{GAP2}$

Space resolution is:

± 0.25 mm

in vert. plane

Fig. 5
Shock wave effect in sonic chamber is constant to:

\[ \pm 1.4 \mu s \]

Fig. 6

Angular resolution is:

\[ \Delta \theta = \pm 0.05^\circ = \pm 0.88 \text{ mrad} \]

Fig. 7
Shock wave effect in sonic chamber is constant to:

\[ \pm 1.4 \mu s \]

\[ (\Delta t)_{GAP1} - (\Delta t)_{GAP2} \ [\mu \text{sec}] \]

Fig. 6

\[ \frac{0.32^\circ}{0.03^\circ} \]

ANGULAR RESOLUTION IS:

\[ \Delta \theta = \pm 0.05^\circ \]

\[ = \pm 0.88 \text{ mrad} \]

Fig. 7
PULSE HEIGHT RESOLUTION IS

\[ \pm 23\% \]

Number of Events

12 units = 1 volt

Pulse height of events with time-of-flight = 18 ± 15 nsec

Fig. 8

MOMENTUM RESOLUTION IS:

\[ \frac{\Delta P}{P} = \pm 8\% \]

Proton by time-of-flight

Fig. 9
from scalers, Ni

Writing of magnetic tape

Testing if Ni's are within prescribed limits

YES

Computing of the spark coordinates, Fitting intersections.

If not, scaler number is sent to typewriter, with error type 1 or 2, corresponding to N too low or too high respectively

Computing trajectory of the recoil particle

Computing the momentum, assuming it is proton

Computing expected pulse height, comparing with obtained pulse height.

If not proton, error type 8

Computing missing mass

to plotter

Plot cos θ and p

on-line

to typewriter

Print cos θ, p, m and event number

We are ready to read new event.

Fig. 10

Fig. 11

MASS-RESOLUTION IS:

\[ \Delta M = \pm 20 \text{ MeV} \]

AT \[ M = 25 \text{ GeV} \]

PROBABLY MDM, SIGNED AS 1.23, DUE TO IMPERFECTIONS
I. AFTERNOON SESSION

VIDICON SYSTEMS

Chairmen: G.B. Collins,
Brookhaven National Laboratory

Secretaries: H. Anders, CERN
B. Zacharcv, CERN
SPARK CHAMBER VIDICON SCANNER WITH DISCRETE SCAN

W. VERNON
Palmer Physical Laboratory, Princeton

A scanning system is described which is relatively simple and flexible. The basic components of the scanner are shown in Fig. 1 with the vidicon scan and tape recorder controlled by the logic. The uniqueness of the system lies in the vidicon's scan format which at present has only as many individually adjusted scan lines as there are spark chamber gaps. Further, the scanning beam is stopped at sparks to allow the recording of their position so that the vidicon's storage properties are being fully exploited.

Figure 2 shows the vidicon construction and equivalent circuit of a small part of the photo-anode (Target). The tube which is presently in use is a General Electrodynamic Corporation type 7525, a high sensitivity, one-inch vidicon. The vidicon operates somewhat like the following: light striking the target causes the photo-conductor resistance $R_p$ to decrease, and $C_t$ begins discharging. When the focused and deflected electron beam strikes the target, it recharges $C_t$. This latter current is the one associated with the image. $R_d$ is the resistance in the presence of no light.

It has been observed that the vidicon is about a factor of ten less sensitive to sparks than to continuous illumination. This number is obtained by photographing both sparks and continuously illuminated fiducial lines in the chamber. For the spark and fiducial images to be of about equal intensity, a one-second exposure of the fiducials is needed. However, when the vidicon looks at the chamber, the fiducials and sparks have comparable pulse heights with a 0.1 second equivalent fiducial exposure time. This behaviour can be accounted for either by assigning a time dependence to $R_p$ or by having $R_p C_t$ long compared to the spark duration.

The vidicon camera (separate from the standard scan control generator) has been reworked so that all voltages are supplied externally and is operated in discrete scan mode with the generator off. A manual

*)

This work is supported by the U.S. Office of Naval Research
switch has been added to return the camera to standard scan for alignment purposes. In discrete scan mode, Fig. 3, the vertical position is set by a 4 bit scanner (16 lines scan) which goes to a diode decoder and individual setting resistors. The horizontal scan is generated by a digital-to-analogue converter (one-half of a digital voltmeter) connected to the 10 bit horizontal scanner. This converter voltage is proportional to the binary number in the scanner and is fed to the current amplifier which drives the horizontal deflection yoke.

Prior to an event the system is cycling in the 16 line format to keep the face charged. A scan sequence is initiated by an "event" pulse. The tape unit is started, all flip-flops are cleared, and the scan is started by connecting the clock to the horizontal-vertical scanner. The tape unit begins recording zeroes in three-column groups until a video pulse stops the scan and causes the binary number in the scanner to be loaded into the shift register. Since the shift register is running synchronously with the tape, the scaler must be held off until the end of a shift sequence. As soon as the scaler number is dumped, the scan continues. The number in the shift register moves over six bits at a time to be recorded. Only 14 bits of the possible 18 are used for data. When the scan has finished the last gap, a delay is initiated to turn off the tape unit such that a 3/4" "inter-record gap" is left on tape between events.

The clock period is set to 2.22 μsec so that \(2.22 \times 25 \times 6 = 1/3 \text{ msec}\). The 25 is the scale-down to the average bit recording rate, the 6 to get down to the average column rate. So, it takes one millisecond to record the position of one spark in one view (scan time for one gap is 2.27 μsec minimum). These count-down scalers also provide the timing pulses for the shift register and other logic associated with recording. In Figures 4 and 5 the pseudo tape recording is that of the straight track event in the chamber drawing (actual chamber has five thick plates in the middle). The gaps in the recording (groups of three columns of zeroes) are a result of the timing and synchronization in the logic. The magnetic tape can be "developed" with a ferrous precipitate as shown in Figure 6.

The video trigger logic is shown in Figure 7. The trigger generator is a zero-cross detector and discriminates on the amplitude of the derivative of the video. A delay gate decodes about 1/20 of the scan after the beam turns on following a scan stop. This is necessary as shown in Figure 8b where the pulses occurring are due to starting the scan. Figure 8a is the current in the horizontal yoke as a function of time in the region of a scan halt where the small spikes show the turn-off and turn-on points. A current lag of about 0.5% is obvious and is caused by capacitors in the circuit to smooth out the scan. The scan is rough due to spikes on the voltage sawtooth from the scanner converter. These spikes occur during flip-flop transitions (50 nsec/stage) with the largest one being the half-way point in the scan.
Figure 9 shows video pulses for fiducials and sparks with a lens f/5.5 stop for the sparks. A discontinuous region near zero for the differentiated pulse indicates the video trigger point (superposed trigger pulse). On the expanded scale the fiducial pulse has a width of about 1/500 of the scan, and the spark is somewhat wider. These widths seem to be the best obtainable with this vidicon and deflection assembly.

Both cosmic ray tracks and fiducial lines have been scanned in the chamber and fitted to straight lines with an iterative, least squares fitting program. Considering random triggering as the only error, optimum conditions yield errors for the horizontal position of a spark with respect to the fitted line between 0.08 and 0.2 percent of the total scan. The smaller number corresponds to 0.35 mm in the chamber and 0.007 mm (3.6 \times 10^{-4} \text{ inches}) on the vidicon face. This optimal triggering condition obtains with the yoke current heavily smoothed which results in absolute spatial locations being uncertain to about one percent of the scan. This uncertainty is due to hysteresis added to the scan by the smoothing elements (see Fig. 8a); a recorded position depends on what was recorded earlier. If the hysteresis errors are reduced to about 0.5\% they triggering errors increase to about 0.2\%. Departure from linearity in the scan is about 3\% but is constant and not included in the above errors.

Figure 10 shows the vidicon recording of a simultaneously photographed event, Figure 11. The two views of the chambers are separated by a line corresponding to the extraneous trigger on the video due to the scalar mid-point transition. A glass plate was inserted in front of the vidicon at 45° to reflect into the camera. This puts both the vidicon and camera on the same optic axis. The spark chamber is 6" \times 6" plates spaced at 3/8", filled with neon-helium mixture and fired by a spark-gap discharging 2500 Pf at 13 KV. The appearance of two lines in the right view of the recording is due to triggering on both the track and its reflection in the fiducial plate because of an optical misalignment. This behaviour with the lens aperture at f/1.9 implies that the sensitivity is too high and, in fact, recording of tracks is satisfactory at f/5.6. The recording of either the track or the reflection, but not both, shows the effect of the dead time after a scan-stop.

The fiducial lines in the picture were photographed after the event recording. Comparisons made between angles on film and the recording, both a later fiducial recording and between the two views of the track, are consistent to within 5 mrad. This is also consistent with the previously mentioned errors although no systematic corrections were made in the comparison.

The conclusion from these tests is that the maximum usefulness of the system can be realized only by smoothing the scan correctly and adding at least one information buffer to avoid stopping at each spark.
Proper smoothing can probably be accomplished with a "jam transfer buffer" between the horizontal scaler and converter; this buffer would then be loaded each clock pulse after the scaler transitions are over.

I would like to express appreciation for help and encouragement frequently given by Professors Cronin and Reynolds. Richard Roth, who has done the computer programming, has also been of much help in many discussions of the system and its use.

This work made use of computer facilities supported in part by National Science Foundation Grant.
Figure captions

Fig. 1 General block diagram of the system
Fig. 2 Vidicon details
Fig. 3 Block diagram of control logic
Fig. 4 Example of a straight track in a 16-gap chamber
Fig. 5 Tape format and recording of example track
Fig. 6 "Developed" magnetic tape showing a typical record
Fig. 7 Block diagram of the video trigger logic
Fig. 8 a) Horizontal yoke current. Both time and current scales are about 1% of a scan line/cm. Time increases to the right
   b) Video pulses due to starting the scan. Upper trace: voltage across the horizontal deflection yoke with brightened portion corresponding to lower trace time interval. Time is 0.5 msec/cm. Lower trace: differentiated video signal, 1% of scan/cm
Fig. 9 a) Video pulse corresponding to a spark. Upper trace: as in 8b. Lower trace: horizontal is 1% of scan/cm. Vertical is 5 mV/cm
   b) Differentiated video from a spark with trigger pulse superposed
   c) Video signal during scan of one gap with no recording. Upper trace: yoke voltage on 5 msec/cm time scale. Lower trace: video signal of four fiducial lines and scaler transition at mid-point. Time scale is 0.25 msec/cm
   d) Differentiated video pulse from fiducial line during recording. Upper trace: as in 9c. Lower trace: time scale is 25 μsec/cm (about 1% of a scan/cm), and video trigger is superposed
Fig. 10 Computer print of event photographed in Fig. 11. The numbers are horizontal positions (1024 maximum) ordered by gap number
Fig. 11 Cosmic ray track. This is a mirror image of Figure 10
Fig. 1

Fig. 2

VIDICON DETAILS
BLOCK DIAGRAM OF VIDICON SCANNING SYSTEM

Fig. 3

VIEW 1

VIEW 2

SPARK CHAMBER IMAGE WITH SAMPLE EVENT

Fig. 4
TAPE FORMAT

RECORDING IN IBM NRZ, LOW DENSITY MODE.

NRZ ⇒ NON RETURN TO ZERO OF THE MAGNETIZATION.
I.E. "O" ⇒ NO CHANGE "1" ⇒ REVERSE THE FIELD

LOW DENSITY ⇒ 200 bits/in ALONG ONE OF THE 6 ROWS.
THE 7th ROW IS FOR PARITY CHECKING, THE PARITY BIT IS SELECTED
SO THAT THE NUMBER OF "1's" IN THAT COLUMN WILL BE ODD.

SPARK NUMBER

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LETTERS ARE EITHER O OR 1.
CAPITOLS ARE THE MOST SIGNIFICANT BITS OF THAT WORD.

O ⇒ VERTICAL (GAP)# OF SPARK
B ⇒ HORIZONTAL POSITION
(NOTE: B=O ⇒ VIEW 1
   =1 ⇒ VIEW 2)

EVENT
START

END OF RECORD MARK

FIG. 5

TAPE MOTION

Fig. 6
DISCUSSION

ISELIN: Does the magnetic tape advance synchronously with the vidicon sweep?

VERNON: The tape does not advance synchronously with the vidicon. It is just that once the tape is started a clock is started where the recording begins and the spacing of each column on tape is kept approximately equal to the IBM convention. In this case, we use two hundred bits per inch and that determines the spacing. If an event has occurred this is approximately the rate at which the shift-register runs. Information is only put into the shift register if available and it is then shifted out onto tape; if there is no information, three columns of zeros are shifted onto the tape.

ISELIN: Do you not lose too much tape?

VERNON: No you adjust the tape speed to match the experiment. If one expects one track in each view, the tape speed that I have now is approximately optimized. Once in a while there are zeros but not too often.

WICKOTT: Do you have any trouble with stray magnetic fields?

VERNON: It is going to take a lot of shielding. In fact, I plan to use the system on top of a magnet in the near future. Of course, one can arbitrarily adjust the position of the whole scan by adjusting what is called the trimming currents; if the magnet is run at the same current there is no worry.
AUTOMATIC DIGITIZATION OF SPARK CHAMBER EVENTS BY VIDICON SCANNER

S.W. ANDREAE, F. KIRSTEN, T.A. NUNAMAKER, V. PEREZ-MENDEZ

Lawrence Radiation Laboratory, Berkeley

PART I : (presented by V. Perez-Mendez)

PART II : (presented by F. Kirsten)

I. Vidicon camera and digitizing logic

1. INTRODUCTION

The large output of spark chamber events recorded on film and the subsequent labour involved in their analysis by use of manually operated digitizing machines has prompted the development of faster and more accurate data processing devices.

The problem of automatic digitization of spark chamber tracks is considerably simpler than in the analogous case of bubble chambers. The simplifications stem from the fact that the selection of spark chamber events is counter-controlled and hence the desired track is accompanied by few, if any, accidental tracks. Furthermore, since in many spark chamber applications the useful tracks fall on straight lines or arcs of a circle (if the chamber is in a magnetic field), the "Pattern Recognition" aspects of an automatic scanning device to be used for bubble chamber pictures reduce to the simpler case of a position-digitizing device with provisions for rejecting obvious background, or random sparks. In the approach we follow here, this last task is left to the versatility of the computer, which sorts out and compiles the digitized information.

The digitizing system we describe below consists of a vidicon television-camera tube with associated electronic circuits built into an electrostatically and magnetically shielded assembly that can operate in an environment of spark chamber and accelerator electrical noise. At present the system is designed to store the locations of two sparks per gap per view of the chamber (this number does not include the often present spurious corner and edge sparking which can be gated out). The digitization is accomplished by using existing Lawrence Radiation Laboratory 20 Nc/s scalers which record the positions of the sparks relative to a system of fiducial slits located at the extremities of each chamber view. The digitized information is temporarily stored in a 6000-bit magnetic core buffer and then transferred onto magnetic tape for subsequent processing by the 7090 computer.
From the description given below it is clear that the same vidicon camera can serve also as the digitizing device to analyze pictures of spark chambers that are taken with a suitable format of views and fiducials. It is also clear that the accuracy, speed, and data-handling capacity for which we are aiming at present is not the maximum attainable with existing electronic components and techniques; we recognize that it is also possible to achieve greater versatility, although at greater cost and with more complications, by designing the system to be "on line" to a computer.

The digitizing logic of the scanner, as described in the following sections, requires a format of the various spark chamber views in which the images of all the plates appear parallel to one another on the faceplate of the vidicon. The simplest case utilizing this format is that of a single multi-gap spark chamber with two perpendicular stereo views projected in a parallel array by mirrors. A polarization experiment is under preparation at the Berkeley 184-inch cyclotron, in which the proton of polarization from a π-π scatter is determined by using the spark chamber to analyze the angular distributions of the proton after scattering from a carbon converter placed in front of the chamber.

2. VIDEO DIGITIZING CAMERA

A vidicon camera is employed because of its high resolution, image storage ability, and simplicity of operation. The operation of the vidicon is illustrated in Fig. 1. The sensitive element consists of a photoconductive layer deposited on a transparent conducting surface. This layer is charged to a homogeneous negative potential by a low-velocity electron scanning beam. Illuminated portions of the target become discharged; the signal output from the vidicon is obtained when the electron scanning beam recharges these spots and the charging current is then measured across the anode resistor that is at the input of the Video amplifier. This amplifier has a gain of 30 with a bandwidth of 10 MHz and is mounted in close proximity to the vidicon anode in order to minimize the stray capacity and noise pickup.

The vidicon camera is well shielded both electrostatically and magnetically. Fig. 2, shows the concentric electrostatic and mumetal magnetic shields which enable the camera to operate in magnetic fields up to 50 G, without affecting the low-velocity electron scanning beam of the vidicon. Since the vidicon stores the optical image it receives on the anode photoconductive layer for many milliseconds, it is possible to delay the start of the scanning and digitizing cycle until the electrical transients produced by the spark chamber discharge have disappeared. In our case this delay period is 20 μs and the electrostatic shielding is more than sufficient to prevent any transients from feeding through to the core storage.
Figure 3 shows the two views of a 10-gap spark chamber as seen by the vidicon. Sparks are digitized by scanning the vidicon parallel to the spark chamber plates. The fiducial arrangement consists of illuminated slits placed on both ends of the spark chamber. The left-hand slits are stopped down so that they mark the central region of each spark gap. As the sweep proceeds in the slow-sweep direction, the first video signal, from a left-hand slit, sets the digitizing logic so that digitization starts on the following fast sweep. If a spark is present, a 20 Mc/s scaler is turned on when the sweep passes over the spark and is turned off when the sweep passes over the right-hand fiducial. A 50 μs fast-sweep time is used; thus our quantizing error is 1 part in 1000. At present, two scalers are available for digitization and they may be used either to digitize two sparks per gap or one spark per gap and the total gap length. To improve accuracy, the digitizing is repeated twice in each gap and the average of these two sweeps is delivered to the buffer store.

The signal that turns the digitizing scalers on and off is obtained from a gated discriminator. This discriminator is set to trip at a level of 50 mV on the output of the video amplifier after two differentiations which produce a "zero cross-over pulse". The first differentiation - with a time constant of 160 ns - trips the amplitude gating pulse which is set at a safe level above the noise background (10 mV). The second differentiation - with a time constant of 50 ns - produces the zero cross-over pulse. These pulses are shown in Fig. 4. A spark is distinguished by the digitizing logic from a fiducial-slit pulse by requiring a further gating pulse which is correlated in time with the sweep pulse, and thus with the spatial position of the fiducial slits. This gating-pulse logic is also used to minimize triggering on spurious random sparks, by requiring that the digitized sparks are in the vicinity of the scintillation counter that triggered the chamber, as shown in Fig. 3. Adjustments of these internal gating signals is accomplished by intensifying the corresponding portions of the sweep on a monitor scope that is simultaneously displaying the spark chamber image. This monitor scope is also used in monitoring the alignment of the digitizing sweeps parallel to the spark chamber plates; the two digitizing sweeps are intensified and can be located at the centre of each gap.

Once an event has been digitized it is necessary to erase completely (i.e., recharge the vidicon target). To accomplish this the electron beam is defocused and the beam current increased. Three 5 ms sweeps of the vidicon target are made immediately after an event has been digitized and the reafer periodic recharging scans are made during the off gate time of the cyclotron beam. The slow-sweep sequence of scan, erase, and recharge is shown in Fig. 5.

At present we are using a 250-line scan. The sweep speed is 50 μs, with a 10 μs flyback. The scanning time is thus 15 ms; an additional 15 ms are required per complete erasure and recharging. With the RCA 7263A vidicon
tube that we are now using, the signal level has decayed to ~50% of the initial value at the end of the full scan.

**Performance Tests**

We have tested the vidicon camera and digitizing logic both with illuminated grid lines and with cosmic rays triggering the 10 plate spark chamber referred to above. These tests show an average signal-to-noise ratio better than 10 to 1 while operating the camera 20 ft from the chamber with an 85 mm lens set at an f/8 aperture. The spark chamber was filled with the usual 90% Ne - 10% He mixture and the energy per spark was ~0.05 Joule.

Under these operating conditions, spark positions were reproducibly located to an accuracy of better than 0.1% of the full sweep, with a drift of 0.14% over a 24 hour period. Two sparks could be resolved and their positions digitized if their relative spacing was >1% of the full sweep length. These figures do not represent the limiting resolution and reproducibility of the vidicon tube; they are a measure of the overall performance, including some noise and drift from the Video amplifier.

It is worthwhile to point out here that it is possible to shorten considerably the present 30 ms dead time per event by using existing faster electronics such as 100 Kc/s scalers. Furthermore, the dead time per event would remain the same if a number of vidicon cameras were used simultaneously to scan various sets of parallel plates in a complicated experimental array. This can be done by providing each camera with its own digitizing scalers and staggering the read-out time for each set of scalers – which only takes a few microseconds – and utilizing the time between sweeps for this purpose.
DISCUSSION

VERNON: Could you say something about the absolute resolution of sparks? I think you mentioned you had photographs also.

PEREZ-MENDEZ: If one assumes a start graticule in one place and a spark in another, then one can say to what accuracy this distance is measured. If one repeats the measurement and then also an hour later and so on, the question is what is the spread in timing. We have done this with a time to height converter and arrived at a certain spread which was 25 nanoseconds. Of course, this is a combination of effects in the electronics and of the vidicon and of the sweep stability of the vidicon and of how well the zero cross-over really picks up the centre of gravity of a spark.

VERNON: So, with a resolution of one part in 2000 one is happy to scan fiducial lines at any arbitrary time, just comparing their position in space with what you measure, but, as I find it, this unfortunately is not the case with tracks. Depending on how careful I am, the resolution varies between one part in 2000 and one part in 1000 or 500 for tracks. I am wondering since you have the same sort of triggering system as I do whether you don't have the same sort of trouble as due to the variation in spark intensities; if you have two tracks instead of one track, the overall change in intensity changes the triggering stability a little bit.

PEREZ-MENDEZ: Well I can answer the question partially in the following way. First of all when we did these tests we changed the light intensity of a slit; that is we just varied it systematically by factors of two until finally the light intensity was such that the gating discriminator was just on the verge of triggering; when you were close to this position then the resolution curve widened up. Then we made some tests with sparks and also took pictures of them. Since the sweep is slightly non-linear we had provision for a calibration scale placed on the chamber that is the calibration scale is fed into the computer and it is there once and for all. We admit an error in the calibration scale so you can see that it was digitizing well but we did not have an absolute comparison.

GELERNTER: Is there any reason why in order to erase the previous event you can't increase the beam current in the vidicon and also increase the sweep speed?

PEREZ-MENDEZ: Well we do that, as a matter of fact, because the erasing cycle takes only 8 milliseconds so we defocus the beam and increase
both the current and the sweep speed, but then we talked to the RCA people
and they told us that irrespective of how much we increased the current
the photo-conductive layer absorbed only so many electrons and you do not
accomplish a complete erasure. Now I don't understand the physics of this
phenomenon but they assure me that this is so, and that it doesn't really
matter at what rate - I am quoting the RCA people - they claim that it
doesn't really matter at what rate you erase providing you go through a
number of erase cycles; that is if you do three erase-cycles at 100 mega-
cycles they say it is as good as having three erase-cycles at 20 mega-
cycles.

GELERNTER: I would guess that they don't understand the physics
of the situation either or else they would have solved the problem.

PEREZ-MENDEZ: We intend to look into this when we finally get
around to speeding up the entire cycle but we have not done it yet. That
is we wanted to make the system work at a certain time so we have followed
what RCA recommended to us.

ROBERTS: I don't remember you saying anything about the linearity
of the sweep and the consequent accuracy of determination of position of a
spark. You said something about the resolution. Not about the accuracy.

PEREZ-MENDEZ: What we have done in our chamber is the following,
The sweep can be made accurate to not much better than about 1% and for a
while we spent some time trying to flatten out this curve but we couldn't
get it better than 1% from linearity. However, it is quite convenient if
a metal bar with little strips of reflecting scotch-light is put in certain
places on the chamber and one shines light on it and in this way calibrates
the vidicon. It picks up these objects remarkably well, and then one can
put as many of these calibration marks as one wants and, at the start of a
day's run, one sweeps through it to record the positions and these coordi-
lates are fed into the computer. If one likes, one can also make the
graticules of small strips of scotch-tape although there may be some re-
flections in the lenses. But it is a cheap way of making whole systems
of graticules because one needs only a single flash lamp by the camera and
then as many of these little strips of scotch-light to indicate to the
vidicon where to start and where to stop. This again emphasises some-
thing that Dr. Vernon said, that you can use existing chambers and then
take the scotch-light and a razor blade and, by cutting the strips out,
it is adapted for vidicon use.

HINE: Continuing this question of linearity, are you sure a
single calibration like that is valid all over the screen? Is it stable
on an hour by hour basis? Could I also ask almost the same question of
Dr. Vernon? Is the relation between his current and spot position as
accurate as it would appear from his talk? Is his hysteresis an indica-
tion that the spot position doesn't quite seem to follow the controlling current.

PEREZ-MENDEZ: First of all about the stability. We have two sweep generators, one which generates fast sweeps and one which generates the slow sweeps. In principle they are independent and any one sweep is as good as another. If you like, one can put calibration marks at one end of the chamber and one at the other end and interpolate in between. You can put as many of these calibration marks in the dead spaces between the gaps of the chamber as you wish.

HINE: Have you been doing so?

PEREZ-MENDEZ: For test purposes we have put one on either end only. The next question about reproducibility. Naturally it would certainly be very desirable not having to perform this calibration every 10 minutes, and these tests demonstrate this is possible because we left the vidicon running for about 20 hours overnight and then looked at the resolution curve. We saw that it only spread out about 50%, that is, it had increased from 25 to about 35 nsec over a 24 hour period.

VERNON: In response to the other question, the absolute spatial position of a fiducial line, for example, where you know the position in space, changes, in my system, by about half a per cent of the whole scan due to hysteresis. I think it can be removed if I just remove the hysteresis causing elements in the system.

WEINSTEIN: Regarding the absolute number of bits you need to record, have you considered representing the position of the second spark with the binary number for the first spark subtracted, to get a very much reduced number of bits for recording and analysis.

PEREZ-MENDEZ: No not really. There are many schemes one can use, but then one worries about how errors are accumulated if, for example, there is a missing spark. After all, the reason for having say ten plates in a chamber instead of two is that the chamber sometimes misses sparks and what one really wants to record is a straight line where the particle went, and one expects to have one gap miss occasionally and still get a good straight line. So we did not want to bias the data by requiring one measurement to be dependent on another.
PART II

II. Digitized data compiler

The data recording system used with the vidicon digitizer is referred to as "Alpha 63". It has been designed as a general purpose system, capable of being used in many different types of experiments. In a spark chamber experiment, it accepts data from the several associated sources as events occur at a random rate. It arranges the data into a pre-arranged format and transfers it to a magnetic-core buffer-store. When the buffer-store is filled, the information is recorded on magnetic tape. The format of the recorded information is suitable for direct entry into a computer such as the IBM 7094.

The block diagram of Fig. 6 shows Alpha 63 and three of the external data sources that it services. These are: 1) the vidicon digitizer, 2) the scintillation counters and associated electronics, and 3) accumulative scalers and manually controlled data registers. Data from the third source are recorded only twice for each experimental run of several hundred or several thousand events and produce what is known as an identification record.

Figure 7 shows the format of the recorded data for one event from the first two sources above. For the case of a 10-gap spark chamber, the data are contained in 14 computer words. Each of these words contains 36 bits as is typical of the IBM 7090 series of computers. Two-thirds of the first word is used as event identification. The details of this portion are shown in Fig. 7b. The first 15 bits contain the serial number of the particular event. Bits 16 through 24 contain other information such as the number of the scintillation counter that detected the particular event.

The remainder of the 14 words contain up to 40 numbers (10 gaps x 2 sparks per gap x 2 views) for a particular event. These addresses are placed in a fixed, prearranged format. Such a format eliminates the requirement of recording gap identification with each address and thereby reduces the required number of bits. As shown, the first two 12-bit words contain the binary addresses of the first and second sparks found in the first gap, first view. In the cases where either the second or both sparks are missing the corresponding 12-bit words contain all zeros. The second two 12-bit words contain the binary addresses of the first and second sparks found in the second gap, first view, etc.

Details of the 12-bit address words are in Fig. 7c. Ten bits contain the binary address, giving a capacity of 1024 possible spark positions. Two bits contain a code which can indicate, for example, if more than two sparks were found in the gap, or if the 10 bits contain the "fiducial address". The
latter represents the distance between the start and stop fiducial marks, and is used as one of the means of calibrating the system. One feature of the system is that the first and last recorded events of a run are automatically caused to be calibration events. At these times, the digitizer is commanded to digitize the distance between the fiducial marks. This indicates to the computer the extent of the active area of the chamber, and additionally allows it to check for drifts in the digitizing system.

In Fig. 6, the block labelled "data combiner" controls the sequence of occurrences during the storage of an event. When the fast electronics detects the signature of a desired type of event, it fires the spark chambers and signals the data combiner. The latter first inhibits further collection of data and then transfers the 24-bits of event identification into the buffer store. Next it signals the vidicon digitizer to commence digitizing the addresses of sparks in the chamber and simultaneously connects the output of the digitizer to the input of the buffer store. The digitizer then issues the forty 12-bit words containing the spark addresses and erases the vidicon target. When finished, the digitizer signals the data combiner. It then resets its data registers, advances the event serial number register by one, and removes the inhibit condition on the fast electronics. The fast electronics now searches for another event.

The buffer store has a capacity of 1024 12-bit words. When filled to capacity by the data from 12 events, the contents of the store are transferred in a block onto the magnetic tape. During the 25 ms required for the transfer, the data combiner inhibits further acquisition of data.

The format of the data on the tape is similar to that in Fig. 7a, except that the words are broken into characters of 6-bits plus one odd-parity bit each. The 12 events are recorded without separation. In computer terminology, this comprises one data record. Each record contains 1088 characters. At a writing density of 800 characters/in., a record therefore occupies 1.25 in. of tape plus an 0.75 in. record gap. A 2400 foot reel of tape has a capacity of 175,800 events.

At the start and finish of each experimental run an identification record is put on the magnetic tape. At the start, its purpose is to record the serial number of the run for the benefit of the computer. At the end of the run, it contains the accumulation of several monitor scalers and other manually-entered conditions of the run.

In systems of this size, it is essential to have readily available facilities for testing and monitoring purposes. Means of monitoring the operation of certain critical parts and of the overall performance are needed. Methods of simulating input signals to some of the blocks should be provided, then, while building the equipment, or in case of malfunction, one can separate it into its functional parts and work on them separately. Amiduring an experiment, one can reassure oneself regarding the operation not only of
the electronics but of the spark chamber as well. Some of the facilities of this type which are built into the digitizer and Alpha 63 are described below.

The vidicon and digitizing logic have what is referred to as an analog monitor scope. It is similar to a television monitor set in that it presents the video information from the vidicon camera tube, but has other important features. The z-axis (intensity) of the analog monitor CRT can be activated by several signals besides the raw video. One source of activation is the amplitude discriminator in the video chain following the vidicon tube. Whenever a vidicon signal exceeds the threshold of this discriminator, a spot on the analog monitor is brightened to indicate that a potential spark has been discovered. As a second feature the particular horizontal sweeps actually engaged in searching for and digitizing sparks can be intensified. Also the positions of gates which may be used to activate the digitizer in only certain parts of the sweep can be shown on the analog monitor.

A second visual monitor is called the digital monitor. The magnetic tape unit has both a write and a read head. The read head scans the digital information on the magnetic tape a few milliseconds after it is recorded. A parity check is made at this time. The digital monitor interprets the data read by the read head, performs a digital analog conversation and plots on a CRT the positions of the sparks as detected, digitized and recorded. The display is a temporary one, but because of the persistence of the CRT, can be seen at least 15 s. It is repeated each time a data record is put onto tape. Reasonable appearing displays on the digital monitor are assurances that the entire system is operating properly.

The visual readout block is a device for monitoring data either from the data combiner or from the characters read from the magnetic tape. The data is displayed on three banks of 36 lamps each. Using the visual readout, one can compare the data bit by bit as received from the fast electronics and after being read from tape.

The reliability achieved with Alpha 63 has been gratifying. It was constructed entirely with silicon transistors (mostly 2N706) and diodes. When used recently with a Bevatron experiment, it ran continuously for several months with only one circuit fault, caused by a transistor failure. Since approximately 4500 transistors were used, this represents a transistor failure rate of the order of 0.01% per 1000 hours for the transistors. A possible alternative to the data recording system described would be one using an on-line computer, thereby by-passing the magnetic tape recording process.
As presently used, the above system is capable of recording information from the 10-gap chamber at a rate of about 30 events per second. About 30 ms per event is contributed by the vidicon and digitizer and about 25 ms per 12 events by the time to transfer by buffer store to tape. The latter time is short compared to the vidicon dead time. Thus, from the standpoint of speed alone, there is little advantage in using an on-line computer.
Figure captions

Fig. 1 A cross-section view of a vidicon camera.

Fig. 2 The vidicon camera removed from its magnetic shield. The deflection amplifiers are on the central printed-circuit cards. The lens is to the left, and the video amplifier card is just visible between the lens and the deflection coil.

Fig. 3 Two views of a 10-gap chamber as seen by the vidicon camera. The fast (horizontal) scan is left to right. The slow (vertical) scan is top to bottom.

Fig. 4 Signals from the vidicon camera. That of a single spark: (upper) after one differentiation; (lower) after two differentiations.

Fig. 5 The slow sweep sequence.

Fig. 6 A block diagram of the Alpha 63 data processing unit as used with a vidicon camera.

Fig. 7 Format of: (a) An event partial record; (b) Event identification word; (c) A spark-address word.
Figure 1.

Fig. 2
Spark chamber as seen by Vidicon

Fast sweep direction → Incident particles

Slow-sweep direction

Target

Gap 1 2 3 4 5 6 7 8 9 10

Particle tracks

Start graticule

Counters $N_1 \rightarrow N_2 \rightarrow N_3 \rightarrow N_4$

Top view

Projected side view

Fig. 3

Fig. 4
**Slow Sweep Sequence**

Fig. 5

**X63 Unit**

![Diagram of X63 Unit]

Fig. 6
### Computer Words

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<td>14</td>
<td>922</td>
<td>1021</td>
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**Note:** Numbers refer to gap/view/spark numbers. e.g. 922 is data of gap 9, view 2, spark #2.

### Event Serial Number

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**Format:** (a) An event partial record; (b) Event identification word; (c) A spark address word.

Fig. 7
DISCUSSION

GELENTER: Have you ever considered or felt the need for digitizing and storing the intensity of the spark as well as its position?

KIRSTEN: Well we had of course considered it - I believe this idea was originally presented by yourself several years ago and we have of course noticed it. We originally thought that we would provide several extra bits for each spark to indicate intensity, but we have not done this in this experiment since, presumably, we are dealing with a single track only and the intensity is not important. But if one is concerned with cases where there are several sparks it certainly would be useful as a means of separating the data from the various sparks.

GELENTER: Were there technical problems that prevented you from recording intensity? All you really have to use is some kind of threshold when you integrate the signal.

KIRSTEN: No the technical problems haven't stopped us simply because we haven't tried them, but I don't know of any reasons why it couldn't be done.

HINE: Could I ask my question about costs?

KIRSTEN: In this case, I believe that the data handling electronics from the data compiler to the magnetic tape control has cost us approximately $50,000. The tape unit itself is not included since we are leasing this.

HINE: Is that including labour?

KIRSTEN: That's including labour, parts and the time used to test the system.

HINE: What about the earlier part of the electronics, with the scalers, the control sets of the vidicon and so on? Is that in the $2000 that was mentioned?

KIRSTEN: No it is not. To duplicate units I believe would require in the order of $5000 per unit and also you would need one digitizing unit for each vidicon camera. The development cost of course is then much higher in this case.
VIDICON SYSTEM AT CHICAGO\textsuperscript{1)}


Chicago

(presented by H.L. Anderson)

SUMMARY

The vidicon system for spark chambers now used, in construction in Chicago, is designed to handle eight spark chambers. These will be used in two magnetic spectrometers. One pair of spark chambers is used in front of a deflection magnet to measure entrance direction. The second pair measures the exit direction so that both angle and magnetic deflection may be determined with high precision for two of the charged particles emerging from a p-p collision.

The system\textsuperscript{2)} follows the plan developed last year at Chicago. It is based on commercial closed circuit TV units connected to an analog to digital converter and circuitry to read the spark positions directly onto a magnetic tape recorder. In scanning a spark chamber event the horizontal scan is synchronized to a 10 Mc clock. Odd and even lines are handled sequentially with different registers. As the electron beam scans the odd lines of the frame a scaler counts the cycles until the first spark is reached. A second scaler continues to count until stopped by a second spark, if there is one. If more than two sparks are encountered an overflow indication is set. The scanning proceeds to the next (even) line where two additional scalers register the spark positions on that line. While the even line is being scanned the odd line scalers write onto the magnetic tape. Conversely, the even line scalers write while the odd lines are being read. In the absence of a buffer storage the system is limited by our present magnetic tape transport to two sparks per line.

Figure 1 is a sketch of the spark chamber and associated optics to allow one vidicon to see both views of the chamber.

\textsuperscript{1)} Since this paper has already been submitted for publication, only an outline is given here.

\textsuperscript{2)} H.L. Anderson and A. Barna, Review of Scientific Instruments (in press).
Eight TV cameras are used to monitor eight such spark chamber modules. The views are displayed as shown in Fig. 2. This arrangement of views is used to simplify the scanning sequence during the digitizing of the particle tracks.

Fig. 2a

REDUCTION OF ASPECT RATIO

The closed circuit television system employs a 525 line monitor operating at 30 cps without interlace. All the cameras operate in a 130 line, 120 cps non-interlace mode, and to assure synchronization are driven by one master sync generator. In this mode, the cameras operate at a rate four times that of the monitor. This reduces the apparent height of the chamber by a factor of four. With this four to one reduction, all sixteen views may be scanned in sequence from the single master sync generator. Moreover, all sixteen views may be observed conveniently on the single monitor screen in a prescribed order as shown in Fig. 2b. This system accommodates the aspect ratio of the spark chambers to that of the vidicon camera without loss of horizontal accuracy.

Fig. 2b
VIDEO SWITCH

A video switch is used for the reassembly of the sixteen chamber views into one monitor frame. The video switch allows only the signal from the proper camera to be transmitted to the digitizer and the monitor and also applies a blanking signal to all other cameras to prevent erasure of the vidicon images. The sequence of blanking and unblanking is illustrated in Fig. 3. The switch can be used to allow one camera to transmit all the time to

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B = blanking signal applied
U = no blanking signal

Sequence of blanking and unblanking for 8 vidicons for 4 to 1 reduction of aspect ratio.

facilitate the focusing of each camera. Also it can unblank all eight cameras at once to allow the beams to scan in parallel, to erase images and help prevent dark current build up on the vidicons.

Prior to an event, all the cameras are scanning in parallel and all are unblanked. When an event occurs, all the cameras are blanked until the end of the monitor frame is reached. This insures starting the video switch in the
proper position without erasure of any of the image. On completion of the monitor frame, the tape recorder is started and the video switch activated during the vertical retrace time. The digitizing of the particle track then begins with the horizontal sweep.

DIGITIZER

The digitizer consists of four 10 binary-bit counters, two each for the even and odd lines. Although 1024 positions are available on the counter only 625 are used. Each horizontal sweep is 62.5 microseconds long. The counters start when the horizontal scan begins and are stopped by the output of a "zero crossing" network when the center of a bright spot on the vidicon is reached. The second counter stops when a second track is reached, and if any more tracks are set an overflow flip flop is set. The odd line counters are transferred to magnetic tape while the even counters are counting and the even counters are transferred while the odd counters are counting. The system is limited to two sparks and an indication of overflow per line by the 62.5 kilocharacter rate of the tape unit.

The spark chambers used in this system have six gaps each and two views of each spark is measured four times per gap, a total of twenty-four per spark chamber.

After completion of one monitor frame, the switch is deactivated and all the cameras scan freely to erase the residual images on the vidicons. A new event is not allowed to trigger the spark chambers during this one erase frame. During this time, auxiliary data such as scaler counts, magnet currents and clock time are written onto the magnetic tape.

FIDUCIALS

The spark chamber modules are equipped with a set fiducial marks which can be flashed and then located by the digitizer to check the linearity of the system. The fiducials may be flashed after every event or less frequently, as required.

The write control writes the data on tape and also adds an identification code which tells which chamber is viewed and whether it is data or fiducial information. The addresses of the sparks and fiducials are written on tape as pure binary numbers. However, the auxiliary data is written in 8-4-2-1 binary coded decimal, because the scalers, etc., are equipped with binary coded decimal readouts and it is more economical to use them in this form than to convert their outputs to pure binary numbers.

The tape format is shown on the following page
THE AUX DATA FORMAT IS NOT FINALIZED
DATA IS IN 8421 BCD CODE. MAY BE WRITTEN THUS:

TAPE MOTION

EVEN PARITY USED

| ONE CHARACTER PER SCALER DECADE | TWO CHARACTER IDENTIFICATION |
---|---|

The scalers have seven decades. In some cases, two scalers will be used as one 14 bit scaler so some provision will have to be made to handle this in the computer programme.

The two identification characters will be alpha-characters.

A block diagram of the logic is shown in Fig. 5. The spark chamber spectrometer array for study of $p + p$ $p + x$ is shown in Fig. 6.
Block diagram of spark chamber television system

Fig. 5
DISCUSSION

COLLINS: What is the solid-angle of this set-up; for example one of the spectrometers?

ANDERSON: Well the solid-angle is different depending on whether one considers the high- or the low-energy particle. The controlling solid-angle in the configuration I showed is the large angle, because of the centre of mass laboratory conversion; in the configuration shown this is $3 \times 10^{-4}$ steradian. If the spectrometer is set to look for a reaction like:

$$p + p \rightarrow p + N^* \rightarrow p + \begin{cases} \pi^+ + N \\ \pi^0 + p \end{cases}$$

we would try to measure the momentum and angles of the two charged particles produced. If one asks what is the solid-angle to find the other charged particle, having found the high-energy proton, it is $3 \times 10^{-4}$ steradian and the combined solid-angle is of the order of $10^{-7}$. With a cross-section of one millibarn, this allows one to get reasonable counting rates with a beam of $10^{11}$ protons/burst. The system should detect these processes if one is willing to collect about a count per hour. It should be possible to detect $10^{-1}$ microbarn/steradian cross-section. So it is capable of detecting rather rare events and that is the sort of thing we are looking for. One of the objects of our research is to look for isobars that are produced with somewhat higher momentum-transfers than have been found so far.

SALVINI: Concerning the positions that one can get with this spark chamber. Since the position of the track can be determined very precisely with this spark chamber, is it correct that other sources of error may be much larger than the possible precision of the spark position in your experiment?

ANDERSON: Well you must have some particular effect in mind?

SALVINI: Possible effect of coulomb scattering or uncertainty in precision of the magnetic field.

ANDERSON: Well no, not in any of the configurations I have calculated so far, because our spark chambers are really quite thin. They are made of 1 mil aluminium foil and, unless one goes below 2 GeV/c on the proton side, that is not a limiting factor.

SALVINI: What is the distance between the spark chambers?
ANDERSON: In the diagram I showed, 5 metres is the typical distance between spark chambers for the high-energy proton before and after the spectrometer. On the low-energy side, the separation is 2.5 metres so that, since we expect to be able to locate the spark to one millimetre, the precision is one part in 2500. You will have to remember that in our case we don't just measure each spark once but we measure six sparks each four times, so that I think we will be better in precision than one millimetre. That is the precision with which we can measure an angle. Now the deflection in the magnet, in the case of the low-energy magnet, is 0.3 radian, so that the measured momentum is one part in 750, which is useful because it permits us to measure well inside the widths of these resonances.

SALVINI: So we understood the Vidicon system is more than adequate?

ANDERSON: For this type of experiment I would say so. That is this type of experiment has the following features, namely that we expect to find tracks essentially perpendicular to the spark chamber plates, since the signature of an event is extremely simple.

I didn't say very much about the programming but we have a programme written which has been through a certain amount of testing, which will establish the relation between the spark and the fiducial marks. If there is more than one spark in the group, the sparks are grouped together into a track, and we then proceed to make a least-squares fit for the track, locate the track with respect to some part of the chamber and measure its angle with respect to the normal. The experiment is such that we expect the more simple type of spark chamber event - usually one straight track. We are prepared to handle two sparks, one from some background or other, and we have an indication when there are three. We think that the programming for such a system should be somewhat more straightforward and less subject to the pitfalls which have developed in more complicated types of signatures. The schedule for this work is that we have a cosmic ray test in which we will line up first three, then all eight of the chambers and also try out the programming to make sure that it really measures cosmic ray tracks.

The present schedule calls for that to be started around the first of May. We hope to have the p-p elastic scattering test, late in the summer, when we hope to be able to have a chance to run with a parasite beam. Then, if we are convinced that we know how to measure to the accuracy we claim, we should be able to turn to experiments first on isobar production, in which we use the same set-up, and later other p-p type experiments. Here, we have been concentrating on the use of the external beam as our particular area of exploration in high-energy physics research.

LIPMAN: Presumably, if you would like to push to much higher repetition rates, the direction in which to go would be to cut down the number of gaps from 6 to say 2 and to scan each gap only once. I would guess then that
you would be able to record something like 30 events per burst. Are there any limitations in your system which would stop you from doing that quite rapidly?

ANDERSON: No. The present limitation of our system is the speed of tape recording, that is, we are limited by the particular tape transport we use, operating at 112.5 inches per second and 556 characters per inch, and we cannot record on that faster without a buffer. At present two registers have to be read out in the time that the electron beam of the Vidicon is scanning one line which is 62.5 µsec. The fundamental time in the commercial Vidicon is 62.5 µsec, and if only a tape is going to be used one is limited to two sparks on a line. If one can use one of the more modern tapes which move faster and have a higher bit density we can improve on this. If one takes this 62.5 µsec, which is the time to read out the information on one Vidicon scan, add another 70 µsec for erasure, then the basic time for reading, say, the equivalent of a sonic chamber or digital plane in the wire chamber, is about 150 µsec. Of course, with buffer storage and many vidicons one can read many planes simultaneously, and then the time between pulses to dump the information onto magnetic tape or an on-line computer. We would certainly like to move in that direction.

If one thinks in terms of taking ten sweeps to read one of our spark chambers, which has six gaps, then it takes in the order 1.5 msec to deal with an event. Then if the beam is 100 msec long as expected, it is quite feasible to get about 60 events/pulses. We even have some plan to do the buffering.

LINDENBAUM: This assumes that the spark chamber can recover in a millisecond?

ANDERSON: Yes that is a good point, namely, one is already limited by the spark chamber recovery, not by the Vidicon. However, one talks about millisecond figures for spark chamber recovery too.

LINDENBAUM: I searched the literature just from that point of view, because we are very interested. That is the real limit in our using sonic detectors. So far I haven't been able to find any proof that any chamber sonic or even wire can recover in a millisecond in an operational case.

ANDERSON: You may be right about this. There are enough people here so that, if someone knows differently, he may speak.

LIPMAN: About three years ago people in the Lundby Group did tests with the spark chamber and showed that you could make them recover in less than a millisecond if you had alcohol as a quencher inside the spark chamber. So I think a millisecond can be obtained.
ANDERSON: I would like to believe that ultimately we will get to one millisecond or two recovery time, but I think your point only emphasizes that the vidicon system is really spark chamber limited.

HINE: Are you still using mainly commercial closed circuit TV systems for these 8 cameras?

ANDERSON: Yes we do. We recently purchased the 8 TV cameras complete with control equipment and they cost $3,000 each.

HINE: What about the rest of the electronics, which is beginning to get more complicated?

ANDERSON: We purchased the rest of the electronics as modules from the Digital Equipment Company. They have been very satisfactory and reliable, and all the digital modules for the eight-chamber system, which is the one we are now assembling, cost $20,000. We have to wire that, and that will take one technician one month or a little less.

ROBERTS: I have two comments, first about the recovery of the spark chamber. The shortest times I know were claimed by J. Fischer at Brookhaven who claims to be able to get events as close together as 200 μsec with a wire chamber. The other point is that, in this 1.5 msec, you do not appear to have allowed for erasure.

ANDERSON: Yes, I added so many μsec for erasure.

ROBERTS: Just one sweep?

ANDERSON: Yes, that is all that is needed.

ROBERTS: That is not what it says in the book.

ANDERSON: I do not care what it says in the book. We have tried it. The point is that the signal-to-noise ratio in the vidicon is not so enormous, and all you really have to do is keep above the noise. So that the requirement of TV that RCA is interested in, namely for television reproduction, is not relevant. That is, once you reduce the secondary image a little, it falls below the discriminator setting and then one erasure is quite sufficient.

VERNON: If you do not mind vacuum tubes, I would like to mention one TV system which is made by Blonder-Tongue, and the total system complete with the channel 6 output is $750. I find it has a very excellent deflection system.
ANDERSON: Yes, I am sure we didn't buy the least expensive system because we were anxious about reliability. We were deeply impressed by the high cost of machine time and very much concerned about the fact that the first time we went to the machine we wanted to put on a good performance so that we wanted everything to work about as well as Sam Lindenbaum's apparatus.
A VIDICON SPARK CHAMBER SYSTEM FOR USE IN ARTIFICIAL EARTH SATELLITES

G.C. Fazio
Smithsonian Astrophysical Observatory,

1. INTRODUCTION

The Smithsonian Astrophysical Observatory has proposed an experiment to search for extraterrestrial high-energy gamma rays using a spark chamber detector in an artificial earth satellite. The use of film-less spark chamber techniques is essential in this experiment, not for speed of data reduction, as in accelerator experiments, but primarily for transmission of the spark information to the earth. An additional advantage of the film-less technique is the ease of reduction of a large amount of data. The received signal can easily be digitized and sent to a computer for analysis. Of the various film-less techniques available, we selected the vidicon system because it satisfied the criteria for accurate spark location, multiple spark detection, and simplicity. In addition, a complete analog and digital vidicon system was available at the Observatory. A similar system is being used by Project Celescope, an ultraviolet telescope experiment in the Orbiting Astronomical Observatory.

2. IMPORTANCE OF GAMMA-RAY ASTRONOMY

Extraterrestrial gamma-rays are important because of the direct knowledge of high-energy and nuclear processes in the universe that can be derived from their detection. This knowledge is direct because the radiation (1) is related rather simply to the nature of its source; (2) travels in a straight line from the source; (3) is detected with an energy differing little from the emission energy; and (4) undergoes little absorption in transit through the universe. The absorption, however, is great enough (i.e. a radiation length of ~75 g/cm²) that this radiation cannot have originated from stellar interiors.

The detection of gamma radiation can yield very fundamental information about high-energy and nuclear processes in stellar atmospheres, interstellar space and galactic haloes. In addition, gamma radiation can yield information about regions of the universe that are opaque to all other forms of electromagnetic radiation.
The methods of production of high-energy (> 50 MeV) gamma radiation are rather simple. The main sources are

i) high-energy proton-proton or proton-nucleon collisions;

ii) proton-antiproton annihilation;

iii) electron bremsstrahlung, i.e. radiation caused by acceleration of an electron in the field of a nucleus; and

iv) inverse Compton effect.

The detection and analysis of this radiation can lead to information on

i) the nature of radio sources, such as the Crab Nebula, Cygnus A, and M87, and whether they are origins of cosmic corpuscular radiation;

ii) cosmic-ray intensity in our galactic disc and galactic halo and in intergalactic space;

iii) the nature of active regions on the sun;

iv) the density of anti-matter in the universe.

3. VIDICON SPARK CHAMBER SYSTEM

Attempts to detect galactic and extragalactic high-energy gamma radiation in high-altitude balloons and satellites have been hindered by background radiation produced by cosmic-ray interactions with the earth's atmosphere and with the spacecraft. Theoretical estimates of the primary gamma-ray flux are dependent on the assumed source, but are of the order 10⁻⁵ photons cm⁻² s⁻¹ steradian.

The usefulness of astronomy in this portion of the electromagnetic spectrum depends on definite intensity and angular distribution measurements of celestial sources of this radiation, in addition to the energy spectrum emitted. It is therefore very important that the background radiation in gamma-ray detectors be understood and eliminated. In an attempt to solve this problem, the Smithsonian Astrophysical Observatory has undertaken the design and development of a vidicon spark chamber system for use in gamma-ray astronomy.

Preliminary tests and analysis of the detector have shown the idea to be very practical and worthy of development. In comparison to present and proposed detectors, this system has the following advantages:
i) it has a large sensitive area;

ii) it has a large sensitive solid angle, with ability to determine arrival direction of particles to within one degree;

iii) it is triggered by counters to display only the selected type of interaction;

iv) once an event is selected, the chamber is sensitive only for about 1 µs; properties (3) and (4) permit the chamber to be placed in a relatively intense background particle flux so that specific interactions occurring with low probability may be detected and recorded;

v) since the system is a visual device, the nature of the entire event can be viewed so as to determine whether all selection criteria are satisfied;

vi) the visual output has an extremely high signal-to-noise ratio;

vii) it has simplicity, versatility, reliability, and low cost of construction and operation, even for large chambers.

The spark chamber detector could be placed in the Orbiting Astronomical Observatory (OAO) satellite. The OAO is a precisely stabilized satellite capable of carrying 1,000 pounds of experiments. The satellite is intended to orbit the earth in an approximately circular orbit at an altitude of 500 miles. The spacecraft is an octagonal aluminium structure, 118 in. long and 80 in. across the flats, with a hollow central tubular area 40 in. in diameter and 110 in. long, which contains the experimental packages.

A proposed gamma-ray detector for use in this satellite is shown in Figs. 1 and 2. The detector consists of 4 spark chambers, labelled (1), (2), (3) and (4), scintillation detectors A and C, and Cherenkov detector B. The incoming photon is converted into an electron-positron pair in one of the five aluminium plates of chamber (2). The plates of this chamber are constructed of 1/8 in. sheets of aluminium. One or both of the electron-positron particles produced are detected by the coincidence of signals from Cherenkov counter B and scintillation counter C. Scintillation counter A will give no signal. Such a coincidence of signals, signified by ABC, initiates a high-voltage pulse that is applied to all the spark chambers. All charged-particle tracks traversing the chamber within a time interval of 1 µs are exhibited as sparks, and the event can be identified as caused by a gamma-ray photon.
Spark chamber (1) verifies that no charged particle entered the system and that the gamma-ray was not produced in the chamber. This chamber consists of five, thin aluminium plates. The exhibit in spark chamber (2) indicates in which plate the photon interacted to produce a pair of charged particles. The interaction mean free path for photons can thus be determined from a collection of such events. Spark chamber (3) exhibits all the tracks of the charged particles produced by the gamma-ray, again verifies the event and, when combined with the view in chamber (2), provides a method of determining accurately the arrival directions. This chamber also consists of five, thin aluminium plates. If the initial photon has sufficient energy, a photon-electron (positron) cascade will develop in spark chamber (4), thus permitting a determination of the photon energy. Spark chamber (4) consists of two groups of five lead plates, each about 0.9 cm thick (1.5 radiation lengths), giving a total interaction mean free path of 15 radiation lengths.

The scintillation and Cherenkov counters serve as "event selectors". The Cherenkov counter detects only relativistic particles, thus preventing all low-energy protons from triggering the chamber. By selection of only certain events above given light levels in the Cherenkov counter, the triggering system can be made even more selective.

In contrast to previous detectors proposed for gamma-ray astronomy, the anti-coincidence system of scintillation counters need be neither extremely efficient nor elaborate. All cases of a charged particle passing through the system without registering in counter A can be eliminated by the display of sparks in chamber (1).

The electron circuitry for amplification of the pulses from the scintillation counters as well as the digital logic to trigger the high-voltage pulse is rather simple. The high-voltage pulse from the chamber is obtained by discharging, through a spark gap, condensers charged to the necessary voltage. The condensers can be gradually charged between firings by a transistorized high-voltage power supply. No vacuum tubes will be used in generating the necessary high-voltage pulse.

The sensitive area of the system for gamma rays is about 500 cm². The solid angle subtended is about 0.7 steradian.

Two vidicon tubes will be used in the system to supply redundancy of data collection; the system will, however, be able to operate on one tube.

To obtain stereoscopic views of the chamber, as well as to collect the light from all the chambers onto one camera, a system of plane mirrors will be used (Figs. 1 and 2). Stereoscopic views at 90° of the tracks in the chamber will permit the determination of their space orientation, and thus the photon arrival direction, to an accuracy within 1°. The absolute orientation of the spacecraft will be known to one minute of arc.
4. TELEVISION SYSTEM

In the present system used by Project Celescope and being built by Electro-Mechanical Research, Inc., there are three methods for transmitting the vidicon image. The primary mode is digital-direct scanning. Here the amplitude of the signal at each image element is converted to an 8-bit word and transmitted directly by a wide-band transmitter to the ground. This is a real-time operation. The second mode is digital store. In this mode the position and amplitude are determined for each image element for which the light amplitude exceeds an adjustable threshold. This information is digitized and transmitted as a 25-bit word (7-bit amplitude, 18-bit position) to the data storage aboard the spacecraft. The third method is analog direct. Here the video signal is transmitted directly to the ground by the wide-band transmitter.

The satellite’s storage capacity for experimental data consists of 4,096 words with 25 bits per word when operating in a 100 per cent redundant mode. The non-redundant operation doubles the capacity to 8,192 words.

The spacecraft communication equipment consists of four radio links: (1) radio command (143 Mc/s); (2) radio tracking beacon (136.44 Mc/s); (3) wide-band telemetry (400.55 Mc/s); and (4) narrow-band telemetry (136.26 Mc/s).

In the digital-direct mode the picture consists of 256 x 256 elements (8 bits/element), and the information is transmitted on wide-band telemetry by pulse code modulation (PCM) at a 50 kilobit/s data rate. The frame time is 2.1 s. In digital-store mode a 256 x 256 element (25 bits/element) picture is used. The frame time is 10.7 s. The analog picture, which consists of 300 line elements, is transmitted by FM with a bandwidth of 62.5 kc/s. The frame time is 0.48 s. For use with a spark chamber the picture element resolution will be modified to give more horizontal and less vertical resolution.

The picture to be transmitted, e.g. the spark pattern, is stored on the light-sensitive face of the vidicon tube. The digital processing of the picture frame is achieved by an analog-to-digital conversion of the amplitude of the vidicon beam current as the stored picture is scanned. The horizontal and vertical sweeps are digitized by application of staircase voltages to each pair of electrostatic deflection plates of the vidicon. The staircase voltage is developed by a digital-to-analog converter. The vertical digital sweep generator also provides a "super-scan" sweep. This is a vertical sawtooth signal about 10 lines in amplitude, which occurs at every step in the horizontal sweep. The intensity of light at the picture element is sensed only during the peak of sawtooth sweep. The deflection of the "super-scan" occurs from a horizontal line that has been read, down 10 lines to the horizontal line that is being read. When the light signal exceeds a preset level, the super-sweep returns, and all sweeps stop, leaving the beam in a portion of the picture already read. The amplitude of the light signal sampled and the horizontal and vertical sweep positions are then transmitted directly, or read out digitally,
at a relatively slow rate into the satellite storage. Data are read out only when the light level stored by the vidicon exceeds a preset level.

5. APPLICATION TO HIGH-ALTITUDE BALLOON FLIGHTS

The vidicon spark chamber system using only the analog mode of data transmission can also be applied to cosmic-ray experiments in high-altitude balloons. A commercial ruggedized vidicon system and transmitter are used in the balloon gondola. The signal is transmitted to a ground trailer, where video tape and kinescope recordings are made. The spark chamber picture can also be viewed on a monitor for real-time inspection. The video tape record is then returned to the laboratory for conversion from analog to digital data for use directly with a computer. The data-reduction problem is thus greatly simplified. The kinescope recording provides an additional permanent film record.

Figure 3 shows a kinescope recording of a \( \mu \)-meson track in an eight-gap chamber, with a gap width of \( 3/8 \) in. The left track is a 90° stereo view. The stereo track is not resolved so well because the back-surfaced mirror used to obtain the view generated multiple reflections. The vidicon used was an RCA 6198 with a magnetic deflection system. Similar quality images of \( \mu \)-meson tracks were recorded in the laboratory by transmission of the analog video signal at a frequency 862 Mc/s with a bandwidth of 4.5 Mc/s.

6. CONCLUSION

The combination of a spark chamber system, vidicon readout of the spark information, and on-line computer analysis of the data can provide a powerful instrument for the search of high-energy primary gamma radiation in balloons and satellites.

ACKNOWLEDGEMENTS

I am indebted to Dr. Henry Helmken, A. Goldstein and F. Licata for contributions to this work, and to Project Telescope for use of the vidicon system.
Figure captions

Fig. 1  Side view of the proposed spark chamber system for the OAO satellite

Fig. 2  Top view of the proposed spark chamber system for the OAO satellite

Fig. 3  Kinescope recording of a $\mu$-meson track (with stereoscopic view) as received from a vidicon viewing the spark chamber
DISCUSSION

ROBERTS: What are the dimensions of the chamber?

FAZIO: The ones proposed for the satellite are 13 by 16 inches.

ROBERTS: There will be a gamma-ray shower, of course, and hence many sparks in one gap. Are you preparing to send back all the sparks and get information about the energy of the shower from that?

FAZIO: Yes. The situation essentially is the following: One does not know when these events are going to occur so one would like to look for as long as possible. Therefore, one would like to see the satellite work for the entire orbit. Now it doesn't take many events to fill up the memory, so one could fill up the memory, then cut off the apparatus and read it out when it comes by. The other alternative is not to use the memory at all and just look many times per orbit; i.e. many ten minute looks per orbit. Now this may not be entirely impossible, since the Smithsonian Astrophysical Observatory is responsible for satellite tracking and, therefore, has quite a few stations around the earth that are continually manned with cameras to record satellite tracks. It could be cheaper to outfit each station with a receive capability analogue-wise than it would be to digitally convert the signal aboard the satellite. So this may be another way out, but there are all three modes available to do this here essentially.

AVRAM: Could you give the total power consumption of your vidicon and peripheral equipment?

FAZIO: At the present time 30 watts are used on the telescope equipment which is an extremely complicated device because there are all kinds of focusing controls and there are innumerable commands available; one can refocus the system in orbit, read just the voltages, read all the voltages and so on. We hope to cut this down considerably with the vidicon but 30 watts are being used now.

NEUMANN: May I suggest that a wire chamber might have the advantage of a slower pulse rise time. You would save a lot of power because you could cut your spark current by orders of magnitude.

FAZIO: That is true. Also, keeping the filament on the vidicon the whole time is the major factor in power consumption. The problem is that one is facing competition, and this experiment had to be proposed last year in order to make a satellite in 1969, so one is forced to do whatever is on hand and make the best of it.
STARK: You mentioned 100% redundancy in the data transmission line. What does it mean - merely repetition?

FAZIO: Yes. One can make the memory repeat itself again to make sure there are no errors in storage.

STARK: What about the correct information you get, in case of an error? If one of the transmissions fails which is the right one?

FAZIO: One would probably reject the whole information. Redundancy in reliability of operation becomes very important in this system but there are many drawbacks; for example, as happens in all satellite experiments one makes an extremely redundant system operate and then the satellite is assembled so that it is very difficult to get at it again. Then, when you actually go to fly you don't know how many transistors are working because it is so redundant that you can't tell whether everything is going or not.

VOICE: Since the point of this is to measure directionality, you are going to have to know the instantaneous orientation of this spark chamber? How did you do that?

FAZIO: The spacecraft has certain capabilities which were engineered into it, and this particular one has a star tracking system built into it which will orientate the vehicle in all three directions to about a minute of arc; if there is a telescope aboard, to give you a fine control, it has the capability of going down to a tenth of a second of arc, in pointing, by star tracking. The advantages of a spark chamber with such a wide solid-angle is that we don't have to aim it at a certain star, we just have to know where the thing is pointing; then, once we have a reference system, then we can calculate everything about the orientation.
VIDICON DEVELOPMENT FOR THE LUND SYNCHROTRON

G. von DARDEL
CERN, Geneva
G. JARLSKOG
Institute of Physics, Lund

(presented by G. von Dardel)

The research programme with the 1.3 GeV Lund electron synchrotron foresees measurements of the polarization of the recoil proton in pion photoproduction by polarized gamma rays. To achieve sufficient statistics it is necessary to cover a large solid angle and to measure the polarization with high efficiency. A spark chamber with carbon plates seems to be the most suitable detector. The required number of events is of the order of $10^7$ which makes it imperative to use a filmless method of recording. The filmless techniques are also particularly well suited for this type of experiment, since only one track is measured in each event and the data treatment is relatively simple. The expected counting rate is about one event per machine pulse, or 12.5 p/sec, later to be raised to 25 p/sec.

As a 40-plate chamber will be necessary to achieve sufficient precision in the determination of the range of the proton recoils, it was clear that sonic or wire spark chambers would require much digitizing equipment and buffer storage facilities and would of course be out of bounds for a university laboratory. The vidicon system seemed particularly adapted to our need, since the photoconductive layer provides a cheap buffer storage for the information in analogue form, from which it can be read out and digitized at the rate an on-line computer can accept.

We have the privilege of having near to the accelerator a small home-built computer, with an operating staff able and willing to make the necessary changes to the machine to allow information to be fed in directly from the vidicon system to the external core memory of the computer. This allowed us to plan the equipment for on-line operation, thus eliminating the need for an intermediate data storage on magnetic tape.

In measuring polarization effects from the usually quite small left-right asymmetries in nuclear scattering, it is imperative to eliminate as far as possible all biases which can give such an asymmetry.
Vidicon systems using the normal television type sawtooth scan have such a bias, particularly if only one spark is recorded per sweep, since two crossing tracks will appear as one track scattered always in the same direction. Even if several sparks can be recorded per track this bias will subsist when the separation of the two tracks is less than the resolution of the system. For this reason, we decided to use the vidicons with a triangular sweep which eliminates this bias. It was then necessary to redesign new sweep circuits for the chosen vidicon, a commercial Philips television camera, type EL 8000. We now use a sweep time of 1 ms, which is much longer than the normal sweep time.

Apart from the feature of the triangular sweep, the principle of the electronics, (Figures 1 and 2) for the vidicon differs little from that used by other groups. The vertical sweep is a staircase sweep which in simple geometries can be directly matched to the spark chamber, so as to sweep once through every gap. For more complicated geometries, such as the case where two views of the spark chamber are displayed side by side with slightly different magnification, we intend to use a guiding system, where a photomultiplier watches a cathode ray screen with a mask in front of it. The photomultiplier produces a correction voltage to the vertical deflection so as to keep the light seen behind the mask constant. This forces the beam to follow any zigzag trajectory determined by the shape of the mask.

The logic of the digitizing circuits is best understood from the pulse shapes of Figure 2 for the particular example of a spark chamber event shown schematically in Figure 3a. Two views are displaced side by side, each confined between a left and right fiducial line with respect to which spark positions are measured. The video signal from the vidicon is amplified and discriminated by a threshold discriminator. A group of four discriminators operated by the triangular sweep generates an identification gate, which allows a distinction to be made between pulses from reference lines and from sparks. In each sweep a gate is opened by the first spark encountered in one view and closed by the following reference line to the left or to the right, depending on the sweep direction. Figure 3c shows the gate signals produced by the picture of 3a. The ability of the circuit to distinguish two tracks is clearly demonstrated. The duration of the gate is then digitized in the standard way by a scaler counting pulses from a 2 mc/s clock. The contents of the scaler after stopping are read out to the computer and the scaler reset. The time needed for read out with our computer is about 10 μsec.

Calibration of the measuring system is carried out on every sweep by a second gate and scaler which measures the distance between the reference lines to the left and the right of each view.
The circuits of the present version is built in a single 6" standard chassis with five plug-in units. Philips standard circuit blocks have been used throughout and greatly facilitated the design, the construction and the testing of the circuit.

Although the apparatus will already in its present form serve the purpose for which it was planned, modifications and extensions could easily be introduced to make it more generally useful. Duplication of the sweep circuits allowing the successive read out of several vidicon tubes will allow greater flexibility in the optical system for the experiments, as it obviates the need for a complicated mirror system. The use of an intermediate flip-flop memory into which the instantaneous scaler position could be dumped would allow many sparks per gap to be recorded. For 1 ms sweep sparks separated by as little as 1/100 of the sweep could be recorded.

It may turn out to be unnecessary to calibrate the sweep circuits in every gap on every picture. Occasional flashing of an artificial track in front of the chamber is probably sufficient for calibration, and would result in a simplification of the circuitry.

We are grateful to Messrs R Dupuis and J. Jevello of the CERN Nuclear Physics Division for the assembling and wiring of the circuits.
Figure captions

Fig. 1  Block diagram of vidicon circuits

Fig. 2  Pulse shapes at various points in the block diagram. Note the change in time scale at the centre of the diagram

Fig. 3  a) Actual test pictures taken with the vidicon system on an artificial spark chamber event

b) The video output after discrimination. The signal at the right hand side of the picture and the distortion of the right reference lines are due to the rim of the vidicon active surface, as in these preliminary pictures the vidicon was not well centred

There are also some spurious dots generated during the vertical fly-back. Since alternate horizontal sweeps are in different directions, delay in the video circuit cause a zig-zag appearance of tracks and reference lines without, however, affecting the distance between them

c) The gate driving the scaler

Fig. 4  Sweep pattern of vidicon system with the signals from sparks blanked out by the identification signal so as to leave only the reference lines
Fig. 1

PULSE SHAPES

HOR. SWEEP
IDENTIFICATION SIGNAL

INTERFERENCE ANTENNA

VIDEO SIGNAL
"SPARKS"
REF. LINES
GATE "SPARKS"
GATE "REF"

HOR. SWEEP
"BEAM GATE"
VERT. SWEEP
FOCUSBING
READ OUT

PREPARE
READ
ERASE

10ms 20ms 50ms

Fig. 2
DISCUSSION

LEVRAI: What is the maximum time one has to do the scanning, after the triggering of the spark chambers. In the Chicago experiment and in the satellite experiment the beam stopped, or several cameras are scanned one after the other.

DARDEL: No deterioration of the picture will occur within the next 20 milliseconds after it has been formed so this is the sort of time one has available - it could probably be prolonged if we wanted.

FAZIO: Yes, one can go much longer than this. If one wants, there are certain tubes that will store for seconds.
II. MORNING SESSION

WIRE CHAMBERS

Chairman : F. Krienen, CERN
Secretaries: H. Bliedon, CERN
B.W. Evershed, CERN
A SIMPLE DIGITIZED CHAMBER

I. PIZER
CERN, Geneva

Whereas wire chamber readout systems using one square-loop ferrite core per wire (1)(2) are attractive, and can use known read techniques, it is also an expensive device, and difficult to produce.

By using printed circuit techniques, and by grouping wires, it has been possible to make a simple chamber for handling single sparks.

The model consists of one set of wire electrodes made by the normal photo-etch technique. The 100 wires are \( \frac{1}{4} \) mm copper on a 1-5 mm fibre-glass backing, spaced every 1 mm over a distance of 100 mm (Fig. 1). The second chamber electrode can be a thin aluminium sheet.

The wires are grouped in ten sets of 10. Each set of 10 passes through a small transformer core. The 10 secondary windings, each of one turn, give ten outputs indicating in which decade a spark has occurred. Having passed through the first set of cores the wires are regrouped and pass through a second set. In this case all the first wires of the first grouping pass through the first core of the second set. The second wires pass the second core, etc. The result of this grouping is that the first set of cores indicate the decade and the second indicate the unit position. The wires all finish on a common mass.

It should be noted that when a spark occurs the current is guided through the appropriate cores, and causes a secondary signal, which we have found to be of the order of 20 volts, and 20 nanoseconds wide on 50 ohms when pulsed with 10 kV from a 125 pF condenser, and 1 cm gap. The core is not used as a memory. The signals are sent to an appropriate memory device such as a string of flip-flops, and indicates, in decimal form, the wire number onto which fell the spark.

The present single fibre-glass board has about 300 mg/cm\(^2\). A mylar sheet or thin fibre-glass can be as low as 25 mg/cm\(^2\).
There seems no reason to exclude the possibility of a single chamber consisting of one plane of electrodes in one direction with the second plane also wires, but in the orthogonal direction, such that one chamber gives both x and y coordinates. The problem is one of insulation, since the cores are only current sensitive. This has not yet been tested. The cores are Philips K300497, 3-ES.

The chamber demonstrated has been used and triggered by cosmic rays and given correct coordinates of sparks.

A further simplification can be introduced by coding each decimal digit into a binary number. This is more suitable for data handling and reduces the number of wires.

When many wires are used the simplification can be seen by the following example: consider an electrode plane of 1024 wires, grouped into thirty-two sets of 32. There would be 64 transformer cores and 64 output signals. If we code each group of 32 wires, using a diode matrix, into a 5 bit binary word we arrive at only 10 outputs, requiring only a 10 bit buffer memory, at the cost of 66 diodes.

Thus a two-dimensional chamber of resolution 1 in 1000 in each direction can record two orthogonal coordinates in one 20 bit word, with nearly no reading delay, since the buffer is set as the signals arrive from the transformer cores.

References

1. J. Fischer et al. ENL 7616, Brookhaven National Laboratory.

Fig. 1  Diagram of 100 wire spark chamber showing grouping of wires for coding.
Fig. 1 Diagram of 100 Wire Spark Chamber Showing Grouping of Wires for Coding
DISCUSSION

GORENSTEIN: Have you succeeded in finding a transparent backing for the wires so that the track may be photographed? A transparent chamber could considerably simplify the optics of many types of experiment.

PIZER: No, I have only had it on mylar which is not particularly transparent and this fiberglass which is also not transparent.

J. MILLER: Are you concerned about the effect of undercutting due to the etching? Will the radius of curvature of the anode wires be sufficiently uniform?

PIZER: I have not done any experiments yet along those lines, but Fischer at Brookhaven may have already done such measurements.

ANDERSON: Could you tell us a little about how these printed circuits stand up against repeated sparking? There is some erosion that can go on because of the heat of the spark.

PIZER: The fact that you don't need very strong sparks means you will not have much trouble. I have not looked under a microscope, but I have certainly seen no damaging effects so far.

ANDERSON: With what counting rates have you been operating?

PIZER: It is less than a million per hour, but I don't know the number exactly.

J. MILLER: There is no damage to the electrodes because the discharge is very gentle. Only 5 kv pulses are necessary to write a core.

MAEDER: What is the recovery time of such a spark chamber? It should be much shorter than for a conventional chamber where one needs a very strong spark.

PIZER: Are you speaking of the chamber itself or the electronics?

MAEDER: I am referring only to the chamber.

PIZER: I don't think there is anything special about the difference between an ordinary chamber and a wire chamber.

SALVINI: The recovery time of a spark chamber is longer the greater the power dissipated in the spark. In this respect, the lower operating voltage of a wire chamber implies a faster recovery time relative to a conventional spark chamber.
COLLINS: This has been measured with the spark chambers by Fischer of Brookhaven, who finds recovery times of 200 μsec.

HINE: Doesn't this coding system suffer from an essential ambiguity if more than one spark occurs? For instance, with your decade coding you are still unable to distinguish between 53 and 27, and 57 and 23. Can this ambiguity be removed?

PIZER: It is true that some information is lost in this type of coding. However, for two sparks, this problem can be solved by using two chambers. For more sparks more chambers would be required and the coding gets rather complicated. Actually, this work was started when interest seemed greatest in one spark-per-gap experiments. I agree that interest is now shifting to multi-spark recognition.

R. MILLER: When we studied the problem of encoding on wires, we noticed that a binary encoding permitted, by the use of polarities, the encoding of both address number and its (two) complement. From this, one can disentangle two sparks from the same pulse.

MAEDER: Can you have sparks directly between two crossed wire planes or do you always have to have one full plane between two wire planes?

PIZER: I believe that it is possible to use crossed wire planes this way, however, I have had no practical experience. There is the problem that in the plane receiving the high voltage pulse, the high voltage would appear on these wires, but if you can insulate your secondary from your primary, I think it is possible, because the transformer is only current sensitive.

COLLINS: We have tried operating with sets of crossed wires at Brookhaven and in principle it is certainly possible. In practice it turned out to be rather difficult to pulse a plane with the cores on it and it seems that at this point it is simpler to make two separate sets of planes each with one set of wires and a stacking plate rather than try to combine them.

PIZER: What was the reason for the difficulty?

COLLINS: We found that the pulsing of one set of wires interfered with the readout of the cores since there was a tendency for the cores to be flipped as a result of the applied pulse.

PIZER: Even when there was no spark?

COLLINS: Yes. I am sure this can be avoided if one goes to enough trouble but it is probably not easily solved.
MAGNETIC SPECTROMETER SYSTEMS USING DIGITIZED DISCHARGE PLANES

G.B. COLLINS, J. FISCHER and W.A. HIGINBothAM
Brookhaven National Laboratory, Upton L.I., N.Y.

(presented by G.B. Collins)

Digitized Discharge Planes are being developed at Brookhaven, together with fast electronic systems to read out the planes and transfer to computers the information they contain on particle coordinates. The first version of these discharge planes has been tested and the results reported by Fischer, Collins and Higinbotham\textsuperscript{1}). These tests showed efficiencies over 99\%, spatial resolution of \pm 0.5 mm, and that the performance of the planes was quite reliable. The planes also contain very little material in the area traversed by particles so that multiple scattering is small (\(\Delta \theta = 1\) mr at \(p = 1\) GeV/c). Multiple as well as single particles can be recorded as shown by Fig. 1. The energy per discharge in these planes is quite small, and we believe counting rates as high as 1000 per 0.2 sec are feasible. In fact, earlier experiments by Fischer\textsuperscript{2}) indicate that in small planes recovery can be accomplished in a few hundred \(\mu\text{sec or less.}\) The combination of high spatial resolution, high speed and large physical dimensions possessed by these planes, makes possible magnetic spectrometers with the following characteristics:

1. Angular resolution \(\Delta \theta \sim 0.3\) mr
2. Momentum resolution \(\frac{\Delta E}{P} \sim 0.5\%\)
3. Solid angle of acceptance \(\sim 10^{-2}\) ster (limited by aperture of magnets)
4. Momentum acceptance of several GeV/c
5. Counting rates \(\sim 1000\) per pulse
6. Resolving times \(\sim 300\) nsec.

These are a representative set of characteristics which can be varied to meet particular needs.
We have planned a series of experiments with magnetic spectrometers which use discharge planes. Two out of the series of experiments now being planned using these spectrometers are:

1. Very small angle elastic P-P scattering

Two discharge planes separated by 10 metres are located in front of a hydrogen target and a magnetic spectrometer with corresponding dimensions is located behind the hydrogen target (Fig. 2). An incident beam of 1000 protons per pulse traverses this array and the coordinates of every proton before and behind the target are recorded. Thus, very small scattering angles (limited by multiple scattering in the target) can be measured without bias. The magnetic spectrometer separates the elastically scattered protons from the inelastic ones.

2. Inelastic processes at large momentum transfers

Two magnetic spectrometers are used in this experiment. A high momentum spectrometer (5 to 20 GeV/c) and a low momentum spectrometer (0.8 to 8 GeV/c) will determine the angles of emission and moments of pairs of protons resulting from the process

\[ P + P \rightarrow P + P + X \]

The missing mass \( M_X \) will be computed on-line and displayed for different ranges of momentum transfer. The high resolution of the spectrometers should make it possible to identify missing masses as small as a single \( \pi^0 \) up to 30 MeV incident energy. The large solid angles should make it possible to explore this reaction to high momentum transfers where the cross-section is small. We are prepared to carry out fast event recognition, i.e. accept or reject events on the basis of the missing mass (or other kinematic quantity) calculated on-line either during the 20 \( \mu \)sec between events, or during the 2 seconds between pulses. Final analysis will be made on selected events from data recorded on magnetic tape.

These are experiments which involve one particle per plane per event. If the discharge planes are used in sets of three, events with two or more particles per plane can be analysed.

*) This experiment was suggested by J. Memes.
References


2. To be published.
Figure captions

Fig. 1  Particle tracks obtained in three digitized discharge planes

Fig. 2  Schematic experimental layout for small-angle p - p elastic scattering using digitized discharge planes
DISCUSSION

MAGLIO: How would you handle an experiment where 4 sparks per gap are required?

COLLINS: Let me suggest that if I take cross planes and then put a third plane at right angles to this, I can cope with almost an unlimited number of particles. The reason being that 3 coordinates of a particle over-determine it. For example, if I have a Y coordinate, an X coordinate and an R coordinate you simply ask the computer to make these agree and if the accuracy is high I can, without any uncertainty, identify as many particles as you wish.

GORENSTEIN: You showed us instances of adjacent wires discharging under the influence of a single ionizing particle. This could add complications to an encoding system. I wonder if this has been observed in other wire chambers.

COLLINS: These observations repeat our observations almost identically.

SALVINI: When the spark chamber is working in a heavy background, for instance, in the electron synchrotron, we found it quite important to be careful with the clearing field. Do you need the clearing field in your chamber, and how much did you try?

COLLINS: The clearing field is connected with the resolving time. In general we have a small clearing field, about 10 volts.

SALVINI: Speaking of the resolving time, how would you define it? If two particles arrive with a distance in time of 100 nsec the spark chamber could confuse the two. Is this your definition?

COLLINS: Yes, it is the time during which a particle will be recorded by a discharge. A particle comes through and then there is an interval I must wait before I apply the voltage to this discharge plane. It is the maximum time which I can delay the application of this voltage and still record the passage of this particle.

FESSEL: You have these discharge planes scattered all round the experimental area. Have you thought about the problem of the sending read and sense lines over long distances?
COLLINS: These problems we simply have not faced. Having never set-up this system I am sure there are troubles of which we know nothing, and this may be one. We have tried running wires around through the laboratory and I have put many cores in series with them and made an attempt to see whether there are any obstacles to this way of doing things. None have shown up as yet but we have not done this on the floor of an accelerator.

STARK: What kind of display are you using and what amount of computer capacity are you using for your experiment?

COLLINS: We don't have the computer, we have asked for one and it has not as yet been approved. We would like to get a very fast computer without a particularly large memory. We do have a 4K memory with 48 bits per word.

ROBERTS: Has sufficient attention been paid to the problem of accurately locating the wires in space, to take advantage of the high accuracy of which the system is capable? In addition the wires may vibrate.

COLLINS: These chambers have very substantial frames, and they have been constructed so that there are fiducial marks on the edge of these frames which are set to a precision of less than 10 mils. We have gone to a lot of trouble to see that we know exactly where these wires are, and I think one will survey these in to an accuracy which is certainly less than 0.5 mm.

ROBERTS: I suppose ultimately you will end up by running an elastically scattered proton beam through it and check it this way?

COLLINS: I admit there is a problem and we have not solved it, but I have a feeling that it can be done.

ROBERTS: I agree that you can get the frames in the right place but do the wires vibrate?

COLLINS: They are tight, they stand still there is no question.
WIRE CHAMBERS FOR INELASTIC e-P SCATTERING

D. MILLER and P. DE BRUyne

Harvard University, Cambridge

(presented by D. Miller)

Any film-less spark chamber system is a delicate compromise between experimental objectives, technical feasibility, manpower, time and style. Many physicists feel that the detector should be a response to a particular experiment; in my view it must be suitable for a succession of experiments and should relate to more general considerations such as the accelerator.

An ordered list of our objectives would include:

1. to reduce the time between conception and publication of an experiment so that the work is topical

2. enough spatial resolution for 1% accuracy in momentum and angle with existing fields

3. a detector nearly transparent to neutral background, unless supplemented with converting material

4. full efficiency for several tracks or a shower

5. an output suitable for quantitative digital analysis

6. a repetition rate higher than the 60 cycle per second rate of our electron synchrotron

7. enough flexibility so that the physical arrangement of scintillators, spark detectors and absorbers can be altered in a few hours

8. enough on-line track identification so that we know the data can be successfully extracted from the background.

Figure 1 shows the electrode geometry. The plane cathode is aluminium 0.025 mm thick. The anode consists of 512 0.127 mm diameter copper wires which are 1.27 mm from each other and 6.34 mm from the cathode. The wires are first glued to a sheet of 0.025 mm mylar for ruggedness and ease of fabrication. Earlier etched versions proved less satisfactory because the wire diameter determines the strength of the pulsed electric field. Our spacer is glass and we blow through helium at one atmosphere.
Voltage pulses are developed with a triggered variable spark gap and delay line clipping. After 50 nsec we apply a 3 kV pulse of 50 nsec rise and 200 nsec duration. With a 150 volt clearing field, the sensitive time is 0.5 μsec.

Figure 2 shows that each anode wire threads through a ferrite core on its way to ground, as Krienens suggested. Before the event each of these charge discriminators is in the zero state. If a particular wire participates in the discharge initiated by the ionization, the corresponding core will switch to the one state. After the event these read and group read currents interrogate the cores in a regular order. Any core in the one state will switch back to the zero state and the accompanying flux change causes an induced output in the sense loop.

We went to be able to change detectors and still use the same core memory. So we have included a disconnect feature between the detector units and the core memory. One memory unit will accommodate four detector units. The memory unit as we receive it from the supplier costs half a Swiss franc per bit. It includes two lines for reading and half a sense loop. The completed memory unit requires 8 man-days. It has connectors which each receive a double-sided printed circuit board. Since the same spacing is maintained from anode to core, dip soldering is useful. Two half physicist-days and 600 Swiss francs yield one hodoscope unit.

Figure 3 is a block diagram of the core reader. Time runs down the slide from the top. When the core memory is full, the reader begins to interrogate cores, counting the wire number as it proceeds. The first read current interrogates 64 cores. The 64 induced outputs, after amplitude and time selection, are stored in the 64 flip-flops of a parallel to series converter. As these are shifted out the end of the converter, the ones are detected. When a one is found, the wire number is transferred to the computer memory and the beam of the hodoscope display is brightened.

Figure 4 shows the physical location of the elements of the system. The hodoscope display provides a projection looking along the anode wires. It is very useful for checking and on-line observation. In practice we raise the voltage applied to the chamber until minimum ionizing tracks look complete. Then on the average 1.5 cores per unit are written. The tracks are independent of voltage over 1.5 kV.

Several interesting observations emerge. Tracks which make a very wide angle with the normal are just as narrow as the normal tracks. This, of course, reflects the electric field distribution near the wires. We have studied the robbing problem by making the cathode of wires also. As you might expect, inductors in each cathode wire provide excellent isolation between discharges. As we went to larger hodoscopes robbing was no longer a problem, so we returned to the plane cathode. In this connection, delay line clipping at the spark gap is very useful for analysing the effects of hodoscope capacitance and inductance.
The reader interrogates cores at 3 Mc per sec and transmits wire locations to the computer memory at 200 kc per sec. So the reading dead time depends on the size of the hodoscope array. For 32 such units with 1/64 of the bits written, the detector must be inoperative for 1.5 msec.

Wire locations are transferred from the computer memory to magnetic tape at 5 kc per sec. The computer memory plays two roles. It buffers the magnetic tape transport from the random events. It also retains an ordered set of wire locations for on-line track identification.

This talk has been limited to features which are constructed and working. So far we have not tackled the serious ambiguity problem. Perhaps the most useful features are the short dead time and the physical flexibility of the detector. For example, I should note that information on wires will turn a corner without mirrors.
Figure captions

Fig. 1  Electrode geometry
Fig. 2  The memory element
Fig. 3  Core reader
Fig. 4  System blocks
ANODE
0.127 MM. DIAM.
COPPER WIRES
ARE 1.27 MM.
CENTER TO CENTER

0.025 MM.
MYLAR

6.34 MM.
THICK
GLASS

0.025 MM.
ALUMINUM
CATHODE

SENSITIVE VOLUME PER UNIT 0.65 M X 0.65 M X 1 MM.

Fig. 1 ELECTRODE GEOMETRY

WRITE LINE
FROM HODOSCOPE

\( \frac{1}{2} \)
\( \frac{1}{2} \)

ONE OF 64 READ LINES
ONE OF 64 GROUP READ LINES

ONE OF 64 SENSE LOOPS GOING TO CORE READER

Fig. 2 THE MEMORY ELEMENT
Fig. 3  CORE READER

Fig. 4  SYSTEM BLOCKS
DISCUSSION

COLLINS: May I ask whether you have pulsed this large discharge plane? We were worried that the increased capacity would cause a large number of cores to be flipped.

D. MILLER: Oh yes, we have had about 2 months experience with it now, but we were also worried about this. We tried to first mock up the situation by using our little chambers and adding some more capacitance because we thought that was all we would be adding when we went to the larger chambers. If you keep the duration of your applied voltage the same then what you realise is that just because the product of C and V is larger you are releasing more charge to the core and you get wider collections of wires in one gap. Our first solution to this was to shorten the duration of the voltage pulse applied to the chamber. This satisfied us at that point so we built our larger chamber with the increased lead inductance due to our disconnect feature. But with so much inductance the voltage pulse was too short so we lengthened the voltage pulse again to accommodate the extra inductance. (Incidentally, the delay line clipping at the pulse is very important in order to understand the effects of capacitance and inductance.) After making these changes we were able to get the desired width collections.

FIZER: Do you make the wire electrodes yourself or purchase them?

D. MILLER: We purchased wires, 5 miles in diameter, in lengths of 15 feet which are pre-glued to mylar in groups of 192 wires across. We did not find this one on the market -- we had to sort of cajole it out of them. We used these 192 wire units by splicing them together to make the 512 wire units that you can see.

ROBERTS: You mentioned something about seeing many simultaneous tracks in the chamber. Does this imply that you are using your chambers in triple arrays?

D. MILLER: What we have done so far is to just use 'n' gap arrays where all the wires are pointing in the same direction. Although we have some ideas about the ambiguity problem which has been discussed earlier, at the moment we have no experience on this.

ROBERTS: In other words you are not really measuring the 3rd dimension at all?

D. MILLER: That is correct. I see no problem, in principle, but we are not doing it and I have tried to talk about things which have been done.
ANDERSON: Could you describe how you stretch your wire planes on the frames?

D. MILLER: Yes, we use a mechanical stretcher which stretches the mylar after the whole unit has been built to the correct area. Then we measure tensions before and after gluing to the glass frames. It is quite important that we have the mechanical strength of the glass and that we make these tension measurements. Once you understand what you want it is easy to reproduce it but it takes a little time to learn what you want.

ANDERSON: But do you only stretch in one direction?

D. MILLER: No, we have 4 sides which can independently be backed off.

NEUMANN: What explains the surprisingly low field of 3 kV on \( \frac{1}{4} \) inch?

D. MILLER: The field is not determined by the separation between the anode and the cathode, but rather by the diameter of the anode wires and the spacing between them. The field distribution is such that under the conditions in which we operate about 5/6ths of the chamber is insensitive.

NEUMANN: If the sensitive area is confined to the region of concentrated fields, how long should the pulse be and what is the corresponding efficiency?

D. MILLER: With this size chamber I think the answer is about 120 nsec. With the earlier chamber, having 1/9th of this area, the answer was about 18 nsec.

ROBERTS: Are you sure that you really are operating with 5/6ths of the chamber insensitive or is it merely that the ions that are formed there have to first be drawn into the so-called sensitive region before they start multiplying?

D. MILLER: You are correct - I am not sure. The only observation that we have which we cannot explain any other way is the fact that we can get tracks which are at a very large angle in respect to the normal essentially the same as those which are along the normal. The explanation could quite possibly be wrong.

COLLINS: Why did you attach copper wires to the mylar and not aluminium?

D. MILLER: Aluminium can be fabricated, but one of the things I learned early in this business is that when you are dealing with American industry and with products which they have not yet made but which you would like them to make - you try for just a certain amount at a time, and if you rock the boat too much you may end up making it yourself. There is no problem in principle.

COLLINS: You have no objection to aluminium?

D. MILLER: No, it is entirely a question of gluing techniques and finding a firm that has those techniques.
AN INTEGRATED WIRE CHAMBER COMPUTER SYSTEM*

J. BOUNIN, R.H. MILLER, M.J. NEUMANN and H. SHERRARD
Institute for Computer Research, University of Chicago, Chicago

(presented by R.H. Miller)

SUMMARY

A wire and core spark chamber designed for on-line operation with a computer has been built and tested. Planes 10 inches in diameter with 256 wires at 1 mm spacing are mounted in such a way that a memory core plane can be attached. Planes may be stacked to form chambers of any depth. During readout, cores are interrogated 32 at a time, and a sub-computer scans the readout, rejecting all empty readouts, but attaching an address to any non-empty readout and transmitting the bit pattern and its address to the computer. This kind of readout, used in conjunction with good scanning strategies, can permit a large (factor 10-100) reduction in the amount of data transmitted to the computer. Tests of the chamber assembly have been run on the computer Maniac III in the Institute for Computer Research. Checks indicate better than 90% spark efficiency at minimum ionization, less than one noise spark per 5 gaps each time the chamber is pulsed, and a mean location error less than 1/2 wire spacing. The computer can reconstruct simulated events for a fictitious experimental arrangement to within the quantization error introduced by the finite structure of the chamber planes within about 1/6 second for an assembly of 32 chamber planes of the kind described.

Wire chambers for use as elements in the controlling logic for pulsing standard (photographic) spark chambers have also been developed.

*) Papers describing this work, have been submitted to Nuclear Instruments and Methods. We expect to submit further reports to that journal as they are prepared.
DISCUSSION

ROBERTS: The main drawback to the use of a wire array as a logical element is the dead time. This is at least a few hundred microseconds.

R.H. MILLER: You have to choose carefully the place you use it in. I don’t know how long it takes Brookhaven to put together a counter hodoscope, but our group put this one together one afternoon and had it running the next morning. This is fairly impressive, showing how quickly and cheaply you can do these things. It's a poor man's system.

PIZER: Would you explain how you made your wire chambers?

R.H. MILLER: The basic scheme is that we have a good sized washing machine if you like. Mike Neumann's department made up a large hexagonal drum and one mounts the frames of a plane on each face of this thing and on the side is a spool of wire with a little guide on it that guides it on and a braking system that maintains wire tension. We are using stainless steel wire down to 2 mils, aluminium wire down to 4 mils, in this fabrication technique. There are various outfits that will build this into a plastic matrix for you for a price. We have never been quite sure just how well the plastic matrix would stand repeated sparking and this system has turned out to be so simple that we just have not looked into the question of altering our schemes.
SECONDARY DISCHARGE SPARK CHAMBER OPERATION

M.J. NEUMANN
Institute for Computer Research, The University of Chicago, Chicago.

ABSTRACT

The double discharge or 3-electrode spark chamber represents an effort to combine the advantages of fine and weak (primary) sparks with the requirements of a simple and efficient computer system.

The basic principle is that the spark occurring in the wake of an ionizing particle is changed into a different type of discharge, the secondary discharge, which is adjusted without losing its spatial position and without dissipation of excessive energy to the requirements of the electronic retrieval system.

It is shown that it is possible to record x and y coordinates from a single spark without excessive pulsing of the detector array in a wire chamber and as a further development one can hold the secondary discharge long enough to act as the sole memory element in the system. This leads to the possibility of retrieving correlated coordinates from multiple events with minimum computer time.

1. INTRODUCTION

As a spark breaks down in the wake of an ionizing particle and right after its decay a conductive channel exists in its place and can lead to the secondary discharge if a proper source of current is available. Henning \(^1\) used such secondary discharges to single out and intensify for photography those sparks which were accompanied by coincident ones; another example of secondary discharge is the accidental involvement of the clearing field source as current supply subsequent to the occurrence of a spark. In the early years of spark chamber operation this used to occur until the destructive properties of the resulting arc discharges prompted precautions to eliminate the chance of their occurrence.
We found it worthwhile to learn to time and regulate secondary discharges for several reasons; some of these shall be described hereafter.

i) It is possible to extend the memory time of a spark chamber with respect to its total information content or any part thereof without time limitation or loss in spatial resolution, if a certain mode of discharge takes over the plasma-column of every primary spark. Fortunately the power dissipated in this discharge can be much lower than the primary spark and threshold of the detectors\(^3\) should be set so that they do not respond to the current of either the primary or secondary discharge. By subdividing one or both planes of each spark chamber deck into wires or other discrete conductors of sufficient resolution, it is now possible to make access to any one of the above described discharge sites or memory elements one by one and intensify the discharge to the level of response of the detectors. Thus the sparks corresponding to multiple events which occurred simultaneously can be read out sequentially, without ambiguity, by any one of the digital or analogue retrieval systems reported on this conference.

ii) In a wire chamber built for digital information retrieval\(^2\) the detection of a secondary discharge of sufficient intensity allows the retrieval of x and y coordinates from a single spark chamber deck if the wire planes corresponding to the pulsed and the ground electrodes are crossed. This means simplification of equipment and computer programme as both wire planes are used as detectors and the same spark yields both coordinate's information—this is one feature the wire chamber did not share previously with other systems.

iii) The effort to minimize the energy and the diameter of the plasma-column in order to achieve best spatial resolution and shortest dead time would cease as one reaches the energy stored in the wire plane capacity\(^3\) or that corresponding to the threshold of the detectors. Certain modes of secondary discharge in combination with isolated charge storage on every wire enable us to decrease the primary spark energy below the above limits. While our secondary discharge spark chamber is in an early developmental stage, a few experiments were performed which lead to encouraging results and these, as well as some speculations are described in the following paragraphs.**

*) In a standard wire-and-core chamber, the cores are the detectors.

**) The contribution of Drs. Charpak, Schneider and others of this meeting and Professor Heinz Raether, Hamburg are gratefully acknowledged.
2. TRIODE AND MULTI-ELECTRODE SPARK CHAMBER

In our preliminary experiments the spark chamber consisted of three wire planes, two of which were separated by a distance of 6 mm and the third was at 1 mm from the ground plane.

The electrical connections were somewhat analogous to a triggered spark gap inasmuch as a conventional pulser circuit caused a discharge in the 6 mm gap if a cosmic ray passed through it and this triggered a secondary discharge in the 1 mm gap which was connected to a constant d-c voltage (just below its static breakdown potential). A similar chamber shown in Figs. 1-3 has more than 3 wire planes to yield x and y information from the same spark.

Figure 3 shows the current waveform of a secondary spark. We discontinued this experiment because similar results are available from a spark chamber with only two crossed wire planes with somewhat more sophisticated circuitry. Also, the delay of secondary breakdown can be minimized if the shadowing effect of the grounded wire plane is eliminated.

We also built a chamber where the secondary gap was formed by a system of interwoven and insulated wires where the shadowing effect could be eliminated.\textsuperscript{(*)}

3. DISTRIBUTED CHARGE STORAGE

Before describing our next experimental model the principle of distributed charge storage should be emphasized. We no longer intend to dump the full charge stored in a spark chamber into the spark - only the charge stored on one single wire. One of the ways to do this is by coupling each wire through a separate capacitor to the primary pulser. This really does not involve a major increase of components as a multiple condenser can be produced by clamping a metal foil over the cable leading away from the spark chamber with proper insulation and cushioning.\textsuperscript{(*)}

It is quite possible that this capacitive coupling of the pulse to every wire would find acceptance in other spark chamber systems described on this meeting in conjunction with the details described in the paragraph on the secondary discharge memory chamber.

\textsuperscript{(*)} This geometry could be useful in the glass covered electrode chamber described by Drs. Fukui and Miyamoto.

\textsuperscript{(**)} Dr. Krienen (CERN) and Dr. Miller (Harvard) achieved somewhat similar results by using series resistors or inductors on each wire. Dr. Fukui and Miyamoto were the first to show, in their glass covered electrode spark chamber the advantage of independence of multiple spark circuits.
4. **WIRE CHAMBER WITH TWO DETECTOR PLANES**

Figures 4 and 5 show this chamber which was originally constructed for an experiment in a magnetic field. The long cables leading all spark chamber wires to detector and memory boards several metres away were utilized to act as bleeder and the primary pulse is lead through a coaxial cable to the "clamp-on" condenser described in the previous paragraph.

Basically this is a conventional wire chamber with crossed wire planes but here two discharge circuits are combined which overlap essentially in the path of the spark or sparks and differ (from the conventional chamber circuit) in the role of the bleeder and the fact that a secondary pulser is added.

Usually (a part of) the pulser current has an option to traverse the space through the spark or go down the bleeder if no spark occurred (for lack of efficiency or any other reason). This is valid for the primary current of our system too, but the secondary current always traverses both the spark site or sites and the corresponding "bleeder" leads.

(On figure 4 the primary current flows through Cx - Pt. x,y-Cy and the secondary current through Mx - Point x,y - My.) Every spark chamber wire has its own dumping condenser, bleeder wire (in the cable) and on the "ground" end a detector and memory element: a ferrite core.

At this point I wish to thank Thomas Nunamaker of this University who suggested building the pulser circuit symmetrically in push-pull, so that the spark chamber planes are pulsed in opposite polarity and swing around the memory boards which are on ground potential except for the secondary voltage.

The advantage of this system is that one spark can be utilized to yield both x and y coordinates, a property which only optical (and our previously described magnetic tape) systems had so far. Thus the number of required discharge planes can be decreased and the computer programme somewhat simplified.

5. **DISCHARGE MEMORY CHAMBER**

Some very preliminary experiments were performed along the lines of the first paragraph of the introduction and we found that the primary discharge can be turned into a very weak discharge which can be held for time periods of 20 μsec and longer without damaging the wires or spreading to their neighbours. Sometimes these secondary discharges took the form of an incipient corona discharge and were visible only as minute spheres on the two wires involved in the discharge and at times they were invisible to the dark-adapted eye.
We are now working on the circuitry required to stabilize with 100% efficiency this discharge form and plan to produce a third intensifying discharge (as Henning did) in order to "readout" the content of such a spark chamber. Two methods of readout are considered: (1) the conventional clocked scanning into x wires while the y wires feed the significant information bits into the computer memory or an equivalent register and (2) an internal discharge controlled wire chamber where both x and y addresses are simultaneously sent out.

References

1. P.G. Henning, Atomkernenergie, 2, 83 (1957)


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TYPICAL SECONDARY DISCHARGE WAVEFORMS:

(a) SECONDARY VOLTAGE - NEGATIVE POLE
500 v/div., 1 usec/div.

(b) SECONDARY CURRENT - NEGATIVE POLE
10 amp/div., 1 usec/div.

PRIMARY VOLTAGE - 7KV
SECONDARY VOLTAGE - 1250V
COUPLING CONDENSERS

3 METER CABLE

READ OUT TO COMPUTER

COINC. TRIG.

PRIMARY PULSE 4-8 KV
(PUSH-PULL)

STEADY OR PULSED SECONDARY VOLTAGE 1-1.5 KV

COINC. TRIG.

X PLANE

Y PLANE

10"x10" SPARK CHAMBER

(Cx,Cy) - CLAMPED-ON CONDENSER: APPROX. 1 pF PER WIRE

C1,C2 - " " " " 6 pF " "

R2 - LEAD WIRE RESISTANCE: APPROX. 10 Ω PER WIRE

Fig. 4

Fig. 5
DISCUSSION

KRIENEN: What gas mixture did you use?

NEUMANN: Neon with 10% helium, and not more than a trace of alcohol.

SALVINI: In which sense do you think you have high multiplicity?

NEUMANN: Anybody can have multiple tracks if he understands that $X_1 X_2 X_3$ and $Y_1 Y_2 Y_3$ correlate according to the one, two and three. Usually it is a computer or the scanner who has to decide this, you almost always have only two orthogonal projections, not three. So there is a basic ambiguity in this two-dimensional type of reproduction. However, if you take this spark as a circuit element and push a current through it, then you decide unambiguously where that spark was. Say you try to observe a shower and you have 15 various parts in it, then you can locate this much quicker than if you have to put back the sophisticated computer programme on top of it.

SALVINI: But your development is quite independent of the fact that it may be difficult to have 15 sparks corresponding to 15 particles, I mean the physical problem of having more than one track.

NEUMANN: It is independent. I am trying to do this work because I think that we were spoiled. The first spark chambers were also light intensifiers and we pushed a lot of energy into a spark, and I think that with the electronics that we have you can really get much weaker sparks. If you consider a physical instrument like this the noise ratio is a first requirement, then I think we should go down and be modest with our current so we have to amplify the current some place to get our detectors going. I think the first place to amplify is ionic amplification inside the spark chamber, that way I think that we can take a little bit of the burden and complications of further circuitry and computer programme upon ourselves. Let me put it this way. Everybody felt sorry for the first spark chamber. The poor thing has so much information that the computer has to help to get it out fast. We have come to the time when we can be sorry for the computer and try to tell the spark chamber to help a little bit. We can do better spark chambers with less money, rather than build more complicated electronic equipment.
DATA HANDLING IN MU MESON PAIR PRODUCTION AT CEA

M. GETTNER, J. LARABEE and R. WEINSTEIN
Northeastern University, Boston

A. BOYARSKI, J. FRIDMAN, G. GLASS and H. KENDALL
Massachusetts Institute of Technology, Cambridge, Massachusetts

J. DE PAGTER
Cambridge Electron Accelerator, Cambridge, Massachusetts

(presented by R. Weinstein)

SUMMARY

Mu pairs produced by the 5 GeV CEA bremsstrahlung beam, were selected by requiring that they pass through 4 feet of iron, strike a trigger counter, and then continue on through another 3 inches of iron and strike a second trigger counter. In addition to the trigger counters there were 134 other scintillation counters for the measurement of angles and ranges. The output of each of the 134 counters was brought to a hodoscope electronic unit (similar to the units described by Fessel at this meeting) made by Space Sciences of Waltham, Mass. The design of our units is a slightly improved model of the one used by Fessel, and failure rates were negligible. Each unit amplified the signal and applied it to an AND circuit, the other input of which was the trigger caused by the mu pair. If both inputs occurred within 30 nsec, a flip-flop was put in a ONE state. The flip-flops were also connected in six shift registers, each 32 deep. After having received parallel read-in from the counter-trigger coincidence, these units were controlled as a shift register, by the "Interface and Command Unit". This latter unit performed the following functions:

a) set 3.5 inches at the start of a new tape roll;

b) start tape recorder when trigger is received; allow tape to reach speed;

8446/mn
c) send shift commands to all flip-flops of the six shift registers;
d) generate kill pulse to fast electronics;
e) compute transverse parity;
f) write LRCU with proper 0.02 inch gap;
g) write end-of-file mark every 64 events;
h) contain additional flip-flops into which manual information could be inserted;
i) contain additional flip-flops into which electronic information is inserted (beam intensity, file number, time of run, square of beam intensity, etc.);
j) send write commands to tape recorder at proper times;
k) keep tape going for 3/4 inch after an event;
l) reset all flip-flops to ZERO upon receipt of a CEA pre-spillout pulse;
m) stop all operations when an end of tape marker is passed;
n) no buffer was used because of the 60 cps repetition rate of CEA. This unit was composed of logic blocks made by Digital Equipment Corporation of Maynard, Mass.

The "Interface and Command Unit" writes on a slightly modified Potter 906 II tape recorder at 75 ips in low density format. The tape recorder was run in NRZ mode. It was started and stopped for each event, and after about 0.5 x 10^6 events, showed no wear. The only service to the recorder was a brief cleaning after every 16 hours of operation.

All data were read from the tape immediately after writing, and stored in flip-flops connected to lights. The lights were arranged in geometrical arrays similar to the counter geometry. Almost all counter failures were detected in this manner. The light board was made by Space Sciences and used both DEC and Space Sciences logic blocks.
Two quite different analyses of data were done off-line on an IBM 7090. A "quick" calculation was done of the single rates of every counter. This "bit count" occasionally indicated counter or electronic troubles. "Bit count" could be done in five minutes at the 7090 (after a three hour wait for the five minutes run). It would be a comfort and convenience to have this operation performed on-line.

The more complete calculations on the data took several hours of computer time, and the full memory of the 7094. A larger computer memory would be desirable. Since (a) backgrounds, and even some classes of background events, were unknown, (b) a knowledge of results had little or no bearing on data taking, and (c) about two man-years of programming would have had to be invested prior to a knowledge that the experiment would work, it is felt that on-line computation of results (as distinguished from on-line bit count) would have been a mistake in our original run.
LINDENBAUM: I would like to comment on Weinstein's question of whether the on-line operation of a computer to process the physics results during the run is necessary or desirable. In our elastic scattering experiments we found that the direct and continuous feedback of the results affected how we ran the programme to a great extent and was a great positive asset. On-line operation of the Merlin Computer was essential to ensure its efficient use during a run of our magnitude including debugging of equipment, debugging of programmes and efficient running of the experiment to ensure proper operation of the equipment and that the desired number of events were obtained. By on-line, I mean access to the computer for as long a period as necessary and as often as necessary. In practice, this means either continuously on-line or at least on-line cyclically with a very short period — a period of the order of a few minutes. This latter technique is only useable if the shared computer and intermediate storage are both adequate with regard to memory and speed of recording and their speed of transmission to the computer. Incidentally, we only calculated differential elastic cross-sections on the Merlin. We then ran tapes to the IBM 7090 for least-squares fitting of data, integration of curves, REGGE-pole analysis, etc. In this coming year's work we will only be able to evaluate about 1O% of our data on-line to the Merlin (8 K memory about 1/7th the speed of the 7090). In the high rate cases tapes will be ferried to the IBM 7090 for the remainder of the work. One last point — in studying up to four prong events (for example, associated production etc.) the sophisticated programming required will lead to an almost insatiable demand for computer capacity and we will easily need the services of a CDC 3200 or equal, for more than the half time we shall be able to get on it.
III. AFTERNOON SESSION

OPERATING SONIC CHAMBER SYSTEMS OFF-LINE

Chairman: G. Manning, Rutherford Laboratory

Secretary: D. Freytag, CERN
           J. Scanlon, CERN
AN EXPERIMENT ON THE ELASTIC SCATTERING OF DEUTERONS ON CARBON

L. BIRD, B. ROSE, C. WHITEHEAD, E. WOOD,
AERE, Harwell

E.G. AULD*, D.G. CRABB, G.W. HUTCHINSON, J.G. MCEWEN,
Southampton University

(presented by C. Whitehead)

1. INTRODUCTION

This experiment was performed principally to gain experience in the operation of sonic spark chambers and in the technique of storing data from sonic spark chambers and counters in a common system. The elastic scattering of deuterons on carbon was chosen in that the techniques demanded were similar in many respects to those needed in an experiment being designed for Nimrod\(^1\). Details of the mode of operation of the data handling electronics have previously been reported\(^2\) and in this present paper attention will be concentrated on techniques of running the experiment and on the analysis of the data.

2. EQUIPMENT

It was expected that in the Nimrod experiment many tens of microphones would be used in the sonic spark chambers and events would be stored as many binary words containing, in all, 700-1000 binary bits of information per event and these words would be presented to the data handling system in only a few milliseconds. The arrival of the data during this time is essentially random and the data handling system must be capable of handling such high rates of random data with a minimal dead time loss. This has been achieved by using separate gated scalers for each microphone but the system we have developed differs in that essentially one master scaler was used and the microphone timing information was stored in a ferrite core magnetic memory matrix and subsequently transferred to paper tape. Methods of entering particle time-of-flight, pulse height and monitor scaler information into the store were also developed.

Fig. 1 shows the layout of the experiment. A 70 MeV deuteron beam from the Harwell Synchro-cyclotron is defined by counters 1, 2 and 3, counter 3 being a veto counter with a 1 cm x 2 cm hole at the centre to limit the beam

*) Now at the Rutherford Laboratory, Chilton

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size at the carbon target. Two spark chamber modules were used to determine the trajectory of the scattered particle. The flight time of the particle between counters 1 and 5 was determined and the pulse height in counter 5 was also measured. The latter two measurements serve to identify the deuterons and also the protons produced in competing reactions. To establish an absolute cross-section the beam particles registered by 123 were counted but only during the time that the equipment and data handling system was ready and able to detect and deal with the information associated with a scattering event. This beam monitoring system was used to obviate the necessity of knowing the dead time correction of the whole system including the data handling equipment and also it rendered the problem of recording the number of beam particles used more amenable.

Fig. 2 shows a section through the spark chambers. The plates were constructed of 0.001" aluminium foil and the chambers had effective areas of 18 cm x 36 cm and 25 cm x 50 cm respectively. A sheet of expanded polyurethane 3 mm thick was placed between the two gaps to improve the acoustic isolation.

A gas mixture of argon and alcohol vapour was continually flushed through the system and each gap was discharged from a common spark gap running at 19 kv but each gap had its own 500 pf storage condenser. Clearing fields of ~60 v were used.

Fig. 2 also shows the mounting of the microphones in the gap which were of the cylindrical capacitor type. The centre electrode was a 5 mm dural rod which was anodised in 1270 sulphuric acid at 10 volts for 10 minutes with a current density of 20ma/cm² to produce an 8 micron thick smooth oxide layer. The second microphone electrode was of 0.0003" soft aluminium foil wrapped over the oxide layer and bonded over a small area at the back. The sensitivity of these microphones was such that at 8 cm from a 15 kv 500 pf point to plane spark and with 15 v applied potential a 40-50 mv signal is developed across the microphone with a rise time not exceeding 1 µsec.

Current amplifiers with a gain of 4000 were used to amplify the signals. Five microphones were used to record sound signals from an event in each two gap module. Four microphones were placed in the corners of the measuring gap and the fifth was located in the adjacent gap opposite one of the previous four. In the analysis it was demanded that the time recorded by this fifth microphone was equal, ±15 µsec, to that time recorded by the equivalent microphone in the measuring gap thus confirming that the two sparks in the module were unlikely to be spurious. The rather large ±15 µsec interval of agreement was determined largely by the maximum obliquity of particle trajectories through the chamber.

A further system was built into each measuring gap to measure the velocity of sound in the chamber itself. This consisted of a point-to-plane spark gap and two further microphones arranged along the edge of the chamber. The microphones were separated by ~15 cm and 27 cm in the two chambers.
The calibration gaps were pulsed from a thyratron at 15 kV and the time taken for the sound to pass from one microphone to the other was determined from a gated scaler and a 5 Mc/s clock frequency. Data taking runs lasted 15 minutes and in the intervening period five measurements were made of the sound transit time for both chambers. Over a period of 10 hours the average change in the velocity of sound during the 15 minute runs was 0.05% and the maximum change observed was 0.3%.

2. THE MAGNETIC MEMORY STORE

Figure 3 shows a simplified block diagram of the buffer store, it consists essentially of a $16 \times 16$ ferrite matrix of Mullard FX 1899 cores driven from a 16 bit binary scaler fed by a 1 Mc/s clock. The scaler is started when the spark chambers are fired and when the signal from the $i^{th}$ microphone arrives the scaler content at that time is transferred non-destructively and essentially instantaneously to the $i^{th}$ row of the matrix. This transfer is made unambiguously to an accuracy of ±1 clock pulse by using the fact that between clock pulses, for a period of 400 ns, all the binaries are in a steady state and using the technique of staticising the transfer is arranged to take place at this time using half write currents from the binaries in the "1" state and a synchronised half write current along the $i^{th}$ row of cores. The half write currents used are ~ 100 mc with a duration of 200 ns.

Particle time-of-flight information was entered into the store by using a time-to-amplitude converter followed by a 100 channel pulse height analyser. The amplitude to digital converter of this analyser produced a train of "address advance" pulses at 500 Kc/s the number of pulses in the train being proportional to the input amplitude and a fixed time after the last "address advance" pulse an "accumulate" pulse was produced which entered the pulse into the analyser store and this same "accumulate" pulse was used as an input to one of the buffer store channels. In this way the analogue information was written into the store and also was accumulated as a time-of-flight spectrum on the pulse height analyser.

The total energy pulse from counter 5 was also stored in the buffer store and on a second pulse height analyser by essentially the same system, a fast linear gate and stretcher replacing the time-to-amplitude converter.

The number of beam particles used in the experiment was recorded by counting the number of $12^3$ coincidences on a scaler event by event. This scaler was gated off from the $12^3$ rate immediately after a scattering event had occurred. At this time the 1 Mc/s clock rate was allowed to enter this same scaler thus adding to the scaler content. An output pulse from the scaler when its content reached 4000 is used to address the thirteenth channel of the buffer store and thus the number 4000 + $N$ is entered into the store where $N$ was the number of beam particles recorded by the scaler. The scaler
is then reset to zero and remains gated off until the data handling process is complete and the counters and spark chambers are rendered active again.

A further input facility in the form of 14 hand switches was used to enter a label into the store event by event. This label indicated target material, counter positions, run number etc.

The read out cycle from the buffer store was conventional. The data was recorded in pure binary on 5-hole paper tape using a Teletype 110 character/sec. punch. The read sequence was that firstly a three character pattern was punched to allow the computer to recognise the beginning of an event, secondly, the 14 hand switch setting was recorded as three 5-hole characters, and thirdly the data channels were transferred using 3 characters for each microphone, each analogue channel and the monitor scaler channel. The total event was thus recorded as ~45 characters and events could be recorded at 2 per second. The data tapes have been analysed on the Ferranti Pegasus Computer at Southampton University.

4. ANALYSIS

On reading in the data tapes the computer first looked for the three character computer code and then proceeded to read the next 42 characters. The characters were transformed, three characters at a time, into decimal numbers and stored appropriately in the computer. If, due to any malfunction of the equipment, less than 42 characters were read before a second computer code pattern was reached the first event was discarded and the read sequence restarted from this second computer code pattern.

When the complete data block had been read in and transformed to decimal code the computer first checked that for each chamber the times recorded for microphones 1 and 5 agreed to ±15 μsec. A failure for either chamber caused the event to be discarded and the next event was read in. If the event passed this test then for each chamber, taking the velocity of sound from the measurement for the run being analysed and taking an assumed value of the shock parameter two values of the x coordinate and two values of the y coordinate were calculated using the microphones in pairs. For each chamber it was then required that the two x coordinate values should agree to 5 mm and similarly for the two y coordinate values. A failure of any one of these tests caused the event to be discarded and the computer noted which chamber was at fault. This scheme was adopted primarily because a complete analysis would have taken too much time on the relatively slow Pegasus computer. The justification of this method of analysis, for this particular experiment, lies in the following facts.

From events subsequently analysed completely with no assumptions of velocity or shock parameter the mean velocity obtained from these complete
solutions agreed to 0.1% with that from measurement with the velocity micro-
phones in the chamber and the standard deviation of scatter of the values
of the computed velocity was 0.2%. The value of the shock parameter obtained
(defined as the extrapolated intercept on the time axis of the time-distance
plot for sparks more than a few centimetres from the microphones) was 30 μsec
with a standard deviation of 3 μsec. It should be noted that this shock
parameter also includes the finite size of the microphones, 2.5 mm radius.
Further sets of data were analysed using the velocity as determined from the
extra pair of microphones and a mean value of 28.4 μsec was obtained for the
shock parameter with a standard deviation of 0.75 μsec for the distribution.
Thus it is unlikely that the assumed value of 30 μsec for the shock parameter
is in error by more than 1.5 μsec and calculation indicates for the chambers
involved the errors in x and y, resulting from an error in the shock parameter,
are less than 0.25 mm for 95% of the chambers. In this particular experiment
this would imply an angular resolution of ~1/10° but in fact the 1° divergence
of the deuteron beam is the limiting factor. Further analysis along these
lines is being followed and it seems that in cases where computation time is
limited, for example in some cases of on-line computation, the method of analysis
using a measured value of the velocity and an assumed shock region can yield
adequate accuracy in the analysis to afford sufficient guide to the conduct of
the experiment.

Returning now to the analysis programme, after the calculation of the
x and y coordinates for both chambers the angle of the particle trajectory
relative to the beam direction is computed and also by projecting back the
particle trajectory a check is made that the trajectory intersects the beam
line at the position of the target. A trajectory that does not originate from
the target is classed as background and is stored separately.

At this stage the sonic chamber data has been analysed and the com-
puter then goes on to calculate the times of flight and the pulse height in
counter 5.

The events are now classified by three parameters; angle of emission θ,
time-of-flight and total energy pulse height and the events are stored in the
computer in this three dimensional matrix. The contents of this matrix are
printed out from time to time or when any register of the matrix reaches its
maximum content. The integrated value of the monitor for this block of data is
printed out at the same time.

Subsequent analysis to separate protons from deuterons on the time of
flight versus energy plots, background subtraction and calculations of absolute
cross-sections was done by hand.

Chamber efficiencies defined as the number of 1-5 coincidences
per number of chamber discharges, were monitored throughout the experiment.
In clean test conditions with the deuteron beam passing through both chambers
efficiencies in excess of 99% were obtained for both chambers. In the scattering position the maximum efficiencies observed were 98% and it is believed that this decrease is probably due to neutrons emitted by the target being converted in counter 5 which was 7 cm thick. Such an event would trigger the spark chambers but no charged particles would have traversed them. As an example, in one run on aluminium, the chambers were discharged 2360 times, 1-5 coincidences were observed on 2300 events for chamber 1 and on 2320 events for chamber 2 end acceptable solutions of events were obtained in 2120 cases and of these 60 corresponded to events not originating from the target. In this case the efficiency of analysis was 89%.

The contributions to the missing 11% are 2-3% from neutral particles, 0.5% from mis-punches, electronic defects (e.g. random in the coincidence system, dead time losses in the fast linear gate and time-to-amplitude converter) and the remainder from imperfect x, y solutions. The latter loss could probably be reduced in that it has been observed that very occasionally one of the recorded microphone times is in considerable disagreement with the other three and using these three microphones and the measured velocity an acceptable solution can be obtained.

It has been mentioned that in the initial analysis agreement to 5 mm was demanded from the coordinates predicted by pairs of microphones on opposite sides of the chamber when the velocity and shock parameter values were assumed. Subsequent analysis has shown that this value of 5 mm was needlessly large and that for chamber 2, the largest chamber, the mean value of the difference in the x solution from microphones 2 and 3 from 1 and 4 was 0.3 mm and the mean value of the difference between the y solutions from microphones 1 and 2 and from 3 and 4 was 0.47 mm. An approximate calculation of the expected deviations averaged over the whole chamber yields values of 0.26 mm and 0.44 mm to be compared with those observed. This latter calculation assumed root mean square errors of 0.1% on the velocity, 0.3 mm on the shock parameter and 1 μsec timing errors.4)

5. RESULTS

Figure 4 shows the angular distribution of deuterons scattered from carbon with an angular resolution of 1° up to 12° and a resolution of 1.5° thereafter. The solid line indicates a preliminary optical model fit to this data using the programmes of Buck et al 3), a further fitting is continuing.

Figure 5 shows the angular distribution for aluminium and again the solid line is a preliminary optical model fit.
References


4. Programmes for this subsequent analysis have been written for us by J. Collie, Rutherford Laboratory, Chilton.
Figure captions

Fig. 1 Layout of the experiment.

Fig. 2 Construction of spark chambers and mounting of microphones.

Fig. 3 Simplified block diagram of buffer store and associated equipment.

Fig. 4 Angular distribution of deuterons scattered from carbon.

Fig. 5 Angular distribution of deuterons scattered from aluminium.
DISCUSSION

LIPMAN: What kind of repetition rate will this system stand?

WHITEHEAD: It is limited entirely by the paper punch system to 2 per second. In fact our real event rate was approximately 10 times that.

ISELIN: What is the maximum carry time through the 14 bit scaler?

WHITEHEAD: 160 nsec.

MANNING: Would you care to make any comment on the possibility of using gray code rather than fast carry scalers?

WHITEHEAD: I will actually talk about this tomorrow in the other paper I am giving. I prefer to leave it till then if you don't mind.

LILLETHUN: Does your shock parameter remain constant within 0.75 μsec over the whole active area of your largest chamber, i.e. over the region from 10 cm from your transducers?

WHITEHEAD: The quoted values are average values taken from a distribution of data from all over the chamber.

LILLETHUN: Do you have any idea whether your shock parameter is larger at large distances from the probes?

WHITEHEAD: We have seen no evidence of this so far, and the sort of agreement we get between the errors we find and those we expect on this assumption makes me think that in our case, where we are using argon and not helium-neon, perhaps the shock region is appreciably smaller, but I have no direct evidence of this.

LIPMAN: Do you have any evidence as to whether your spark chambers will fire when two particles go through them? There is a story that argon is not a good mixture for getting more than one spark.

WHITEHEAD: We have in fact seen two sparks in our chambers, for instance, we forgot to switch on the clearing field in the chamber crossed by the beam, and our efficiency was very poor. We then looked at the output of the microphones on an oscilloscope and we saw two quite distinct sound pulses, one coming from the position where the beam was going through the chamber, just on the residual ionization there, and the other from the genuine event. A 60 V clearing field removed this effect completely.
OPERATION OF A SONIC SPARK CHAMBER SYSTEM

A. LILLETUN, B. MARGIC, C.A. STAHLBRANDT and A. WETHERELL
CERN, Geneva

G. MANNING, A.E. TAYLOR and T.G. WALKER
Rutherford Laboratory, Chilton

(presented by A.E. Taylor)

1. INTRODUCTION

The main part of the work summarized in this report took place in CERN a little over a year ago\(^1\), although there is included some more recent work at the Rutherford laboratory\(^2\).

This work was orientated towards a study of the very small angle p-p elastic scattering and spark chambers seemed to offer the usual advantages of good spatial resolution coupled with large solid angle. In this experiment, the event in the spark chambers would be very simple, namely one track only. It seemed natural therefore to use a sonic technique\(^3\) for the location of the track as this permitted the immediate digitization of the information and hence reduced the time for data analysis. Also the system could be regarded as one capable of being hooked up to a computer for on-line analysis.

2. PRINCIPLE OF THE METHOD

The position of the spark is obtained by measuring the time taken by the sonic signal produced by the spark to arrive at the detector placed at a known distance. If the velocity of propagation were constant, this distance would be \(v_0 T\). However, the pressure waves produced by the spark are shock waves and the velocity is therefore a function of the amplitude of the wave. There is an excess velocity \(\Delta v\) which is a function of the distance from the spark and the energy in the spark. This is illustrated in Fig. 1, which contains the principle of the method used. The functional relation of distance and time is approximated by writing for sufficiently large distances,

\[
R = v_0 T + \Delta R_1
\]  

(1)
where \( v_0 \) is a velocity taken as constant and could be regarded as an asymptotic velocity. The term \( \Delta R_1 \) is called the spark size because its inclusion could be represented by an infinite velocity of propagation over the distance \( \Delta R_1 \) followed by a constant velocity \( v_0 \) thereafter.

The accuracy with which the distance \( R \) is measured is then the accuracy to which \( R = v_0 T + \Delta R_1 \) is a valid approximation, i.e. the amount by which \( \Delta R_1 \) varies as a function of distance and spark energy. The object of the preliminary tests was to find out how \( \Delta R_1 \) varied.

3. MEASUREMENT OF \( \Delta v_0 \) AND \( \Delta R_1 \) AS A FUNCTION OF \( R \) AND \( E \)

Measurements were made of

i) the velocity \( v \) as a function of distance \( R_1 \) for two spark energies, \( E = 0.15 \) and 0.2 Joule (\( E = \frac{1}{2} eV^2 \)),

ii) the spark size \( \Delta R_1 \) as a function of \( E \) (from 0.10 to 0.2 Joule) and \( R \) (from 1 to 20 cm).

A test spark, with tungsten points of separation 3 and 5 mm was used in open air. Plotted in Fig. 2 is the excess velocity as a function of distance for the two spark energies.

The excess velocity \( \Delta v_0 = v - v_0 \) in open air, seen in Fig. 2, was found to be well represented by the inverse square law:

\[
\frac{\Delta v}{v_0} = \frac{\Delta R_1^2}{R^2}.
\]  \( (2) \)

Equation (2) would imply that the value of \( \Delta R_1 \), used in eq. (1) would vary as

\[ A \tan^{-1} \frac{R}{A} \]

reaching a maximum of asymptotic value of \( \pi A/2 \). This is obtained by taking the eq. (2) and calculating the time taken for the sound to go from \( R_1 \) to \( R_2 \), which is

\[
T_2 - T_1 = \frac{1}{v_0} \int_{R_1}^{R_2} \frac{dR}{1 + \frac{A^2}{R}}.
\]  \( (3) \)

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A measurement of $\Delta R_1$ in air is shown in Fig. 3 for different spark energies. The solid lines fitted to the data are $\Delta R_1 = A \tan^{-1} \frac{R}{A} + B$. Although good fits are obtained to the variations in $\Delta R_1$ for $R > 1$ cm, if the inverse square law dependence of $\Delta V / V_0$ held at all distances, $B$ should be zero. The fact that a non-zero value is required may be related to the conjecture that at distances comparable to the spark size the energy is dissipated into a cylindrical volume rather than a spherical one as at larger distances. If it is assumed therefore that the variation of $\Delta V / V_0$ at these small distances is $K/R$ rather than $\Delta^2 / R^2$ and the two laws are matched in this region ($\sim 1$ cm), then the absolute magnitudes of $\Delta R_1$ shown in Fig. 3 are obtained within $1/3$ mm.

It should be pointed out, that all these measurements are in open air where the shock-wave envelope is a sphere, whereas in the spark chambers the shock-wave envelope is essentially a cylinder with the chamber plates as its base. The results in open air show that the geometrical factor was sufficient to describe $\Delta R_1$ versus $R$, without the attenuation factor due to the absorption of the wave (dissipation of sonic energy), usually given by $e^{-\mu R}$.

The variation in velocity in the spark chambers is therefore probably also given by geometry alone, namely

$$\frac{\Delta V}{V_0} = \frac{K}{R}, \quad (4)$$

for all distances, neglecting the absorption of energy by the plates or in the gas. Integration of eq. (4) gives:

$$\Delta R_1 = K \log (R + k)/K. \quad (5)$$

Using the value of $K$ obtained in matching the measurements in air, the estimated value $\Delta R_1$ is shown in Fig. 4 for the spark chambers and spark energy used ($0.05$ Joule). The observed value of $\Delta R_1$ in the spark chamber was on an average $4$ mm, in good agreement with the estimated value in Fig. 4. At large distances absorption of the sound energy will limit the value of $\Delta R_1$.

The measurements also showed that $\Delta R_1$ in open air (Fig. 3) varied as the square root of the applied voltage, which together with the inverse square law dependence on distance of $\Delta V / V_0$ implies that

$$\Delta V \propto \sqrt{E}. \quad (6)$$
This result was also obtained by McFarlane\textsuperscript{4}). With the above assumptions the variation of $\Delta R_1$ in the chambers would have a different dependence on $R$; it would be expected to vary approximately as $R$ or as the applied voltage. The measurements in the spark chambers are in good agreement with such a dependence, although this does not necessarily prove the assumption of eq. (5). Based upon these conjectures of the behaviour of the shock-waves between plates, it was felt that, operating with an energy as low as 0.05 joule and with microphones at least 15 cm from any spark, errors in the determination of distances arising from the fact that the microphones are in a shock wave region would be sufficiently small. The error in determining spark positions would be relatively less sensitive; for instance, the latter error from two microphones 15 cm and 50 cm, respectively, from the same spark would be an estimated 0.2 mm, and this is a bias which could be corrected in the final analysis if required.

4. Determination of Particle Position

The role of the spark chamber in our set-up was to determine the point of the particle passage through the centre plane of the chamber, i.e. the chambers were used as hodoscopes. Each chamber had two gaps, and the average of $x$ and $y$ from the two gaps was taken as the real particle position in the centre plane.

The spark chambers were designed with the above points in mind and the design of one of the chambers is shown in Fig. 5.

Rutherford and Patterson\textsuperscript{5}) measured the deviations between spark and particle positions for particles incident between $0^\circ$ and $15^\circ$ and found that 25% of the events had deviations $> 0.5$ mm. Clearly, if an accuracy of particle location in the sonic system of better than 0.5 mm is aimed at, it is necessary to have multiple-gap chambers to reduce the possibility of including events with deviations of $> 0.5$ mm between the averaged spark and the particle positions.

We use two-gap chambers and require that (i) both gaps in each of the six chambers fire, and (ii) that sparks in two gaps be "connected", i.e., that their coordinates in gap 1 be equal to those in gap 2, within a certain limit. Both these requirements lower the efficiency of our system.

Four transducers placed in each gap of the chambers make it possible in principle to measure the velocity $v_0$ and spark size $\Delta R_1$, in addition to $x$ and $y$ of the spark, for each event using the assumption that $\Delta R_1$ is a constant. In this manner, the need for temperature and spark energy regulation and control was eliminated. To determine the spark coordinates $x$, $y$, it is necessary to solve four simultaneous quadratic equations in $x$, $y$, $v_0$ and $\Delta R_1$. 

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The assumption of $\Delta R_1 = \text{constant}$ introduces errors in the determination of the spark coordinates. In practice, by placing the transducers 15 cm from the edge of the active area of each gap, these errors were estimated to be sufficiently small ($< 0.3 \text{ mm}$). Since the following talk is on details of the programmes which can be used, I need only say that all the results presented here used the simple programme for spark location.

No description is given of the electronics used except to say that a 10 Mc/s clock was used for timing. Nor is there included any description of the transducers except to say that both piezoelectric and capacity transducers were used.

In order to keep a check on the performance of our detectors and give a little more information about the scattering event, a visual display system has been built recently. Using the times from opposite probes, the approximate $x$ and $y$ coordinates in each gap are displayed on the face of an oscilloscope. This indicates whether the chambers are working and whether we have correlated events in adjacent gaps. Also the correlation in the $y$ coordinate throughout the 6 chambers indicates whether we have more than one spark.

5. RESULTS OBTAINED WITH SIX SPARK CHAMBERS IN A PROTON BEAM

Since most of the tests were made parasitically during runs on the PS using the diffracted proton beam, the momentum used varied from one run to another in the range 12 -- 26 GeV/c. The intensity was usually about $2 \times 10^4$ protons per burst but with varying duty cycle and in some runs there was the finite possibility of more than one proton passing through the chambers in their sensitive time. The results mentioned in this section are taken from a set-up (Fig. 6) at 26 GeV/c where this possibility appeared small.

5.1 Accuracy of particle location

Distributions of the differences between spark coordinates in the two gaps of chambers 3, 4 and 5 are shown in Fig. 7. The central part of these distributions can be fitted with a gaussian of standard deviation 0.28 mm

$$
\exp \left[ -\frac{1}{2}(x_n - x_{n-1})^2/(0.28)^2 \right].
$$

To this distribution must be added a broader one extending to ± 5 mm to include the 3% of events in these chambers outside the central distribution. However, in chamber 6, 15% of the events were outside. This difference between chamber 6 and the others is probably due to the background associated with the larger sensitive area of chamber 6, namely 750 cm$^2$ compared with 100 cm$^2$ for chambers 3 and 4, and 350 cm$^2$ for chamber 5.
This central distribution is in accord with previous photographic measurements of the deviations of spark position from particle position. If the latter deviations can be represented by a gaussian of standard deviation \( \sigma \) about the particle position, then our distribution of

\[
\frac{x_n}{n} - \frac{x_n}{n+1}
\]

should show a standard deviation of \( \sqrt{2}\sigma \). These results (Fig. 7) would then imply for normal incidence a standard deviation \( \sigma = 0.2 \text{ mm} \) in good agreement with the value \( 0.25 \text{ mm} \) determined in the photographic method\(^5\). The fact that there are less (\( \sim 3\% \)) events outside this distribution than observed in the photographic measurements (\( \sim 25\% \)) might be due to the use of thinner plates (30 \( \mu \) instead of 150 \( \mu \)) and hence less chance of scattering and lower number of \( \delta \) rays. Also the angular spread of the incident protons was much less than the 0 - 15° used in the photographic method. The accuracy with which the spark position locates the particle track is the basic accuracy in the use of spark chambers. Since we use two gaps in each chamber and take an average of the coordinates,

\[
\bar{x} = \frac{1}{2} \left( x_n + x_{n+1} \right),
\]

we would expect \( \bar{x} \) to have a gaussian distribution around the particle position with an rms deviation of 0.14 mm. If in the final analysis we demand that \( |x_n - x_{n+1}| < 0.5 \text{ mm} \), we would reject the events in chambers which would be outside the central distribution, and at the same time lower our efficiency. For the run at 26 GeV/c the efficiency defined as the percentage accepted events was \( \sim 70\% \).

However, for particles not passing through the centre of the chambers, account must be taken of biases as mentioned earlier. Also uncertainty in probe position (0.1 mm) was comparable to this uncertainty in \( \bar{x} \) and would affect the absolute accuracy of particle location, but the relative accuracy from particle to particle should not be dependent on this. Some check on the absolute accuracy of particle location was made in the following way.

The relative coordinates of sparks in two chambers placed one behind the other was obtained from the simple programme. One chamber was then moved with respect to the other; in an 8 GeV/c proton from Hiramod, in effect from the centre of a square 16 \( \times \) 16 cm to 8 positions round the edge of the square. The programme reproduced these movements to an accuracy of 0.2 mm which was within the known accuracy of movement.

5.2 Equality of \( \Delta R_1 \) for all probes in one gap

We have checked the basic assumption of our method of computing, namely that \( \Delta R_1 \) is equal for all 4 probes in a gap. The computer programme gave the differences \( D_x \) and \( D_y \) between the computed spark coordinates and the
experimentally measured distances projected on to the axes. \[ \Delta R_1 = v_0 T + \Delta R_1 \]
projected on to the axes.

The strong correlation between \( D_x \) and \( D_y \) is shown in Fig. 8 for chamber 5 with the beam passing through the central part. Half the fluctuations in \( D_x \) and \( D_y \) can be attributed to the timing resolution of ± 1/4 \( \mu s \) inherent in the use of the 2 Mc/s oscillator to form the delay time. This would give a correlated fluctuation of 0.25 mm cut of the 0.5 mm individual fluctuations, leaving a correlated fluctuation in \( D_x \) and \( D_y \) of 0.25 mm. That this remaining fluctuation was from fluctuations in spark energy has been checked by measuring simultaneously the distributions in pulse height on the transducers and the distribution in \( \Delta R_1 \). Knowing the variation of each with change in energy of the spark allowed the correlation to be made. Including a small percentage of \( C_2H_5OH \) reduced the widths of these distributions. The mean value of \( D_x - D_y \) in chambers 1-4 is 0.001 cm and the mean value for each gap does not significantly differ from zero when account is taken of the uncertainty in each transducer position (0.1 mm). In these chambers \( D_x - D_y \) was sensitive only to transducer position and differences in \( \Delta R_1 \), and to this extent \( \Delta R_1 \) is the same for all four probes.

The results from chamber 6, however, suggest that \( D_y \) is significantly different from \( D_x \), \( (D_y - D_x = 0.7 \, \text{mm}) \). In this chamber the sparks occurred at very different distances from the transducers, 60 cm, 35 cm, 15 cm and 35 cm, respectively. The difference between \( D_x \) and \( D_y \) may therefore be attributable to a variety of causes:

1. genuine difference in \( \Delta R_1 \) arising from the logarithmic dependence of \( \Delta R_1 \) on \( R \), giving an estimated effect of + 0.15 mm;
2. uncertainty in each transducer position which from the results in other gaps could be an effect of ± 0.2 mm;
3. finite rise-time of the transducer response together with the differing signal strengths at different distances giving an effect of + 0.3 mm;
4. sensitivity to incorrect velocity \( v_0 \), giving a difference of ± 0.14 mm for an uncertainty \( \Delta v/v_0 \) of ± 1.10²;
5. thermal expansion of the perspex frame affecting the separation of opposite transducers differently in the x and y directions.

These several effects would be sufficient to explain the significantly non-zero value of \( D_x - D_y \) in chamber 6 and illustrate the factors which affect the determination of position for non-central sparks.
5.3. Angular and momentum resolution

If the uncertainty between track and particle locations is that suggested above, then the angular resolution and momentum resolution should be given by this uncertainty taken together with the separation of the chambers and the bending in the magnets of the spectrometer (Fig. 8).

We obtained the $x$ and $y$ coordinates in all chambers corresponding to zero scattering angle by measuring the spark distributions in $x$ and $y$ with an empty target. The central values $\bar{x}$ and $\bar{y}$ then defined positions corresponding to $\Theta_x = \Theta_y = 0^\circ$. At the same time this measurement gave the angular resolution of our system as $\pm 0.11$ mrad in both horizontal and vertical directions. The expected geometrical resolution was $\pm 0.05$ mrad and the difference could be accounted for by multiple Coulomb scattering in and around the target and in the spark chambers.

With this experimental value of the angular resolution, the expected momentum resolution of $P_1 - P_2$ was $\pm 60$ MeV/c for the 26 GeV/c run, where $P_1$ and $P_2$ are the momenta measured with the first 3 and last 3 chambers, respectively. All the events in that run were contained within a base width of $P_1 - P_2 = 250$ MeV/c which at this level represents $\pm 2\%$. 

8446/Jan
PROPERTIES OF THE SONIC SPARK CHAMBER SYSTEM

1. Accuracy in the determination of spark position in a gap (averaged over 6 chambers). ± 0.20 mm

2. Accuracy in the determination of position of particle passage through a 2-gap chamber (averaged over 6 chambers) allowing for estimated bias in the largest chamber used ± 0.30 mm

3. Angular resolution of the system, as measured in a 26 GeV/c proton beam ± 0.11 mrad

4. Momentum resolution of the system, as measured in a 26 GeV/c proton beam ± 0.25%
References


2. Private communication.


4. W. McFarlane, Phil. Mag. 17, 24 (1934).

Figure captions

Fig. 1  
\[ T \text{ versus } R \text{ relation for two spark energies } E' \text{ and } E'' \quad (E'' > E') \]
and constant ambient temperature. The slope of the lines at large distances approaches a constant and gives the velocity \( v_0 \). The intersection of the extrapolated straight line with distance axis gives the spark size \( \Delta R_1 \), while that with the \( T \) axis gives \( \Delta T_1 \).

Fig. 2  
Fractional excess velocity \( \Delta v_0 \text{ in air} \), for spark energy \( E = 0.15 \) Joule versus 3 mm gap and 0.2 Joule versus 5 mm gap.

Fig. 3  
Spark size \( \Delta R_1 \) as a function of distance \( R \) for various spark energies in open air (spherical geometry). It is evident that \( \Delta R_1 \) approaches a constant for \( R > 12 \) cm. The solid lines are given by \( A \tan^{-1} \frac{R}{A} + B \) (see eq. 3 of the text). Values of \( A \) range from 3.17 to 3.46 mm with estimated uncertainties \( \approx \pm 0.05 \) mm.

Fig. 4  
Variation of spark size \( \Delta R_1 \) with distance \( R \) between the spark chamber plates, as estimated from measurements in air with a test spark (see eq. 5). Absorption of the shock wave energy in the gas and in the plates is neglected and with this assumption there is no end to the shock wave region in a spark chamber. This is to be compared with Fig. 3.

Fig. 5  
Sonic spark chamber: 1) Perspex frame. 2) Perspex rods covering the gaps. 3) Transducers. 4) HV leads. 5) Al foils 30 \( \mu \) thick. 6) Test spark (not used). 7) Gas inlet and outlet. 8) Plastic window since replaced with Al foil. Whereas this drawing shows 5 gaps, only 2 gaps were actually used.

Fig. 6  
Beam counter and spark chamber layout for measurement of the angular and momentum distribution of protons scattered by hydrogen.

- 8446/mn -
Fig. 3

Fig. 4
Fig. 6

Fig. 7

Fig. 8
DISCUSSION

MAGIC: I just would like the speaker to write down a table of the results obtained. Could you just list the results, angular resolution etc.

TAYLOR: A table will appear in the proceedings. It shows the value which we might expect for the angular resolution within the geometry which we had. We concluded that the experimental resolution could be almost entirely due to the scattering around the target; there is material in the target, there is air around the target. If we have this experimentally determined angular resolution it implies the momentum resolution also, taken together with the bending angles. All this means is that we expected the difference between $P_1$ and $P_2$ to be given to an accuracy of ± 60 MeV/c and in fact all the events were within 250 MeV/c. That is the complete distribution for the differences between momentum measured for the incoming particles and momentum measured for the outgoing particles, which were $\sim 26$ GeV/c.

BARDON: Could you explain what $Dx$ and $Dy$ are actually? I am afraid I didn't understand.

TAYLOR: The programme takes the four times that we get from the four microphones, 1 to 4, and gives us a computed position of the spark which we can call $X$ computed. The distances fed into the programme are $R_1 = v_0 T_1 + \Delta R_1$. The $Dx$ is the difference between this value of $R_1$ projected on to the axis and the computed $X$. The flutter in $Dx$ reproduces the fluctuation in $\Delta R_1$. 

8446/ga
DESCRIPTION OF THE MATHEMATICS INVOLVED IN THE RECONSTRUCTION
OF SPARK POSITIONS IN AN ACOUSTICAL SPARK CHAMBER

E. LILLETHUN and P. ZANELLA
CERN, Geneva

(presented by P. Zanella)

1. INTRODUCTION

This paper describes mathematical methods to find a spark position in an acoustical spark chamber. Programmes based on such methods have been written in FORTRAN for the IBM 7090 computer and are used at CERN for the analysis of data from acoustical spark chamber experiments.

2. THE PROBLEM: DEFINITIONS AND ASSUMPTIONS

In general one measures the time-of-flight $T$ of the pressure wave formed by the spark, from the spark position to a suitable detector. The detector will be called a probe. The distance $R$ between the spark and the probe is, of course, given by

$$R = \int_0^T v(t) dt$$  \hspace{1cm} (1)

where $v(t)$ is the rapidly varying velocity of a shock wave, asymptotically decreasing to the velocity of sound, $v_0$.

The computations described here are all based on the assumption that the probes are kept sufficiently far from the active spark chamber area, so that the velocity with which the pressure wave reaches the probes, can be safely approximated by $v_0$.

Figure 1 shows approximately the behaviour of the velocity of a shock wave as a function of time, i.e. distance from the spark. The two curves refer to different spark energies. The higher energy gives rise to a higher initial velocity, but both curves tend to $v_0$ at large distances.
If a measured time $T$ is outside the shock wave region, one may rewrite equation (1) as follows: (Fig. 2)

$$R = \int_0^T v_o \, dt + \int_0^T (v(t) - v_o) \, dt = v_o T + \Delta R = v_o (T + \Delta T)$$

(2)

The sound velocity varies with temperature and depends on the gas mixture. Let us call $\delta v_o$ the uncertainty in the value of $v_o$. Similarly, let us indicate with $\delta(\Delta T)$ the uncertainty in the estimate of $\Delta T$, which varies with the spark energy.

Assuming that $T$, which is measured electronically, is known to a greater accuracy than $v_o$ and $\Delta T$, we can write the following expression for the relative error of $R$:

$$\frac{\Delta R}{R} = \frac{\delta v_o}{v_o} + \frac{\delta(\Delta T)}{T + \Delta T}$$

(3)

To make an example, if we assume that during a run the variations of $v_o$ are within $\pm 0.2\%$ and that $\Delta T$ may have uncertainties of the order of $\pm 2\ \mu$sec, then the error in $R$ can be as large as $\pm 2$ mm for a spark $50$ cm from the probe.

Now, let us define a linear chamber simply as two probes positioned sufficiently far from the active area, both probes being used to calculate the $X$-coordinate of the spark along the line connecting the detectors. If $2a$ is the length of the segment between probe 1 and probe 2 and if $X$ is measured from the centre of this segment, we have:

$$X = \frac{R_1^2 - R_2^2}{4a} = \frac{v_o^2}{4a} \left[ (T_1 + \Delta T)^2 - (T_2 + \Delta T)^2 \right]$$

(4)

and we can write the following expression for the relative error on $X$:

$$\frac{\Delta X}{X} = 2 \frac{\delta v_o}{v_o} + 2 \frac{\delta(\Delta T)}{T_1 + T_2 + 2\Delta T}$$

(5)

which gives for a spark position $50$ cm from probe 1, under the assumptions made in the example above, an error of $\pm 0.65$ cm in the $X$-coordinate of the spark if the probes are placed $80$ cm apart, i.e. spark $10$ cm from the centre of the chamber.

If the two probes are, for example, $160$ cm apart, the error becomes $\pm 1.9$ cm under the same conditions. In this case the spark is $30$ cm from the centre of the chamber.
Finally, let us define a two-dimensional chamber as a set of 4 probes positioned sufficiently far from the area of the chamber where we want to calculate spark's coordinates, as to allow the following assumptions to be valid:

i) The velocity with which the pressure wave reaches any probe is \( v_0 \).

ii) \( \Delta T \) has the same value for all the probes.

From the assumptions above, the following four basic equations can be written for any two-dimensional chambers:

\[
\begin{align*}
R_1 &= v_0 (T_1 + \Delta T) \\
R_2 &= v_0 (T_2 + \Delta T) \\
R_3 &= v_0 (T_3 + \Delta T) \\
R_4 &= v_0 (T_4 + \Delta T)
\end{align*}
\]

where

\[
R_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \quad (i = 1, 2, \ldots, 4)
\]

The calculations of spark position \((x, y)\) from these equations are discussed below.

3. **Solution of the Basic Equations**

The methods of solution fall into any of the following four classes, depending on whether the variables \( v_0 \) and/or \( \Delta T \) are considered known or unknown:

<table>
<thead>
<tr>
<th>CLASS</th>
<th>KNOWN</th>
<th>UNKNOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>( v_0, \Delta T )</td>
<td>( x, y )</td>
</tr>
<tr>
<td>II</td>
<td>( \Delta T )</td>
<td>( x, y, v_0 )</td>
</tr>
<tr>
<td>III</td>
<td>( v_0 )</td>
<td>( x, y, \Delta T )</td>
</tr>
<tr>
<td>IV</td>
<td></td>
<td>( x, y, v_0, \Delta T )</td>
</tr>
</tbody>
</table>

3.1. **Class I**

The spark position is overdetermined. To make good use of the four equations, one can split the two-dimensional chamber into two linear chambers, considering probes 1-3 and 2-4 as separate sets. Coordinate \( X \) can be calculated from the first probe set and \( Y \) from the second, using equation (4).

The errors due to \( v_0 \) and \( \Delta T \) indetermination have been already discussed for linear chambers. Since they increase with the distance of the spark from the centre of the chamber, this very simple method is generally unsuitable for large chambers.
3.2 Class II

Two velocity independent equations can be obtained from the basic set (6), as follows:

\[
\begin{align*}
\frac{R_4}{R_5} = & \frac{T_1 + \Delta T}{T_2 + \Delta T} = C_1 \quad \text{(constant)} \\
\frac{R_2}{R_4} = & \frac{T_2 + \Delta T}{T_4 + \Delta T} = C_2 \quad \text{(constant)}
\end{align*}
\]  

(7)

Hence, introducing \(x\) and \(y\):

\[
\begin{align*}
x^2 + y^2 - 2 & \left( x_1 - \frac{c_1}{1} x_3 \right) - 2 \frac{y_1 - c_1 y_3}{1 - c_1} + \frac{x_1^2 + y_1^2 - c_1^2 (x_3^2 + y_3^2)}{1 - c_1} = 0 \\
x^2 + y^2 - 2 & \left( x_2 - \frac{c_2}{1} x_4 \right) - 2 \frac{y_2 - c_2 y_4}{1 - c_2} + \frac{x_2^2 + y_2^2 - c_2^2 (x_4^2 + y_4^2)}{1 - c_2} = 0
\end{align*}
\]

(8)

These are the equations of two circles in the plane of the chambers. Each circle is defined by two probes and its centre lies on the line connecting these two probes. This circle is the geometrical locus of the positions that the spark determined by these two probes can assume by letting the velocity \(v_0\) vary continuously.

The intersections of the two circles are solutions of the problem. One can easily choose from the two solutions the one of physical interest by imposing physically reasonable limits to the values of \(x\), \(y\) and \(v_0\).
The explicit solution is

\[
\begin{align*}
x &= \frac{D_2 - D_4 - 2(B_2 - B_4)y}{A_2 - A_1} \\
y &= \frac{L \pm \sqrt{L^2 - HM}}{H}
\end{align*}
\]

where

\[
\begin{align*}
H &= (A_2 - A_1)^2 + 4(B_2 - B_1)^2 \\
L &= (A_2 - A_1)^2 B_2 + 2(B_2 - B_1)(D_2 - D_1) - 2A_2(A_2 - A_1)(B_2 - B_1) \\
M &= (A_2 - A_1)^2 D_2 + (D_2 - D_1)^2 - 2(A_2 - A_1)(D_2 - D_1) \cdot A_2
\end{align*}
\]

The spark position computed by this method is free from errors due to velocity estimate and it is only affected by errors due to \( \Delta T \) indetermination.

3.3 Class III

Two \( \Delta T \)-independent equations can be extracted from the basic equations (6):

\[
\begin{align*}
R_1 - R_2 &= v_o (T_1 - T_2) = \text{const.} \\
R_2 - R_4 &= v_o (T_2 - T_4) = \text{const.}
\end{align*}
\]

This case presents many analogies with the preceding one: The equations (10) represent two hyperbolas each being determined by a couple of probes.

The spark defined by two probes describes one such hyperbola when \( \Delta T \) assumes all possible values. The solution of the problem has to be found among the intersections of the two hyperbolas.

The spark position, as calculated by this method, is free from errors due to an error in the value of \( \Delta T \) common to all probes. The in-accuracy is caused by errors in the imposed value of \( v_o \).

3.4 Class IV

It is possible to construct two equations independent of \( v_o \) and \( \Delta T \):

\[
\begin{align*}
\frac{R_1 - R_2}{R_3 - R_4} &= \frac{T_1 - T_2}{T_3 - T_4} = K \quad (\text{constant}) \\
\frac{R_1 - R_4}{R_2 - R_3} &= \frac{T_1 - T_4}{T_2 - T_3} = I \quad (\text{constant})
\end{align*}
\]

8446/min
Equations (11) are of the fourth degree in \( x \) and \( y \). The behaviour of the curves of constant \( K \) and \( I \) within the active area of a chamber is shown in Fig. 3 and Fig. 4, respectively. It depends only on the probe positions. The times-of-flight \( T_1, T_2, T_3, T_4 \) define a value of \( K \) and a value of \( I \), which select two curves in the families represented by equations (11). The spark position is at the intersection point of these two curves within the active area of the chamber. Since the direct solution of equations (11) is rather difficult, we have calculated the spark positions by the following method:

1) First a good approximation to \( x \) and \( y \) is obtained using the method described under Section 3.2.

2) Then the solution is iteratively improved up to the desired accuracy by linearizing the equations (11) in a small region around the approximate spark position.

3) To avoid regions where \( K = \infty \) or \( I = \infty \), the inverse of \( K \) or \( I \) are used whenever their values are greater than 1.

The solution found by this method is free from errors due to \( v_0 \) and \( \Delta T \) estimates. Its accuracy will be discussed in the next section.

3.5 Applicability and accuracy of the method of Class IV

The last method provides a solution of the spark position problem which is only dependent on the values of the times-of-flight.

Three major questions arise in this connection:

a) For a given probe configuration and with infinite accuracy on the \( T_i \), does geometry alone dictate any limits on the active area?

b) How accurately can the spark position be calculated if a certain inaccuracy is allowed in the measured times-of-flight?

c) Which probe configuration gives most accurate coordinate determination for a given spark chamber size?

Concerning question a), since the spark position is calculated by intersecting the two curves \( K \) and \( I \), one can find a geometrical solution wherever the angle between these curves is different from zero. Figs. 5 and 6 show how this angle varies in the plane of a chamber. Obviously the region near zero degrees must be excluded from the active area. Or one can consider, in that region, the intersection of one of the curves above with the curve of constant \( J \) where

\[
J = \frac{R_1 - R_2}{R_2 - R_4} = \frac{T_1 - T_2}{T_2 - T_4} = f(K, I).
\]
Alternatively one can try to displace the probes such as to push the bad regions out of the active area.

Figures 7 and 8 show an example of a successful operation of this kind. Probes 1 and 3 were displaced by 12 cm in opposite directions.

Where the accuracy is concerned (question b), an IBM 7090 FORTRAN programme has been written, which produces a map of the values of

\[ \frac{ds}{dR_i} \] (i = 1,4)

according to the following formulae:

\[ \frac{ds}{dR_i} = \sqrt{\left( \frac{dx}{dR_i} \right)^2 + \left( \frac{dy}{dR_i} \right)^2} \] (12)

where

\[ \frac{dx}{dR_i} = \frac{\partial I}{\partial y} \frac{\partial K}{\partial R_i} - \frac{\partial K}{\partial y} \frac{\partial I}{\partial R_i} \]

\[ \frac{dy}{dR_i} = \frac{\partial I}{\partial x} \frac{\partial K}{\partial R_i} - \frac{\partial K}{\partial x} \frac{\partial I}{\partial R_i} \] (13)

\( S \), as defined in (12), represents the distance between the actual and the measured spark positions. Its value is zero if there is no error in the times-of-flight.

Figure 9 shows the propagation, through the left half of a rectangular chamber (160 x 85 cm), of the error in the time \( T_1 \) measured by Probe 1.

Figure 10 shows the effect of errors in \( T_2 \) in the same chamber.

Figure 11 refers to another rectangular chamber (75 x 85) and shows the propagation of the error due to Probe 1 through the active area of the entire chamber.

8446/min
Now, assuming that:

\[ dR_1 = dR_2 = dR_3 = dR_4 = dR \quad \text{(max. error in } R_1) \]  

(14)

from

\[ dx = \frac{\partial x}{\partial R_1} dR_1 + \frac{\partial x}{\partial R_2} dR_2 + \frac{\partial x}{\partial R_3} dR_3 + \frac{\partial x}{\partial R_4} dR_4 \]  

(15)

follows

\[ \frac{dx}{dR} = \frac{\partial x}{\partial R_1} + \frac{\partial x}{\partial R_2} + \frac{\partial x}{\partial R_3} + \frac{\partial x}{\partial R_4} \]  

(16)

and similarly

\[ \frac{dy}{dR} = \frac{\partial y}{\partial R_1} + \frac{\partial y}{\partial R_2} + \frac{\partial y}{\partial R_3} + \frac{\partial y}{\partial R_4} \]  

(17)

hence, one can define \( \frac{ds}{dR} \) as follows:

\[ \frac{ds}{dR} = \sqrt{\left( \frac{dx}{dR} \right)^2 + \left( \frac{dy}{dR} \right)^2} \]  

(18)

The computer can provide a map of \( \frac{ds}{dR} \) over the entire spark chamber.

The above equations (14) through (18), show that one can determine the probe configuration to be chosen for a given spark chamber area and for a given requirement on the accuracy of coordinate determination.

On the other hand, they can also be used to show the limitations on useful areas in already existing chambers.

4. DISCUSSION OF THE TWO SPARKS PROBLEM

All the considerations above refer to acoustical spark chambers built to handle a single spark. We want to add some remarks on the possibility of extending the detection capabilities of these devices to the handling of two simultaneous sparks. The chambers should in principle be able to detect the positions of two sparks provided that a sufficient number of probes is placed around the gap. The unknowns of the problem are seven:

\[ x_1, y_1, x_2, y_2, \Delta T_1, \Delta T_2 \text{ and } v_0 \]
Therefore seven microphones should be enough. Where are these detectors to be placed? An important condition must be obeyed: that the pressure wave from a spark reaches at least three probes.

One way of solving the problem could then be that of determining first which four probes have detected the same spark, and use the corresponding times-of-flight to calculate $x_1$, $y_1$, $\Delta T_1$ and $v_0$. The remaining three times-of-flight would then be used to detect the second spark, making use of the known velocity $v_0$.

By pure geometrical considerations one can construct an active area which fulfils the condition above. Fig. 12 shows how to construct such an area from any given probe configuration. To increase the dimensions of the active area, the number of probes should be augmented. Fig. 13 shows an example of rectangular active area realized with eight probes. Wherever the two sparks occur in that region there will always be at least three probes receiving the wave from each spark.

We may mention that programmes are being written at CERN by Mr. Lefebvre, to deal with the two sparks, and that a chamber with eight probes has been constructed by Maglić for the tests.

In view of the limitations on the choice of experiments to be done with acoustical spark chambers, due to the restriction to only one spark per gap, we feel that this is a very important problem to solve.

ACKNOWLEDGEMENT

We would like to thank Dr. J.P. Scanlon, who initiated the study of the errors of spark location, for help with computations and for enlightening discussions.
Figure captions

Fig. 1  Approximate behaviour of the velocity of a shock wave as a function of time. The two curves refer to different spark energies.

Fig. 2  Graphical representation of \( R = v_0 (T + \Delta T) \).

Fig. 3  Example of curves of constant \( K \).

Fig. 4  Example of curves of constant \( I \).

Fig. 5  Maps of the angle between curves of constant \( K \) and \( I \).

Fig. 6  ditto.

Fig. 7  Effects of the displacement of 2 probes on the angles between curves of constant \( K \) and \( I \).

Fig. 8  ditto.

Fig. 9  Propagation of errors in spark position determination, due to inaccurate measurement of time-of-flight by Probe 1. The curves are labelled with numbers giving the error in position as fraction of the error in the computed \( R_1 \). Chamber dimensions are 160 cm \( \times \) 85 cm.

Fig. 10  Propagation of errors in spark position determination, due to inaccurate measurement of time-of-flight by Probe 2. The curves are labelled with numbers giving the error in position as fraction of the error in the computed \( R_2 \). Chamber dimensions are 160 cm \( \times \) 85 cm.

Fig. 11  Propagation of errors in spark position determination as described for Fig. 9. Chamber dimensions are 75 cm \( \times \) 85 cm.

Fig. 12  Construction of the useful area for two sparks for a given 7 probes configuration.

Fig. 13  Rectangular useful area for detection of two sparks, realized with an 8 probe configuration.
\[ \frac{\Delta V}{V_o} v(R) - v_o = \frac{K}{r} \]

Fig. 1

\[ R = \int_0^T v(t) \, dt + \int_0^T v(t) \, dt + \int_0^T (v(t) - v_o) \, dt = v_o (T + \Delta T) = v_o T + \Delta R \]

Fig. 2
Fig. 3

CURVES OF CONSTANT $K = \frac{R_1 - R_2}{R_3 - R_4}$

Fig. 4

CURVES OF CONSTANT $I = \frac{R_1 - R_4}{R_2 - R_3}$
Fig. 5

PROBE 1

PROBE 2

PROBE 3

PROBE 4

156 cm

ANGLE BETWEEN CURVES OF CONSTANT K AND I

\[ K = \frac{R_1 - R_2}{R_2 - R_1} \]

\[ I = \frac{R_1 - R_3}{R_2 - R_3} \]

Fig. 6

ACTIVE AREA
Fig. 7

Fig. 8
POSSIBLE ACTIVE AREA FOR TWO SPARKS
(WITH 7 PROBES)
EXAMPLE OF RECTANGULAR POSSIBLE ACTIVE AREA
FOR TWO SPARKS (WITH 8 PROBES)

Fig. 13
ELLISON: I am a bit worried to know if when you have done these computations you do in fact get physically reasonable values of $\Delta T$ and $V_0$.

ZANELLA: What we do is to keep on testing $V_0$ and $\Delta T$ and if they are too far from physically meaningful values we reject the solution.

LINDENBAUM: I was going to say this tomorrow, but in answer to your question, we actually started the other way. Being ignorant, we got a computer programme to find the solutions exactly. We found that you could trade large differences between $V_0$ and $\Delta T$. For example, we could get a solution for $X$ and $Y$ which was physically sensible and not too far from the actual $X$ and $Y$, but we got a $\Delta T$ which we knew wasn't true.

MACLIC: As Taylor showed, $\Delta T$ is not common to all four probes. In fact $\Delta T = \log T_i$. That is why an exact solution is hard to obtain. The iterative procedure, however, averages $\Delta T_i$'s.

ROBERTS: For seeing more than one spark, microphones with good recovery might be preferable to special programmes and indefinite increase in the number of microphones. This must certainly be possible. I don't know any theoretical reason why one shouldn't be able to build such microphones.

ZANELLA: Yes, we have thought about this possibility. However, since we have existing programmes to handle things we just try to increase the number of microphones and limit the active region.

ROBERTS: I should like to see what happens with five sparks.

ZANELLA: At present we think that two sparks is already a difficult problem to solve and we don't think of more sparks.

ANDREWS: We have a microphone where you can clearly see two sparks, but we haven't yet got any electronics that will allow you to sort the two out, so it may in fact be easier to use single response microphones and the simpler electronics than to devise more complicated electronics for microphones with two pulses.

R.H. MILLER: It is interesting that this two spark solution completely sidesteps the question as to whether you get in trouble when one sound wave crosses another. I wonder if anybody has yet demonstrated that you can let one sound wave cross another without getting into some interesting kind of non-linearity or apparent velocity variation as it does.
BARDON: We have made an intense region of sparking with a source in one area of the spark chamber and detected sound waves passing through that area, and have been able to locate the spark.

MAGIC: I didn't understand this last sentence.

BARDON: We are able to locate the spark but I am afraid that this is not really an answer to the question. I think that all we have proved is that the disturbance caused by the local heating of the gas does not interfere with the spark measurement.

MAGIC: If the spark is far away from the region of interference, the shock wave is a plane wave and can pass the obstacle without being disturbed. The scattering of sound by sound has been studied in artillery and the effect is basically the same as putting an obstacle between the receiver and the emitter.
ACOUSTICAL SPARK CHAMBER SYSTEM FOR THE STUDY
OF SMALL ANGLE PROTON–PROTON SCATTERING

G. COCCONI, A.N. DIDDENS, E. LILLETHUN, J. PAHL,
A.C. SHERWOOD, J.P. SCANLON, C.A. STAHLERANDT,
C.C. TING, J. WALTERS and A.N. WETHERELL

CERN, Geneva

(presented by E. Lillethun)

1. INTRODUCTION

The work described here is a confirmation of that described by
A.E. Taylor earlier this afternoon. I have tried to leave out points
that have already been discussed in his report. The present set-up is
shown schematically below:

![Diagram of spark chamber system]

Fig. 1
2. **CONSTRUCTION OF SPARK CHAMBERS**

Figure 2 shows a view of a partly assembled spark chamber. The chamber is made from perspex in order to reduce the possibilities for high voltage breakdown. It is sealed with O-rings to prevent leaks and contamination of the gas and encased in aluminium to reduce the electromagnetic radiation from the spark. This radiation could in some cases lead to a disturbing pickup in the electronics system.

The construction of the probe carrying the microphone (a lead zirconate transducer) is shown in Fig. 3. Since the transducer positions act as the fiducial marks in an acoustical spark chamber it is necessary to be able to locate them very accurately. For this purpose croseses are engraved on the probe sockets which are screwed on to the spark chamber. When the precision-made probes are tightly seated in the sockets, the distances from the croseses to the transducers are known within 0.1 mm. This allows a change of probe without a remeasurement of the transducer position.

3. **MULTIPLE SPARKS**

The present system is not able to handle more than one spark per gap per event. A perfect event is one in which all gaps (two in each chamber) give a single spark. This puts a severe limitation on the admissible instantaneous rate of particles through a chamber. The delay between particle passage and high voltage application is about 0.5 μsec due to the electronics and the long distance (35 m) between the first and last chamber. Therefore, the sensitive time of the chambers must be kept to about 1 μsec. In this case an instantaneous rate of $10^5$ particles per sec (e.g. $10^4$ particles in a 100 msec burst, will produce double sparks in 10% of the events in a gap.

The effect of increased particle flux on the efficiency of the whole set-up can be seen from Fig. 4. At the time when these data were taken the system was not in its best mood. The beam burst length was about 100 msec. If one attributes the rapidly falling efficiency to double or multiple sparks the conclusion is that general background must be kept very low (1 particle per cm$^2$ gives 1500 particles in our largest chamber which is 30 cm x 50 cm), a difficult task since most of this background in a high-energy experiment consists of muons of high energy.

It should be noted that Fig. 3 shows the most pessimistic result since one has required a good spark in each gap. One may allow an event to be "rescued" if only one gap is missing on either side of the target, by making use of the fact that the trajectory of a particle is a straight line in the vertical projection before and after the scattering. If a gap has no spark or if the coordinates obtained in the two gaps of one chamber are
different, the straight line fit through the remaining gaps shows which spark is the wanted one. The rescue process has been tried successfully as can be seen from Fig. 8 where the dotted line represents clean events and the full line the total of clean and rescued events. The two distributions are very similar.

4. **RECORDING OF EVENTS**

The electronics used in the system have been described elsewhere\(^1\). In general a coincidence in the triggering system sends a high voltage pulse (10 kV) to the spark chambers and, after a pre-set delay, opens the gates of a bank of scalers fed by a 10 Mc/s oscillator. The signals from the transducers, after amplification and shaping, shut the gates of their respective scalers. If no transducer signal has arrived within 3 msec the scaler gate is shut by a signal which also starts the data recording. The data from 60 scalers are stored on magnetic tape in the form of BCD characters, 200 ch/inch, in about 180 msec. This limits the rate of data acquisition to one event per burst.

We are now developing an on-line system with a small, fast computer which will reduce the scaler readout time to about 2 msec. The computer will also be used for continuous checking of the data and for simplified reconstructions of sample events. With the increased data transfer speed we will be able to record 10 to 20 events per burst, allowing us to study regions where background events are dominating (e.g. lower the minimum scattering to 2 mrad, an angle which still sees the wings of the main beam).

5. **COMPUTATION**

The computer programme for the experiment falls naturally into three parts:

1. **FINDXY**, a programme which computes the spark coordinates from the recorded times. The mathematics behind this programme was discussed by P. Zanella in the preceding paper.

2. **ALIGN**, which treats events triggered by the non-scattered beam. The alignment of the chambers is done by this programme by finding the mean positions of the beam in the chambers.

3. **PPSCAT**, which handles the scattered events, using the coordinates found by FINDXY to compute momenta and scattering angles. It stores each event in the proper momentum-angle interval and at the end of a run transforms this to cross-sections and forms histograms of these. (See Fig. 7.)
In order to illustrate the use, and misuse, of FINDXY, the pro-
grame discussed by Zenella, Fig. 4 shows the difference between the x
cordinate in the two gaps of a 30 cm x 50 cm chamber. In the central
position the distribution is very tight, a Gaussian with a standard deviation
of 0.14 mm, 20 cm from the centre the equivalent distribution has been
smoothed out over 4 2 mm. This behaviour is actually expected, as can be
seen from Fig. 11 in the preceding paper by Zenella. I would like to stress
that the wide distribution is entirely caused by the computation. The
times recorded in the two positions both show equally tight distributions.

6. TEST RESULTS

During tests at the CERN proton-synchrotron recently we obtained
the distributions of the momentum of the incoming proton beam (Fig. 6), the
momentum difference between incoming and outgoing non-scattered beam of
18.1 GeV/c (Fig. 7) and the scattering angle of the same beam (Fig. 8). The
scattering material present was 3 mm of plastic scintillator and 2 m of air.

The standard deviations of these distributions give the resolution
of our system and are 0.05 GeV/c (\(\Delta p / p = 0.28\%\)) and 0.11 mrad for the momentum
difference and scattering angle respectively. These encouraging results
show that the experiment can indeed be done with the acoustical spark chambers,
and with an on-line computer we should be able to study p-p elastic scattering
at angles down to 2 mrad.

ACKNOWLEDGMENT

We would like to thank R. Donnet for his assistance with the
experimental equipment.

Reference

1. C.A. Stahlbrandt, Proceedings of the International Symposium on
Figure captions

Fig. 1  Schematic diagram of present experimental set-up (see page 183)

Fig. 2  Partly assembled acoustical spark chamber

Fig. 3  Construction of the probe holding the lead zirconate transducer

Fig. 4  Efficiency of 10 gap set-up as function of single particles through the last chamber

Fig. 5  Difference between x-coordinate in two gaps of a chamber. This demonstrates that there are certain regions in the chamber where the programme does not work well (see text for details)

Fig. 6  Momentum distribution of incoming proton beam of 18.1 GeV/c

Fig. 7  Distribution of the difference between incoming and outgoing non-scattered beam of 18.1 GeV/c protons (computer output)

Fig. 8  Distribution of the scattering angle measured in a non-scattered beam of 18.1 GeV/c protons
DISTRIBUTIONS OF $x_1 - x_2$ IN 30 cm x 50 cm CHAMBER

IN CENTER OF CHAMBER

20 cm FROM CENTER OF CHAMBER

Fig. 5

MOMENTUM DISTRIBUTION OF INCOMING BEAM

Fig. 6
Fig. 7

**Angular Distribution of Unscattered Beam**

Fig. 8
DISCUSSION

MAGLIC: The chamber for which you showed that in the centre the resolution has essentially a full width of 0.5 mm and for 20 cm off the centre has 4 mm - isn't this just the chamber for which Zanella's programme of propagation of errors showed exactly that this poor behaviour would be expected due to the relative geometry of the probes and the active area?

LILLETHUN: This is quite right.

MAGLIC: Can you observe a phenomenon like this with a chamber for which Zanella's programme shows that it should be good everywhere?

LILLETHUN: We have not really studied it yet.

ANDERSON: Could you say something about the attenuation in the spark as you increase the distance, the size of the chamber. What can you say about the upper limit of size of sonic spark chambers?

LILLETHUN: I wouldn't like to say much about the upper limit. In our case we use lead zirconate transducers and our signals are not very large, but on the other hand if you use electrostatic microphones then you can always raise the bias voltage and get larger pulses. In our largest chamber which has 30 by 50 cm active area we have observed a drop in pulse height from one end to the other of about a factor 4. We found that it was going more rapidly than 1/R.

MANNING: Would members of the audience like to comment on the size of chambers they have made. We ourselves have made chambers with an active area of 110 cm length. Has anyone made chambers of larger size?

ANDREWS: We have made chambers up to 130 cm and this is nowhere near the limit. I shall show curves of pulse height against distance which may be extrapolated. It is then a matter of how much amplification you are prepared to use.

LIPMAN: With regard to the size of chambers, I wanted to make the point that it doesn't matter if the signal drops off providing that the noise level is low. With our chamber we found there was an important mechanical pickup from the discharge condensers onto the spark chamber. We found enough pickup signal coming through that we were getting fairly close to the limit on our large chambers, but by shock mounting the actual discharge condensers that supply the energy we were able to get over this difficulty.
WINZELER: Does your set-up integrate over the azimuthal angle too?

LILLETHUN: Yes. If we consider the fourth chamber, the one which actually defines the scattering angle, we cut out the direct beam with a hole in the triggering system and we include the whole solid angle up to something like 7 mrad, from thereon we use only one side.

WINZELER: Why then use these three counters behind the chamber?

LILLETHUN: It is in order to have three separate triggering systems to make things more selective. It gives us a momentum selection so as not to trigger on all the inelastic particles.
5 March, 1964

IV. MORNING SESSION

SONIC CHAMBER SYSTEMS AND TECHNOLOGY UNDER DEVELOPMENT

Chairman : G. Charpak, CERN
Secretaries: B. Levrat, CERN
            J. Walters, CERN
A SONIC SPARK CHAMBER SYSTEM USING LONG MICROPHONES

B.D. JONES and J. MALOS
H.H. Wills Physics Laboratory, University of Bristol, Bristol.

W. GALBRAITH and G. MANNING
Rutherford High Energy Laboratory, Chilton.

(presented by G. Manning)

1. INTRODUCTION

This paper reports on the development of long microphones for use in sonic spark chambers. Details are given of tests carried out with these microphones in chambers designed for use in an experiment on elastic charge exchange scattering of neutrons by protons. The experimental arrangement will be described together with the computational procedures that are used in the data analysis.

2. EVALUATION OF SPARK COORDINATES USING FOUR LONG MICROPHONES

Four long microphones are arranged in a rectangle to completely surround the sensitive area of the spark chamber, see Fig. 1. The time interval between the occurrence of the spark and the first sound wave reaching the microphones are recorded by suitably gating scalers counting on 6 Mc/s oscillators, resulting in four numbers $N_1$, $N_2$, $N_3$ and $N_4$.

The spark coordinates can then be written as:

\[
\begin{align*}
  x &= N_3 \nu + \Delta - X = X - N_4 \nu - \Delta \\
  y &= N_1 \nu + \Delta - Y = Y - N_2 \nu - \Delta 
\end{align*}
\]

where $\nu$ is the velocity of sound in the gas and $\Delta$ is a constant determined by the timing delay used before opening the gates of the timing scalers and the effective size of the spark.
Solving equation 1:

\[
\begin{align*}
 x &= \frac{(N_3 - N_4) (X - Y)}{N_2 + N_4 - N_1 - N_2} \\
 y &= \frac{(N_1 - N_2) (X - Y)}{N_2 + N_4 - N_1 - N_2} \\
 v &= \frac{2(X - Y)}{N_2 + N_4 - N_1 - N_2} \\
 \Delta &= X - \frac{(N_3 + N_4) (X - Y)}{N_2 + N_4 - N_1 - N_2}
\end{align*}
\]

(2)

Figure 2 shows the sensitivity of the determination of the spark coordinates to errors in the distances recorded by individual microphones. The curves have been evaluated assuming that these errors are equal for all probes (δ) and they have been combined to give a root mean square error (<dx> or <dy>).

\[
\frac{<dx>}{\delta} = \left[ \frac{1}{2} + \frac{x^2}{(X - Y)^2} \right]^{\frac{1}{2}}
\]

\[
\frac{<dy>}{\delta} = \left[ \frac{1}{2} + \frac{y^2}{(X - Y)^2} \right]^{\frac{1}{2}}
\]

It can be seen that if one is to use this type of analysis, square or nearly square chambers should be avoided.

2.1 Advantages of long microphones over conventional point microphones

The use of long microphones offers several advantages over conventional point detectors:

i) The calculation of spark coordinates is made very simple (see equation 2). (The corresponding calculation for four point detectors involves the solution of four simultaneous quadratic equations.) This makes the production of an analogue display of the spark coordinates very simple.

ii) The sum of the times recorded by opposite microphones is independent of spark position and is constant within limits set by variations of velocity and effective spark size. This forms a useful control during the testing and setting-up of the spark chambers and is also a check against multiple sparks. The equivalent check for point detectors can in general only be made after determining the spark coordinates.
The variation in amplitude of the signal given by the long detector is less for sparks at different positions in the chamber than is the case for point detectors. This results because the earliest output always corresponds to the shortest, i.e., perpendicular, distance and also because the length of the microphone reached by the sound wave in a given short length of time increases as the square root of the distance between spark and detector. This latter effect gives a partial compensation for the reduction in amplitude of the sound wave.

2.2 Construction of microphones

Two types of microphones were constructed, electrostatic and piezoelectric. Fig. 3 shows the construction of both types. The piezoelectric microphones proved to be the best and they have been adopted for this experiment. Detectors of lengths from 25 to 110 cm have been made. The piezoelectric crystals used are lead zirconate titanate. The individual strips of 0.4 cm width, 0.1 cm thick and 7.5 cm long are cemented with conducting araldite to a brass backing bar which has been milled flat to within 0.005 cm. The silvered front faces of the crystals are soldered together.

2.3 Tests of microphones with test sparks

Figure 4 shows typical pulses from both types of detectors. The pulses from the piezoelectric microphones have rise times of the order of 1 µsec, and amplitude of a few millivolts. The output of the microphones is amplified (gain 200) and fed through 20 m of 50 Ω cable to the counting room. The pulses are detected there by tunnel diode discriminators set to trigger at 0.05 - 0.1 volts.

Figure 5 shows the amplitude observed for test sparks at different positions with respect to the microphone for typical detectors of both types. Fig. 6 shows times recorded for test sparks at fixed distances from different parts of the microphones. The error bars represent standard deviations for individual determinations of the times. It can be seen that a timing accuracy of better than 1 µsec can be achieved over the full length of the microphone.

2.4 Tests of microphones in single gap chambers

Four piezoelectric microphones were mounted in a single gap, thin plate, spark chamber and tests were made using β particles from a Sr⁹₀ source detected by two thin scintillators in coincidence to trigger the spark chamber. The chamber was accurately moved with respect to the source and scintillators and the average coordinates determined from about 100 sparks are compared with the coordinates set in Table 1. The deviations between set and evaluated coordinates have a root mean square value of 0.03 cm.
A further check was made by plotting histograms of the sums of times recorded by opposite probes, see Fig. 7. This also indicates that a standard deviation of 0.03 cm is expected for the determination of coordinates.

2.5 Tests of microphones in multiple gap systems

Groups of 3 or more gaps placed in a straight line have been triggered both by cosmic rays and an 8 GeV/c proton beam. A straight line was fitted to the recorded coordinates by a least squares method and the standard deviation errors determined for a large number of sparks. Fig 8 is a histogram for 3 gaps triggered by cosmic rays. The standard deviation is again seen to be about 0.03 cm.

These measurements also gave an efficiency for single gaps of greater than 99.5%.

3. EXPERIMENTAL ARRANGEMENT FOR CHARGE EXCHANGE SCATTERING EXPERIMENT

A neutral beam is taken at 0° from an internal target in NIMROD, γ-rays are absorbed by 7.5 cm of lead, the beam is collimated and passed through sweeping magnets resulting in a neutron beam of width about 5 cm and height about 8 cm. The beam is passed through a 60 cm long, 15 cm diameter hydrogen target and a trigger is formed by a coincidence between a threshold Cherenkov counter and momentum defining scintillation counters on either side of the spectrometer magnet. Anticoincidence counters before and around hydrogen target reject charged particles entering the system and bias against inelastic events. The scattering angle is determined by two spark chambers, 350 cm apart, before the magnet and the momentum by these and two further chambers also 350 cm apart after the magnet. The momentum resolution of the system is expected to be ≤ 4%. The angular range covered is 0 - 45 mrad and the angular resolution will be ≤ 0.5 mrad.

The experiment will look for protons produced in the target of the full energy of the circulating beam in the proton synchrotron resulting from elastic charge exchange scattering both in the internal and external targets. The resolution required is that to distinguish an energy change of a pion mass in 8 GeV, i.e., ≤ 2%.

Three gaps are used for all spark chambers, each gap being fed by a separate condenser (1000 pF). The chambers are made with 0.003 cm aluminium plate, mechanically stretched onto aluminium frames and stuck with araldite. The live plates have a window frame of mylar as insulation. The gap between the plates is 1 cm and is made gas tight by an inflated hollow gasket. Ne He (80% 20%) gas is used.
The microphones are shock mounted on small rubber rings from the aluminium channel frame forming the earth plate and are held in contact with positioning bolts which are accurately located (accuracy of \( \sim 0.005 \) cm) in jig-bored holes. The separation of the microphones is known to 0.01 cm.

4. **ANALOGUE DISPLAY**

The position of the sparks in all 12 gaps is reconstructed on a storage oscilloscope as an analogue display. This display shows as 12 dots the vertical trajectory of the particle and a further 12 show the horizontal trajectory. The demagnification for the vertical display is 2.5:1 permitting a resolution in real space of one or two millimetres. The horizontal demagnification is 25:1. This analogue display is extremely useful and allows any event to be immediately approximately analysed for scattering angle and momentum. It provides a constant monitor of the functioning of all 48 microphones.

5. **COMPUTATIONAL DETAILS**

The numbers registered by the scalers are recorded on punched paper tape which is later fed into a computer.

\( x, y, \nu \) and \( \Lambda \) are evaluated for each gap using equations 2. The velocity for each gap is compared with an average velocity for that gap determined from the previous events and the solution is permitted providing the velocities do not differ by more than some predetermined amount (typically 1%). If the velocity test is passed a similar check is made using 2. Here a typical limit of 0.05 cm is used. These two simple tests are found in practise to remove cases of two sparks and yet do not reduce the efficiency by rejecting good events.

Straight lines are then fitted to the evaluated coordinates in the horizontal and vertical plane before and after the magnet. There are a maximum of six possible sparks for each fit but events are accepted if some gaps have failed providing that at least two gaps give solutions for each chamber position. This requirement of only two gaps out of three is of considerable benefit as it results in a high efficiency even though the individual gaps have a few per cent inefficiency. In addition the experiment can continue even if a gap ceases to function completely.

The individual spark coordinates are compared with the straight lines fitted and gaps having deviations of greater than 0.05 cm are rejected and a new fit made. The final vertical plane trajectories are compared before and after the magnet to reject events in which the particle has been scattered in the vertical plane between the second and third spark chambers.
The scattering angle, bending angle in the magnet, and other relevant information can then be printed out or recorded on magnetic tape for further analysis and grouping.

The whole system is now operational and is at present undergoing tests in its final form.

ACKNOWLEDGEMENTS

We wish to acknowledge the help of Mr. B.T. Payne in the design and construction of the electronic equipment, and Messrs. A.G. Parham, J. Burrows and P.D. Day for valuable assistance.

The experiment on charge exchange scattering is being undertaken by the following physicists in addition to those concerned with the development of the microphones and chambers (who are listed as authors for this report): Drs. N.H. Lipman, D. Reading and R. Van der Ray, and Messrs. J. Jafar and D. Ryan.
<table>
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<th>Mean Values computed by acoustic method</th>
<th>Differences between read and computed coordinates</th>
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Results of measurements in a spark chamber.

Comparison is made of mean spark coordinates as measured directly and as calculated by the acoustic method. Values of y and Δ also given. Eight source positions are listed in chronological order. At each position sparks were produced in the chamber in a region 0.4 x 0.4 cm². About 100 readings were taken for each source position and an average was taken of the computed coordinates. The estimated standard deviation of the mean coordinates due to the source size is 0.013 cm. The values of Δ have been corrected for the delay introduced before starting the timing scalers and so represent effective spark sizes.
Figure captions

Fig. 1 Microphone geometry and labelling system. The microphones are numbered 1, 2, 3, 4. The origin of coordinates O is at the centre of the outer rectangle defined by the sensitive faces of the four microphones (70.282 x 34.722 cm²). The inner rectangle represents the sensitive area (50 x 15 cm²) of the chamber.

Fig. 2 Average accuracy of coordinate determination calculated for different spark positions and shapes of chamber.

Fig. 3 i) Section through electrostatic microphone

a) Aluminium alloy bar of 0.6 x 3 cm², cross-section with a slot of 0.4 x 0.6 cm² cross-section milled into it.

b) Alloy strip 0.2 x 0.5 cm².

c) Araldite (MY 753 + HY 951) to support and insulate b).

d) Air gap of thickness 0.01 cm.

e) Aluminised mylar diaphragm. The mylar was 6μm thick; the aluminized layer ~1 μm.

ii) Section through piezoelectric microphone

a) Brass bar 0.6 x 2.5 cm².

b) Conducting araldite.

c) Crystal of lead zirconate titanate 0.4 x 0.1 cm² silvered on upper and lower faces.

Fig. 4 Output waveform of piezoelectric (shown on left) and electrostatic microphones taken with a test spark at 20 cm. The vertical scales are 2 mV/cm (left) and 5 mV/cm, while the horizontal scales are 2 μsec/cm (upper left), 5 μsec/cm (upper right), 10 μsec/cm (lower left) and 20 μsec/cm (lower right).

8446/μm
Fig. 5  
Amplitude of first pulse for piezoelectric (upper) and electrostatic microphones as a function of position of test spark. The discriminator levels used are shown. The arrows indicate the limits of the sensitive regions of the microphones.

Fig. 6  
Intervals of time between the occurrence of sparks in air and the detection of sound at the piezoelectric (upper) and electrostatic microphones. The timing is seen to be constant within ~1 μsec corresponding to a spatial accuracy of ~ 0.3 mm. Each point represents the mean of ten readings and standard deviations for individual sparks are shown.

Fig. 7  
Sums of times recorded by opposite pairs of microphones uncorrected for changes in ~ or Δ. 1 μsec corresponds to 0.5 mm for the gas used in the chamber.

Fig. 8  
Histogram of deviations of calculated spark coordinates from least squares fitted line. Results were obtained with 3 gaps. The abscissa is the square root of the sum of the squares of the deviations for the three sparks.
Fig. 1

Fig. 2

Fig. 3
Fig. 6

Fig. 7
Fig. 8

\[ \sqrt{\sum (\delta x)^2} \text{ cm} \]

\[ \sqrt{\sum (\delta y)^2} \text{ cm} \]
DISCUSSION

PEREZ-MENDEZ: What is the dead time of your system?

MANNING: The dead time of this particular system is determined completely by the readout, which I did not mention. The readout at the moment is on punched paper tape only. The reason for this is that the experiment is expected to have a trigger rate of the order of 0.1 per machine burst and therefore taking 4 seconds to print out is no real limitation. I think in practice we would prefer to speed it up, and equipment is being built which eventually will make it faster.

PEREZ-MENDEZ: I also wanted to know what the recovery time of the microphones is?

MANNING: Of the order of 5 msec, depending on their length. Obviously the sound hits them for a long time and therefore they continue to ring for a long time. It depends on their overall length.

LILLETHUN: What is the overall length between the first and last chamber, and what is the delay between particle passage and the application of the high voltage?

MANNING: The path is of the order of 15 metres. The distance between chambers A and B is 350 cm and also between C and D. The overall delay we have between the particle going through the first chamber and putting the voltage on that chamber is of the order of 300 nsec. This is predominantly flight time and cable length.

VERNOR: Is it true that in these microphones this long ringing time is associated with the fact that the crystal is a very high 'Q' resonant circuit?

MANNING: We find that you can excite the microphones very easily by tapping them for example and they have a characteristic frequency of the order of 20 kc. Although we have no real proof of it, we think this is due to oscillations going along the microphone. In other words the first pulse you get is characteristic of the transient pressure, but the ringing after that is characteristic of the ringing of the whole probe assembly.

VERNOR: There was something pointed out to me by Professor Dicky's group in Princeton. They have had this sort of problem in using this type of transducer and in order to reduce the dead time it is possible to redrive with 20 kc frequency out of phase to damp out the oscillations. You essentially reduce the 'Q' of the crystal then and it might be of some use to people who might want to look for second sparks.
MANNING: I think if people want short probe dead times it is probably better to use capacity probes. They are much less susceptible to excitation from the backing; quite clearly the thing which you have to disturb is the front membrane, and this is rather difficult to excite from the back. We found, in practice, that the cross talk we got through excitation through the backing in capacitor microphones was very small, and also the signal dies out much more rapidly and it doesn't have this characteristic 20 kHz frequency.

ANDERSON: Do you make any attempt to match the impedance of the long condenser strip microphones with your cable?

MANNING: No. We use a 50 Ω cable of the order of 2 metres to 3 metres long. This cable goes into an amplifier which has a gain of the order of 200 and is the only amplifier in the system. We then transmit through a 20 metre cable length. Now the input circuitry to this amplifier is just that we feed through a 1K resistor and have 2 diodes back to back. The reason for this is that any large voltage pulses you get from the electrical pick-up are limited and are then clipped by the diode. This circuit does nothing to small pulses which feed into the input of the amplifier which has an input impedance of 20K.
A CURVED ACOUSTIC SPARK CHAMBER *) **)

U. AMALDI, Jr.
Laboratori di Fisica, Istituto Superiore di Sanità, Rome

The acoustic spark chamber we shall describe is meant to be a hodoscope to be added to a counter system to improve their spatial resolution and for this reason could better be called an acoustic spark "counter".

Quite often it is necessary to measure the angle of charged particles produced or scattered in a small target. The best detector geometry would be, of course, a spherical spark chamber. This geometry offers the advantage of a big solid angle together with the property that the particle tracks are always perpendicular to the chamber plates. We think that such detectors could be very useful, for instance, in colliding beam experiments.

The difficulties one expects to encounter in the use of a curved spark chamber are due to the many reflections the sound undergoes along its path. It is thus necessary to study the behaviour of sound shock waves in a curved gap. This is one of the aims of the present work.

There are technical difficulties in constructing a spherical spark chamber of large radius (by "large" we mean a radius of the order of 50 cm so that a 2 or 3 cm target could be considered pointlike ). Thus as a first step towards large solid angle curved spark chambers we have chosen a cylindrical geometry.

Our spark chamber has only two gaps; in this way the electronics is very simple and, on the other hand, there is still the possibility of distinguishing a "spurious spark" (a single spark in one of the gaps) from an "event" (two aligned sparks).

*) More details about the same subject are contained in the report ISS 63/26.

**) This work has been partially supported by the Istituto Nazionale di Fisica Nucleare.
The spark chamber is shown in Fig. 1. In two plexiglass plates 10 mm thick slits are machined 0.6 mm thick and 1 mm deep; aluminium foils 0.4 mm thick and 10 cm high are held by these slits and constitute the chamber plates. The aluminium near the probes has been replaced by bakelite laminas 15 cm long having the same thickness as the aluminium foils. Mylar foils glued all around insure the chamber's vacuum tightness. The useful angle of the chamber is 130°.

To detect the sound wave we use solid dielectric probes.

The probe we have constructed is drawn in Fig. 2; it is mounted on a UHF connector. The mylar foil is 30 μ thick and the O-rings insure both electrical insulation and vacuum tightness. The mylar foil is aluminium coated on the external surface. The DC voltage applied to the central electrode is 180 V and is supplied by four small batteries in series enclosed in a metal box to avoid any electrical pickup from the spark. The probe dimensions are quite big because our gap is large and we want to collect as much energy as possible.

The probe response to a shock wave from a spark outside of the chamber is shown in Fig. 3a. The spark is obtained by discharging 2000 pF charged to 10 kV; the distance between the spark and the probe is 20 cm. It is seen that the probe output is clean; some of the late oscillations are probably due to sound reflections on the spark and probe holders. The rise time of the pulse is about 3 μsec.

The electronics does not require any special discussion. Four gate circuits are opened by the "event" pulse and 1 MHz frequency feeds through. The probe outputs are amplified by means of transistor amplifiers (amplification variable between 250 and 1000, input impedance 200 kΩ) and shaped by pulse shapers whose thresholds are at 1.5 V. These pulses close the four gates. The 1 MHz pulses fed through are counted by fast scalers.

In the following we shall measure the angular position of the artificial spark in a gap starting from the probe head and we shall call it α. Moreover by N1 and N2 we shall indicate the numbers read on the scalers stopped by the two probes in the same gap. Having only two probes per gap it is not possible to take into account the fact that the velocity of the shock wave varies with the distance from the production point. We are thus forced to neglect the "spark size" parameter AR discussed in detail in Ref. 1. The obtainable accuracy in the determination of the position of the sparks will thus be much poorer than the one obtained with four probes in a flat chamber1).
If we call \( y \) the distance of the spark from the mean plane of the chamber in the vertical direction, the equations which determine \( x \) and \( y \) are:

\[
x^2 + y^2 = (kN_1)^2
\]

\[
(x - \alpha)^2 + y^2 = (kN_2)^2
\]

where \( r \) is the gap radius and \( \alpha \) is the angular distance between the two probes.

From (1) we get:

\[
\alpha = \frac{k^2}{2\alpha N_1^2} (N_1^2 - N_2^2) + \frac{\alpha}{2}
\]

\[
y = \pm (k^2 N_1^2 - \alpha^2 r^2)^{\frac{1}{2}}.
\]

To check experimentally the validity of eqs. (2) and (3) it is necessary to produce sparks in very well known positions. Because we did not have at our disposal a narrow beam of particles we have put in each gap a small movable plexiglass carriage holding a needle in an easily variable position. The application of a 13 kV pulse to the chamber plate touching the conductor connected to the needle results in a spark between the needle itself and the grounded plate facing it. We shall call these sparks "artificial sparks". During these tests air is contained in the chamber; the positions of the carriage are varied by means of nylon strings coming out of the gaps near the acoustic probes.

The top trace in Fig. 3b is the output of one of the probes for \( \alpha = 135^\circ \), the second for \( \alpha = 75^\circ \) and the third for \( \alpha = 150^\circ \). Prior to the main oscillations due to sound transmission in air, some sound is received by the probe for \( \alpha = 75^\circ \) and \( \alpha = 135^\circ \). The more natural interpretation is that they are due to sound partly transmitted through the aluminium plates and then reemitted in air. For this reason we have cut the gap plates into segments 7 cm long. As is shown in Fig. 3c (to be compared with Fig. 3b) this is enough to prevent such a transmission. The oscillations which are left after the first peak are due to true sound waves arriving at the probe and they last about 2 msec.

In Fig. 4 we have plotted \((N_1^2 - N_2^2)\) as a function of \( \alpha \). The needle was sparking at the centre of the gap towards the inner plate. The dimensions

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of the points are of the order of the errors obtained repeating the measurements in the same position. In spite of the many reflections suffered by the sound in the gap the relation between \( a \) and \( (N_1^2 - N_2^2) \) is exactly linear, as predicted by eq. (2). It must be noted that for \( y = 0 \), \( a \) is linear not only in \( (N_1^2 - N_2^2) \) but also in \( (N_1 - N_2) \). In fact \( (N_1^2 - N_2^2) = (N_1 - N_2)(N_1 + N_2) \) and for \( y = 0 \), \( (N_1 + N_2) \) does not depend upon \( a \) and is proportional to sound velocity. Moreover, for \( y = 0 \) the angle \( a \) obtained applying eqs. (1) and (2), where the "spark size" \( \Delta R \) has been neglected, equals the solution of the correct equations

\[
\alpha R = kN_1 + \Delta R
\]

\[
(a - \alpha) R = kN_2 + \Delta R.
\]

Other measurements have been done under the following conditions: needle at the centre of the gap sparking towards the outer plate and needle on one side of the gap sparking towards the inner and the outer plates. The differences \( (N_1^2 - N_2^2) \) measured in these conditions coincide, for the same \( a \), with the values plotted in Fig. 4 within less than 0.16 units of the vertical scale. Because 2.9 units correspond to 10° we conclude that the error in the determination of \( a \) for all \( y \)'s is less than 0.6 degrees. A big contribution to this error comes from the fact that we have neglected \( \Delta R \) in eqs. (1) and (2). With more probes in a curved gap it should thus be possible to achieve an accuracy closer to the one obtained in flat chambers. We recall that in our chamber 0.6° correspond in space to about 6 mm. Because this error is of systematic origin, it must be interpreted as a total maximum error.

From Fig. 4 and eq. (2) we get \( (r = 55 \text{ cm}) \):

\[
k^2 = 0.9462 \times 10^{-2} \text{ cm}^2
\]

\[
\alpha_M = 149.1^\circ
\]

Eq. (3) in principle determines also the \( y \) position of the spark. Using the experimental value (4) for \( k^2 \), we find that it is possible to get a good value for \( y \) if the spark is not too far from one of the probes (less than about 40°).

The chamber has also been tested with cosmic rays. In this case the applied voltage is 14 kV and the coupling capacitor is 6000 pF. While the results of the calibration obtained with artificial sparks have been confirmed, it is observed that almost no sound is transmitted through the plates before the main pulse. The most reasonable interpretation of this fact is that in the case of artificial sparks the carriage in the gap transmits oscillations to the plates.
In Fig. 5 the response of a probe to cosmic ray sparks is shown for \( \alpha = 15^\circ \) and \( \alpha = 135^\circ \). The rise time of the first peak of these pulses does not depend upon \( \alpha \) and it is about identical with the value obtained in free air. The pulses due to artificial sparks on the contrary showed a pronounced dependence of the rise time upon \( \alpha \). To explain this result we first note that the energy of the cosmic ray spark is bigger by more than a factor of 4 than the energy of the artificial sparks. Moreover, a comparison of Figs. 3 and 5 shows that the cosmic ray pulses are much bigger and cleaner than the artificial ones. These two facts tend to indicate that the shock wave was not developing properly in the tests with artificial sparks and suggest the conclusion that in a curved gap an energetic shock wave can propagate, guided by the plates, preserving its rise time.

ACKNOWLEDGEMENTS

We are indebted to Dr. B. Maglić for useful discussions and to Professor M. Ageno for his continuous interest.

Reference

Figure captions

Fig. 1  Spark chamber mechanical construction.

Fig. 2  The solid dielectric probe.

Fig. 3  

a) Response of a solid dielectric probe to a spark in free air; left: \((0.2 \text{ msec/cm}) \times (30 \text{ mV/cm})\); right: \((15 \mu\text{sec/cm}) \times (30 \text{ mV/cm})\).

b) Probe response to artificial sparks in the curved chamber after the amplifier (amplification \(\approx 200\)). From the top:

\[
\begin{align*}
\alpha &= 135^\circ \ (0.2 \text{ msec/cm}) \times (2 \text{ V/cm}) \\
\alpha &= 75^\circ \ (0.2 \text{ msec/cm}) \times (2 \text{ V/cm}) \\
\alpha &= 15^\circ \ (0.2 \text{ msec/cm}) \times (5 \text{ V/cm})
\end{align*}
\]

c) Same as b) after segmenting the chamber plates (amplification \(\approx 500\)).

Fig. 4  \((N_1^2 - N_2^2)\) as a function of the angular distance of the artificial spark from the probe (see text).

Fig. 5  Probe response to cosmic ray sparks before the amplifier. From the top:

\[
\begin{align*}
\alpha &= 15^\circ \ (10 \mu\text{sec/cm}) \times (50 \text{ mV/cm}) \\
\alpha &= 150^\circ \ (0.2 \text{ msec/cm}) \times (50 \text{ mV/cm}) \\
\alpha &= 135^\circ \ (10 \mu\text{sec/cm}) \times (20 \text{ mV/cm}) \\
\alpha &= 135^\circ \ (0.2 \text{ msec/cm}) \times (20 \text{ mV/cm}).
\end{align*}
\]
DISCUSSION

LIPMAN: I haven't quite understood whether the sound follows a straight line or whether it follows the curvature of the aluminium foil or whether it follows the curvature of the lucite? Could you explain this?

AMALDI: The only way the sound reaches the probe is by following the curvature. Probably due to the fact that the sound path is well guided by this small chamber there is no loss in the rise time of the pulse.

ANDERSON: But what about the attenuation in the pulse height. Does the amplitude of the pulse vary depending on where the spark is?

AMALDI: It varies, but not very much. The amplitude, when the spark is near the probe, was of the order of 70 millivolts, and of the order of 30 millivolts when the spark was near the far end of the chamber. I would like to remark that the rise time of my probe is quite slow in comparison with others. The reason is probably that the area is quite big.

MACLEOD: Have you thought about how many microphones you will in fact need when you extend this to a spherical system? Your conditions about guiding the sound will presumably no longer hold under these conditions.

AMALDI: I think that for a hemispherical chamber I would use of the order of 5 microphones - 1 on the vertex and 4 on the sides, but I have not considered the ambiguity problems.

CHARFAK: Is the velocity you expect in a curved path exactly the same velocity as in a straight line?

AMALDI: I don't know enough about sound propagation to answer your question.
The purpose of this talk is to describe briefly the main aspects of electronics in handling sonic spark chamber information.

One can distinguish three main periods of development corresponding to particular electronic requirements:

1. Measuring

2. Measuring and Recording

3. Measuring, Transfering to Computer, Computing and Recording

Before discussing these three items I should like to remind you in short of the basic data acquisition system that we developed at CERN some 1-2 years ago for electronic experiments. The idea is to have plug-in units which can be scalers (25 Mc/s, 250 kQ/s, etc.), hodoscope units (10 inputs, gate 30 ns), analogue to digital converters, etc. Each unit is a word of 24 bits maximum. The logic can select 30 words and present it to a recorder (printer, puncher, magnetic tape computer). Some 11 of these systems are used as standard equipment in CERN. Fig. 1 shows the principle of it. The content of the word appears as 24 bit parallel information on 24 lines common to all words, (see Fig. 2). This system is the basis of our actual work for sonic event recording but new equipment is in preparation for fast on-line work. To come back to sonic spark chamber measurements, we use the following principles:

1. MEASURING

1.1 The classical scaler system

To each microphone probe is attached a scaler. All scalers are fed by a common oscillator (~5 Mc/s) but each one is gated "on" by a DC signal arriving between the chamber trigger and its corresponding probe signal. Available CERN scalers are used for doing these measurements.
Since four scalers are generally used for one gap, the necessary number of scalers for a sonic spark chamber experiment is high. It is possible to design a cheaper scaler with less bits and a somewhat slower speed but a new system is now in development called "The Sonic Event Recorder" which is cheaper and offers future possibilities in electronic data handling.

1.2 The sonic event recorder

It consists of two units:

- The fast carry scaler
- The memory unit

These two units are now in the construction stage and will be ready this spring. The principle of the recorder is indicated schematically in Fig. 3. The scaler is a time clock. Timing pulses (≈ 2 Mc/s) are supplied in the interval between the chamber trigger time and a maximum time adapted to the chamber size. The information contained in this scaler (16 bits, binary) is applied to a ferrite store memory through "half-current drivers" (here 70 ma). The other driving current (120 ma) is generated when a signal coming from the probe has been quantized or synchronized through one of the 32 inputs. Word erasing or reading requires 400 ma. The core memory 16 x 32 was obtained by connecting two Siemens type B64506 Al-X495 16 x 16 in series.

The fast carry feature of the scaler is of primary importance if the information in the scaler has to be presented to the memory at each cycle. Using a gate system the carry time will not be over 50 nsec.

The frequency of 2 Mc/s quoted above will in fact correspond to a frequency of 4 Mc/s in a classical gated oscillator system. This gain of 2 is obtained by triggering a ringing circuit, avoiding therefore the possible one cycle error at the beginning.

The sonic event recorder is made compatible with the existing CERN scalers system and due to an internal group selection it requires only four addresses of the standard 30 position channel selector. A standard logic can then read the Sonic Event Recorder (SER) + 26 normal scalers or equivalent.

It is important to note the major difference of principle of the SER with other types of memories (computers, pulse height analysers). In SER 32 words can be written at the same time since the 32 probe inputs are independent. This feature may be useful in later data acquisition systems.
Example: Use in a wire chambers system.

It may be desirable to convert the geometrical position of a switched core in a wire chamber into its real coordinate, for example to reduce unnecessary computation in an on-line experiment.

The idea is to arrange the wire chamber cores in a shift register, to shift its content in synchronism with the SER time scaler and to observe the output. Each time a switched ferrite is found a "probe" pulse is sent to the sonic event recorder. The value recorded is the coordinate of the switched core. The advantage of the system is that "zero or empty" coordinates are avoided.

For one spark systems 32 chambers could be used. For \( N \) sparks \( \frac{32}{N} \) could be used, provided simple selectors of \( N \) positions are added to branch from one probe input to the next. Thus, for 4 sparks per chamber, 8 chambers could be used. The number of wires is practically unlimited \((2^{16} - 1)\).

2. RECORDEDING

2.1 Standard CERN print punch equipment

The standard CERN print punch equipment with punched tape was used for the first "sonic" experiments. The need was soon evident for a much more compact way of recording, at least for this type of experiment.

2.2 Magnetic tape

Simple modifications were made to the print-punch logic to make it suitable for magnetic tape driving (speed), and a "magnetic tape adapter" was added to produce IBM code, voltages, etc. (Fig. 4). A complete electronic box was also provided to drive the tape deck, to write, to read, to check lateral and longitudinal parities (Fig. 5). This unit is transistorised and is logically attached to the tape deck which is an IBM 7330, also transistorised. It works at a speed of 36 inches/sec and is used at 200 characters/inch.

Typically 10,000 events of 50 scalers can be recorded on a standard 2,400 feet reel. Each event takes about 100 msec to be recorded, allowing about 2 events per burst.

Two magnetic tape systems have been completed for the physics groups (Cooconi, Maglic) and both are working satisfactorily.

Figure 6 shows the 7330 in its CERN made trailer equipped with an air conditioning system. Fig. 7 shows a typical installation with scalers, readout logic, magnetic tape adapter and magnetic tape logic. Two logics were used here to allow 60 scalers to be used instead of the standard figure of 30. This is as yet not with the sonic event recorder.
Lateral and longitudinal parities are continuously checked by reading immediately (8 ms) after writing. If any error is detected the tape backspaces to the last good event and rewrites the badly written event which was in this case not erased (scalers reset blocked by the error signal). The event is rewritten until it is correct. A small creeping effect at each backwards–forwards movement (about 2.3 mm) gives the possibility of passing over bad spots of the tape. The backspace process is very useful against spurious pick up signals occurring in the experimental hall. Since a warning signal is given for every backspace, failures are easily detected. Of course these magnetic recording systems can be attached to any counter experiment using the basic scalers system.

3. TRANSFER TO A COMPUTER ON-LINE

There is an intermediate stage that could have been considered before the computer on-line; it is the use of a buffer memory designed to accept any desirable number of events per burst with later transfer to tape. In this case computation and feedback facilities would still be missing and the cost approaches the price of a cheap computer, therefore this solution was no longer considered.

3.1 Ferranti Mercury on-line

When the Mercury first became available for on-line work the basic CERN print-punch logic was again used with an additional "computer adapter" for pulse shaping and signals exchanges (synchro, busy line) Fig. 9a.

Information is transferred at a rate of about one decade (or character) per 180 µs + 10 ms (unavoidable to keep logic standard), the total for 30 scalers being about 65 ms allowing roughly 3 events per burst. But the important feature of information feedback to the experimental hall exists and provides typewritten results of warnings and also an analogue display of wanted points on an X-Y plotter. The digital to analogue converter (Fig. 9) provides a 1/512 resolution. It receives the X and Y values from the computer and also the "plot" command. This unit is now under test in the laboratory and is an extension of a similar unit with lower resolution which was already working on-line. A magnetic tape unit is also provided in parallel with the computer by means of another interconnecting "computer adapter" (Fig. 9b). The tape records events occurring when the computer is busy (long computation, typewriter working) or if the computer is not used!

Even with its limitations the system has proved the considerable advantages of an on-line computer for electronic experiments.
3.2 SDS computer on-line (available summer 1964)

The SDS 920 can accept a 24 bit word every 8 μsec; this makes 0.8 μsec for 100 scalers. This changes by an order of magnitude the number of events that can be accepted in a burst. This number is then only limited by event rate, dead time of chambers, etc.

A new transfer logic is in preparation to transfer the existing scalers and the existing plug in units at the 8 μsec rate. It will be ready in June-July when the computer arrives.

To spare extremely valuable computation time it is necessary to use the binary system as much as possible, therefore physicists should start getting used to the octal values which are a decimal representation of a binary number split into groups of 3 bits.

Ex: $1100011101001110 = 143516$

($= .1/100/011/101/001/110$)

Standard CERN scalers can easily be modified to binary and, even if not modified, their contents can be transferred and converted into binary in the computer. Indirect advantage of the modification to binary: a maximum of $2^{24}$ counts can be accepted instead of $10^6$ ($2^{24} = 16,777,216$)

3.3 CDC on-line

It accepts groups of 10 bits at the rate of 10 bits/μsec. The 24 bits of our standard equipment will have to be split into 3 groups giving 3 μsec per scaler. Not to make existing equipment obsolete the speed will have to be limited to about half that speed. We have seen that this can be accepted although it is still "too fast" for many experiments and many events per experiment, all on the same channel.

4. CONCLUSION

We have tried to show some digital electronic realisations in the field of film-less spark chambers in relation with the trends. No doubt that similar circuits will be and are necessary for videocon or "discharge planes" systems.

The trend is now to more and more events. These events may need later computation for a new reconsideration of the measurements. It is quite important therefore to feel the need for a very high density and relatively cheap recording medium and to consider this problem more seriously.

Direct physical feedback from the computer to the experiment should also be used extensively to make full use of the available fast processing power.
Figure captions

Fig. 1  Block diagram of scalers print-punch system
Fig. 2  Principle of readout
Fig. 3  Principle of the sonic event recorder
Fig. 4  Magnetic tape adapter
Fig. 5  Magnetic tape logic unit
Fig. 6  Air conditioned trailer for the tape unit
Fig. 7  Typical experimental set-up showing scalers, logic and tape unit
Fig. 8  a) Computer adapter 1
          b) Computer adapter 2
Fig. 9  Digital to analog converter
Fig. 3

Principle of recording for sonic spark chamber using ferrite memory and common time scaler

Fig. 4
DISCUSSION

VERNON: I did not quite understand when you talked about adding a clock starter in order to remove the uncertainty in the first clock count. How do you do this, and do you really gain anything?

ISELIN: If you have a free running oscillator unconnected with the gate pulse generated by the event, you may make an error of up to T (the clock period) at the beginning of the time measurement, as well as at the end. What we propose is this: suppose we arrange that the oscillator is gated so as to start at a fixed position with respect to its clock cycle then we can eliminate completely the uncertainty associated with the beginning of the clock measurement.

VERNON: Is it not rather difficult, electronically, to make this kind of gated oscillator so that the first pulse is in fact a true clock pulse?

ISELIN: Well this is a question also that it will be interesting to discuss. Shall we take a quartz oscillator or a normal oscillator?

VERNON: Well I don’t know, but what I am thinking of is a common problem to several systems including my own and I think perhaps you get something for free by measuring that time difference that is just past gating, storing and adding one more bit of resolution and one more bit of storage.

ISELIN: We have made in fact a trigger circuit, not a quartz circuit, which was stable at something like $10^{-5}$. A trigger oscillator with two transistors and a coil and condenser, so it does not cost too much and we are planning to make the same but with a quartz trigger circuit.

TREBST: I would just like to make a small remark to the question of the gated oscillator mentioned by Dr. Vernon. There is another method where you have a free running oscillator which can be of high stability and which runs with somewhat higher frequency and is demultiplied by a factor of 3 or 4.

ISELIN: Yes. We have thought about making a 25 Mc oscillator. We would then have only the error associated with 25 Mc but it requires a division by 10 and so we are just trying to make a simple triggered oscillator.

LINGJAERDE: In a CERN Report on the HPD device that came out in 1961 and which is unfortunately out of print now, it is described how one can make a gated clock by taking a commercially available card from Digital Equipment Corporation and adding one diode and one resistor. You then have a gated clock which does what you require. We have used this for 2 or 3 years now.
ISELIN: I am not worried about the circuit. I think the principle of gating a clock is good. In all the circuits used in CERN I don't know of anyone who uses a triggered clock system, and I am just worried about the factor of 2 we are losing.

BOYARSKI: Can you give me an estimate of how many times you have got to back space during one reel of tape?

ISELIN: It happens that we have got whole tapes through without any back space (i.e. without any error in recording), but generally it is a few times for a reel.

BOYARSKI: I was wondering how necessary it is to have a back space ability for your equipment, since the requirement doesn't arise very often.

ISELIN: I think it is extremely important to have a device in the system which gives a warning signal indicating either a recording error, or if it persists, perhaps a more serious electronic failure.

ANDERSON: I want to ask how you manage to go back without losing the data of the event?

ISELIN: When we have made a writing process we erase all that was in the scalers. Now this erasing is conditioned by the error flip-flop so if during the writing we detect any mistake, we immediately drop the reset of the whole system. It then notices that there has been a mistake and the reset is blocked by the error flip-flop and another attempt at writing is made. Only when the signal has been satisfactorily written on tape are the scalers reset.

ANDERSON: How much time does it take to stop the tape, go back, erase and rewrite?

ISELIN: It depends on the number of scalers, - about 0.3 sec. It doesn't matter very much since normally it happens only two or three times a reel.

LILLETHUN: I would like to comment about the erases and errors on the tape. It has been very useful to have this facility because we have run into trouble when a little piece of dust has come on the writing head and the magnetic tape unit has been trying without success to write this event down. If we did not have such a detecting device to tell us that something was wrong this could go on for quite some time and we just wouldn't be able to record more events. Unfortunately we are not on-line at the moment so we have to have other devices to tell us when things go wrong. This is a simple and very good device which doesn't cost much and
doesn't waste any time. We have had several reels run without any warming
squeaks coming, but on the other hand we have also had a tape where it has
been squeaking continuously and where we just had to discard the tape and
take another one instead.

PIZER: It seems to me this re-writing problem can be put in a
slightly different way. You get a warning signal anyway from the parity
check and you can have that signal whether you re-write or whether you
don't re-write. You can either leave the computer to decide that what you
have written is incorrect, or you can re-write.

GELERNTER: After hearing of the exotic 10 and 20 Mc clock rates
that have been used, and granting you can gate the oscillator easily
enough, have you had any trouble getting physicists to accept the 2 Mc
clock rate ?

ISELIN: Yes. We have had discussions with the programming
people and the physicists. Frequencies from 2 Mc to 10 Mc have been used.
With a triggered oscillator the 2 Mc is equivalent to the 4 Mc ungated
oscillators now being used and this is sufficiently accurate to satisfy
the physicists.

PIZER: I would like to ask whether anybody in the audience can
guide us or advise us whether it is really necessary to put magnetic tape
units which are in the experimental hall in some kind of controlled envi-
ronment or can one leave them unprotected ?

WEINSTEIN: We have run a Potter 906 II, seven channel tape re-
corder in a small data hut on the experimental floor of CEA. The tape
deck was on the experimental floor for about 9 months and was stop-started
$0.5 \times 10^6$ times. It was in a cabinet whose air intake was filtered, just
as many people run ordinary electronics. Other than this filter, and
going the hut floor cleaned periodically no precautions were taken against
the rather dusty environment. The tape deck showed no wear, and we encoun-
tered no difficulty in recording or reading at any time. Our tapes were
acceptable to IBM over the entire period of running. The tape head and
pinch rollers were cleaned about every 16 hours. (A five minute operation.)
The data hut had air conditioning with very little control ($\Delta T \sim 20^\circ F$),
and a small humidifier.
1. INTRODUCTION

In Liverpool the group listed above have two experiments in preparation which will use acoustic spark chambers. The first, for which preparation is almost complete uses two chambers in a pair spectrometer which will be used to measure the energy of the photons from \( \pi^- + D \rightarrow N + N + \gamma \). The second will use six chambers associated with two bending magnets to measure the quasi-elastic scattering of 400 MeV protons in nuclei. The microphones and electronics for the two experiments are similar and so will be described first.

2. THE MICROPHONES AND TIMING SYSTEM

To simplify the computation of spark position from the measured times microphones running the full length of each side of the chambers are used. Piezoelectric microphones have been used with the pair spectrometer chambers but these were sensitive to low frequency sound transmitted from the spark through the body of the chamber and arriving before the sound in the gas. In future the microphones used will be the capacitor type as these have proved cheap and easy to make even when long, they are sensitive only to sound in the gas and give larger outputs than the piezoelectric type. The capacitor microphones have diaphragms of 6 \( \mu \) mylar aluminised lightly on one side. Because of the well known difficulty of polarisation changes if the mylar is used as a dielectric in such microphones the aluminised surface is put facing the rigid metal back electrode and the two separated by a fine nylon gauge made from threads about 30 microns in diameter. This is sold in Britain as nylon chiffon and is a maximum of about 60 microns thick with a space of about 200 microns between threads. A typical method of construction is illustrated in Fig. 1. The microphones are polarised with a voltage of not more than 180 volts. If the chiffon is not clean there is some electrolysis of the aluminium on the diaphragm.
The output from the microphones is amplified and used with appropriate gating to stop scalers which have been started when the chamber was fired. The clocks run at 1 or 2 Mc/sec but this is to be increased to 5 Mc/sec. When all the scalers are stopped or a fixed time has elapsed, the contents are transferred in blocks to a buffer and punched on paper tape at 30 or 100 characters per second. The system will cope with one event per second.

3. VARIATION OF THE VELOCITY OF SOUND WITH DISTANCE

In all the chambers the gas mixture used is argon with alcohol. The argon is welding grade and is bubbled through alcohol at the input so it is presumably not saturated. As there was no data on the behaviour of sound velocity in this gas a dummy chamber was made with trigger sparks set along one plate (at 10 cm intervals) so that the spark would occur at one selected point. The plates of this chamber were 122 x 26 cm and 5 mm apart. Microphones were placed along the short sides at a distance of 129 cm apart. A range of time delays for the spark positions was obtained and indicated the usual rapid fall of velocity near the spark followed by a slower decrease. A differential velocity curve obtained by subtracting time delays for adjacent spark positions and dividing it into the distance between them is shown in Fig. 2.

A graph of the sum of the times for the sound to reach the microphones at each end is shown in Fig. 3 as a function of the distance from one end of the chamber. The central part could be satisfactorily predicted using a linear fit to the differential velocity curve at large distances.

Using the dummy chamber the variation of pulse height with distance from the spark was examined. In Fig. 4 the total pulse height and the pulse rise after one μsec are plotted against distance from the spark. It will be seen that the rate of change of the plotted quantities and the apparent rise time of the pulse alter at about 20 to 30 cm from the spark. This is the distance at which the initial rapid variation of sound velocity finishes.

In Fig. 5 the variation of the sum of the times to the two microphones from a spark in the middle of the chamber is plotted against the voltage supplied to the spark gap. The velocity increases with spark power as is expected for shock waves but the effect is not large.

In the large chambers used with the quasi-elastic scattering experiment the sparks will never be closer than 13 cm to a microphone so the correction for the velocity variation may be made accurately using empirically derived data.
4. **THE PAIR SPECTROMETER**

The essential features of the pair spectrometer are shown in Fig. 6. Each of the two spark chambers in the magnet gap has two microphones so the spark position is determined only in one dimension. The variation of the geometrical efficiency with energy is shown in Fig. 7.

In the table the various contributions to the resolution width are listed.

5. **THE QUASI-ELASTIC SCATTERING EXPERIMENT**

Two bending magnets will be placed at about 45° on either side of the beam line. One spark chamber will be placed before each magnet and two after. The chambers will have plates of thin aluminium foil to minimise multiple scattering which will be the ultimate limitation on the energy resolution of the system. The largest chambers will have a useful area 96 cm x 20 cm with the microphones as an outer rectangle 120 x 45 cm. There will be a total of 24 microphones in this experiment so the present timing device will produce large amounts of paper tape. It is hoped that in 1965 the scaler outputs may be transferred directly to a data processor.
<table>
<thead>
<tr>
<th>Foil thickness cm</th>
<th>Conversion efficiency %</th>
<th>Resolution full width at half height keV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>1.2</td>
<td>200</td>
</tr>
<tr>
<td>0.02</td>
<td>2.4</td>
<td>330</td>
</tr>
<tr>
<td>0.03</td>
<td>3.6</td>
<td>450</td>
</tr>
<tr>
<td>0.04</td>
<td>4.8</td>
<td>590</td>
</tr>
</tbody>
</table>

Qualitative breakdown of resolution at 0.02 cm.

Radiating foil:
- Ionization loss: 200 keV
- Multiple scattering: 140 keV
- Bremsstrahlung: 20 keV
- Opening angle pair production: 1 keV

Angle of incident \(\gamma\) ray:
- Vertical: 15
- Horizontal: 110

Accuracy of Spark location (1/3 mm):
- Dependent on field: 140 (occurs twice)
Figure captions

Fig. 1  Cross-section of a capacitor microphone showing a typical method of construction. The voltage applied should not exceed 200 volts to avoid breakdown in the gas.

Fig. 2  Differential velocity as a function of distance from the spark. The gas was argon with alcohol and the pulse was delivered by the circuit in Fig. 5 with V = 10 kV.

Fig. 3  The sum of the times taken for the sound from a spark to reach microphones 129 cm apart as a function of the distance from one microphone.

Fig. 4  Pulse height and rise in the first μsec as a function of distance from spark to microphone. This varies discontinuously at about 20 cm.

Fig. 5  Total time to two microphones 129 cm apart from a spark near the centre of the chamber as a function of voltage supplied to the spark gap circuit shown.

Fig. 6  Schematic layout of the pair spectrometer. The magnet gap is 11 cm.

Fig. 7  Geometrical efficiency for detecting pairs produced in the materialising foil as a function of γ-ray energy. The total efficiency is the product of this factor, the conversion efficiency (nearly independent of energy) and the solid angle the foil presents to the ray source.
Typical Microphone Cross-section

Fig. 1

Fig. 2
Fig. 3

Fig. 4
Fig. 5

Fig. 6

Fig. 7
DISCUSSION

MANNING: We have found that the rise time from the capacity probes in general is relatively slow, - of the order of several microseconds. How much of your apparent change in velocity is possibly due to changes in the amplitude, or did you amplify or attenuate the pulse when you went further or came closer?

ANDREWS: What we do is to amplify the pulse so much that by the time you get past two or three stages all you are effectively looking at is the first small part of it. This rises as a parabola and the rise of that parabola is governed entirely by the weight of the mylar. You can make your microphone in lots of different ways, but as far as we can see, unless you can get something thinner than a quarter mylar you can't change that. We believe that the variation is very small. It would actually have to be rather large (i.e., many microseconds) to give a velocity change effect, and it is certainly less than one microsecond. Any electronic error is probably much less. We were very surprised with the variation of velocity I described, but it ties in with things that were said yesterday. I think the CERN people have seen something similar, but as I say, I don't think it really matters. Also it should be pointed out that we are using argon, which sparks at a higher voltage, so you have to apply something like twice the voltage you do with neon-helium. You thus get a much more powerful spark for any given size of chamber, by a factor or something like 4. Neon-helium would presumably be much better; the initial fall off would happen much more quickly.

LIPMAN: Well just carrying on with this question, you have about four times as much energy. Does this mean that your \( \Delta \) is very much larger? I am talking about the extrapolated \( \Delta \) as a distance. Ours' was typically five or six millimetres. Would yours' be four or five times larger than this?

ANDREWS: In fact just off-hand I suspect maybe a factor of 2; I have never tried to extract that particular piece of information.
ACOUSTIC SPARK CHAMBER SYSTEM FOR BEAM MOMENTUM MEASUREMENT

R.J. ELLISON, R. MARSHALL, A.J. WYNROE and B. DICKINSON
University of Manchester, Manchester.

D.M. EINNIE
Imperial College, London.

(presented by R.J. Ellison)

1. **INTRODUCTION**

   In this note we describe an acoustic spark chamber system for momentum measurement of a particle beam. We intend to use the system at the Rutherford Laboratory in an experiment to investigate rare decay modes of the $\omega^0$. The system is designed to produce parallel outputs, one of which is an actual value of momentum. The accuracy of this analogue circuit is rather high and for many types of experiment may be quite adequate. The other virtues of the system are the extreme simplicity of the spark chamber design and its flexibility.

2. **SPARK CHAMBER DESIGN AND CONSTRUCTION**

   The use of circular foil chambers and modular construction gives important advantages in the precise location of the transducers and the stretching of the aluminium foil are both facilitated. Figure 1 shows the general appearance of a 3 gap chamber.

   A foil module, shown in Fig. 2, consists of a perspex annulus with a 12 micron aluminium foil bonded onto each side. The foil must end before the earthed front plate of the transducer and in order to preclude edge sparking the edges of the foil slope away into a wedge shaped groove so that the gap separation at the edge is 50% greater than the normal gap separation. Before bonding the aluminium foil the perspex annulus is compressed in a hose clip. Unstretched foil is then bonded on to each side of the perspex ring along the sloping surface, with a toluene solvent epoxy resin (Araldite 107). When the bond is set, the clip is unscrewed and the perspex expands to normal size, stretching the foil. The flatness of surface obtained is limited only by the accuracy of the perspex surface. This method has been used successfully with both 18 cm and 26 cm diameter annuli.
frames show a tendency to bend out of a place and we have found that the annuli must be about 6 mm thick. There is a dead space of this amount between active gaps.

The transducer module also defines the gap separation. The 4 holes which hold the transducers (see Fig. 4) are drilled accurately with respect to the 16 locating holes. When a chamber is stacked and screwed up with studding through the locating holes, the transducers are accurately located (to 0.2 mm) one above the other. Figure 5 shows a section through a transducer. A 4 mm x 2 mm x 1 mm lead zirconate titanate crystal fits closely in the hole and location to the accuracy of the hole is possible. The hole is then filled with the damping material (tungsten- "Araldite" mixture). The output signal is taken from the back face of the crystal via miniature co-axial cable to a sub-miniature socket which is screwed on to the outside wall.

Partly because of the high mechanical coupling between the crystals and the chamber body itself, and partly because of reflections, it is found necessary to line the walls of the chamber with felt.

3. OPERATION AND PERFORMANCE

Small crystals (4 mm x 2 mm x 1 mm) have been found to be most satisfactory. First, they approximate more nearly to point detectors and so enhance resolution. Secondly, it has been found that the angular response of a plain crystal transducer is a function of the crystal dimensions. Figure 6 shows a set of angular response curves obtained with crystals of 5 mm, 2 mm and 1 mm widths. The better response of the smaller crystals at large angles is probably due to diffraction. The crystals are mounted with their longest dimension normal to the foil. Measurements were taken to check on the linearity of the system and to measure the "effective spark size". The distance between the detector and a spark produced between 2 metal points was measured with a travelling microscope and the time delay was read off a scaler. The full width at half height of the histograms obtained was \( \sim 1 \) \( \mu \)sec. The width is almost wholly determined by the clock frequency at which the scalers were operating.

Results were obtained with discharge capacities within the range 160 pF - 1000 pF, (spark energies 0.0025 - 0.01 joule), and the two extreme cases are plotted in Fig. 7. The intercept on the abscissa gives the effective spark size and under these conditions, with sparks in air, its value increases from 1.8 mm to 2.8 mm within the range of spark energies used.

As well as producing a small effective spark size, low energy sparks do little damage to the thin foils and since they are used here in conjunction with small crystals, large post amplification is required. A typical output
voltage of 200 mV is obtained from the current sensitive transistor pre-
amplifier with a spark energy of \(~0.0025\) joule. (Noise level is \(~5\) mV).
A current sensitive preamplifier gives an acoustic signal with \(~1\) \(\mu\)sec
front edge as opposed to \(~2\) \(\mu\)sec for a charge amplifier. The outputs of
the preamplifiers are taken to standard types of discriminator circuits with
a bias variable from 20 mV to 1 volt.

The spark chambers are located in two pairs on either side of a
bending magnet quadrupole system such that the 2nd and 3rd spark chambers
are at conjugate points. Thus, to 1st order, a measurement of spark position
in each of these two chambers is sufficient to define the momentum.

The electronic logic system (Fig. 8) has been designed to be
as flexible as possible. Since the system is to be used on a beam line the
high particle flux may result in some old tracks in the spark chamber still
having finite efficiency for spark production. This can be tolerated to
some extent for a system in which all tracks are nearly parallel by taking
the outputs of the sonic detectors through preamplifiers and discriminators
to majority gates in order to select when at least a certain number (say 3
out of 4) of the gaps have fired at the same place. These logic systems
plug in on a patch panel and the type of logic can be readily changed. The
firing of a single gap or a pair of gaps at some other position would not
be recorded and would not affect the results. The outputs from the majority
gates are used as stop signals for scalers counting up to 5 Mc/sec clock
pulses and for the analogue momentum display.

When the chamber is pulsed very high interference currents are
generated and we use a clamping pulse to hold open the scaler gates regard-
less of discriminator pulses for the first 50 \(\mu\)sec or so. This seems more
convenient than opening the scaler gates after a fixed time, and it avoids
error arising from variation in this delay.

The analogue system has three uses:

1) Checking correct operation of spark chambers, preamplifiers
discriminators and logic circuits.

2) Providing a reasonably accurate value for the momentum of each
particle.

3) Enabling a spark chamber to be used for beam profile measurements.
The system we describe will handle up to 10 particles in each
machine pulse from Nimrod.

The formulae for \(x, y\) the coordinates of the spark, in terms of
the times (\(t_1\) and \(t_2\)) taken for the acoustic signal to reach two detectors
which subtend on angle of 90\(^\circ\) at the origin are:
\[ x = \left\{ \frac{v^2}{t_1} - \left[ \frac{d + \frac{v^2}{4d} (t_1^2 - t_2^2)}{2} \right]^2 \right\}^{\frac{1}{2}} - d, \quad y = \frac{v^2}{4d} (t_1^2 - t_2^2) \]

(2d is the separation of the detectors).

In view of the much greater complexity of the calculation of \( x \) we use \( t_1 \) and \( t_2 \) to get \( y \) and \( t_2 \) and \( t_3 \) to get \( x \) using the formulae

\[ x = \frac{v^2}{4d} (t_2^2 - t_3^2), \quad y = \frac{v^2}{4d} (t_1^2 - t_2^2) \]

The electronic system used to compute one cartesian coordinate is shown in Fig. 9, \( T_1 \) and \( T_2 \) are linear ramp current generators feeding into an integrating capacitor \( C \). The pulses of duration \( t_1 \), \( t_2 \) from the bistable are fed on to the bases of transistors \( T_2 \) and \( G1 \) respectively. The value of the current is controlled by the emitter voltages on \( T_1 \) and \( T_2 \) and it increases linearly with time after \( t = 0 \), up to a maximum of \( t = 1 \) msec. When the gates \( G1 \) and \( G2 \) are closed then no current flows into \( C \). In the quiescent state, \( T_1 \) and \( T_2 \) are virtually cut off and the voltage on \( C \) is clamped by \( S \), a chopper transistor. At \( t = 0 \), the clamp is released, the gates are opened and current flows out of \( T_1 \) and into \( T_2 \). The charge on \( C \) does not alter substantially until one gate only is cut off. Then the charge on \( C \) is given by

\[ Q = CV = \int_{t_2}^{t_1} I \, dt = \frac{K^2}{2} (t_1^2 - t_2^2) \]

A short time later, a read pulse samples the charge on \( C \) via gate \( G3 \). After the read cycle has finished, a reset pulse closes all gates and the integrating condenser is discharged.

The time of the read pulse and the slope of the ramp are capable of being altered so that the system can be used with different sizes of chamber.

Some sources of error could be:

1) Change in the velocity of sound. Since the electronic origin is at the centre of the spark chamber, this effect only alters the scale and will not be very serious.
2) **Zero drift.** The bottoming of the chopper transistor is very well defined and drift in the operational amplifiers is at the most 4mV/°C with ± 2.5 V peak output. Drift is, in fact, negligible.

3) **Ramp non-linearity.** Parabolic accuracy is excellent because of the cascode format of the squaring circuit. Any asymmetry in T₁ and T₂ can be monitored by replacing C with a resistance and measuring the current in it. First order corrections can be made by means of the variable resistance R₂ and the remaining error is very small.

The ramp should go through the origin t = 0 or if a correction for the effective spark size is needed, then through t = 0 - δ. The correction can be provided by a small pedestal at the beginning of the run up.

Two of these circuits enable an x,y display on a cathode ray oscilloscope to be made. A multi-channel display can be obtained by using several circuits.

When using two chambers for a momentum analysis as described earlier, the momentum is immediately computed since a subtraction of two voltages is all that is required.

Momentum is proportional to \( X₁ - mX₂ \) where m (the magnification of the magnet system) is adjusted by varying the gradient of the ramp in one circuit. Extra information can also be fed in here and it is possible to do "missing mass" calculations in some favourable cases.
Figure captions

Fig. 1 3 gap acoustic spark chamber
Fig. 2 Plan view of foil module
Fig. 3 Section through foil module showing method of adhesion at foil edge
Fig. 4 Plan view of perspex annulus with transducers mounted on inside diameter
Fig. 5 Transducer mounting section through perspex annulus showing mounting of piezoelectric crystals
Fig. 6 Variation of angular response with size of piezoelectric crystal
Fig. 7 Distance versus time curves
Fig. 8 Block diagram of sonic electronic system
Fig. 9 The electronic system used to compute one cartesian coordinate
Fig. 1. 3 GAP ACOUSTIC SPARK CHAMBER

Fig. 2. PLAN VIEW OF FOIL MODULE.

Fig. 3. SECTION THROUGH FOIL MODULE SHOWING METHOD OF ADHERION AT FOIL EDGE.
**Fig. 5** Transducer Mounting
Section through Perspex annulus showing mounting of piezoelectric crystals.

**Fig. 6** Variation of angular response with size of piezoelectric crystal

![Graph showing variation of angular response with size of piezoelectric crystal.](image-url)
**Fig. 7. Distance versus time curves**

(a) 180 \( \mu \)F Discharge capacity

(b) 1000 \( \mu \)F Discharge capacity

**Fig. 8. Block Diagram of Sonic Electronic System**
FIG. 9. THE ELECTRONIC SYSTEM USED TO COMPUTE ONE CARTESIAN CO-ORDINATE
DISCUSSION

PEREZ-MENDEZ: How do you propose to distinguish the \( \omega \) from the \( \rho \) ?

ELLISON: We don't in this context. We actually want to examine what happens to decay reactions in the neighbourhood of the \( \omega \). In the decay we just want to identify the mass of the missing particle and look at decay modes of the \( \omega \).

BARDON: You have a remarkably low energy in your spark. Could you tell us please what is the gap size, the gas you use and also can you say anything about repetition rates and efficiency?

ELLISON: I can't say anything at all about repetition rates. This is a thing that we shall be doing in the next few weeks. I can say that the gap is the normal 6 millimetres with 5 kilovolts applied. The gas used is a neon-helium mixture. Remember that our larger chambers have an effective diameter of about 26 cm whereas the smaller ones are 18 cm in diameter so they are rather small chambers. Because their self capacity is something like 30 pf we can therefore use 180 pf capacitors quite satisfactorily.

FIZER: If I understood you correctly the precision with which you measure a spark position is rather higher than what other people have been saying. Is that not so?

ELLISON: I don't think so, no.

MAGLIC: What is the momentum resolution, \( \Delta p/p \), you expect to get?

ELLISON: About 0.1%.

MAGLIC: Could you describe how you measure the missing mass?

ELLISON: The reaction is \( \pi^- + p \to n + \omega \). We do neutron time of flight from a counter just before the target to an array of 6 scintillators 3 metres down the beam line from the target each at an angle of \( \sim 4^\circ \). Since we are just above threshold, both the neutron and the \( \omega \) go forward at the centre of mass velocity and therefore if one looks in the forward direction one can get away with a fairly crude momentum measurement and an accurate measure of the time of flight. One can then get the missing mass out rather simply.

MAGLIC: What is your resolution for the time of flight?

ELLISON: We are hoping to get down to 1 nsec or slightly better.
MAGLIC: What is the percentage accuracy of the neutron momentum measurement?

ELLISON: I can't quote this off-hand, I can quote what it comes to in mass—this is what really matters. It is about $\pm 4$ or $5$ MeV in mass.

MAGLIC: This is a remarkably low error.

ELLISON: Well it is just above threshold, the first few MeV. This is the great point. Of course the cross-section is very low.

AMALDI: I am quite surprised about the low value of the energy in your sparks. You showed a slide giving the acoustic spark size as the function of the capacity. Does the rise time of the pulses on the probes change or not depending on the capacity?

ELLISON: It is about a microsecond for the different probes and varies very little with distance.

AMALDI: So you are sure to be far away from the shock wave region. This is very different from the results of other laboratories. Everybody uses much higher energies.

ELLISON: Well it is a factor of 10 or so, I think people should use lower energy sparks.

ROBERTS: If I understood you correctly, you said you were hoping to get a tenth of a percent momentum accuracy in a pion beam? Could you give us more details of this?

RINNIE: The method, in principle, is capable of a little better than that. If you simply use the sparks from the chambers on either side of the magnets in our beam then I think it is somewhat worse, but adequate for this purpose. Such a system has chromatic aberration in it because of the quadrupole focusing; this can be removed by using 3 sonic chambers and then the limit is probably somewhat better than 1 in a thousand.

ROBERTS: In that case I would like to hear what kind of scattering materials you have in a beam where you can get down to that kind of accuracy, because scattering in a couple of metres of air is enough to spoil that sort of precision.

ELLISON: There is a vaccum pipe in the system over a large fraction of the beam path. The actual chambers use half than $(0.0005 \text{ in})$ foils.

VERNON: What is the momentum of the pions?

ELLISON: 1.2 GeV/c.
DIGITIZED SONIC SPARK CHAMBER FOR OPERATION WITH COUNTER HODOSCOPE, DATA HANDLING SYSTEM AND ON-LINE COMPUTER*)

K.J. FOLEY, R.S. GILMORE, S.J. LINDENBAUM, W.A. LOVE, S. OZAKI,
E.H. WILLEN, R. YAMADA and L.C.L. YUAN

Brookhaven National Laboratory, Upton, L.I., N.Y.

(presented by S.J. Lindenbaum)

1. INTRODUCTION

For some experiments which yield relatively low background and event counting rates but require a high spatial resolution, a spark chamber is a useful detector. In order to incorporate such detectors into our data handling system with on-line computer, we began development of a suitable sonic spark chamber system(1), (2). We have tested, both in a test chamber and in air, various microphone designs, the necessary digitization electronics and a method of computation. The preliminary report on the tests will be made here. Figure 1 (a) and (b) shows a test chamber assembly.

2. THE MICROPHONES

All the microphones tested were of the capacitor type. The movable electrode is always made of .00025" aluminized mylar foil. This is stretched over a stationary electrode, charged to 300 volts.

i) Point Microphone. Figure 2 shows the construction of the point type microphones. The stationary electrode is a silver solder rod with the end shaped to give a 1/16" diameter contact area with the mylar foil. The tension with which the mylar is stretched over this rod may be adjusted to optimize the output signal pulse height and rise time.

ii) Cylindrical Microphone. Figure 3 shows the construction of a microphone which has slower response than the point microphone but has larger output and better geometrical properties. The stationary electrode is a ½" diameter by 3/8" long brass cylinder with axis perpendicular to the spark chamber plane. A .0035" thick nylon cloth is stretched between this

*) Work performed under the auspices of the U.S. Atomic Energy Commission.
electrode and the mylar foil. This reduces the required tension on the mylar.

iii) Long Microphone\(^2\). Figure 4 shows the construction of the long microphone. This microphone gives a slow rise time, but less dependence of pulse height on the distance between spark and microphone. The stationary electrode is a long brass rod 1/8 x 1/4" in cross-section embedded in a plexiglass plate. Again the nylon cloth is stretched over the electrode before the mylar foil is applied. The tension of the mylar foil all along the rod may be adjusted to give uniform response over the length of the microphone.

A summary of the properties of the three types of microphones is given in Table I.

3. **ELECTRONICS**

Figure 5 shows a block diagram of the electronics used to determine the position of a spark. A signal from a counter telescope triggers the spark chamber. This also provides a pulse to set a flip-flop which provides a time gate signal. A sonic wave produced by the spark travels through the spark chamber gap and generates a pulse when it reaches the microphone. This pulse is amplified and then fed via a discriminator to reset the flip-flop previously set by the telescope signal. Thus, one gets a square output pulse of width essentially equal to the transit time of the sonic wave through the chamber gap. This time interval is measured by a 5 Mc/s oscillator clock. The scaler used for this purpose is 10 Mc binary scaler with a provision to feed the information to one data handling system.

In order to avoid electrical pick-up from the spark, the timing circuit is not activated until 45 \(\mu\)sec after the trigger to the spark chamber is generated. Also a provision was made to reset the timing system after ~ 9 msec if no microphone signal arrives. A timing diagram is shown in Fig. 6.

4. **METHODS OF LOCATING SPARKS**

Several methods for locating sparks have been tried with a chamber gap involving four of the point probe microphones. The quantities to be determined are the x and y positions of the spark, the velocity of the sound wave, \(v\), and the effective spark size \(\delta\). Since four microphone times are available there are four second order simultaneous equations which may be solved exactly for the four unknowns. However, small errors (\(0.5\) mm) in the microphone positions used in the calculations or in the scaler times (\(0.1\%\)) lead to large errors in spark position determinations. Since these parameters will typically be measured to this accuracy, this procedure does not seem very promising. A better result is obtained by an iteration procedure on an averaged
solution. In this technique, it is assumed that the velocity and δ are known approximately. Using this velocity and δ four intersections of the four circles with centres at the microphone positions are calculated. These four intersections are used to calculate an average x and y. Using the average x and y, an average v and δ are calculated, which in turn are used to calculate a better value for x and y. It is found that by the second iteration, the difference between the average values of x and y and the true values is about the same as the error in the location of the microphone or in the scaler times.

Calculations were also made with the output from a chamber using four of the long microphones. Because the four equations in four unknowns are linear, their solution is greatly simplified. The greater complexity of the equations for the point microphones presents no problem for a digital computer. Because of the non-linearity of the equations, however, small errors in the parameters (microphone positions, times) propagate and become greatly magnified. This trouble does not occur in the solution for the long microphones. It should be noted, however, that the sum of the times for the two opposite pairs must be different since the difference of these two sums appears in the denominators of the expressions for x, y, v and δ.

Tests have been made with cosmic rays through two-gap spark chambers with four point microphones in each gap and also with four long microphones in a one-gap chamber. Fig. 7 shows a diagram of an arrangement planned for an experiment using spark chamber, hodoscope, data handling system and on-line computer.
<table>
<thead>
<tr>
<th></th>
<th>Point Microphone</th>
<th>Cylindrical Microphone</th>
<th>Lone Microphone (3')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nylon Mesh</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Risetime and Output Voltage (0.2 Joule Spark)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>at 3.5 cm</td>
<td>0.2 µs, 70 mV</td>
<td>1.5 µs, 140 mV</td>
<td>3 µs, 100 mV</td>
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<tr>
<td>at 31 cm</td>
<td>1 µs, 7 mV</td>
<td>4 µs, 20 mV</td>
<td>3.5 µs, 32 mV</td>
</tr>
<tr>
<td>at 100 cm</td>
<td></td>
<td></td>
<td>3.5 µs, 14 mV</td>
</tr>
<tr>
<td>Dependence on distance of output voltage (beyond 10 cm)</td>
<td>~1/r^{1.5}</td>
<td>~1/r^{1.7}</td>
<td>~1/r^{0.58}</td>
</tr>
<tr>
<td>Angular dependence of output voltage</td>
<td>± 25% in - 45° ~ + 45°</td>
<td>± 10% in - 90° ~ + 90°</td>
<td></td>
</tr>
<tr>
<td>Uniformity of output along the length</td>
<td></td>
<td></td>
<td>± 5%</td>
</tr>
<tr>
<td>After-ringing</td>
<td>Strong</td>
<td>Small</td>
<td>Small</td>
</tr>
</tbody>
</table>

* These tests were performed with a test spark without plates.
References


Figure captions

Fig. 1  a) Sonic spark chamber using four "point" microphones.
       b) Sonic spark chamber using four "long" microphones.

Fig. 2  Construction drawing of "point" microphone.

Fig. 3  Construction drawing of cylindrical microphone.

Fig. 4  Construction drawing of "long" microphone.

Fig. 5  Block diagram of spark chamber electronics.

Fig. 6  Spark chamber timing diagram.

Fig. 7  Experimental arrangement for planned sonic spark chamber experiment.

Fig. 8  a) Scope trace of point microphone. Signal is negative; it shows fraction of a µsec rise time (sweep time 10 µsec/cm) and considerable ringing.

       b) Scope trace of long microphone. Signal is negative. Sweep time 10 µsec/cm.
STRUCTURE OF POINT MICROPHONE

(1) POLYETHYLENE SPACER  
(2) INTERNAL ELECTRODE, 62.5 mil at top  
(3) 1/4 mil OUTSIDE ALUMINIZED MYLAR FOIL CEMENTED TO TOP OF (4)  
(4) MOVABLE BODY TO STRETCH (3)  
(5) BASE  
(6) PRESS FIT CAP TO HOLD (3)  
(7) BNC CONNECTOR

Fig. 2

STRUCTURE OF CYLINDRICAL MICROPHONE

(1) MICARTA SUPPORT  
(2) 1/4" x 3/8" BRASS CYLINDRICAL ELECTRODE  
(3) 3.5 mil NYLON CLOTH, STRETCHED & CEMENTED TO (1)  
(4) 1/4 mil OUTSIDE ALUMINIZED MYLAR FOIL, CEMENTED TO (5) WITH SILVER EPOXY RESIN  
(5) BRASS ANGLE TO STRETCH (4)  
(6) BOLT TO PULL (5)  
(7) BOLT AND NUT TO FIX (5)  
(8) BASE  
(9) SHIELD  
(10) UG 58U CONNECTOR

Fig. 3
STRUCTURE OF LONG MICROPHONE

(1) 1/4" PLEXIGLASS BASE PLATE
(2) 1/8" x 1/4" BRASS INTERNAL ELECTRODE
(3) 3.5 mil NYLON CLOTH, STRETCHED AND CEMENTED AT BOTTOM
(4) 1/4 mil OUTSIDE ALUMINIZED MYLAR FOIL, CEMENTED TO (5) WITH SILVER EPOXY RESIN
(5) 40 mil AL STRIP
(6) LUG TO STRETCH (4) THROUGH (5)
(7) BOLT AND NUT TO PULL (6)
(8) BOLT AND NUT TO FIX (5)
(9) SHIELD
(10) PLEXIGLASS ASSEMBLY PLATE REMOVED LATER

Fig. 4

SPARK CHAMBER ELECTRONICS

Fig. 5
Fig. 2, TIMING DIAGRAM

SPARK TRIGGER
0 20 45 MICROPHONE SIGNAL 2 msec 9 msec
START TRIGGER
DELAYED TRIGGER
MICROPHONE SIGNAL
MICROPHONE DISCRIMINATOR GATE
ON OFF
FLIP FLOP OUTPUT
OFF ON
FLIP FLOP RESET BIAS
ON
OSCILLATOR GATE OFF

Fig. 6

S = SCINTILLATION COUNTER
C = CERENKOV COUNTER
H = COUNTER HODOSCOPE
(SC) = SPARK CHAMBER

FROM BEAM COUNTERS
FROM TRIGGER COUNTERS
ELECTRONICS FOR PARTICLE IDENTIFICATION
SPARK CHAMBER & HODOSCOPE FAST GATE TRIGGER GENERATOR
SPARK CHAMBER DRIVING SYSTEM
HIGH SPEED COMPUTER
DATA TAPE RECORDER

FROM SONIC PROBE
SONIC SPARK CHAMBER TIMING SYSTEMS
HODOSCOPE FAST GATES
HIGH SPEED SCALER
DATA INPUT STACKER
BUFFER MEMORY 48 BITS WIDE 4096 WORDS DEEP

FROM HODOSCOPE COUNTERS
DATA INPUT STACKER
BUFFER MEMORY 48 BITS WIDE 4096 WORDS DEEP

Fig. 7
DISCUSSION

ZANELLA: When you are calculating the spark position you use a value of Vo and ΔT and I can understand then why you have to stop your iteration. But in the method I explained yesterday I don't use any Vo or ΔT value; we used the program in the region where the iteration converges.

LINDENBAUM: I think I could say we ran into the same problem as you. We tried an experimental way of getting comparable errors. The program was written by Willen of our group and he tried many iterative procedures. We stopped at a point where he felt he was able to get comparable errors with the errors introduced.

FESSEL: In connection with the last system you showed if you want to use that for inelastic events, it seems to me you are going to be plagued continually by having more than one event per chamber.

LINDENBAUM: That set-up was only for elastic scattering. We will get some inelastic events as a by-product because of the magnetic spectrometer. In these series of experiments the inelastic are always in a by-product category. But we do have one limit and that's why we backed it up with scintillators. The limit is that when we get more than one track per chamber we have to reject that event. So there is sort of a happy medium, and we will run at that rate where things are optimised.

LIPMAN: The ringing time on your slab microphones look very short. Could you give me the figure for it to get some idea when you could fire a chamber again?

LINDENBAUM: I would like to emphasize that we didn't concentrate on the ringing properties of the microphones. I would not like to quote a figure because we didn't investigate this aspect. For instance, a change in the screw tensions might change everything.

ANDREWS: I think you will find if you use nylon chiffon you can account for all the wave shake entirely by air compression. I don't think the mechanical properties of the tension of the diaphragm come into it.

LINDENBAUM: Well we found otherwise. The slab microphone has set screws all along its length, and we found that adjusting the tension affects, not only the rise time in signal but, what is more important, the uniformity.

NEUMANN: Would it be of interest to make a combination spark chamber and wire chamber? If one could make a wire chamber where the wires are not used to retrieve information but to hold this spark for a number of milliseconds
on weak intensity which does not strike your microphone, and then strengthen
them one after the other and pick up the signal with sonic probes.

LINDENBAUM: Well it certainly sounds like an interesting idea.
I don't know enough about this kind of thing to have an opinion on it but
we are certainly after a device which can handle multiple tracks. There are
several candidates for this, - one is the sonic chamber itself, putting in
more microphones, as Maglić and other people mentioned. Another is the wire
chamber and that is, I think, the hot candidate. Then what you mentioned is
another one, and there may even be others. We have an open mind on all the
detectors and we are interested in anything which can handle multiple events.
V. AFTERNOON SESSION

ON-LINE COMPUTER USE: DISCUSSION OF IDEAS AND SYSTEMS

Chairman: G.R. Macleod, CERN

Secretaries: F. Lefebvre, CERN
             H. Överas, CERN
             A. Wilson, CERN
1 KM DATALINK FROM PS AREA TO COMPUTER LABORATORY

F. MARCIANO, C. MAZZARI, G. GENOVA and H.J. SLETENHAAR
CERN, Geneva.

(presented by H.J. Slettenhaar)

1 km Datalink PS ↔ Mercury Computer

1. INTRODUCTION

A 1 km connection between the Mercury computer and the South and East Hall of the Proton Synchrotron has been installed. It contains two multicore cables each consisting of 20 twisted pairs. One cable is used for input to the computer and the other one for output from the computer.

The Mercury computer has seven input and seven output channels. Each channel allows the parallel transmission on ten wires of signals representing ten binary digits. One input and one output channel has been allocated for on-line use. The ten output wires from the computer associated with this channel are not only used for the transfer of information but also for the selection of different input and output devices. At present input can be transferred from

a) a scaler logic unit;

b) three sets of ten hand keys from which complete remote control of the programme can be obtained.

Output from the computer can be sent to

a) 2 x 9 bit Digital to Analog converter;

b) output Punch or output Typewriter.

See block diagram Fig. 1.

2. RESULTS OF THE DATALINK TEST

With the first link Mercury ↔ SC of 250 m length, no special circuits were needed. The maximum transfer rate of Mercury is 9000 bits per
second. Nevertheless the Detalink itself could be used for much higher transfer rates up to maximum 500,000 bits per second at 1 km. Tests were made with square pulses of 2 μsec width 3 V. See Figs. 2 and 3.

3. CIRCUITRY

The transmitter/receiver circuits are shown in fig. 4.

Each transmitter circuit consists of a long-tailed current switch of two NPN transistors such that a constant current is flowing through the twisted pairs. An input signal will cause a current change-over in the two wires. The two wires are terminated at the end of the cable by two common base circuits. Output can be obtained from both collectors, depending on which polarity is needed.

The noise to signal ratio is so small that no special circuitry like differential amplifiers is used to reject the common mode signals. The signals are just passed through a simple one-transistor amplifier.

The cable acts as a delay line and has a delay of 7μ sec at 1 km. The input signals to Mercury are strobed at the computer end.

With the present system only 12 input and output wires are used out of 20 each.
Figure captions

Fig. 1 Datalink system block diagram.

Fig. 2 Oscillogram of the input and output and squared output waveforms.

Fig. 3 Oscillogram of the input and output waveforms of one pair and the cross-talk output of the other pair at a pulse repetition rate of 250 KPS.

Fig. 4 The transmitter/receiver circuit diagram.
DISCUSSION

LINGJAERDE: Couldn't you tell what sort of cables these are? I think they are the normal telephone cables which are used in PS.

SLETTHENHAAR: It is the normal multicore cable which is standard at CERN at the moment.

LINGJAERDE: I think you should say too how to use them.

SLETTHENHAAR: The cable is made in star quad construction, the opposite leads being connected as pairs. Further specifications are:

- Lead resistance: 35 Ohm/km (0.5 mm²)
- Mutual capacitance/pair: 70 nF/km
- Characteristic impedance: 400-75 Ohm (1-1000 kHz)
- Type used: y (s+) y 5 x 4 x 0.8 mm
- Manufacturer: Hackethal- Draht- und Kabel Werke, Hannover, Germany.

HINE: Have you any figure for the cross-talk?

SLETTHENHAAR: The cross-talk was around 200 mV on a passive pair in an active quad with a signal of 4V, which makes a cross-talk attenuation of 60 dB.

ISELIN: I think it is quite important to realise here that the reason why one uses twisted pairs is that we are much less sensitive to spurious pulses, because signal transfer is symmetrical and you have no earth problem. I think all this helps to make this system interesting.

SLETTHENHAAR: It is also about 10 times cheaper than coaxial cables at the same length.

GUTMANN: Did you transform the Mercury computer for on-line applications or not?

SLETTHENHAAR: Apart from some minor modifications, no. We might do in the near future when the machine will only be used for on-line purposes.
A SONIC SPARK CHAMBER SYSTEM WITH ON-LINE COMPUTATION FOR STUDYING THE REACTION $\pi^- + p \rightarrow f^0 + n$ AT 3 GEV/C

L. BIRD, B. ROSE, D. WEST, C. WHITEHEAD and E. WOOD,
AERE, Harwell

D.G. CRABB, G.W. HUTCHINSON, J.G. MCEWEN and R. OTT,
Southampton University

D. AITKEN, J. HAGUE, R. JENNINGS and A.J. PARSONS,
University College, London

E.G. AULD,
Rutherford Laboratory, Chilton

(presented by C. Whitehead)

1. INTRODUCTION

A data handling system for use with sonic spark chambers is being developed using a ferrite core store with a capacity of 128 sixteen bit words and with the facility for on-line connection to a Ferranti ORION computer. The experiment for which this equipment is being developed will be in the first case, a study of the reaction $\pi^- + p \rightarrow n + f^0$ [1] at 3 GeV/c. The reaction is to be identified by detecting the neutron at angles up to 30° in the laboratory system, its energy being determined by time-of-flight over two to three metres. The missing mass in the reaction will be determined from the input pion momentum, measured for each event by a system of sonic spark chambers and a bending magnet, and from the neutron energy and angle of emission. It is also intended to determine the spin of the $f^0$ by studying its subsequent decay into two charged pions. The latter measurement is made by measuring the direction of emission, the momentum and the sign of the charge of a single pion emerging in a forward direction in the laboratory corresponding to a centre-of-mass decay angle between 10° and 30°. The centre of mass decay angular interval of 60° to 120° is covered by separate sonic spark chambers which determine the angle of emission of both the decay pions. These chambers will also detect the $K^+ K^-$ decay mode of the $f^0$ which should occur in 1-2% of the decays. A beam intensity of $5 \times 10^4 \pi^-$/burst is expected to yield ~100 events/hour.
2. **THE EXPERIMENTAL LAYOUT**

Figure 1 shows the layout of the experiment. The sonic spark chambers 1, 2, 3 and 4 together with bending magnet 2 serve to measure the pion input momentum. Chambers 5 and 6 define the pion trajectory into the 30 cm hydrogen target. The neutron counter consists of six 30 cm diameter, 30 cm long right cylinders of plastic scintillator each with a separate veto counter mounted immediately in front. Spark chambers 7, 8 and 9 together with bending magnet 3 determine the angle of production, the momentum and the sign of a forward decay pion. Chambers 10 and 11 detect both decay pions for decays between 60° and 120° in the centre of mass.

The high pressure gas Cerenkov counter C together with scintillation counters A, B and C define an incoming pion and counter D, run in anticoincidence, marks the disappearance of the interacting pion from the beam and serves to reduce the coincident rate C ABC which is to be put in coincidence with the six neutron counters, a further counter E detects charged particles traversing EM 3.

3. **THE SPARK CHAMBERS**

Each chamber is a two gap module and the details are given in references 2,3). The plates consist of 0.001" hard aluminium foil and a layer of expanded polyurethane foam serves to further reduce the acoustic cross-talk between the two gaps. The method of mounting the cylindrical capacity type microphones is as previously 2,3). These microphones however differ from those described earlier in the anodising technique used. 2% oxalic acid anodising solution has been used with 70 volts applied potential and a current density of 50 to 100 mA/cm². The other electrode used for the microphone is a layer of 1 μ aluminium foil laid over ~180° of the cylinder and bonded in place at its extremities. Examination under X 500 magnification after sectioning and polishing show a smooth oxide layer 8-10 μ thick. The microphone bias potential is used in the same sense as the potential used for anodising and the breakdown voltage is 300 volts or higher. This is in contrast to the previous microphones where the microphone bias was in the opposite sense to that used for anodising and the breakdown potential was then only 50 to 100 volts. The average sensitivity of these microphones when used at 30 V bias is 8 to 10 times that of L2T flat piezoelectrics 5 mm x 3 mm x 1 mm thick and 16 to 20 times that for cylindrical piezoelectrics 3.17 mm in diameter and 5 mm wall thickness. 72 of these microphones have been tested and 90% of them have the same sensitivity ± 30%.

Only 12 have been tested yet for azimuthal response but all 12 show a uniform response over more than 120°; the limits of the response being the bonding at one extremity of the foil and the electrical connection at the other. Microphones have been made with response uniform over 270°.
It has been observed that the variation of signal with distance using these microphones in a spark chamber is of the form \( V = \frac{V_0}{d^n} e^{-0.027d} \) and to compensate for this variation the voltage bias applied to the microphones is no longer d.c., but has the inverse form \( E = E_0 d e^{+0.027d} \). Using this technique with a chamber 70 cm x 50 cm the signal from the microphone is constant to ±20% for sparks anywhere in the chamber. For such a chamber and with these microphones the voltage ramp rises to 5 to 10 volts in 3 nsec.

Figure 2 shows a view of the front of the chamber; four microphones are mounted at the positions 1, 2, 3, 4 and a fifth microphone mounted in the second gap of the module at a position opposite microphone 1. Thus as a minimum, five microphones are used in each module. The spark chamber gap containing the four microphones is termed the measuring gap and the other the check gap. The time of arrival of the signals are to be recorded for all five microphones and in the subsequent analysis it is required that flight times 1 and 5 should agree to an extent depending on the angle of incidence of the particle. Such agreement renders it highly probable that the two sparks were in fact associated with a single traversing particle and were not spurious.

A calibration point-to-plane spark gap is mounted at position S, midway between microphones 1 and 4, in each gap of the module. These calibration gaps are discharged by a completely separate system from that for the spark chambers. These gaps are included for the following reasons:

a) As an aid to setting up the microphones and data handling system.

b) As a running check during the course of an experiment that the system is functioning correctly.

c) As a method of determining the velocity of propagation of sound in the chamber during the experiment.

4. DATA

At least 65 microphones will be used in the experiment and the flight times determined from these microphones will be recorded as 65 sixteen bit words in the ferrite store using a clock frequency of 4 Mc/s.

The neutron flight times are taken as from counter C to the neutron counters and will range from 20 nsec to 50 nsec and will also be recorded in the ferrite store. A time expander is being developed for us by Electronics Division, Harwell for this purpose which expands a 50 nsec time interval to 250 µsec. The timing resolution sought is 1 nsec and will be determined chiefly by photomultiplier characteristics (a single 58 AVP is used on each scintillator cylinder) and the 30 cm length of the neutron detectors.
A single word is reserved for this neutron time-of-flight information and six bits are reserved elsewhere to indicate which of the six neutron counters was triggered.

The number of beam particles incident on the hydrogen target during the time when the equipment was active will also be recorded as previously and a similar provision is also being made to record other monitoring type information event by event.

A 14 bit word is reserved to specify information such as target full or empty, bending magnets on or off etc, and as a run number. As these changes occur relatively infrequently this 14 bit word will be set by hand switches and will be recorded together with all the timing information etc. for each event.

The magnetic fields of BM 2 and BM 3 will also be recorded, in the first instance, by hand switches as the magnet stability should be adequate (better than 1 part per 1000) but the possibility of recording the magnetic field directly via a nuclear magnetic resonance method is being investigated.

5. THE DATA HANDLING SYSTEM

Figure 3 shows a simplified block diagram of the data handling system. The coincidence CABCDPM is used to trigger the spark chambers and this same pulse opens the gate allowing a 4 Mo/s clock train to enter a 16 bit fast carry binary scaler, as stated previously2,3 the method is now to enter the content of this scaler at time t₁ (the time of arrival of the signal from the i-th microphone) into the i-th row of the store. With a 4 Mo/s clock only ~100 nsec would be available to transfer the scaler content unambiguously to the store. This situation is eased by the master binary scaler feeding a Gray or Reflected Binary Register. This register is essentially 16 flip-flops, one to each of the binaries in the master scaler, and these flip-flops only change their state when their associated binary changes from "0" to "1" and not from "1" to "0". This has the effect of reducing the frequency of change of each of the 16 bits of the word by a factor of 2 and increases the time available for the transfer of the Gray Code Register to ~200 nsec. Pleasey ferrite cores are used in the store and half write pulses of 0.22 amps and 100 nsec duration are applied, after staticising, to the i-th row and down the columns for which the Gray Code Registers are in the "I" state thus transferring the content of the master binary scaler transposed into Gray Code into the i-th row. In this way the times are recorded to ± 250 nsec with essentially random access to the store and it is believed that 16 or more rows can have the same number transferred into those locations without error should such a remote possibility occur.
The other advantage of Gray Code is that the addition of one to any Gray Coded number changes the state of only one bit so that should the staticising be slightly misphased only an error of one unit is introduced in contrast to the binary case where the same misphasing would give rise to errors up to $2^14$. In this way the times of arrival of the sound wave at the 65 microphones are transferred to the store. The expanded neutron times-of-flight are entered in an exactly similar way and monitor scaler contents are entered into other locations by stopping their accumulations of beam particles at the time of the event, clocking up the scaler with the 4 Nuc/s clock train and entering into the store the, say, 10,000 out signal from the scaler overflow. In this case the number entered into the store is $10000 - N$, where $N$ is the scaler content at the time of the event.

Sonic flight times in the chambers to be used will not exceed 4 msec and at this time the clock gate is closed and also gates on the 128 rows are closed. These latter gates are only opened 100 µsec after an event to remove the possibility of pick up from the discharge of the spark chamber entering spurious numbers into the store.

At the end of this 4 msec period, information from hand switches or bistables can be entered by parallel access. In this mode the Gray Register is set by a bank of hand switches or bistables and this word transferred to its appropriate location in the store. Four such parallel access words will be provided in the store.

Thus after 4.5 msec the store contains, say, 65 flight times and 5 scaler contents in Gray Code and 4 labels in binary. In general this information is now transferred to magnetic tape. A Potter Tape Deck MT 120 has been chosen with a tape speed of 120"/sec, 200 bits per inch and a start-stop time of 5 msec total. The content of the store is transferred serially to tape, the 65 sonic channels and the 5 scaler channels being converted to binary for transfer and the parallel access channels being transferred in the binary form they have in the store. This transfer is made non-destructively and the store content is in fact transferred twice to the magnetic tape in successive blocks. It is also possible to have a decimal print out of the content of the store using a binary to decimal converter and a Solatron High Speed Printer with 15 lines/sec and, for entirely off-line checks, the information can be transferred to 5 hole paper tape at 110 characters/sec.

The time for transfer to magnetic tape is 42 µsec/word and thus the total time per event using all 128 words would be $4.5 \text{ msec} + 2 \text{ msec} + 126 \times 42 \times 2 \mu\text{sec} + 3 \text{ msec} = 20 \text{ msec}$.

On line use with the ORION computer can be split into four categories.

a) One in n events passed immediately to the computer for checks and a small amount of analysis.
b) Short periods, relatively frequently, during which time the events of the previous hour, say, are passed to the computer for analysis sufficient to be a guide to the conduct of the experiment.

c) Complete or near complete analysis of many events and transfer of the events to a computer magnetic tape in computer format for subsequent analysis in further detail or analysis on a faster computer, for example the Ferranti ATLAS.

d) Complete on-line running with every event passed to the computer for, probably, checks and partial analysis and transfer to a computer tape in computer format for subsequent detailed analysis.

e) The sampling of one in n is achieved by this system in the following way. The nth event is transferred to tape as described in two identical blocks and then immediately the tape is reversed and the 2nd block is transferred back to the buffer store word by word using parallel access. The first block is then written into the store over the second block. This technique is used to eliminate errors due to drop-outs. Any drop-outs occurring in this transfer can be counted. The store should then contain the same information as originally and this is then transferred word by word by command of the computer.

The direct data link into the ORION computer accepts 48 bit words of which 32 bits will be available for our use and two 16 bit words from the buffer store will be combined to form a 32 bit word for entry to the computer. The time taken to enter the word is 32 μsec thus requiring ~ 2.2 msec to transfer the entire content of the buffer store to the computer. The maximum possible delay in initiating the transfer of the store content to the computer will be 10 msec but the average delay is likely to be only 100 μsec. Interruptions in the transfer can occur as we will share the direct data link with the HFD but these interrupts should not exceed 3 msec and should be infrequent. The amount of computer store for programme will be limited to a few hundred instructions for this mode of operation.

Under condition b) all the events accumulated on tape for the past one or two hours are transferred to ORION via the buffer store as above. For this mode of operation a more comprehensive programme can be stored in ORION and for a period of a few minutes events can be analysed with sufficient detail to guide the experiment. The limitation under this condition will be the number of events to be analysed and the time for analysis compared to the computer time available.

Under condition c) data collected over many hours will be passed to the computer during a break in the experiment and at the end of the experiment. Permanent storage of the data in computer format on a computer tape
takes place at this time and detailed analysis is performed or, depending on the loading on the computer, the analysis is deferred until later.

Condition d) is critically dependent on the loading on the computer. It can be accommodated as for condition a) with n = 1 when each event will be stored on the Potter Tape deck and passed to the computer or the event can be passed solely to the computer.

6. FORMAT OF DATA AND CHECKS

It is intended that after an event has occurred and has been transferred to magnetic tape, all the calibration spark gaps will be fired and this pseudo-event will then be recorded and stored on magnetic tape. Coincidence type equipment is also being constructed that will give a visual indication that for each module the signals from microphones 1, 4 and 5 were in coincidence with a resolving time of say 5 µsec and further that the signals from microphones 2, 4, and 3 were in coincidence. This visual check indicates that all the microphone channels are functioning correctly. Events passed to the computer will consist of the block of data from the real event plus the block from the pseudo-event. From the pseudo-event the velocity of propagation of sound in each chamber can be rapidly computed by the computer and these values will be used to analyse, in the first instance, the event proper.

At the beginning and end of every run an identifying label is transferred to the Potter tape and by recognising these run labels any run can be located on the tape for transfer to the computer via the buffer store. A further experimental label is written in the first few characters of each event block and this will be used to indicate any relatively minor change of condition in the experiment during a run.

Under conditions a) and b) the following checks of the reliability of the data will be made:

A. - for the pseudo-event

i) The times recorded from microphones 1, 4 and 5 should agree with each other to 5 µsec and this time should agree to within 1% of that expected from the separation of calibration spark and microphone.

ii) Similarly for microphones 2 and 3.

iii) Two values of the velocity of sound can be calculated from microphones 1 to 4 and these should agree to 0.5%.
Under regime c) a complete solution of the four times from the measuring gap will be sought, its validity being determined by the velocity of sound and the shock parameter given by the solution. In parts of the chamber (i.e. symmetry axis) where the coordinate solutions are somewhat independent of the values of velocity and shock parameter confirmation of the solution will be sought using the velocity as determined from the calibration sparks.

8. CONCLUSION

This experiment is scheduled for Phase II on Nimrod which is a six months period commencing in July and 100 hours have been allocated to this experiment. A further period has been requested to further the study and to extend this technique to other resonant reactions.

References

1. Resonances in the reaction $\pi^- + p \rightarrow p + X$ will also be sought during this experiment.

2. "The use of sonic spark chambers and data handling technique in a scattering experiment", presented by C. Whitehead at the International Symposium on Nuclear Electronics, Paris, November 1963;

Figure captions

Fig. 1 Layout of beam line for the experiment.

Fig. 2 Plan view of spark chambers showing positions of microphones 1 to 5 and calibration spark gap S.

Fig. 3 Simplified block diagram of 4 Mc/s ferrite core store and associated electronics.
ON-LINE TRACK IDENTIFICATION FOR WIRE CHAMBERS

D. MILLER and C. FREED
Harvard University, Cambridge, Mass.

(presented by D. Miller)

Our wire chambers are coupled to a control computer manufactured by Digital Equipment Corporation. As you heard the other day, 18 bit wire locations are transferred into a data buffer in the computer memory. And they are also transferred from the data buffer out onto magnetic tape. This data buffer isolates the tape transport from the randomness of the event rate. It also retains wire locations in the computer memory as long as possible, so that on-line track identification and display are feasible.

An event can be transferred into the data buffer without interrupting the programme. The programme is just deferred for 5 μsec per word. Clearly there is plenty of computer time remaining for on-line track identification and display.

However, what can be done depends on the event rate and detector array size and this will change from experiment to experiment, indeed, from day to day. How should we programme the computer so that it will keep busy, always working on the highest priority job which is unfinished but still possible?

Fortunately our computer is equipped with a programme interrupt system which allows us to assign priorities to various programme operations. If a lower priority job is being done, and it becomes possible to start a higher priority job, the computer interrupts the lower priority task, keeping track of where it is, does the higher priority task, and then returns and recommences the lower priority task. We have assigned priorities to all jobs we will want the computer to do at low counting rates or off-line.

At higher counting rates we will not have time for all these features on-line. So we will have to be satisfied with a few on-line features for all events or a more detailed on-line analysis for a smaller sample of events. And what we desire will change from hour to hour.

Our solution is to use a programme status register whose bits tell the programme whether or not a particular on-line feature is to be included. We can quickly add or subtract features of the programme. But we cannot change the priority of features.
The following list shows the on-line features which have been included so far:

COMPUTATION PRIORITIES

1. TRANSFER A SPARK LOCATION FROM THE COMPUTER MEMORY TO MAGNETIC TAPE
2. TRANSFER A SPARK LOCATION FROM THE CORE READER TO THE COMPUTER MEMORY
3. KEEP MAGNETIC TAPE TRANSPORT MOVING
4. PREPARE INCOMING DATA CHANNEL FOR ANOTHER EVENT
5. DISPLAY SPARK LOCATIONS IN ONE VIEW (LOW INTENSITY)
6. FOLLOW ALL PARTICLE TRACKS IN ONE VIEW USING A STRAIGHT LINE CRITERION
7. DISPLAY TRACK LOCI IN ONE VIEW (HIGH INTENSITY)
8. FOLLOW ALL PARTICLE TRACKS IN OTHER VIEW
9. MATCH TRACKS IN DIFFERENT VIEWS
10. TRANSFER TRACK KNOWLEDGE TO MAGNETIC TAPE
11. TYPE OUT TRACK KNOWLEDGE

If priorities 1, 2, 3 and 4 are satisfied, the tape transport is running between characters and the data channel is awaiting the next event. So the programme returns to its track identification task. It transfers an event from the data buffer into a display buffer. Remember that these wire locations are arranged in order of increasing number. It is easy to look for them.

First the programme finds a spark in the first gap. Next it counts the number of adjacent wires and finds the centre of this spark. Then it predicts a scan width just below in the second gap. It tests one wire location after another until it finds one inside the scan width. Then it finds the centre of this collection of adjacent wires and makes an improved prediction for the third gap. In this way the programme works its way down a straight line track, improving the prediction as it goes. If there are two collections within a scan width, the best choice is made. As soon as two gaps are empty within the scan width, the track end is declared. For each track the
entrance position, slope relative to normal and number of admitted wires along the track are recorded. We can handle straight lines which cross with no difficulty. So far all is in one view.

At this point we display all wire locations at low intensity and display the locus of collection centres at higher intensity. In fact, under console control we can see the programme find one spark centre after another. This feature is most valuable off-line. At low priority, we write the track identification results on magnetic tape and on the type-writer at the console.

In general our philosophy has been that there is no point in identifying tracks on-line unless you also display the results on-line. Also you rarely want to transfer track identification results onto magnetic tape on-line unless you service all events. All I have done is to sketch the present state of our programme for on-line analysis. It is developing on the firing line on a day-to-day basis.
LINK AND PAIR (CDC-3600 PROGRAMMES FOR THE ASSOCIATION OF SPARK IMAGES INTO TRACKS)

R.F. CLARK
Argonne National Laboratory, Argonne

AIRWICK is a spark chamber data processing system being written at Argonne for the CDC-3600. It is able to handle data originating from photographs, vidicon systems and sonic or wire chambers and will furnish a set input into geometry and kinematics programmes. There are three sections, each having increased generality in the system. In order, they are:

1. PREPROS - Preprocessing
2. PAIR - Three-dimensional reconstruction
3. LINK - Linking of sparks into tracks

AIRWICK SYSTEM

![AIRWICK System Diagram]

Data Input

PREPROS (Preprocessing)

PAIR (3-dimensional reconstruction)

LINK (Linking into tracks)

Geometry and Kinematics Programmes
We believe that an important contribution to date has been the establish-
ment of this processing order rather than the normally conceived one of
PREPROS, LINK and then PAIR. In three-dimensions tracks which intersect
will almost always intersect because of a vertex. The physical separation
of sparks will be at least as great as in the projection and in most cases
will be significantly greater, an effect which tends to normalize distances
between sparks.

As we describe our approach, it should be remembered that dealing
with a problem by computer often necessitates techniques which are not
obvious and are certainly not those a human would use if faced with the
same problem. Many of the ideas and much of the terminology we use have
come from graph theory and from the applications of decision theory to
pattern recognition. Two references are The Theory of Graphs by Claude
Berge (Wiley, 1962) and Decision-Making Processes in Pattern Recognition
by George S. Sebestyen (Macmillan, 1962). Ideas from these two areas have
not been given sufficient consideration in attacking the problems of auto-
matic data processing.

The approach taken in PAIR originated when we undertook the auto-
matic processing of film taken by the Argonne Group at CERN in 1962. A
typical stereo pair is shown in the photograph, Fig. 1 a and b. Using this
stereo pair for an example, we will describe the basic reconstruction process.

Upon entry into PAIR we know in which gap sparks lie and can restrict
our attention to one gap. We order the sparks in each view and can now
visualize the situation (using the example below) in a 10 x 12 matrix, where
the 10 sparks in view 1 represent the rows and the 12 sparks in view 2 represent
the columns. Each element of the matrix will refer to a possible pairing
P(i,j). Using the coordinates of the spark centroids for spatial reconstruc-
tion, assigning an element in the matrix a value of one if the new spark is
in the chamber and a value of zero if it is not, we obtain an incidence
matrix with a "block diagonal" property.
"BLOCK DIAGONAL" PROPERTY OF INCIDENCE MATRIX

\[
\begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

ith row corresponds to ith spark in view 1

jth col corresponds to jth spark in view 2

i,jth element of matrix corresponds to pairing P(i,j)

Since the sparks have been ordered, the incidence matrix has the property that once a one is followed by a zero in a row or column, all remaining elements in the row or column must be zero. This is due to the fact that if a spark in one view can be paired with two sparks in the other view, it can be paired with all sparks between them. We can separate the blocks and can consequently focus our attention on resolving the ambiguities in a single block.

We will use as an example, gap 13 from the photograph, where we have the following measured data and incidence matrix
**INCIDENCE MATRIX FOR GAP 13**

<table>
<thead>
<tr>
<th></th>
<th>(937.0)</th>
<th>(1030.5)</th>
<th>(1490.0)</th>
<th>(1789.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1020.5)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(1192.5)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>(1204.5)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>(1653.5)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(2016.0)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

We define a decision function on the pairing $P(i,j)$ which takes into consideration:

1. The value of the $i$th element of the incidence matrix.

2. The widths (intensity) of the sparks.

3. The order in which sparks appear in the gap.

4. The "clarity" with which we "see" each spark.

5. The position of the spark in the chamber (which will not be considered in the following discussion).

6. Weights, which are programme parameters, for the factors given in 2 through 5.

Functional values will range from 0 to 100. The larger the value, the greater the chance of an unambiguous reconstruction.

Below we show how the portion of the function pertaining to the widths of the sparks is calculated. Normalized widths are computed by dividing the spark width by the sum of the spark widths in the same block and view.
CONTRIBUTION OF WIDTHS

\[ W(i,j) = A(1 - |w_1 - w_2|) \]

\[ A = 60 \]

\[ w_1 = \text{normalized width of spark in View 1} \]

\[ w_2 = \text{normalized width of spark in View 2} \]

<table>
<thead>
<tr>
<th></th>
<th>(17)</th>
<th>(10)</th>
<th>(11)</th>
<th>(12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10)</td>
<td>55.7</td>
<td>55.7</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>(4)</td>
<td>46.1</td>
<td>54.5</td>
<td>53.3</td>
<td>X</td>
</tr>
<tr>
<td>(6)</td>
<td>49.3</td>
<td>57.6</td>
<td>56.5</td>
<td>X</td>
</tr>
<tr>
<td>(8)</td>
<td>X</td>
<td>X</td>
<td>59.8</td>
<td>58.6</td>
</tr>
<tr>
<td>(9)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>59.8</td>
</tr>
</tbody>
</table>

We now calculate the order contribution

CONTRIBUTION OF ORDER

\[ O(i,j) = B \left( 1 - \frac{|i - j|}{P} \right) \]

\[ B = 10 \]

\[ P = \max(5,4) - 1 = 4 \]

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>10.0</td>
<td>7.5</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>(2)</td>
<td>7.5</td>
<td>10.0</td>
<td>7.5</td>
<td>X</td>
</tr>
<tr>
<td>(3)</td>
<td>5.0</td>
<td>7.5</td>
<td>10.0</td>
<td>X</td>
</tr>
<tr>
<td>(4)</td>
<td>X</td>
<td>X</td>
<td>7.5</td>
<td>10.0</td>
</tr>
<tr>
<td>(5)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>7.5</td>
</tr>
</tbody>
</table>
and the "clarity" contribution

**CONTRIBUTION OF CLARITY**

\[ C(i,j) = K \left( 1 - \frac{S(i) - 1}{R} \right) \left( 1 - \frac{T(j) - 1}{R} \right) \]

\[ K = 30 \]

\[ R = \max(5,4) = 5 \]

\[ S(i) = \text{number of possible pairings with spark } i \]

\[ T(j) = \text{number of possible pairings with spark } j \]

<table>
<thead>
<tr>
<th>(3)</th>
<th>(3)</th>
<th>(3)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2)</td>
<td>14.4</td>
<td>14.4</td>
<td>X</td>
</tr>
<tr>
<td>(3)</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
</tr>
<tr>
<td>(3)</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
</tr>
<tr>
<td>(2)</td>
<td>X</td>
<td>X</td>
<td>14.4</td>
</tr>
<tr>
<td>(1)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

We then compute the values of the decision function and are ready to begin the selection of our pairings.

**VALUES OF PAIR DECISION FUNCTION**

\[ D(i,j) = W(i,j) + O(i,j) + C(i,j) \]

<table>
<thead>
<tr>
<th>80.1</th>
<th>77.6</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.4</td>
<td>75.3</td>
<td>71.6</td>
<td>X</td>
</tr>
<tr>
<td>65.1</td>
<td>75.9</td>
<td>77.3</td>
<td>X</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>81.7</td>
<td>87.8</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>91.3</td>
</tr>
</tbody>
</table>

8445/wn
Since the maximal value of the decision function does not exceed all other values by 10 per cent, we calculate a "comatrix" whose values are given below:

**COMATRIX OF D(i, j) VALUES**

$$A(i, j) = \sum_{n} D(n, j) + \sum_{m} D(i, m) - 2D(i, j)$$

<table>
<thead>
<tr>
<th></th>
<th>207.1</th>
<th>231.3</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>292.1</td>
<td>289.5</td>
<td>298.7</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>297.7</td>
<td>295.3</td>
<td>294.3</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>236.7</td>
<td>173.0</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>87.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These values give a measure of the degree to which all other sparks in View 1 could pair with spark j and all other sparks in View 2 could pair with spark i. Since the minimal value in this matrix $A(5, 4)$ is 10 per cent less than all other values, we choose as our first pairing:

(Spark 5 in View 1) $\leftrightarrow$ (Spark 4 in View 2)

These sparks are removed from further consideration by deleting row 5 and column 4 in the original matrix. We therefore obtain:

**REMAINING D(i, j) VALUES**

<table>
<thead>
<tr>
<th></th>
<th>60.1</th>
<th>77.6</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>64.4</td>
<td>75.3</td>
<td>71.6</td>
<td></td>
</tr>
<tr>
<td>65.1</td>
<td>75.9</td>
<td>77.3</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>81.7</td>
<td></td>
</tr>
</tbody>
</table>

**RECALCULATED A(i, j) VALUES**

<table>
<thead>
<tr>
<th></th>
<th>207.1</th>
<th>231.3</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>292.1</td>
<td>289.5</td>
<td>298.7</td>
<td>X</td>
</tr>
<tr>
<td>297.7</td>
<td>295.3</td>
<td>294.3</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>148.9</td>
<td></td>
</tr>
</tbody>
</table>

Again our 10 per cent criterion makes no decision and we recalculate the comatrix. As before, we are able to make a choice and we choose as our second pairing:

(Spark 4 in View 1) $\leftrightarrow$ (Spark 3 in View 2)

8446/mn
Our processing is now reduced to:

<table>
<thead>
<tr>
<th>REMAINING D(i,j) VALUES</th>
<th>RECALCULATED A(i,j) VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>80.1</td>
<td>207.1</td>
</tr>
<tr>
<td>64.4</td>
<td>220.5</td>
</tr>
<tr>
<td>65.1</td>
<td>220.4</td>
</tr>
</tbody>
</table>

No pairing decision can be made from the first matrix or its comatrix. We therefore return to the matrix of D(i,j) values. Since all values within 10 per cent of the maximal value do not lie in the same row or column, we select the maximal value and our third choice is the pairing:

(Spark 1 in View 1) \(\longrightarrow\) (Spark 1 in View 2)

We now have:

<table>
<thead>
<tr>
<th>REMAINING D(i,j) VALUES</th>
<th>RECALCULATED A(i,j) VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>75.3</td>
<td>75.9</td>
</tr>
<tr>
<td>75.9</td>
<td>75.3</td>
</tr>
</tbody>
</table>

As before, the 10 per cent criterion fails to separate a pairing in the two matrices. We return to the first one and find that all values within 10 per cent of the maximal value lie in one column, and we make a simultaneous fourth choice, pairing:

(Spark 3 in View 1) \(\longleftrightarrow\) (Spark 2 in View 2)

(Spark 2 in View 1) \(\longleftrightarrow\) (Spark 2 in View 2)

This exhausts the matrix and we have now established pairings for all the sparks in both views. If we look at the photograph, we see that these are exactly the choices a human scanner would have made.

LINK has been written to accept a random list of coordinate triples and with some knowledge of the chamber but none of the topology of the event, link these points in space into tracks. Our approach, is at present a local rather than a global one, assembling sparks into track segments and track segments in tracks.
Output from LINK is in the form of "trees" with a directory indicating the root of each tree.

Tree starting at B

Tree starting at C

Tree starting at A

Associated with each spark will be a vertex order and links (if any) to adjoining sparks. A vertex order 0 indicates an isolated spark, 1 indicates a track end-point, 2 indicates a spark interior to a track or a vertex of a "Y".
A vertex order $N \geq 3$ indicates the vertex of an $(n-1)$-pronged "Y" or an $N$-pronged "V". This structure gives a reasonable description of the actual physical event taking place in the linking region and is amenable to certain generalized data processing techniques. The vertices which are of interest to the physicist will lie within some small sphere about the vertices of order 2 (or more) in the tree but, in general, these vertices will not coincide.

For each of ten sub-regions in the linking region, we define a linking distance $W$. In each sub-region, we execute a loop through gaps 1, 2, ..., $N$, establishing intra-gap links between sparks within gap $i$ whenever the distance between them is less than $W$. An attempt is made to link sparks in gap $i$ with sparks in gap $i + 1$ using a linking distance $W$. If this attempt fails, we try to establish links using a distance $2W$. This inter-gap linking effort is then terminated regardless of the outcome.

If there can be at most one track in the linking region, a parameter can be set which forces the linking of all sparks using the criterion of minimum distance. In the more general case, when there is a possibility that two or more tracks can be present, this forcing of links cannot be done.
At the present time, we simplify matters by searching through our linked sparks and if a spark of vertex order greater than 3 is encountered, processing is abandoned. If none are encountered, another search is made for sparks of vertex order 1. If none are encountered, we again abandon processing. Extrapolation attempts are made from all sparks of vertex order 1, in which we look along a line between the spark and its predecessor and link the spark to the first spark found in a cylinder of radius M (where M is the maximum linking distance) about this line.

If no spark is found within a distance L, the extrapolation procedure is terminated. When extrapolation attempts have been made from all sparks of vertex order 1, we exit from LINK and the tree structure is transmitted to geometry and kinematics programmes for final processing.

We do not feel that this formulation of LINK is the most desirable one. As a next step, we would like to have some way of removing the restrictions on the vertex order, but we feel that a completely satisfactory solution will come only with the formulation of a global approach to the problem. A more detailed reference to the AIRWICK System is "AROMA-AIRWICK: A CHLOB/CDC-3600 System for the Automatic Identification of Spark Images and Their Association into Their Association into Tracks", AMD Technical Memorandum No. 64, Argonne National Laboratory, February 1964.
Figure caption

Fig. 1 a and b  A typical stereo pair of spark chamber film taken by the Argonne Group at CERN in 1962.
DISCUSSION

ANDERSON: Could I ask how long it takes to process one of these events?

CLARK: For the pairing procedure approximately 1 sec, and for the linking procedure it will be in the vicinity of 3 to 5 secs. An attempt has been made to structure this thing so that the topology becomes more simple. If you have some prior knowledge of the topology, the programme may be reduced by as much as a factor of a hundred in the event of one relatively straight line, we hope.

GELERNTER: How valuable was the width information in enabling you to make pairings?

CLARK: We experimented with the parameters to a great extent until we found the ideal weights that could be assigned to them. We would have used additional criteria had we been able to think of any that seemed to be of importance; but the one most important thing was the width contribution, the next seemed to be the confusion that the spark itself was in. If it was in an area with many other sparks where things were less clear, and if we can measure the complexity of the neighbourhood of the spark and transmit this information, it seems to be very useful. This procedure actually works quite well. The fact that you are now in three dimensions gives the following advantages: your problems of linking improve as far as computer processing time is concerned; the total computational time is less than doing two views separately and then merging them; and the separations between tracks become very great, I mean, things which appear very complex on the projections seem to disappear for the most part.

GELERNTER: Since there are such variations in intensity from gap to gap, I speak for example of robbing of energy from a spark by a high-energy particle that appears to live further down, is width information of any use in constructing a single track from gap to gap?

CLARK: No, it doesn't seem to be. Actually, the knowledge within the gap seems to be better than that going across. You can't count on a particular spark being of the same width as one in the next gap. There seems to be very little correlation here. But within the gap certainly regardless of the stereo view whether its 90° or small angle stereo spark has a tendency to be a cylinder, and the width information is in general fairly uniform.

NOTE: On the problem of automatic scanning and track recognition of spark chamber pictures, see also reference 4) of the paper given by G.R. Macleod in Session O.
FESSEL: Do you have any trouble with tracks in a magnetic field that have spread?

CLARK: Again, no two pictures we have processed are alike. A spiral in one of them has been nicely reconstructed in space. But I am not sure that I understand what you mean.

ROBERTS: I could comment on that, I thing what you mean is the order of displacement in the magnetic field, that is of course present in the pictures but its not very large its a few millimetres per gap and the programme doesn't have any trouble following it.
REMARKS ON ON-LINE COMPUTER USE

R.H. MILLER

Institute for Computer Research, The University of Chicago, Chicago.

The on-line projects described so far in this conference have represented large commitments of equipment, money and manpower. They have also relied on extensive engineering capability. The advantages of on-line computers should be available to more modest programmes. I encourage all of you to think about how a computer could help in your experiment, and hope some possibilities have occurred to you.

At the Institute for Computer Research of the University of Chicago, we have active programmes directed toward developing on-line use of computers in experiments, as do some of our good neighbours at Argonne and at the Digital Computer Laboratory of the University of Illinois. It is noteworthy that most of the current on-line computer use has been developed by laboratories that have home-made computers. Among these, the SMP, Chloe, PEPR, Hough-Powell and Lindenbaum's experiments are outstanding examples. The reason for this probably lies with the existence of engineering capability that accompanies these home-built machines. At the Institute for Computer Research, we have such a home-built machine — Maniac III, that is crudely equivalent in vocabulary to a 7090 at about 1/4 the speed. Our main programme directed toward on-line experiments has been the spark chamber work reported yesterday, but our interests spread over many fields, of which high-energy physics is only one. Our experimental data links can move data about 1/10 of the computer's internal transfer speed.

There are various levels to which a computer may be used on-line with an experiment. In discussing this point, one may easily become involved in semantic questions as to just what is a computer. In a sense, the devices that encode the output of vidicons or of acoustic chambers for transcription onto magnetic tape are special purpose computers. I do not want to become involved in those semantic questions, so I will simply ignore them. Further, it is not clear just what is to be regarded as on-line use, or how much use should be made of a computer. The computer could be used to facilitate calculations to be made during an experiment; or, if it is to be part of the data-logging system, it could simply provide a buffer storage to smooth out tape unit use; it could multiplex the output to several tape units; or it could carry the reduction all the way to the final numerical results before
producing any output. Between these, there is almost a continuum of possibilities. It is largely a matter of taste how far one goes - influenced by the degree to which one wants to become involved with the computer technology and to which one wants to handle the data at intermediate stages. I rather incline to the view that the on-line reduction at the time of the experiment should be to a "Minimum-redundancy" form, with individual events being transcribed on a permanent medium at that point, for subsequent tallying of the results. Whether the "minimum-redundancy" form should include checks of legality of the events (i.e. whether a scattering event occurred within the target) is again a matter of taste. Under these conditions, the computer may limit the data rate, and events that you have not been clever enough to allow for in the programme will be lost. This last is probably the only significant loss of events. However used, it may be advisable to regard the computer as part of the experimental apparatus, rather than the other way around, or as some mysterious black box that you are, by some divine grace, permitted to use.

There is some question about whether a special purpose or a general purpose computer should be used for these on-line applications. I am undecided about this at present, and I have heard arguments among computer people on both sides. The circumstances will determine which is best. In general, if cost is not important, a general purpose computer will provide more flexibility. In many cases, suitable general purpose machines are surprisingly inexpensive. Lindenbaum's data handler is part of any general purpose machine, and it is possible that a general purpose computer might be competitive in real cost. Alternatively, there may be problems (e.g. pattern recognition) for which any general purpose computer is too slow, and then a special purpose machine is definitely indicated.

Not all experiments are suitable for on-line computer use. In principle, any experiment may benefit from an on-line computer, but certain kinds of experiments will benefit in a more obvious way, and perhaps the exploration should begin with them. Experiments in which many similar events are expected are particularly suitable, but it would seem inadvisable to attempt experiments in which the event sought is particularly rare or unusually difficult to analyse. A computer and spark chamber combination will not, in my opinion, compete with bubble chambers for many applications - single event studies, for example. If a computer is used along with automatic data transcription, there is danger of missing discoveries because one has not been clever enough a priori to write a programme to handle that kind of event, and the programme may throw it out. Such events will be lost, unless there is also a permanent record of all events prior to the analysis stage.

With the ambiguity problem in chambers, it had been pointed out that there is little difficulty of principle in analysing multi-track events. However, extra computation time will be required to analyse the events. The human eye is exceptionally good at "pattern recognition", and an event that is difficult to disentangle by eye will certainly give a computer a lot of trouble.
As a strong protagonist of on-line computer use, it feels strange to me to find myself in the position of urging some caution following what I regard as some flamboyant promises about the potentialities of on-line computer use.

A few admonitions in closing:

1) A lot of homework is necessary before the experiment. Lindenbaum's experiment is a good example of this, and its historical development is an example of what may be expected if that degree of involvement is anticipated.

2) The availability of results during the experiment allows some freedom in modifying the course of the experiment, but not complete freedom. The large investment in both hardware and software required limits any changes to those that are consistent with the advance preparation. In particular, unexpected discoveries may be very difficult to pursue, and may require planning a new experiment.

3) Experimenters may be reluctant to change their equipment or programmes. This is noticeable to some extent with ordinary experiments, but is likely to be aggravated by the additional investment of time and effort involved in most on-line experiments.

4) A computer in the system cannot prevent mistakes of judgment by the experimenter.

5) The data rate must be balanced against the load at the computation centres and the reduction time per event, to avoid obtaining more data than can be handled in the existing facilities.
DISCUSSION

MACLEOD: If I may open the discussion on this paper by asking Dr. Miller exactly what he is questioning about on-line computers. As Maglif explained the other day, in 0.5 to 0.9 sec he has the momentum and scattering angle computed and available in the experimental area. This seems to me to have the essence of on-line operation.

R.H. MILLER: There is a matter of degree here. On-line operation may involve a very low rate of data transfer, but then the full advantage of on-line operation is not realized. I want to address myself to the higher data rates, but certainly some advantages can be obtained also at low rates.

MACLEOD: Does this imply that you do not regard the other aspects of on-line use - which is the sample computation - as of equal importance with the data acquisition? I can understand your remarks in terms of high data acquisition rates, but I think equally important is the means of having some feedback of computed information.

R.H. MILLER: My whole contribution was full of hedge and you have perhaps, picked up some of the more obvious ones. These are all matters of degree, and I mention only the extreme examples of simple data acquisition up to and through writing the paper. Carrying out sample calculations is one of the stages between these extremes, but I think the farther you can go towards writing the paper in the computer the more you are taking advantage of on-line operation. But you'll find yourself computer limited at some point. I don't think you can really say very much in general about this. Each application has to be decided on its own merits. My own inclination is to go rather far in having the computer do a lot of the work.

PEREZ-MENDEZ: Since in every experiment you have to accumulate a certain number of events for you to see what is happening in the experiment, I would like to know what the particular advantages would be of being on-line continuously as distinct from having access to the computer every 10 minutes or every hour to compute the number of events you have accumulated and then monitor the experiment that way.

R.H. MILLER: This depends on the particular experiment. I can imagine experiments in which you get events once an hour in which there is not much advantage to having the computer full-time, but you might want to see what that event was immediately.

PEREZ-MENDEZ: If you only get one event an hour you don't want to tie up the computer for that hour, you just want to have access to it once an hour.
R.H. MILLER: I am assuming that a computer of this type has interrupt facilities, and any intelligent use of it has it doing other things when it is not tied up with the experiment.

PEREZ-MENDEZ: But if you require to interrupt the computer and it is not immediately available it implies that you must have some form of temporary storage for information until you can use the computer.

R.H. MILLER: This depends to a certain extent on monitors and so on. Normally, it would be available in a fraction of a second, and if you only get one event an hour you can't complain about the loss of a few seconds providing you don't lose the event in the process. Most of the automatic retrieval devices have their own storage. For example, the acoustic chambers seem to load up a set of scalers which may be retrieved at any later time.

HINE: I think there is one unambiguous criterion as to whether you want an on-line computer or not. If you want to get an answer back from it before you have forgotten what the question was, you need an on-line computer. If you don't mind that you have forgotten what the question was then you can put the results on tape. That is true however small the data rate may be.

MACLIE: We heard yesterday that a slow on-line computer at Columbia University was helping a physicist inside a magnet to adjust the chamber. It was very slow communication, of the order of a second, but this didn't matter since he could only move the chamber a few centimetres per second. I would say that the generality obtained in a bubble chamber cannot be repeated in a spark chamber; but we need a knowledge of what type of physics is going to be done in the future. For instance at very high energies the momenta cannot be measured even in a bubble chamber with normal magnetic fields. Therefore it may become sufficient to do angular correlations and indeed recently it has been suggested in some papers that much physics can be done from angular correlation only, without measuring particle momenta.

R.H. MILLER: I would like to make 2 points; the first being that I was asked to outrage the populace - in which I seem to have succeeded. The second point is, I would ask you to repeat the omega minus experiment in your spark chamber.

WEINSTEIN: In 1958 some very good physicists said that all future work would come from bubble chamber analysis and they were wrong. I think we are equally as wrong in that the techniques we will be using 10 years from now have not been invented yet. And to say that the bubble chamber, because of its high density of data and magnificent angular resolution, is the
instrument, is to say that spark chambers are only 3 years old. If you have a wide gap spark chamber and you took a picture of it and put it on RPR how do you distinguish between this and a bubble chamber, other than it's a low density medium and has a high repetition rate?

R.H. MILLER: You can do something with a single event in a bubble chamber and I will not argue that you can't do it in a spark chamber, particularly if you photograph the spark chamber, but if you transmit the spark chamber contents to a computer and do some processing on them without transcribing the raw events onto magnetic tape, you do not have much chance of handling that event.

FESSEL: You said earlier in your talk that this project required extensive engineering back up, and I personally would say that it is not true. We have built up the system I described with very little engineering support, by using knowledge which is available to most engineers in the open literature.
SOME REFLECTIONS ON SYSTEMS FOR THE AUTOMATIC PROCESSING OF COMPLEX SPARK CHAMBER EVENTS

A. ROBERTS
Argonne National Laboratory, Argonne, Illinois

The following note considers some possible systems for the automatic recording and analysis of digitized data from events of arbitrary complexity, and inquires as to their possible advantages over existing spark-chamber data-processing systems.

1. THE SCANNING PROBLEM

Before discussing hardware, we will take up the most important and vexing software problem, that of scanning, or event recognition. Let us call the recorded data for each occurrence a frame, and use "event" to designate a selected sample of frames which are of interest for further processing; because of background, improper triggerings, etc., not all frames contain events, although the proportion may be high. Also, we are by definition dealing only with "complex" events. By this designation we exclude events in which only a few straight tracks occur, like elastic or inelastic scatterings. Programmes for the automatic scanning of events at this level of complexity have been written and operated.\(^1\) A typical "complex" event might be the associated production of a lambda and K\(^0\), and their subsequent decay into charged particles observed in a magnetic field. To identify such an event by automatic scanning, a non-trivial computation is required. Even though programmes for this kind of scanning do not yet exist, let us assume, in order to proceed further with our argument, that they can and will be written.

In conventional analysis of complex events, frames are first scanned and a selection made of interesting events for measurement. The economics of this stage of processing impose stringent limitations on automatic data-processing systems. Consider, for example, a system producing 1000 frames per hour, a moderate rate for spark chambers. If all these frames are processed through a modern high-speed digital computer the total cost of such processing is likely to be several thousand dollars per hour of accelerator time. If only a few of these frames are interesting, as may well happen, then the cost per useful event becomes very high indeed. In contrast, human scanning of spark chamber pictures is usually cheap, since a scanner can easily examine several hundred events per hour.\(^2\) The operating cost of a large modern digital computer is in the neighbourhood of $10 per second; but 10 cents is a high
figure for the cost of a single frame seen by a human scanner. It is clear
that when we talk of automatic data processing, including event recognition,
of large numbers of frames, either the yield of good events must be high,
or conventional scanning must be interposed to avoid excessive cost.

We conclude that either, 1) we should use automatic data process-
ing mainly for those complex events that appear on a large fraction of all
frames, so that the high cost of processing a frame is amortized by a large
amount of useful data, or 2) there must exist some other advantage of au-
romatic processing to justify the cost. One such advantage would be the produc-
tion of on-line results. This capability may well be restricted to a small
fraction of the data, until such time as complex event recognition on com-
puters becomes feasible and cheap. Meanwhile, 3) since automatic scanning
methods compare unfavourably with conventional procedures on the basis of
cost, any contemplated automatic data-processing system for complex events
should provide for human scanning. This means a suitable display must be
provided; this can never be as cheap or convenient as film.

2. AUTOMATIC MEASUREMENT SYSTEMS

After event recognition comes track reconstruction and measurement,
and then kinematic analysis. We ask whether spark chamber systems capable
of carrying out these steps automatically can be envisaged. We have space
to consider only a few, and we select the wire array systems2,3) as showing
great promise.

The wire array system

The volume in which tracks are to be observed contains a number of
detecting units. Each detecting unit, for the sake of illustration, may
consist of a single thin-foil spark chamber plate and an array of parallel
wires. Let the wire direction be the y-axis, the orthogonal axis in the
plane of the array be the x-axis; the dimension along the gap between the
wire array and the thin plate will then be the z-axis. In existing wire
array systems such a unit is used to give data which are digitized in x and z,
but in which no information is available about the y-direction. At present
it is also customary to abandon almost all information about the intensity of
a spark and simply to record the appearance of the spark by a single binary
bit, using a ferrite core attached to each wire. Intensity information is
thus reduced to the minimal required to say that a spark exists or not.

To obtain information as to the y-coordinate, a second unit must be
added as close as possible to the first in which the wires run parallel to the
x-axis rather than the y, thus giving a pair of crossed arrays. In this unit
the information obtained consists of the z-coordinate and y-coordinate, and the
x-information is missing. Regarding these two crossed arrays as a single unit
we can then obtain, for some average value of z, the x and y coordinates of a
sample point on a track traversing the pair of units. The well-known hodoscope ambiguities arise in the output of such a system; thus if two sparks occur, the first array will give the information that sparks are present in coordinates $x_1$ and $x_2$ and the second that sparks are present in coordinates $y_1$ and $y_2$. The ambiguity consists in associating a given value of $x$ with the correct value of $y$, the two possible choices being $x_1 y_1$ and $x_2 y_2$, or $x_1 y_2$ and $x_2 y_1$. Only data external to the double wire array can resolve this ambiguity, since we have abandoned all intensity information; therefore, a third "redundant" array at an angle (usually 45°) to the other two is introduced.

It is not generally realized how effective a redundant array is in eliminating such ambiguities (see Appendix 1). Thus, even if one has five sparks in an array consisting of 10 wires along each axis, as might be the case in one square centimetre very close to a target, a single redundant array at 45° will remove over 99% of all ambiguities even with no intensity information available. In practice, the firing of more than one core by a single spark is likely to be a source of more difficulty.

As a result of a new development initiated by Charpak, Favier and Massonet(4), it may be possible to add an analog measurement of $y$ to a single wire array. These authors showed that by measuring the ratio of the currents to ground produced by a spark, the location of the spark in one dimension can be accurately determined. Thus, going back to our first array, in which the wires are along the $y$-axis, if a spark occurs on a given wire and the two ends of the wire are grounded, the currents to ground will be equal only if the spark occurs in the exact centre of the wire. At any other point along the wire the two currents will divide inversely as the impedance to ground from those points. The ratio of the currents thus determines the location of the spark. Charpak et al, have shown that the accuracy of such a determination, in the case of a plane conductor, is comparable with that of the digitizing in the other two planes, namely, a half millimetre or better. Appendix 2 outlines in some detail just how a wire array system with one analog coordinate might be set up.

We must now consider the accuracy needed, and here we run into real difficulty. We need the ferrite core on each wire to provide $x$-coordinate information; no equivalent substitute can be imagined. However, the presence of such a core on a wire will introduce a serious perturbation in its impedance to ground. One can try to cancel such a perturbation by putting a dummy core at the other end of each wire; but the impedance of a core must necessarily vary with current amplitude, since the cores are designed to operate between two fixed states of magnetization. The idea of using current ratios to 12-bit accuracy (or even 10-) consequently begins to look impractical.
We might, however, consider some type of analog information other than the current ratio. Thus, for example, consider a time-of-flight signal. Suppose, for the sake of argument, that we substitute for each wire an electrical delay line and read the time it takes for each signal to reach the end of each line. Then the ferrite cores need not perturb the reading seriously, since they can be included in the electronic circuit. The difficulty again is to achieve the accuracy we require. The time required is more like that used in acoustic chambers, where the required 12-bit accuracy is just achieved with transit times of the order of a msec. This will be quite difficult to obtain with electrical delay lines.

Conceivably a magnetostrictive or acoustic signal produced by the spark on the wire itself might be used for this purpose. In this case the 10 wires connected together could all pass through a common pick-up, and the ferrite core would no longer have the deleterious non-linear effect pictured above. The ferrite core would, as before, switch the output of the pick-up into a suitable storage.

3. CONCLUSIONS

In summary, the non-visual system seems at present to offer no decisive advantages for events sufficiently complex to require the intervention of human scanners. The need to provide a visual display for scanning complicates the system; and the programming of track reconstruction, geometry, and kinematics analysis will be comparable if not identical with that for visual systems. Thus we may conclude:

i) It appears that it may be technically feasible to construct systems to record in digital form events of high complexity, at high speeds. If realized, such systems will be complicated and presumably expensive.

ii) To process complex events, human scanning is at present far less expensive than computer recognition, whose feasibility is not established. Consequently, a display system suitable for scanning should be provided, unless a large fraction of all frames taken is to be processed.

iii) Such a system has no clear advantage over one using conventional camera-film recording, human scanning, and automatic measurement and processing of selected events (e.g., CHLOE-AIRWICK).

The author acknowledges stimulating and useful discussions with Arthur S. Melmed, of Argonne National Laboratory.
Appendix I. The Hodoscope Ambiguity Problem

Condition for an unresolved ambiguity: Let there be \( m \) sparks on \( N \) wires, and a redundant \( Z \)-array at 45°. Then the condition that an unresolved ambiguity occurs is that a configuration exists like Fig. 1.

\[
\begin{array}{c}
\text{z}_3 \\
\text{x}_1 \\
\text{z}_2 \\
\text{z}_1 \\
\text{y}_2 \\
\text{y}_1 \\
\text{x}_2
\end{array}
\]

a. There must be two sparks on \( x_1 \)
b. There must be two sparks on \( y_1 \)
c. \( (x_1 - x_2) \) must equal \( (y_1 - y_2) \)

Then the ambiguity is \( x_1 \, y_1 \, z_2 \) or \( x_2 \, y_2 \, z_2 \).

Figure 1

Given an array of \( N \) wires, with \( m \) sparks at random in the array; what is the chance that there be two or more sparks on one or more wires? The problem is identical with that of putting \( m \) balls into \( N \) boxes. For each ball in turn the probability is the ratio of the number of occupied boxes to the total number, corrected for the probability that some box already has two balls in it. The successive terms are:

First ball \[ P_1 = 0 \]
Second ball \[ P_2 = \frac{1}{N} \]
Third ball \[ P_3 = (1 - \frac{1}{N}) \frac{2}{N} \]
Fourth ball \[ P_4 = (1 - \frac{1}{N}) (1 - \frac{2}{N}) \frac{3}{N} \], etc.

So the total probability for \( m \) balls is:

\[
P_m = 0 + \sum_{i=1}^{m-1} \frac{(N-1)}{N} \cdot \frac{i}{N} \cdot (N - i); \quad (1)
\]
For large \( N \), small \( m \), a good approximation is:

\[
P_m = \frac{m(m - 1)}{2N}
\]

(1a)

The probability that there be two sparks on one \( x \) wire is given by (1). The probability that there be a second spark on wire \( y_1 \) is just \( \frac{m - 2}{N} \) (two sparks already being assigned).

The probability that the second spark on \( y \) be spaced at the right distance is \( R \), where \( R \) is the probability that the ambiguous location desired lies within the confines of the array, and is given by \( 1 - \frac{(y_2 - y_1)}{N} \) (dimension of array). The average value of this quantity is 0.5, so that the total probability of ambiguity is:

\[
P = \sum_{i=1}^{m-1} \left( \frac{(N - 1)!}{N! (N - i)!} \right) \cdot \frac{m - 2}{N} \cdot \frac{1}{2N}
\]

For small \( m \), large \( N \),

\[
P = \frac{m(m - 1)(m - 2)}{4N^3}
\]

For \( m = 5 \), \( N = 10 \), \( P = 0.496 \times 0.3 \times \frac{1}{20} = .0075 \)

Thus, even for this very dense case, the probability of an unresolvable ambiguity is negligible.

Appendix 2. The Wire Array Detector with a Current-Ratio Analog Measurement

Suppose that we equip each wire with a current ratio detector so that the two currents to ground, \( a_i \) and \( b_i \), in the \( i \)th wire are measured. One can imagine that we do this by inserting a diode and condenser for storage of the current pulse at each end of every wire. The passage of a particle through the array would, as before, give digitized data on \( x \) and \( z \), and also analog data, the currents \( a_i \) and \( b_i \) flowing to ground. We achieve four advantages in this way: we obtain \( x \), \( y \) and \( z \) from a single array; we remove the hodoscope ambiguity; we restore the intensity information previously lacking; and we
can record many simultaneous sparks in each array (but only one on any one wire). We do this at the expense of a degree of complication in the storage and readout of information, whose magnitude we must now investigate.

Let the data on the coordinates of a given spark be assembled into a single word. If we allow 12 bits each for \( x, z, a_1, \) and \( b_1 \), all the information about a given spark is contained in a single 48-bit word (including a few spare bits). Consider an event of moderate complexity in which there are five tracks, on each of which there are 50 sparks whose coordinates are to be stored. This yields a total of 250 48-bit words for a single event; this nominal value is intended merely to be representative. Let us assume there are 50 arrays of 2000 wires each. As a workable arrangement we consider the following:

1. Let there be a ferrite core on each wire; since the system will contain something like \( 10^5 \) wires, this will now require something like \( 10^5 \) cores. We may estimate a minimum cost of \( \$20,000 \) for the ferrite storage. We cannot afford to spend very much on memory elements for the storage of the analog information: if the analog storage elements were to cost a dollar apiece, that would be \( \$200,000 \) for the analog memory alone.

We require a procedure whereby a single analog memory location is used for 10 or more wires, with auxiliary information as to which wire the stored analog data came from. For this purpose we can, of course, use the ferrite cores already provided on each wire for \( x \)-coordinate information. We must also provide a multiplexer whereby an analog-to-digital converter can scan a large number of memory locations to readout the stored analog information, digitize and store it in a reasonable time. Since multiplexers and analog-to-digital converters are expensive, we must limit ourselves in the number of these used.

We thus assume we can connect, say, 10 wires in parallel, each with its own ferrite core, and that despite the shunting effects of the other nine wires and the need to extend the leads to each wire for some distance to get the ferrite cores out of a magnetic field, the signals will still be usable.

Let the analog memory locations be divided into \( a \) and \( b \) groups of 10,000 apiece, and assume a multiplexer that can scan 100 locations, and read a given analog storage in about 5 \( \mu \text{sec} \) (these are available). We require a method of serial arrangement of the 10,000 analog storage numbers to be readout 100 at a time in a sequence of 100 readouts. If it requires half a \( \mu \text{sec} \) per readout, 100 readouts would take 50 \( \mu \text{sec} \). We should be able to improve on this, since our typical event requires only 250 analog-to-digital conversions, or an average of 2-1/2 per hundred locations. Consequently, scanning each hundred locations would waste a great deal of time. If we can save a factor of 10 here, that brings the total readout time down to 5 \( \mu \text{sec} \), which is a perfectly acceptable time, comparable with that required for fast tape storage.
The serial storage between different analog locations envisaged here can be accomplished by means of delay lines (not necessarily completely passive). Thus, for example, consider a single array of a thousand wires in which the wires have been connected in groups of 10 to individual analog storage locations. Let the hundred analog locations now be connected into a long delay line so that the contents are serially stored along the line. If the interval between adjacent locations on the line is now something like 50 μsec, then at the storage location at the end of the line the signal will arrive every 50 μsec. In advance of its arrival it must be known whether the contents of a given location are null and do not require reading. A computer-controlled readout will consequently be required for the multiplexer, and the necessary information to store and process the information arriving on the delay lines will be extracted from the ferrite core storage.

An additional stage of multiplexing is desirable. Rather than putting a hundred analog signals serially onto one delay line, it would be preferable to multiplex once again and take, say, 10 such signals on each of 10 delay lines, store them and then re-code the final results. We expect on the average only 5 signals per wire array, so that such multiplexing ought to be possible.

With regard to programming, we note that the output of the system is in every way similar to that obtained part of the way along the course of a CHLOE-AIRWICK analysis, at the stage where the picture has already been digitized, corresponding sparks in different views identified and paired, and we are ready to go into the routine called LINK.
References


6. R.K. Clark, paper presented at this meeting.
DISCUSSION

COLLINS: It seems to me that the cost of $2 per event multiplied by the number of events you could get represents an extremely large sum of money, but in most cases it isn't the way it would work out. You are not interested in carrying out a $2 analysis of all these events. If for example you are doing an experiment like looking for a 'W' particle produced by strong interactions, you are interested in one event in a million and before you have had to invest any money in analysing events you will use the fast computer to select events on the basis of kinematics. All you have to do is to use your high priced computer to analyse one millionth of the events.

ROBERTS: Are you implying that it is going to be cheaper to analyse the million events than the one which you are interested in?

COLLINS: When you mention at the same time a million events and $2 an event to analyse them, it is not the way it will work. The computer will select out a relatively small number of events for which you are interested in carrying out elaborate calculations.

ROBERTS: For the type of events I have been discussing, for the complex events I don't know what to do, and I don't think anyone does. The events you are speaking of I think consist of straight lines which I would not classify as complex.

COLLINS: Let us consider a situation in which the event that I want is not extremely difficult to analyse, but represents one among very many other events that you are not interested in. You use the on-line facilities of your computers to make this distinction, and for this reason it is indeed useful to have detecting systems which can cope with the extremely large number of events.

ROBERTS: I think that it is not useful to collect more data than you can afford to analyse.

ANDERSON: I wonder if the difficulty here doesn't rest on the fact that while at some part of this conference we talked about millions of events, these were very simple scattering events, in which we were looking for certain characteristics which could be reduced to one or two parameters; an angle and a momenta, or an invariant mass, or possibly two invariant masses and an angle. But when you talk about complex events I wouldn't know what to do with a million complex events of the kind of complexity that I am thinking of if these had no common features. That is
if the events have to be described in a multi-dimensional space they would
be difficult to handle conceptually unless there were special common features
which could be transcribed on to a space of more manageable dimensions. We
should then be able to simplify the programming on this basis. So far the
complex events that we have had and that have been analysed by bubble chambers
rarely numbered more than a few hundred. This makes more understandable
the effort to extract the full information from each event.

ROBERTS: I think this is one of the difficulties with the bubble
chamber. Consider weak interactions: if we talk about decays of various
particles there is nothing inherently different about the leptonic decay
of the omega and the leptonic decay of the neutron, and the number of neutron
decays that have been observed is numbered in the hundreds of thousands.
To do an equivalent job on the decay of the omega which is equally interest-
ing would require the same number of events. We are used to thinking of
50 \( \lambda \) decays as a large sample not because there is anything in the physics
which says that the \( \lambda \) decay is any different from the neutron decay, but
just because they are expensive.

LINDENBAUM: That is what I meant in my talk the other day when
I said that we could easily use up all the computers at CERN, Brookhaven
and the whole East coast, so this gets rid of a lot of this argument should
we be on-line or off-line. In a sense what happens is that with these rapid
techniques you are computer limited, so that you can only process so many
events; while the events times the complexity is a number which you can
handle in some functional way; but you may want to record many many more
events than that, and you may, even if you don't record them on tape, do
some kind of fast logic either through trigger circuits or computers or both.
You still gain something by building your system to handle a million events
because you can then decide if you only want to analyse a number per day to
select that number out of the million events. The real problem, as I see it,
is that there has been a technological change in the way of doing things
which opens up a way of doing physics which is really going to be limited by
the computer. This is one of the reasons why I have felt it is very important
to be able to handle a lot of these events because then you can at least
have a better chance of selecting what you do. You might do these hundred
at a thousandth of a microbarn eventually instead of at a microbarn.

D. MILLER: I think it's pertinent to this discussion to remind our-
selves that the hydrogen bubble chamber is essentially a homogenous medium
in which you are usually interested in interactions within the medium where
we can't control what happens, whereas the spark chamber opens up through
its flexibility the possibility of our having the interactions more where we
want, and in particular most of the systems we have heard about this week
which involved momentum determination have involved spark chambers which are
fore-and-aft welded to the magnet rather than inside.

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sample point on a track traversing the pair of units. The well-known hodoscope ambiguities arise in the output of such a system; thus if two sparks occur, the first array will give the information that sparks are present in coordinates \( x_1 \) and \( x_2 \) and the second that they are present in coordinates \( y_1 \) and \( y_2 \). The ambiguity consists in associating a given value of \( x \) with the correct value of \( y \), the two possible choices being \( x_1 y_1 \) and \( x_2 y_2 \), or \( x_1 y_2 \) and \( x_2 y_1 \). Only data external to the double wire array can resolve this ambiguity, since we have abandoned all intensity information; therefore, a third "redundant" array at an angle (usually 45°) to the other two is introduced.

It is not generally realized how effective a redundant array is in eliminating such ambiguities (see Appendix 1). Thus, even if one has five sparks in an array consisting of 10 wires along each axis, as might be the case in one square centimetre very close to a target, a single redundant array at 45° will remove over 99% of all ambiguities even with no intensity information available. In practice, the firing of more than one core by a single spark is likely to be a source of more difficulty.

As a result of a new development initiated by Charpak, Favier and Massonet\(^4\), it may be possible to add an analog measurement of \( y \) to a single wire array. These authors showed that by measuring the ratio of the currents to ground produced by a spark, the location of the spark in one dimension can be accurately determined. Thus, going back to our first array, in which the wires are along the \( y \)-axis, if a spark occurs on a given wire and the two ends of the wire are grounded, the currents to ground will be equal only if the spark occurs in the exact centre of the wire. At any other point along the wire the two currents will divide inversely as the impedance to ground from those points. The ratio of the currents thus determines the location of the spark. Charpak et al, have shown that the accuracy of such a determination, in the case of a plane conductor, is comparable with that of the digitizing in the other two planes, namely, a half millimetre or better. Appendix 2 outlines in some detail just how a wire array system with one analog coordinate might be set up.

We must now consider the accuracy needed, and here we run into real difficulty. We need the ferrite core on each wire to provide \( x \)-coordinate information; no equivalent substitute can be imagined. However, the presence of such a core on a wire will introduce a serious perturbation in its impedance to ground. One can try to cancel such a perturbation by putting a dummy core at the other end of each wire; but the impedance of a core must necessarily vary with current amplitude, since the cores are designed to operate between two fixed states of magnetization. The idea of using current ratios to 12-bit accuracy (or even 10--) consequently begins to look impractical.
We might, however, consider some type of analog information other than the current ratio. Thus, for example, consider a time-of-flight signal. Suppose, for the sake of argument, that we substitute for each wire an electrical delay line and read the time it takes for each signal to reach the end of each line. Then the ferrite cores need not perturb the reading seriously, since they can be included in the electronic circuit. The difficulty again is to achieve the accuracy we require. The time required is more like that used in acoustic chambers, where the required 12-bit accuracy is just achieved with transit times of the order of a msec. This will be quite difficult to obtain with electrical delay lines.

Conceivably a magnetostrictive or acoustic signal produced by the spark on the wire itself might be used for this purpose. In this case the 10 wires connected together could all pass through a common pick-up, and the ferrite core would no longer have the deleterious non-linear effect pictured above. The ferrite core would, as before, switch the output of the pick-up into a suitable storage.

3. CONCLUSIONS

In summary, the non-visual system seems at present to offer no decisive advantages for events sufficiently complex to require the intervention of human scanners. The need to provide a visual display for scanning complicates the system; and the programming of track reconstruction, geometry, and kinematics analysis will be comparable if not identical with that for visual systems. Thus we may conclude:

i) It appears that it may be technically feasible to construct systems to record in digital form events of high complexity, at high speeds. If realized, such systems will be complicated and presumably expensive.

ii) To process complex events, human scanning is at present far less expensive than computer recognition, whose feasibility is not established. Consequently, a display system suitable for scanning should be provided, unless a large fraction of all frames taken is to be processed.

iii) Such a system has no clear advantage over one using conventional camera-film recording, human scanning, and automatic measurement and processing of selected events (e.g., CHLOR-AIRWICK).

The author acknowledges stimulating and useful discussions with Arthur S. Nelmed, of Argonne National Laboratory.
Appendix 1. The Hodoscope Ambiguity Problem

Condition for an unresolved ambiguity: Let there be \( m \) sparks on \( N \) wires, and a redundant Z-array at 45°. Then the condition that an unresolved ambiguity occurs is that a configuration exists like Fig. 1.

\[ \begin{align*}
  z_3 & \quad z_2 \\
  x_1 & \quad x_2
\end{align*} \]

- a. There must be two sparks on \( x_1 \)
- b. There must be two sparks on \( y_1 \)
- c. \((x_1 - x_2)\) must equal \((y_1 - y_2)\)

Then the ambiguity is \( x_1 y_1 z_2 \) or \( x_2 y_2 z_2' \).

Figure 1

Given an array of \( N \) wires, with \( m \) sparks at random in the array; what is the chance that there be two or more sparks on one or more wires? The problem is identical with that of putting \( m \) balls into \( N \) boxes. For each ball in turn the probability is the ratio of the number of occupied boxes to the total number, corrected for the probability that some box already has two balls in it. The successive terms are:

First ball \( P_1 = 0 \)

Second ball \( P_2 = \frac{1}{N} \)

Third ball \( P_3 = (1 - \frac{1}{N}) \frac{2}{N} \)

Fourth ball \( P_4 = (1 - \frac{1}{N})(1 - \frac{2}{N}) \frac{3}{N} \), etc.

So the total probability for \( m \) balls is:

\[
  P_m = 0 + \sum_{i=1}^{m-1} \frac{(N-1)!}{N^i (N-i)!} i
\]

(1)
For large \( N \), small \( m \), a good approximation is:

\[
P = \frac{m(m - 1)}{2N}
\]  

(1a)

The probability that there be two sparks on one \( x \) wire is given by (1).

The probability that there be a second spark on wire \( y_1 \) is just \( \frac{m - 2}{N} \),
(\text{two sparks already being assigned}).

The probability that the second spark on \( y \), be spaced at the right
distance is \( R \), where \( R \) is the probability that the ambiguous location
desired lies within the confines of the array, and is given by \( 1 - (y_2 - y_1)/\)
(dimension of array). The average value of this quantity is 0.5, so that
the total probability of ambiguity is:

\[
P = \left( \sum_{i=1}^{m-1} \frac{(N - 1)!}{N^i (N - i)!} \right) \cdot \frac{m - 2}{N} \cdot \frac{1}{2N}
\]

For small \( m \), large \( N \),

\[P = \frac{m(m - 1)(m - 2)}{4N^3}\]

For \( m = 5 \), \( N = 10 \), 

\[P = 0.496 \times 0.3 \times \frac{1}{20}\]

\[= .0075\]

Thus, even for this very dense case, the probability of an unsolvable ambiguity is negligible.

Appendix 2. The Wire Array Detector with a Current-Ratio Analog Measurement

Suppose that we equip each wire with a current ratio detector so
that the two currents to ground, \( a_i \) and \( b_i \), in the \( i \)th wire are measured. One
can imagine that we do this by inserting a diode and condenser for storage of
the current pulse at each end of every wire. The passage of a particle through
the array would, as before, give digitized data on \( x \) and \( z \), and also analog
data, the currents \( a_i \) and \( b_i \) flowing to ground. We achieve four advantages in
this way: we obtain \( x \), \( y \) and \( z \) from a single array; we remove the hodoscope
ambiguity; we restore the intensity information previously lacking; and we
can record many simultaneous sparks in each array (but only one on any one wire). We do this at the expense of a degree of complication in the storage and readout of information, whose magnitude we must now investigate.

Let the data on the coordinates of a given spark be assembled into a single word. If we allow 12 bits each for $x, z, a_1$, and $b_1$, all the information about a given spark is contained in a single 48-bit word (including a few spare bits). Consider an event of moderate complexity in which there are five tracks, on each of which there are 50 sparks whose coordinates are to be stored. This yields a total of 250 48-bit words for a single event; this nominal value is intended merely to be representative. Let us assume there are 50 arrays of 2000 wires each. As a workable arrangement we consider the following:

1. Let there be a ferrite core on each wire; since the system will contain something like $10^5$ wires, this will now require something like $10^5$ cores. We may estimate a minimum cost of $20,000 for the ferrite storage. We cannot afford to spend very much on memory elements for the storage of the analog information: if the analog storage elements were to cost a dollar apiece, that would be $200,000 for the analog memory alone.

We require a procedure whereby a single analog memory location is used for 10 or more wires, with auxiliary information as to which wire the stored analog data came from. For this purpose we can, of course, use the ferrite cores already provided on each wire for x-coordinate information. We must also provide a multiplexer whereby an analog-to-digital converter can scan a large number of memory locations to readout the stored analog information, digitize and store it in a reasonable time. Since multiplexers and analog-to-digital converters are expensive, we must limit ourselves in the number of these used.

We thus assume we can connect, say, 10 wires in parallel, each with its own ferrite core, and that despite the shunting effects of the other nine wires and the need to extend the leads to each wire for some distance to get the ferrite cores out of a magnetic field, the signals will still be usable.

Let the analog memory locations be divided into a and b groups of 10,000 apiece, and assume a multiplexer that can scan 100 locations, and read a given analog storage in about 5 μsec (these are available). We require a method of serial arrangement of the 10,000 analog storage numbers to be readout 100 at a time in a sequence of 100 readouts. If it requires half a msec per readout, 100 readouts would take 50 msec. We should be able to improve on this, since our typical event requires only 250 analog-to-digital conversions, or an average of 2-1/2 per hundred locations. Consequently, scanning each hundred locations would waste a great deal of time. If we can save a factor of 10 here, that brings the total readout time down to 5 msec, which is a perfectly acceptable time, comparable with that required for fast tape storage.
The serial storage between different analog locations envisaged here can be accomplished by means of delay lines (not necessarily completely passive). Thus, for example, consider a single array of a thousand wires in which the wires have been connected in groups of 10 to individual analog storage locations. Let the hundred analog locations now be connected into a long delay line so that the contents are serially stored along the line. If the interval between adjacent locations on the line is now something like 50 µsec, then at the storage location at the end of the line the signal will arrive every 50 µsec. In advance of its arrival it must be known whether the contents of a given location are null and do not require reading. A computer-controlled readout will consequently be required for the multiplexer, and the necessary information to store and process the information arriving on the delay lines will be extracted from the ferrite core storage.

An additional stage of multiplexing is desirable. Rather than putting a hundred analog signals serially onto one delay line, it would be preferable to multiplex once again and take, say, 10 such signals on each of 10 delay lines, store them and then re-code the final results. We expect on the average only 5 signals per wire array, so that such multiplexing ought to be possible.

With regard to programming, we note that the output of the system is in every way similar to that obtained part of the way along the course of a CHLOE-AIRWICK analysis5), at the stage where the picture has already been digitized, corresponding sparks in different views identified and paired, and we are ready to go into the routine called LINK5).
References


6. R.K. Clark, paper presented at this meeting.
DISCUSSION

COLLINS: It seems to me that the cost of $2 per event multiplied by the number of events you could get represents an extremely large sum of money, but in most cases it isn't the way it would work out. You are not interested in carrying out a $2 analysis of all these events. If for example you are doing an experiment like looking for a 'W' particle produced by strong interactions, you are interested in one event in a million and before you have had to invest any money in analysing events you will use the fast computer to select events on the basis of kinematics. All you have to do is to use your high priced computer to analyse one millionth of the events.

ROBERTS: Are you implying that it is going to be cheaper to analyse the million events than the one which you are interested in?

COLLINS: When you mention at the same time a million events and $2 an event to analyse them, it is not the way it will work. The computer will select out a relatively small number of events for which you are interested in carrying out elaborate calculations.

ROBERTS: For the type of events I have been discussing, for the complex events I don't know what to do, and I don't think anyone does. The events you are speaking of I think consist of straight lines which I would not classify as complex.

COLLINS: Let us consider a situation in which the event that I want is not extremely difficult to analyse, but represents one among very many other events that you are not interested in. You use the on-line facilities of your computers to make this distinction, and for this reason it is indeed useful to have detecting systems which can cope with the extremely large number of events.

ROBERTS: I think that it is not useful to collect more data than you can afford to analyse.

ANDERSON: I wonder if the difficulty here doesn't rest on the fact that while at some part of this conference we talked about millions of events, these were very simple scattering events, in which we were looking for certain characteristics which could be reduced to one or two parameters; an angle and a momenta, or an invariant mass, or possibly two invariant masses and an angle. But when you talk about complex events I wouldn't know what to do with a million complex events of the kind of complexity that I am thinking of if these had no common features. That is
if the events have to be described in a multi-dimensional space they would
be difficult to handle conceptually unless there were special common features
which could be transcribed on to a space of more manageable dimensions. We
should then be able to simplify the programming on this basis. So far the
complex events that we have had and that have been analysed by bubble chambers
rarely numbered more than a few hundred. This makes more understandable
the effort to extract the full information from each event.

ROBERTS: I think this is one of the difficulties with the bubble
chamber. Consider weak interactions: if we talk about decays of various
particles there is nothing inherently different about the leptonic decay
of the omega and the leptonic decay of the neutron, and the number of neutron
decays that have been observed is numbered in the hundreds of thousands.
To do an equivalent job on the decay of the omega which is equally interest-
ing would require the same number of events. We are used to thinking of
50 $\lambda$ decays as a large sample not because there is anything in the physics
which says that the $\lambda$ decay is any different from the neutron decay, but
just because they are expensive.

LINDENBAUM: That is what I meant in my talk the other day when
I said that we could easily use up all the computers at CERN, Brookhaven
and the whole East coast, so this gets rid of a lot of this argument should
we be on-line or off-line. In a sense what happens is that with these rapid
techniques you are computer limited, so that you can only process so many
events; while the events times the complexity is a number which you can
handle in some functional way; but you may want to record many many more
events than that, and you may, even if you don't record them on tape, do
some kind of fast logic either through trigger circuits or computers or both.
You still gain something by building your system to handle a million events
because you can then decide if you only want to analyse a number per day to
select that number out of the million events. The real problem, as I see it,
is that there has been a technological change in the way of doing things
which opens up a way of doing physics which is really going to be limited by
the computer. This is one of the reasons why I have felt it is very important
to be able to handle a lot of these events because then you can at least
have a better chance of selecting what you do. You might do these hundred
at a thousandth of a microbarn eventually instead of at a microbarn.

D. MILLER: I think its pertinent to this discussion to remind our-
selves that the hydrogen bubble chamber is essentially a homogeneous medium
in which you are usually interested in interactions within the medium where
we can't control what happens, whereas the spark chamber opens up through
its flexibility the possibility of our having the interactions more where we
want, and in particular most of the systems we have heard about this week
which involved momentum determination have involved spark chambers which are
fore-and-aft welded to the magnet rather than inside.
GENERAL DISCUSSION ON ON-LINE COMPUTER USE

MACLEOD: Before we start the general discussion I would like to make a few remarks which will do nothing more than confirm that we are in some disarray. The first thing I have noticed is that there has been very little mention of the programming involved in this type of work. In talking to people during the last two days it has been apparent that considerable effort has gone into this, and from what I have seen at CERN shortage of experienced physicist-programmers is one of our limitations. I would welcome comments during the discussion on this matter.

As far as on-line computers are concerned, there are those who are in favour and those who are against, and, by and large, these appear to correspond to those who have on-line computers and those who do not! There is nobody who has been near an on-line computer who has said he did not like it. There are also experimenters who do not have one, but have seen, by being constrained to work off-line, the advantages of being on-line. On the other hand there are others who do not have one and who have said that it is not really necessary. There are certainly experiments where it does not make sense to put in a tremendous amount of money and effort in a very complicated data analysis system. In particular, in experiments where you are looking for rare events it is questionable whether this type of technique is applicable and, at present, looking for complex events as mentioned by Roberts, also seems beyond our grasp. Nevertheless, there is a large class of experiments where the on-line computer does make a great deal of sense.

I would like to remind you of some of the points on which we have heard apparently diametrically opposed views expressed. If I can start with Lindenbaum, he essentially is in favour of everything. He is not reticent about it, and he said he thinks his kind of experiment could use a 6600 full-time plus any other computers one can find on the East Coast. Many other speakers have had reservations about this kind of philosophy. Nobody seems to disagree that computers can usefully fulfill the data acquisition function. There have been several people who have not actually described an on-line computer, but have talked of special purpose devices which look so like an on-line computer that the distinction is rather fine.

As far as the checking and control function is concerned, Bardon mentioned how useful this was in his setting-up process. Weinstein, who was in fact speaking of an experiment which was off-line but which had a three hour turn around time, said that for checking and control he would have liked this three hours to have been a few minutes, which was essentially wishing that he had the machine on-line. These speakers emphasized the advantage of having a computer giving you back information to check the functioning of one's apparatus either during the set-up time or during the actual experimental run. Only Fessel said anything about a computer really controlling
experimental parameters. I think he was the only one who is thinking in terms of using the computer to do some automatic control or monitoring of the parameters in his experiment, and this again is something which I think it would be useful to discuss. I personally think this is a very valuable direction one can follow, but obviously I am not in tune with the rest of the conference in so far as there has only been one speaker who has brought this point up.

As far as the sample computations are concerned, Lindenbaum is being somewhat modest in this respect. In the experiment he described he used Merlin full-time to process all his data on-line, but Merlin is, in the terms of our discussions, essentially a small computer; in his next series of experiments he spoke, in fact, of only analysing something like 10% of his data on line, so he really was making rather modest requirements for his on-line computer. Fessel regretted very much that it was only six months after he had completed his experiment that he discovered there was a bump in his gamma ray spectra at about 2.9 GeV. Had he had this information during his run, he would have looked at it, which is a way of saying that he felt the lack of having the machine on-line for doing sample computations. Bardon mentioned he ran across to his 1620 and put a deck of cards in to get this kind of information, to compute a sample of his events and get the answers back quickly and this helped very much during his setting-up. On the other hand, Weinstein, in contradiction of the usual adage, seemed to believe that a lot of knowledge is a dangerous thing. And he did not think it desirable to have sample computations done during his experiment.

Under the function of display, everybody whether running on-line or off-line has, I think, made some mention of the usefulness of having some kind of visual display of their data to check on the operation of their equipment, or to see how the data is coming in, and see how it looks, so that on the question of data acquisition and data display there seems to be very little disagreement.

The question was raised as to the suitability of special purpose or general purpose equipment, and one speaker also mentioned an analog device to get his data rather than using a digital computer. I think the main question that one would like this discussion to clarify, is to what extent an on-line computer responds to some particular need in high-energy experimentation at the moment. One can quibble about the definition of an on-line computer; personally I think it is more or less clear that in this context one means a counter or spark chamber set-up running in an accelerator beam, with wires connecting it to a computer which does some processing of the data in parallel with the data recording. I think this is a definition of an on-line computer that nobody will disagree with. Now I invite contributions to a general discussion on the use of on-line computers.

D. MILLER: Perhaps an example would start us off. Let us imagine that we talk about one of the missing-mass systems, and through the use of kinematic information coming back quickly, the experimental group can easily
decide to focus their attention on a particular portion of the kinematic situation. Let us say that they have available high-resolution equipment capable of detecting 'n' charged pions behind a magnetic field, and let us say they have a small target and have behind this spark chamber elements capable of observing the 'n' pions, and a scintillation counter which is going to participate in the triggering system. Now I can conceive the situation which by setting the discrimination level on this scintillation counter it would be possible for them to admit to their spark chambers - capable of observing 'n' pions - 1-2-3-4 pions. If they now lower their triggering requirement severely, they are going to be overwhelmed with background, and if they raise their triggering requirement severely they are going to be perhaps only making quantities of observations about a process that is already well defined and would contribute very little to the existing knowledge. Then we have a situation where despite their best calculations they have the need to decide just how wide to open the gates. How good use can they make of their beam time? How much will they be able to sort out afterwards, and therefore how large a class of events can they admit?

WEINSTEIN: I would like to comment on when I think on-line computing is useful. An experiment in which the class of background is understood is condition number one. Let me give you an example of what happens if the class of background is not understood, by considering a much more trivial problem. The class of modes of operation of our tape recorder was not understood prior to using it. We therefore designed an extremely general tape recorder which turned out in actual operation to be vastly over-designed. Now I have a feeling that there is a direct analogy to programming. If you programme prior to the knowledge of your backgrounds, you tend to vastly over-programme and you tend to waste time programming and occasionally you tend to overlook the dominant background, which also happened in one of our experiments. Now for the second condition: if the backgrounds are known, I think that if you have had to sit around so long waiting for beam time that you could have been writing the programme - then you should have been writing the programme. Finally, I think that if the computation time is much larger than the inter-event time, one should not be computing on-line, unless a very small fraction of the events will satisfy your need for on-line decision. For example, if you can collect 1000 events in a day and it takes 5 days of computer time to analyse those 1000 events, and you really need the full thousand to know what the next step is, I think it is clearly improper to do this on-line. It is rather proper to take the data blind, analyse off-line, then come back on-line with a bit more intelligence. I, therefore, see at least three criteria as prerequisites for on-line computation, namely: a knowledge of the background, a time before the experiment in which the programme can properly be done, and the requirement that the computation time does not exceed the inter-event time.
R.H. MILLER: Weinstein has touched on an interesting point which I would like to mention in regard to the programming. Although I do not claim a wide experience in programming I have seen that programming problems are usually straightforward if the problems are well defined. It is only in the case where the problem is rather ambiguously defined that one gets into a severe programming problem; of course as you strive for more and more generality you get a vaguer definition, consequently the programming gets more and more difficult. But I have the very strong impression that the main problems that exist in writing these kinematics programmes, and track reduction programmes, are problems which the physicists themselves must reduce to a rather clear-cut definition before they can be handed to a programmer. Once reduced to that status I see no very large problem in handling the detailed preparation.

MACLEOD: Commenting on Weinstein's remarks, I do not quite understand what you mean by over-programming and certainty of what your background is before you start. If you look at it the other way round when you start to do an experiment to look for a particular kind of event, is it not correct to think that you can define the characteristics of the event you are looking for, such that you can select out of the data you record events which fulfil these conditions? i.e., keeping all the things which look useful and then making more detailed analysis of those which fulfil these conditions, afterwards to select out the real events.

WEINSTEIN: If we, in our case, had kept the events that looked good and thrown off the events that looked bad we would have had no experiment. In the events that looked good were a class which had to be statistically subtracted, and the events that had to be subtracted could only be identified properly by looking at those which one would normally throw out. Now I grant that I cannot reason on a general plane instantaneously, but I do not see how before the fact one can write a programme for such a situation. For example, we are tracking charged particles in a background of neutrals. Now the neutrals sometimes cause sparks which occasionally overlap and look exactly like a track. How frequently this happens, and how important a background it is could only be determined at this machine, which had never been run before, by taking a sample of the data and going through it. If we threw away bad events which gave us the data on the neutrals, we could not have subtracted this background.

MACLEOD: If something masquerades as the type of event you are looking for, isn't it a valid part of the setting up procedure to pick up that kind of event and look at it and so gain more knowledge that you should accept or reject as you go on? I do not see really how this involves you in doing what you call over-programming before you get to the real experiment. It seems to me that this is part of the feedback of information as you are setting the experiment up and understanding more and more what is going on.
WEINSTEIN: What you are calling set-up I am calling an experiment. I think this is our only disagreement.

ROBERTS: It is perhaps worth while to recall at this point that the most successful uses of on-line computers like Lindenbaum's have been those in which there was a large amount of preparatory time in which everything about the experiment that might go wrong was discovered and put right, and it is only then that you really are prepared to take the maximum advantage of on-line computers.

MACLEOD: Surely one of the things you can do with the on-line computer is cut down this study time, and make much better use of the accelerator time you get. I quite agree that with a data handling system as complex as those we have been speaking of, it is imperative to do a very careful preparation which, as Lindenbaum has stressed in his own particular case, was nearly 2 years. In doing this you learn much better how to do the experiment, but I think the computer also plays an important role in this preparation and study.

BARDON: A clear example of the opposite situation is a case where we use an on-line computer to give us essentially immediate information on studying how the sonic spark chamber system would behave in active use at the cyclotron, and also making a study of what the background conditions were, and what we could do about them with the beam on in a few hours rather than much more laborious studies without an on-line computer.

COLLINS: Unless I missed it you did not include a use of an on-line computer which is just the topic that Roberts and I were discussing. That is the prompt elimination of a large mass of useless data, and as an example, suppose you wanted to determine the polarization of a proton coming out of an interaction, and you wanted to scatter this on some scatterer, a very small fraction of these protons are scattered. You are interested only in the ones which are scattered, and you would like not to record more information than needed to make this selection. For this an on-line computer is, if you are accumulating data very rapidly, almost a necessity. One can hardly afford tapes to store all these events.

MACLEOD: Is not this perhaps a semantic difficulty? In my talk in Session 0 I think I defined the sample computations to include this sort of thing; it is on the basis of the result of these sample computations that one can use the computer as a variable logic element. Maybe I should have included that under data acquisition function. This is a perfectly valid example of a case where I think it is essential, as you say, to use the computer to reject events simply because you cannot in fact store them. If you were to store the raw data in this kind of experiment with a very high data taking rate, you would never be able to look at it all and compute it off-line because you would have got so much.
LIPMAN: I feel that this is a very strong case in favour of the on-line computer, but frequently also one would be forced to do off-line computing until one understands all the problems. In our coming experiment at NIKHS (the n-p charge exchange) you may get 1000 events in a day, and you may have a week or two's detective hunt through the data, putting it through a whole lot of different systematic tests before you get all the bugs out of the experiment. I do not think one can anticipate all the problems ahead of time as would be demanded by on-line computing, so quite frequently you will find it preferable to use off-line computing, but also a certain amount of analog display. The on-line computer can check that the data makes to first order some sense, but off-line computing is demanded to put the data to all possible tests.

MACLEOD: You are essentially making a plea that during setting-up time one should separate the data acquisition function from the sample computation?

LIPMAN: I think that this may frequently be the case, especially for rather low counting rate experiments where one does not have to keep up with the data in the way of having on-line computing. In other words you get your 1000 events, and you spend a first day testing if all spark chambers fired, the second day you check which probes failed, and the third day you check the uniformity of response of the chambers and by the seventh day you are checking whether the momentum spectra makes sense or not. You will frequently find that you just cannot solve it all in one quick calculation.

MACLEOD: I do not think anybody was suggesting you could, but for each of the items mentioned the computer could be very useful in just looking at one problem at a time and getting this information back quickly during your run.

LINDENBAUM: The more I listen to these discussions I wish I had started out what I wanted to say by a long definition of what I meant by on-line computing. Macleod has filled in a good deal and so have other people. I think nobody really is against when you are running an experiment to find out as much as you can about how it is working, and how you can improve it and what the results are. To argue whether you are for or against on-line computing you have to ask yourself whether this will promote this end. Now if you do not know how to programme you obviously cannot do it. If you will not put the time in the programming in advance or do not have a proper computer, you cannot either. If you are not organized enough in this particular field, you certainly do not benefit from on-line. But the principle of using a computer as much as you need, and in most cases this means on-line at least for part of the project, I think is correct.
MAGLIC: We can say that any form of data taking even on magnetic tape is identical to relaxing the trigger requirements. The more parameters of an event you record, the more you relax the trigger requirement. The triggering process is also a computer with a binary decision: yes or no. If we want to get 10 times the number of events per burst then we must relax our trigger requirements. Asymptotically, this means that the faster computers we have, the more we shall be relaxing trigger requirements. Eventually we will have no trigger requirements. This way, we would have deceived the main purpose of spark chambers: that you preset the logics for the type of event desired. We have bubble chambers which actually do that; a bubble chamber has no trigger requirements and has all information in it. I therefore do not expect the computing requirements for a number of events to go to infinity.

I regard on-line computing as necessary only when the result is essential for the next step.

A year ago when we started our experiments on film-less spark chambers we made a distinction between the irrevocable experiment and the controllable experiment, and this is exactly the definition of the on-line use, as in the case of Fessol's experiment where only 2 months later they realized what they should have done, but it was too late.

I would welcome comments on the amount of necessary on-line display. Is it sufficient to display numbers for every second event (sampling), or is it better every 5 seconds to have a histograms of 50 events that you wish to check?

LILLETHUN: I would like to point out in this connection that there are at least 4 different types of experiments that we are talking about. One is fairly simple and well defined experiment, then there is a complex experiment, and then both of these can be either short term or long term experiments. The on-line computer is very important in the long term job. In that case one should start with short test runs, maybe without the on-line computer, and take time to digest the results in order to understand some of the problems before writing the programme for on-line computing. In many of the short term experiments it may not be worth while to have the on-line computer because the experiment may be done before all details have been understood.

I would also like to comment on the checking of the experimental data by an on-line computer. Here one may be split into 2 groups, either one wants to check the data thoroughly before one stores it or one may want to store as many sets of data as possible and let the bigger and faster computer handle them afterwards. For our experiment, the p+p scattering, it will be of great importance to register as many events as possible. If we take 10-20 events per burst on the PS we may not be able to check whether the events
were caused by beam particles or scattered particles. We will only make very simple checks in order to weed out obviously bad events but the data recorded after these tests may still include 10 times as many unwanted as wanted events. The bigger and faster computer off-line will select the proper events. In this case the on-line computer is to a large extent used as a buffer.

LUNDQVIST: It seems to me that it is very difficult to generalize these things. If you, for example, want to utilize the high-energy accelerators most efficiently, you certainly make a beam of highest intensity and you make, say, the liquid hydrogen target as long as possible, of the order of one metre or two. Then you have a spark chamber which looks at the very large volume of liquid hydrogen where you certainly have more than one event, and if you then can handle the techniques of looking at more than one event you like to put it on-line, but otherwise you certainly have to wait and look at the data afterwards. Of course it is also a matter of accuracy in the data handling. If you have spark chambers of the order of one metre or two, then it is very difficult to visualise the techniques for on-line measuring to the inherent accuracy in spark chamber of these large systems. For example, designing experiments at high-energies on the FS, it looks to me often very difficult to find really technical justifiable ways of doing it on-line unless the cross-sections are very large.

ANDERSON: A similar type of discussion had to do with the development of the pulse height analyser. This in a sense is a kind of special purpose computer, and over a certain period the pulse height analysers in certain types of experiments became very popular. Then the requirement grew, and the question arose whether you should have not 100 channels or 200 channels, but maybe a 1000 channels and multi-parameter and have built in subtraction and comparison techniques. At a certain point it became obvious that it was cheaper and better to go to a general purpose computer than to build a special purpose type of multi-channel analyser, and I think that the people who manufacture these things and have gone to a very complicated array, have been rather unsuccessful in selling them. The tendency has been that those who have developed a need for a somewhat more complicated type of analysis of the experiment, have turned to the general purpose computer and added an appropriate interface.

R.H. MILLER: I would like to comment on the statement made a few moments ago on the general idea that one should have these experiments completely set-up, and that you must be ready to go the moment you connect up to the computer. As a counter example of this I would mention that most of the development work that we have been doing on testing spark chamber planes, has in fact made use of an on-line computer. And we would use the computer for perhaps a few minutes a day during which time we had the spark chamber set-up and running. In fact this turned out to be an extremely useful way to
determine what the chamber was doing, and we could really make much more exhaustive tests than we would ever have attempted to do without this. If the facilities of getting into the computer exist, and also the facility with the accelerators exists of getting a little bit of beam one day or so, you can often make preliminary checks without having the full grown programmes available, without having to have all the hardware available. Usually the programmes involved for this are quite simple provided you can decide what it is you want to ask of the computer.

ANDREWS: There are very few questions you can ask about whether the physics is right, coming from the experiment, that you can make unless you have a density distribution in one or two dimensions. The sort of display you look at on a klick sorter is a density distribution, and therefore it takes quite a lot of events to have a useful result. There presumably will be lots of cases where you must have this sort of physics information before you can make some decision, and then it seems to me that the question of whether you do the calculation on-line or carry the tape to the computer to do it, is a question about time and storage capacity, and whether it may be better to do the calculations quickly and thereby reduce the number of parameters over which you will sum or average in some way to get your display. A lot of people have talked about experiments where they have displays of spark chamber sparks while they are actually doing an experiment. In the experiments we are planning to do, this would be no use. The momentum one gets for two particles is a three-dimensional vector in each case, and you can only tell whether you are getting sensible information from the energy. If one puts it on to tape, or something it may take quite a long time to do this, but if one can send it on-line to a computer then in time, perhaps an hour or so, one can immediately sum over the energy and obtain a display to see whether this is sensible or not. Either one is looking at the apparatus or one is looking to see whether the experiment is going right as a whole, and there are all sorts of odd little considerations like this which make every experiment different.

MACLEOD: Perhaps Lindenbaum could comment on this because you stressed rather in your presentation that you had, I think, 12 different distributions of physical data which you could pick up more or less by pressing a button during your run.

LINDENBAUM: Well, actually we had a very simple display, it was one Tektronix scope, but it had a sort of a coding button on it. The computer constructed the elasticity of our events. In the momentum analyser case it plotted the momentum over the incident momentum, and we saw the peak in the background. In the kinematic case it plotted the kinematic angular relation for those events which were co-planar and those which were not. Now that is all we did with data displays and that showed us that things were working right. Most of our checking was really done with numbers. For example, our average run took a half-hour and we printed out a profile distribution of all of the counters so that we could see at a glance with very
excellent statistics by just looking at the numbers, and we got graphs plotted out — computer type graphs where you would see if there was a dip. Then in addition to that we kept various checks, even using the 7090 we checked these least square fits to make sure the data was smooth, for example. They were not peaks like Weinstein is talking about, but we never call anything a peak under 5 standard deviations in our laboratory so we do not have these problems. If we call it a peak at 5 we say it would be nice to run to 8 or 10 or 12 so we can make sure. If you run 10 to 50 events and then you say: look I got one point with a 5 standard deviation peak — it is not very convincing at that time. So basically the quantities you want can be both displayed and also computed to any extent that you wish. You do not need a very elaborate display. I think that the computing part is, for us, the most convincing check rather than the data displays.

MACLEOD: Miller, do you have any comment on this? You particularly mentioned using your display on your PDP1 in a rather different way, in fact as an instrumental check.

D. MILLER: I think it has some connection with what Andrews was talking about because one thing which has occurred to us is the usefulness of putting a storage scope on these tracks in the chamber in order to see how the angular distribution is building up in the chamber.

MACLEOD: Could I come back to this point which I first mentioned of programming? I think it should be rather useful, at least for my own edification, if rather a bore to you, if I asked you more or less laboratory by laboratory how much work you have in fact put into programmes, because we still go on talking about this, but nobody says how much work they have put in. Could I perhaps ask the individual speakers who have described work using computers on-line in an experiment just how much programming work they have buried into their system before they finally came off the accelerator?

LINDENBAUM: I think I stated that the actual writing of the programme was three man-months. I perhaps ought to modify that a bit. There are two parts to writing a programme — one is deciding the logical operations and the other is putting it into machine language. Since we designed our experiment and decided how we were going to run the experiment a long time before the programme was written, the actual coding took only a few months. Then we found that the programme could be changed at will very easily. There was a period of changes at the beginning of a few weeks where major changes were made, and there were things added to the programme as we went along. Now if you have written a thing in machine language it is not as though you were starting from scratch or have picked up somebody else's programmes and put them together. For the two-prong events we can re-write programmes, or I should say perhaps Bill Love can re-write programmes, rather readily. We have another younger man in the group who has written all the sonic spark chamber programmes with very little experience. He rattles these programmes off after a few months in our salt mine, and we do not think for what we
have done with two-prong events it is much of a problem. We look at this as a step by step progression. You have to build up your confidence level, and things always get easier when you do this. Our next step is between two- and four-prong events. We are not interested in a sixteen-prong event, and even if we felt we could find an omega minus we would not look for it. If we proceed this way I do not think the amount of work is that tremendous because we are using the old counter technique which is to look for a very selective event. I think the bubble chamber programme is quite different, they look for everything. If you set-up one of these on-line experiments, you look for a specific event. Suppose you just look for your \( \pi^- + p \rightarrow \Lambda + \Theta \) and leave out the sigma and the cascades and all the multi-track events, you would be amazed how much simpler the programme becomes. So I do not think that the direction we are engaged in right now presents any insurmountable programme problems. I think that learning from the bubble chamber is the wrong way to learn how bad things are for this kind of approach. We will eventually come to the same trouble or maybe worse because we can do more things. Probably they will look at us and say we are so complicated and they are so simple, but that is in the future, not now.

FESSEL: I want to agree with Lindenbaum on two points. One is that the programmes are not hard to write if you know what you want them to do. We are in a situation where we know what we want to do because we have at least already used the apparatus. We know what the problems are and the sort of things we have to look for, and in that sense I do not think that writing the programme is a very major job. Probably one to two man-months have already been invested, and probably two to four more will be before we are done. The second number is a guess. This does not include the time that was spent developing large 7090 programmes to process the data for the final results. That took several man-months and is not related to the on-line programme.

MACLISE: We have not completed our experiment, but a lot of programming effort has been involved so far. The development of the system to calculate spark coordinates from sonic signals took one man-year. The on-line programme has required the full-time use of a competent programmer, who also has a knowledge of physics. Moreover, one finds that every member of the group has to be able to programme in that perhaps twice a week we want a quick answer to somebody's suggestions on either propagation of errors or new ideas etc. We find it necessary that absolutely every physicist can quickly write a programme. Hence all the physicists spend 15 to 20% of their time programming, together with two people working full-time in charge of the system.

LILLYTHUN: Maclie mentioned one man-year in order to find the spark coordinates. I would like to correct this to two man-months or so. That is all that went into finding the coordinates, the rest of this time has been spent on other programmes. It seems to me that the programming is not the
least time consuming part of an experiment. The difficulty lies in specifying the problems and these specifications may change with time as the physicist gets to know his experiment better and better. These problems would have to be understood and solved whether one uses a computer or not, and the programming for the computer is a rather straightforward job.

Following are the figures on the programming effort agreed upon by Lil lethum and Maglič after the session:

Lil lethum

Sonic spark-chamber programme for a system of six chambers aimed at measuring small angle p-p scattering:

Autocode: 2 man-months
Fortran: 2 man-months

Maglič

Developing of a simplified sonic spark-chamber programme for Mercury computer on-line (autocode) to the point of a smooth operation: 3 man-months; programme for the whole missing mass spectrometer with its testing:

On-line (autocode): 1 man-month
Off-line (Fortran, magnetic tape): 3 man-months.

MACLEOD: The thinking is part of the programming job. The coding itself, once you know what you want, you can give it to a very junior coder for example. Deciding what you have to programme is part of the job, and should be included in your estimation of the work.

WEINSTEIN: I just wanted to add our numbers to the pool. It took 1 1/2 man-years to learn to sort the data into classes of events and then another 1 man-year to learn to compare it to theory, so that our total programming time on the first experiment was three man-years.

BÄRDON: Our programming is separated into programming for calculating spark coordinates in a sonic spark chamber system which turned out to be very simple and short, and programming for tests of a very general nature, since we had no idea what would happen when we ran with the beam, so we tested it. We programmed all kinds of efficiency tests, background, checking and so on. Then there is the programming for the 7094 where we analyse the tracks, and we get out their momentum and angles. I would say that all this took about 1 physicist and 1 programmer for 1 year. In addition to that we had an
equivalent amount of work going into something else entirely, which is the
calculations for the expected theoretical spectrum in muon decay.

LINDENBAUM: I should have added that in all the estimates I gave,
I subtracted the time when a guy really learns how to do it. That does not
count now. You should talk about a guy who has done all he can to become
proficient, and how long does it take after he has reached that stage.

MACLEOD: This is just to get competence in handling a computer.
You do not include in that, thinking about how the problem is going to be
programmed?

LINDENBAUM: Correct.

MACLEOD: Do any of the groups who have not yet run an experiment,
but are getting close to it have anything to say on this matter?

VERNON: All we have is the programme which reads the tape, con-
structs line segments, projects the event in a picture you can look at and
lists the line segments with their slopes and positions which is all you
need for simple tracks. That has taken a 1 man-month, but by a very good
physicist and programmer. Now this was done in a very elementary step by
step procedure illustrating very well the importance of understanding what
you want as you go along. We did also start out two or three months ago
with a girl who was a fairly good programmer, trying to write a link programme
to generate line segments, but with no real success yet.

PÉREZ-MÉNDEZ: We have spent a few weeks writing programmes to take
our raw data and to reconstruct tracks, and to give the track coordinates.
That is all we have prepared before this experiment.

ANDERSON: Perhaps I can answer the question in a slightly different
way. It seems to me that many of the experiments we planned in high energy
physics utilized quite a large group, and so we might ask what fraction of the
total time that is put in by the physicists and perhaps some of the engineers
who work on the experiment goes into programming. At the moment, in my own
experience, it is about 10%. It is not enough. I am sure we will have to
do more than that, but it is still a very small fraction of the total amount of
thought and effort and organization that goes into an experiment.

WHITEHEAD: In the first experiment I described, which was not on-
line, the programming was done by one man for the entire experiment. This
took in time approximately four months from beginning to end, and he was also
vitaly concerned with all other aspects of the experiment. I would not like
to say what fraction of time he spent on programming. For the next experiment
the same man is concerned with the programming, we will also have the part-time
use of two people from the computer section of the Rutherford Laboratory, so
as a fraction, this would come again to be about 10% of our total strength.
JONES: With the straight microphones, as used for the n-p elastic charge exchange experiment at the Rutherford laboratory, programming problems have been trivial. It took about 1 man-week to produce the basic working programmes. These have been only slightly modified since they were produced and then mainly for domestic reasons, e.g. changing from the MERCURY to the ORION computers. We plan to output results of computations on to magnetic tape when further simple routines will pick results off the tape for histogram compilation, measure of gap efficiencies etc. The whole programming should not total more than about 1 man-month.

LINDENBAUM: I think the question Anderson raised about the percentage being important is relevant. In our case, and we are head over heels in this, 20% of the total group time is about right.

ANDREWS: We are not very worried about this because we feel that any graduate student in the University who does an experiment is probably going to spend a large proportion of his time programming in order to work out his results. If he spends another quarter of his time programming for others this is not so serious.

MACLEOD: I am worried about this point because if one is going to branch more into using computers as an integral part of one's experiment then a gradually increasing percentage of one's experimental effort is going to go into this, and I think it is rather important to have some feel for what this involves. If I could say in conclusion it seems that the amount of effort which goes into programming for this kind of experiment does not seem to be an outrageously high fraction of the total group effort, it nevertheless has to be counted in the order of 10 or 20% from what we have heard, and I think, that as we are going to use more and more computers in the analysis, whether on-line or later, this fraction will increase. As far as the use of on-line computers is concerned it seems after all that there is not all that much disagreement. Whether this is partly because of the CERN tea or not I do not know, but it seems that most people do agree that for a large class of experiments one can gain a tremendous amount through having some rather short turn around time in computed information coming back. The proportion of the data that one processes during the experimental run is something which seems to depend specifically on the experiment. The main support for on-line use seems very much to be in the direction of data acquisition and preliminary reduction; the control function, which everybody has been particularly emphatic about, together with the display provide an extremely powerful way of keeping a track on just how one's experiment is running. Thank you.
6 March, 1964

VI. MORNING SESSION

NEW METHODS AND PROJECTS UNDER DEVELOPMENT

Chairman : A. Roberts,
Argonne National Laboratory

Secretaries: F. Iselin, CERN
P. Zanella, CERN
ULTRASONIC CAVITATION INDUCED BY NUCLEAR RECOILS

B. HAHN

CERN, Geneva -- University of Fribourg

SUMMARY

Previous work $^1$ on ultrasonic cavitation induced by neutrons is reviewed. The sound pressure amplitude reached with a non-focussing Ni-sound generator in the liquid CCl$_4$F (at 20°C) was approximately 6 atm, with was sufficient to obtain continuous sensitivity for nuclear recoils due to neutron reactions for neutrons from a Pu-Be source. It was pointed out, that higher pressure amplitudes could be obtained with an arrangement in which the sound waves are focussed. The required pressure amplitudes for sensitivity for particles of different specific energy loss have since been measured for the same liquid by means of the spinner method$^2$), which allows to obtain radiation sensitivity in the negative pressure region down to minimum ionization. The corresponding sound pressure amplitudes would be for fission recoils 1.1 atm, for recoils from $\alpha$-decay 6.0 atm, for recoils from neutron reactions (Pu-Be source) 6-15 atm, for $\alpha$-particles (Bragg maximum) 14 atm, for $\gamma$-rays (minimum ionization) 60 atm.

For fission recoils, and $\alpha$-recoils it has been found that the sensitivity has a very sharp threshold, going from zero to 100% sensitivity in a few per cent of the pressure amplitude. The ultrasonic cavitation due to neutrons in CCl$_4$F in an open container of a movie picture is shown in three pictures in Fig. 1.

References


Figure caption

Fig. 1  Cavitation in CCl₄F due to Pu-Be neutrons; sound pressure head on top, neutron source at the left.

a) source far away;
b) near by;
c) close by to the liquid container.
NEUTRON INDUCED ULTRASONIC CAVITATION.

C. WEST
University of Liverpool

D.V. Lieberman, in 1958, submitted a thesis at the University of California entitled "Radiation-Induced Cavitation". He reported some experiments on the cavitation threshold of pentane and acetone, and came to the conclusion that recoil carbon, or oxygen nuclei were responsible for the reduction in cavitation threshold that he observed in the presence of a neutron source. A similar effect, in water, was reported in the Proceedings of the third I.C.A. Congress in Stuttgart, 1959, by Sette\textsuperscript{2}). Also in 1959, Lieberman published a short paper on this effect\textsuperscript{2}).

The mechanism was thought to be similar to that put forward by Seitz\textsuperscript{3}) to explain the action of the normal bubble chamber. In this case, the recoil nuclei would deposit their energy as a thermal spike, which would give rise to a small vapour bubble, or cavity. If this cavity is larger than a certain critical size, it will be further expanded by the excess of internal pressure. In ultrasonic cavitation, the pressure in the surrounding liquid may go negative during one half of the cycle, provided the pressure amplitude is high enough, and this will tend to increase the size of existing bubbles.

Sette and Vanderlingh, in 1961, published a paper\textsuperscript{4}) in which they found that the acoustic cavitation threshold in water was increased when the tank containing the water was shielded by lead screens. When the screens were erected the threshold slowly increased to a new value, the change being half completed in a time of the order of an hour. A radium-beryllium source had the effect of lowering the threshold, with roughly the same time constant. When the neutrons had to pass through a paraffin moderator, reducing the maximum neutron energy to about 1 MeV, before they entered the liquid no alteration of the threshold was observed. Their results could not be explained solely on the basis of Seitz's theory. They were using aerated water and it seems likely that this may partly explain the effects they observed.

In 1961, B. Hahn carried out some experiments using centrifugal forces to produce large negative pressures in a liquid\textsuperscript{5}). He found that when an \(\alpha\)-emitter was dissolved in the liquid, the average waiting time before the liquid fractured, or the negative pressure required to make it fracture in a given time, was reduced. A neutron or \(\gamma\) source brought near to the spinner had a similar effect. Hahn investigated the \(\alpha\) decay sensitivity of some 28 liquids. (The results were not in complete agreement with the predictions of Seitz's simplified theory.)
In collaboration with R.N. Peacock, Hahn published two more papers on the subject of neutron induced ultrasonic cavitation. Several liquids were investigated and in some cases continuous sensitivity to neutrons was achieved, notably with CCl₃F, marketed as freon 11 or aerosol 11. Cavitation bubbles were created, when the neutron source was brought up to the container, in the pressure maxima of the standing wave system. No bubbles were observed in the absence of the source. The conditions required for this continuous sensitivity were critical.

One of the great difficulties associated with this work was that the transducer used to set up the sound field was non-focussing and there was a large pressure amplitude at the radiating face. This caused spontaneous cavitation at the liquid-soundhead interface, resulting in erosion of the face, and possibly more important, these cavitation bubbles tended to decouple the head from the liquid, limiting the power that could be fed in.

At the sound pressure amplitude they could attain, no sensitivity to a γ source was expected or observed.

A small bubble in a liquid is acted upon by the resultant of internal and external pressures, and the surface tension forces which tend to collapse it. If the balance of pressures tends to expand the bubble there will be some radius, the critical radius, above which the bubble will grow and below which it will collapse, since the effective pressure due to surface tension is inversely proportional to the radius.

If we write

\[ P_e = \text{external pressure} \]
\[ P_i = \text{internal pressure} \]
\[ \sigma = \text{surface tension} \]
\[ R_c = \text{critical radius} \]

Then

\[ \frac{2\sigma}{R_c} = P_i - P_e \]

or

\[ R_c = \frac{2\sigma}{P_i - P_e} \]

This is the radius of a bubble or cavity which would be in static, though unstable, equilibrium. It is perhaps worth remarking that bubbles of air much smaller than this exist in water that has not been thoroughly degassed. It is thought that minute bubbles may be stabilised in cracks in solid particles and by a kind of membrane formed of organic impurities.

In a bubble chamber, \( P_i \) would be about the vapour pressure under the initial conditions, and \( P_e \) the pressure after expansion, although this is a grossly oversimplified view as the conditions around a nucleation centre will be different from those existing in the bulk of the liquid. In the case of ultrasonically induced cavitation, \( P_e \) may be taken negative during part of the cycle and in fact negative pressure operation of a bubble chamber has been achieved by this method and also by piston expansion\(^8\).
It is believed that the recoiling atom loses the energy it has received from a neutron at a high enough rate to form a small bubble or cavity filled with vapour. As explained above, such cavities may be expanded by the sound field if they are larger than the critical size. An example, in C Cl₂ F under 5 atmospheres negative pressure the critical radius is about 800Å. The energy loss of a carbon, chlorine or fluorine atom near the end of its track would seem to be adequate to form a cavity of this size.

Evidence that this is indeed the mechanism in a normal bubble chamber containing a dissolved α emitter (giving recoil particles which have a high \( \frac{dE}{dx} \)) has been given by G. Riepe and B. Hahn. In order that the energy deposited by the recoil atom is not lost to the surrounding liquid by thermal diffusion, the cavity must grow towards the critical size fairly rapidly, although a moderately subsonic velocity of the bubble wall would be sufficient. Seitz shows that in this case the energy lost in work done against viscous friction may be non-negligible. An exact analysis of the initial stages of bubble growth up to the critical size, seems to be very difficult, and in any case, even if such a calculation were made, the uncertainty in the values of surface tension and viscosity under the somewhat unusual conditions prevailing would make any interpretation of the results dubious.

A toroidal transducer geometry was chosen for the experiments carried out at Liverpool. It is possible to arrange the dimensions of the transducer so that the pressure amplitude is high at the centre of the toroid, and possibly at other points, but quite low at the radiating face. In this way, the main difficulty experienced by Hahn would be overcome. A suitable magnetostrictive ring of about 6 cm internal diameter was obtained, on loan, from Mullard Equipment Ltd. This was operated at its fundamental frequency of about 18 Kc/s. The pressure amplitude inside the ring is expected to follow approximately the zero-order Bessel function, with the first zero at the face.

Figure 1 is a photograph of this transducer in operation in aerated water at a relatively low power level, about 120 watts. Even at 300 to 400 watts no cavitation was observed at the walls, showing that the pressure amplitude was indeed very low at the interface.

To obtain useful results, in the experiments on neutron induced cavitation, it was found necessary to use degassed liquids in the sensitive region. A number of containers were made which would fit inside the toroid. Coupling between the transducer and the liquid under investigation was achieved by immersing them in water, which also provided cooling. When the liquid used had an acoustic impedance very different from that of water, some cavitation bubbles could be observed in the cooling water near the face. This did not seem to be serious and no erosion was detectable. The containers were required
to be a fairly close fit, within 0.5 cm or so, in the transducer to avoid serious cavitation in the bulk of the cooling water.

In the early experiments, the transducer was suspended horizontally. This was convenient, and a flow of cooling water was maintained all around the transducer by natural convection currents. Filling of the containers was simple and degassing was easily achieved by turning on the sound field with a vacuum over the liquid. Large bubbles formed at any time drifted up to the top of the liquid and were lost. Unfortunately, observation was awkward with this arrangement, and it was difficult to obtain adequate cooling of the working liquid. To overcome these problems the transducer is now suspended in a vertical plane, the working liquid being pumped continuously round the system and through a heat exchanger. Cooling water is directed through the gap between transducer and container. Fig. 2 shows a photograph of the transducer and a container and Fig. 3 a diagram of this system. Degassing is accomplished by turning on the sound field while the reservoir is connected to a vacuum pump. The containers were usually glass, although polythene and perspex were both tried.

When the amplifiers are operating at their full power of about 300 watts, the sound pressure amplitude near the centre of the toroid is about seven atmospheres. This could be increased to around twelve atmospheres if more power were available, before the transducer saturated. Some benefits might be expected from this.

In operation, the sound field is turned on, at full power, and the liquid degassed until no further cavitation is observed. At this stage a continuous hissing sound is heard, which appears to come from cavitation in the cooling water.

Of the fluids investigated so far, only C\textsubscript{2} Cl\textsubscript{2} F and C\textsubscript{2} Cl\textsubscript{4} have shown neutron sensitivity. With these liquids, discrete clicks are heard, when a neutron source is brought up. When the transducer is in the horizontal position, some of the bubbles apparently associated with these clicks grow rapidly, and make their way to the surface. No clicks are heard in the absence of the source. If the liquid has been insufficiently degassed, the source may initiate cavitation which continues noisily, even after the source has been removed. This form of cavitation takes the appearance of streamers of bubbles originating from almost stationary points in the liquid.

One can calculate, approximately, the number of neutrons which should give knock-ons forming nucleation centres in the sensitive region. One must assume a most ignominious fate for those cavities formed during the unfavourable portion of the pressure cycle, to account for the fact that only about 10-20\% of the expected number of bubbles are heard. The lack of detailed information on the rate of loss of energy of the heavy knock-ons makes the calculation of the number of cavities expected rather difficult. Some experiments are planned which it is hoped may cast some light on the matter and upon the general mechanism of radiation induced cavitation.
It is supposed that the clicks originate from single cavitation bubbles nucleated by recoil atoms. In a liquid containing only heavy atoms, the range of these knock-ons is very short, and the bubble would be formed essentially at the point where the neutron collided with a nucleus. This being so, the device offers the possibility of constructing a "continuously" sensitive hodoscope, provided the position of the bubble can be fixed. Actually, without knowing more about the fate of cavities created during the time that the pressure is around its (positive) maximum, one cannot say whether the device could be truly continuously sensitive or not. The fact that fewer bubbles than expected are observed would imply that, at least with the present apparatus, sensitivity is obtained only during a rather small proportion of the cycle.

The most obvious way of locating the bubble is to utilize the click associated with it and picked up by hydrophones, to operate timing units, just as is done in the acoustic spark chamber. This approach is being followed up at Liverpool. It turns out to be rather difficult, on two levels.

Firstly, there is a very high sound intensity radiated from the transducer almost throughout the liquid. It is extremely difficult to pick-up the sound of the click unambiguously through this continuous background although the human ear, which is a very sophisticated device, does so easily. This problem has not yet been satisfactorily solved. One possibility is the use of a localised sound field, with the hydrophones placed well away from the region of high pressure amplitude. Also, provided the hydrophones themselves are not overloaded, it should be possible to filter out the unwanted frequencies from the transducer.

Secondly, unlike the acoustic spark chamber, there is no zero marker readily available from which to start the timers. In principle, of course, this is unnecessary, but in practice its absence is likely to make life harder.

B. Maglić has suggested the use of a liquid scintillator as the working fluid. This is a very attractive idea. The scintillation flash would give the time at which the cavity is formed. One would have to know, however, whether the click occurred with a constant delay after the initial formation of the cavity. The scintillation would also provide a time marker for use in a time-of-flight measurement in the usual way.

None of the usual hydrocarbon based liquid scintillators could be used, since neutron-proton collisions would result in large flashes but no bubbles, the rate of loss of energy of a proton being too low to create a cavity of the critical size. A scintillator can be made up using hexafluorobenzene C\(_6\)F\(_6\). This would seem a good liquid to try, if one can afford it, and a small sample has been obtained on which preliminary tests are being made.
In conclusion, the effect offers the possibility of constructing a useful particle detector. Much work, however, remains to be done before a practical device can be constructed. A full understanding of the mechanism at work has still to be reached; the details of the early stages of cavity formation up to the critical size, in particular, remains obscure.

References


Figure captions

Fig. 1 A toroidal transducer in operation in aerated water.
Fig. 2 The transducer and its container.
Fig. 3 A diagram of the system.
DISCUSSION

LIPMAN: What is the best duty factor you can hope to obtain with your "son-et-lumière" system?

WEST: I get about 15% at the moment. The maximum is somewhere around 50% but I think you will be lucky to get more than 25%.

ANDREWS: If you use a liquid scintillator as the working fluid, you lose the principal advantage, insensitivity to other particles, and you have to sort out then what originated the bubble. Would it not be easier to use a number of microphones and do your timing by differences between the times of flight?

WEST: Yes, this is the original method that was intended, but actually if you could use a sono-luminescent pulse then presumably you would only get this when you get a bubble. Actually this also provides a method for investigating this kind of effect because there is quite a great deal of disagreement as to what phase this sono-luminescent pulse occurs.

MANNING: Why is the device not sensitive to charged particles? Presumably you can cause a nuclear recoil with a charged particle as well as with a neutron?

WEST: Well I do not think it is very likely.

MAGLIC: You did not have charged particles of sufficiently high-energy to penetrate in this vessel. Could sono-luminescence be used for measuring time of flight of the neutron?

WEST: I do not know.

COLLINS: Have you speculated on how high energy neutron you could detect by this means? I presume there is a point at which the neutron makes a recoil with so much energy that it makes several bubbles of maybe a track and then it would not work this way.

WEST: Well, yes, the neutron source I use has about 10 MeV. Now the lightest atoms in this liquid are carbon and their maximum recoil energy would be about 2-3 MeV. Now, carbon has its maximum rate of loss of energy somewhere around 3 MeV in a liquid like that, and actually one can calculate that you have to be somewhere fairly near this maximum, so that what one would expect was that if the knock-on had a very high energy then it would only be giving other knock-ons which eventually gave bubbles. The knock-on itself would not begin to give a bubble until it got somewhere around this maximum energy. And the track is so short that the chances of it giving more than one are pretty small.
PRENTIS: Do you know how much light you got from this sono-luminescence? What is the typical light pulse?

HAHN: The height of sono-luminescent pulse is comparable to that of a scintillation in a NaI-crystal produced by a Cs 137 gamma ray. (Photopeak). I would also like to mention that the rise time of the sono-luminescent pulse is faster than 6 nsec.
A MAGNETOSTRICTION METHOD FOR SPARK LOCALIZATION

G. GIANNELLI*)
Institute of Physics, University of Bari, Bari

In spark chambers, because of the high peak values of the current in the spark and of the small diameter of the spark, high magnetic fields are associated with the sparks.

Also, in wire spark chambers, with small diameter wires, the magnetic fields produced by the current in the wire can reach high values. In fact, high frequency currents, as the spark current is, flow on the surface of the wire. Generally the current is uniformly distributed on the surface and there is no magnetic field into the wire.

Near the spark however, the current crowds towards the spark and the magnetic field penetrates into the wire.

Experiments have shown that, in wires made of magnetostrictive materials, an elastic deformation is produced just in correspondence with the spark, that propagates along the wire as a longitudinal elastic wave and can be detected as is done in magnetostrictive delay lines.

The interval of time between the instant of the discharge and the arrival of the signal at the detector is a measure of the distance between the spark and the detector.

Spark chambers that use this phenomenon for spark localization would have one of the electrodes made of an array of parallel wires.

Experiments have been performed on a simple model, in which one of the electrodes was a single wire and the other was a plate.

The wire was connected to ground only at the two ends of the region of the spark chamber proper, while it extended beyond in order to delay the reflections of the signals from the ends of the wire, and at one side to allow place for the detector.

*) On temporary leave from C.C.R. - Euratom, Ispra, Italy.
In one experiment two parallel wires 2 mm apart have been used. The detector, that utilizes the variation of magnetic induction that mechanically stresses produce in magnetic materials, is made of a coil coaxial with the wire.

For good resolution the detector must be small. A ten-turns coil of 0.05 mm diameter copper wire, directly coiled on the magnetostrictive wire has been used. A system for polarizing the wire under the detector was also provided.

A 6 mm gap was used. The gas was argon at atmospheric pressure.

Experiments have been performed both with a single spark produced along the ionized track of an $\alpha$-particle normal to the chamber gap, and with spurious multiple sparks as are obtained raising the voltage applied to the chamber well above the threshold value.

Wires of annealed nickel, 0.35 mm diameter, and of Fe-Co 50%-50% alloy, hard, 0.2 mm diameter, have been experimented*). The sound velocity in nickel is 4.6 mm/μsec and in the Fe-Co alloy is 5.3 mm/μsec.

It has been found that signals are generated both in correspondence of the sparks and of the ground contacts (Fig. 1).

The general shape of the signals is not very different in the nickel and in the Fe-Co alloy wires. They are composed by a triangular pulse, whose width at the base is 0.4 μsec generally followed by a smaller amplitude tail of opposite polarity.

The mean values of the pulse amplitudes, in typical conditions, have been of 30 μvolt per turn of the detector coil in nickel and 80 μvolt in the Fe-Co alloy.

Between the ground contact and the spark signals a background noise has been observed. It appears that this is due to elastic deformations produced along the wire by magnetostrictive effect by the discharge current, where the magnetic field penetrates inside the wire in consequence of irregularities in the shape of the wire or in the state of its surface, that is where the cylindrical symmetry of the current distribution is lost. It is important to choose pieces of wire free from defects, like indentations, and to polish them accurately.

*) Kindly supplied by the firm Vacuumschmelze.
It has been found that no spurious signals are induced in wires parallel to the one from which the spark starts and 2 mm apart.

Experiments with spurious sparks have shown that signals from multiple sparks on the same wire can be obtained. In one case well resolved signals have been obtained from sparks that were 2 mm apart.

This method of spark localization has been first developed\(^1\) in view of the application of spark chambers in experiments in which there can be many sparks per gap. One advantage of the method is that in such applications it gives the number and the position of the sparks without ambiguities.

Reference

1. G. Giannelli, "Digitalizzazione di camere a scintilla" communication presented to the Frascati Congress, 6th May 1963, report INF 63/54 of Frascati National Laboratories"
Figure caption

Fig. 1 Oscillogram of the magnetostrictive signal produced by a spark on an annealed nickel wire of 0.35 mm diameter.

The spark was produced along the track of an $\alpha$-particle.

The waveform between zero and 5 $\mu$sec is due to electrical interference produced when the chamber is triggered.

The pulse at 6.4 $\mu$sec is the signal generated in correspondence with one of the ground contacts.

The signal at 14 $\mu$sec was generated in correspondence of the spark.
DISCUSSION

MACLEOD: Could you say something about the limits of the spatial resolution which you achieved?

GIANNELLI: I have an event where there are 3 sparks over a space 4 millimeters wide.

ISELIN: Am I right in understanding that it is the only chamber which can resolve many sparks without ambiguity?

GIANNELLI: Yes, one of the coordinates of the sparks is given by the wire, the other coordinate is given by the time of arrival of the spark on the wire.

ROBERTS: Is it premature to ask what kind of precision in location of a spark can be obtained?

GIANNELLI: I didn't make any particular experiments on this problem. I have only measured the photographs of the signals and compared the sound velocity given for this material and it agrees to better than 1%. Another point worth mentioning is that the distance was not measured between a zero point given by the spark discharges but was measured between two corresponding points on two signals.

ROBERTS: The obvious extension of this seems to be to put a detector at each end of the wire and then the sum of the two signals is constant and the difference gives you the location.

LIFMAN: What might appear to be a limitation of the accuracy is that with the normal sonic method you have times of the order of hundreds of microseconds and you have rise times of the order of one microsecond, whereas in this method the times that you are measuring are only a few microseconds and the rise time of the pulses as shown on the oscilloscope traces seem to be 200 nsec. Admittedly you do choose a fixed point on that pulse, but this rise time will be your limiting accuracy and may be larger than in the normal sonic method.

ROBERTS: In this connection since the velocity of the signal is about 5 mm per microsecond, then a tenth of a microsecond is really 0.5 mm and this is already usable.

FIZER: It seems to me that one has the problem with a multi wire chamber of needing quite a good amplifier per wire. Have you thought of some means of combining all these signals by using different lengths of delay wire and passing all of them through the same detector?
GIANNELLI: I should think it is possible to put the coils directly in series up to a certain number. Such a coil has an impedance of about 2 ohms, and for the signal one is interested in with a load of 2 ohms the amplitude is halved. Since one is at this low impedance level one can put many coils in series.

PIZER: Yes, but you don't want to lose the information which says which wire the signal was on.

GIANNELLI: You could use more coils for each wire and connect the series coils from different wires so as to get a coded output on the wire from which the signal comes.

MAEDER: I would like to remind you that there exists a possibility of increasing the signal without losing the resolution by arranging say 10 little pick-up coils one after the other and putting them in by an external circuit that acts as a delay line which has the same propagation speed as the elastic wave. By this means you can expect to have a gain in pulse amplitude of at least a factor of 10.

ROBERTS: In response to Pizer's question, I would like to say that I have considered the problem of multiplexing analog detecting of this sort in general, and that it is a solvable problem although it's not quite as simple as it sounds. One method would be simply to put many wires through one coil and use a ferrite core on each wire, using it as a conventional wire detector to tell you which of the wires went off.

LINDSAY: With reference to the timing possibilities, surely this signal given by a single edge of current is in fact a beautifully doubly differentiated signal one could use as a zero crossed to establish the position.

PEREZ-MENDEZ: Can you put all the wires in series, have one amplifier and then you would know from the delay period which wire is the one which responded?

GIANNELLI: You cannot bend the wires very sharply and so get them in series.

PEREZ-MENDEZ: Can they be stretched over the edge of a chamber for example?

GIANNELLI: I think the only way would be in a cylindrical chamber.

MAEDER: There would be a possibility of coding the signal which comes from any particular wire by just doubling the signal by letting it have a reflection close to the pick-up coil. That is, one would cut the wire just a few millimeters after the coil and then get double pulse which could have different spacings on different wires. Again you have to sacrifice something, namely, the possibility of distinguishing close pairs.
GIANNELLI: For multiple spark experiments, I used the following set-up. I inserted a mylar film and a metal strip about 2 cm wide between the wire and its supporting insulating sheet. The wire was electrically connected to the strip at one end, the strip being grounded at the opposite end. The idea was to reduce the inductance of the wire. Between the spark and the end where the wire was connected to the strip, the inductance is that of a line very close to ground, but from the spark position to the ground connection of the strip, the inductance is that of the strip, which is lower than that of an isolated wire. I don't know whether this arrangement is necessary, but it was the one used to get multiple sparks and the corresponding magnetostriction signals.

LIPMAN: I can see little point in making a hybrid system as Roberts suggested, using cores to tell which wires went off and then finding the distance down the wire with the magnetostriction. Surely this system would be complicated and it would be easier to use magnetostriction alone, have 2 planes of wires and take signals off wires in parallel. In other words, all magnetostriction or all core method. I don't really think there is much sense in combining the two.

HINE: If you take the earth connection from each wire and wrap that round another nickel wire so that all the earth connections are wrapped at intervals along another nickel wire, then the spark earth current will set-up a second wave in the other wire. The time delay there gives you the address of the wire, while the time delay down the chamber wire gives you the distance up it. You have what Lipman is after.

GIANNELLI: I would like to add one thing. In iron cobalt systems we must have only one ground contact because the signal from the currents coming from the two ground contacts have opposite polarity. Thus the signal becomes rather confused when there are two ground contacts in this system.
DETERMINATION OF THE POSITION OF SPARKS
BY MEANS OF MEASUREMENT OF CURRENTS

G. CHARPAK, J. PAVIER *) and L. MASSONNET
CERN, Geneva

(presented by G. Charpak)

When a discharge occurs in a spark chamber it is associated
with several physical effects containing the information about the
spatial position of the spark. We have investigated some of the electro-
magnetic aspects of the spark.

The use of the finite velocity time for the electric charge
to propagate at two opposite ends of the ground plate has been proved to
be feasible\(^1\). It requires, however, special structure for the ground
electrode in order to increase the path of the currents. The recent
progress in the making of printed circuit electrodes could justify new
attempts along this line.

The use of the intensity of the pick-up signal in a loop placed
on the side of the chamber has also been tried. The loop was part of a
ringing circuit of low frequency, excited by the spark. The height of
the signal was strongly depending on the position of the spark, with a
high power of the distance.

The method that proves, however, to be the most simple and easy
to operate is to measure the relative distribution of currents when
several channels are offered to the current for leaving the electrode
after the discharge\(^2\). Fig. 1 illustrates the method, with two outputs
to ground.

The charge \(Q\) carried by the storage capacitor is split in two
parts, \(Q_1\) and \(Q_2\), according to the relative impedance of the two paths
to ground. If the impedance of the connections of the plates to ground
is low when compared to the impedance of the electrodes, then the current
splitting depends only on the relative path length on the electrode,
i.e. the position of the spark. Measuring the difference between \(Q_1\) and
\(Q_2\) can be done in several ways.

*) Visitor from Institut du Radium, Faculté des Sciences, Orsay.
The most simple is to use a transformer where the primary is the ground connection passing through the centre of a ferronagnetic core. Ten turns around the core give signals of sufficient amplitude.

With a tuning capacity $C$ (Fig. 2) of 30000 pF, the ringing frequency of the external circuit is rather low (0.5 MHz). With a diode circuit only the first half oscillation is selected and a clean pulse of several volts is obtained, of a height depending on the position of the spark. The following observations have been made.

The spark itself gives rise to very high frequency currents and the impedances are governed by the high frequency properties. Because of the skin effect, only the properties of the surfaces are important. The impedance of a path depends strongly on its coupling to neighbouring ground leads. For this reason, rigid ground connections are preferable.

The dependence of $Q_1 - Q_2$ over the position is linear in the central part of the chamber. End effects appear when the spark occurs at the ends. This can be made of little importance by extending the ground electrode outside the chamber.

The dependence of the currents on the coordinates is not cartesian when the connection to ground is made through limited area. Considerable improvement is obtained when the connection to ground is done through two lateral slabs of a material with a conductivity much higher than the conductivity of the electrode. This gives the method a very great flexibility.

It is possible, by properly choosing the shape of the ground electrodes to obtain directly the information in various coordinate systems, for instance, cylindrical coordinates (Fig. 3).

The limit to the accuracy is given by the fluctuations in the total charge $Q_1 + Q_2$. By using one additional core through which the total current has to pass before reaching the ground, or by using two additional windings on the two cores of Fig. 1, with the addition of the pulse heights, one obtains a monitor signal eliminating this effect. Analogue circuits may give directly the ratio $Q_1 - Q_2/Q_1 + Q_2$.

The signal can be obtained within time shorter than the memory time of spark chambers and this can be used, as an additional logical element, to trigger other spark chambers.

The analogue display can allow fast combination of the signals from several spark chambers. For instance, in a pair spectrometer, the sum of the diameters of the two electrons can readily be obtained, thus giving directly the energy of the $\gamma$-ray.
It does not prevent the use in parallel of any other method if it is judged preferable for any reason, since normal spark chambers are used.

The simplicity of the data extraction can allow the extraction of the data from complex arrangements. For instance, in a range chamber with a great number of gaps, it is very easy to obtain the number of gaps traversed by the particle, together with information about eventual missing gaps, or spurious sparks.

The weak point of the method now is its inability to identify multi-spark events. In this respect it is different from the sonic method where the addition of probes gives redundant data. There, the addition of a new lead to ground, on one electrode, brings more information but also changes the current passing through all other leads. We see a way out of this difficulty by the use of electrodes with printed circuit wires on fibre glass and epoxy*). These electrodes present considerable advantages.

1. The conductors are linear and only connected at the end. All end effects then disappear**). The response is linear on the whole length. The response is independent of the lateral position, thus giving a perfect cartesian system.

2. It is easy to split the electrodes in independent elements, for instance cm by cm. The currents of an element of 1 cm are passing through a flipping core, before going all together through the central hole of the core giving the coordinate information. The flipping cores are then interrogated first to know whether more than one spark has occurred.

References


*) Thin electrodes of this type have been provided by Philips, Zürich.

**) This has been observed by Mr. Jeanjean, at the Faculté des Sciences d'Orsay (private communication).
Figure captions

Fig. 1  Diagram of the extraction of information from the chamber. The pulse-height is proportional to \( Q_1 - Q_2 \) or \( Q_1 + Q_2 \), depending on the relative winding direction of the two cores. \( C \) is a capacity controlling the frequency of the external circuit (~30000 pF). \( R \) is a resistor used to shift the zero out of the middle of the chamber. \( L \) is a choke to absorb the fast transients.

Fig. 2  Ground electrode structure giving cartesian coordinates. The current on each side is extracted through contacts of silvered brass.

Fig. 3  Spark chamber giving directly the scattering angle. A hole through the chamber eliminates the direct beam. Two concentric ground connections of high conductivity give directly the distance of the spark to the centre of the chamber.
Shaped pulse proportional to $Q_1 - Q_2$

Fig. 1

Fig. 2

Fig. 3
DISCUSSION

CHAIRMAN: Are there any questions on this very interesting development?

R.H. MILLER: Your discussion seems to be based on the current division being controlled by resistance of the lines and I have the impression that it would largely be controlled by the inductances of this system, and particularly with this annular system you described, it is not quite clear to me that you are going to get the information independent of y because of the inductance structure of this system if you have single grounding points.

CHARPAK: You wouldn't use single grounding points. You would take the precaution of taking out the current along the circumference. I agree with you that the division is controlled by the inductances of the different lines. For instance, if the return to ground happens to come closer to one side the circuit becomes asymmetrical. It is good to have rigid connections and be aware that uncontrolled metallic masses moving around the chamber may change the properties.

LIFMAN: For the question I would like to ask I wish to use the blackboard if I may? It is not quite clear to me that you would get complete uniformity of response in your system because you have the current coming out from a single point so what you are trying to measure is R1 to R2 and you are hoping that R1 to R2 will be as X1 is to X2, but depending on the position of the spark of course you will get various current patterns through the space, and it is not absolutely clear why you get uniformity which is as good as it is. As you come out towards the side one would also expect these non-uniformity effects. But if I may go on - one other solution to this problem which I see is that you could have copper printed lines, on aluminium electrodes, in the direction perpendicular to the measured coordinate. In this case when the spark occurs the current is distributed up and down the copper strips and then you will get complete uniformity of the spark. Now you said that perhaps you would put a series of cores on the end of a printed wire electrode in order to get information on which wire went off. Of course it may not be necessary to go over to a digital system. You could, for example, have a delay line, as Mervyn Hine suggested in the discussion of Giannelli's paper, and let these be transformers and simply find the delay at which the wire goes off.

ROBERTS: I would like to also add a brief comment of my own here. I mentioned yesterday that we had considered these cores. There is only one objection I can see for putting cores for identifying the wires and that is that if they are the usual type of computer cores they introduce a non-linear impedance which may make the accuracy of location much worse.
MAEDER: It was mentioned previously that the approach using magneto restrictive wires would be the first chamber which would consist of only one plane and gives everything, but it seems you can have the same thing if you do go over to a complete wire chamber and put ferrites around each wire. Now you use it on one hand, for distinguishing the individual wires and on the other hand, on both sides for determining the position of the spark along each wire and you thus get all the coordinates even for multiple tracks as long as they are not multiple tracks on the same wire, for which the probability would be small.

CHARPAK: The only thing, it seems to me, if you have to go to the complexity of a wire chamber, which is after all quite a good system, why not use completely a wire chamber with its storage cores. Then our system does not give you much more except the fast response that you may want to use or not want to use.

MAEDER: But it solves the problem of multiple tracks?

CHARPAK: Yes, but the wire chambers resolve it already.

MAEDER: But then you have to use at least three planes. One horizontal, one vertical and one at 45° and here you could do with just one single set.

MALDI: I think that this system is very good. In fact we made a chamber of this type and we have tested it in Frascetti in an experiment we are doing but it seems that a remark has to be made. We have used a mesh as suggested by Charpak for the plate because it has a higher resistibility and we have a single gap and measure one dimension. This is useful in our case because we have to tune a beam which has a horizontal focus irrespective of the vertical focus so we send the pulse directly on a kick sorter, and there we see the image in the horizontal plane without any information about the vertical plane, which is what we want. It is clear that if the system is very simple this is a wonderful system. It can be done in a day, but if the system comes out a bit complicated you need for each gap a kick sorter in a certain sense. What do you do when you like to digitize in amplitude? You transform it in a digitized form with a height to time converter. With the sound you get immediately the time transformation. So my impression is that it is very useful for simple systems but less useful for a complicated system.

ROBERTS: We could summarize this by saying that since the information here is analog information it is considerably more expensive to record it than digital information, and consequently more suitable for smaller systems. Are there any more questions?

COLLINS: If I am not mistaken there is some advantage in retaining the wires not necessarily the cores because I think if you have large planes the capacity of this system means that the energy that goes into the
discharge is large and therefore you produce a lot of ions and the recovery
time is increased, whereas if you just discharge one wire the energy is less
and so you can operate at a higher repetition rate.

CHARPAK: This is the case when the wires are on the high voltage
side.

COLLINS: Yes.

CHARPAK: You want to say that the reason why at Brookhaven you
reached these high rates of $10^4$ sec is because of the low capacity of the
wires.

COLLINS: I think so.

CHARPAK: But with iodine discharge chamber working at low voltage
we had found that we can operate at a very high rate also, although it was
between two planes. The dead time was about 100 µsecs. The pulse will be
much smaller, and further development work is necessary to know whether we
can use this method under such conditions.

VERNON: Is it possible that you may have developed a simple analog
divider to normalise the difference of the charge to be able to use only
one pulse height analyser?

CHARPAK: It is certainly possible, and I know that in Frascati
a circuit is being built that is extremely simple and it gives directly
the ratio of the two pulses. In the experiment we are planning now we are
going to have information printed from a set of scalers. But that is a
rich man's method because we have these CERN scalers which are very con-
venient.

MELMED: Have you made any measurements on the current distribution
on the wire system as opposed to the measurements you showed on the slide
which I assume was for a plate system?

CHARPAK: This has been done at Orsay and with a wire chamber they
said to me they had absolute linearity from one end to the other.

QUERCIGI: What happens if the other electrode is a spiral?

CHARPAK: It seems to me that if you use a spiral there is a problem
of triggering. You want to have a good rise time, so if you apply a pulse
on a spiral maybe your rise time will suffer a little bit. But you can
probably overcome this by having the spiral and then a concentric metallic
electrode separated by a dielectric and you pulse these electrodes so by
capacitive coupling probably you bring the whole spiral to a given potential,
and it seems to me that when it will work; it will take some time for the
currents to go out and that will tell you if you make a time difference, where the spark has occurred. And also if you measure the difference in current at the two ends.

R.H. Miller: Is there any limitation as to the fractional accuracy you can get out of this? In principle the spiral you are beginning to talk about is a very long wire one that maybe some 10 metres long or something like this, and then if you start talking about one millimetre resolution you are beginning to talk about one part in $10^4$ and there would be some question as to whether you can retain fractional accuracies like that.

Charpak: The accuracy could in principle be better than the level of the spark accuracy itself.

R.H. Miller: I would be surprised if you could locate it to within a millimetre in a kilometre.

Charpak: If you have an analog display there is a problem in your time conversion but if you have plenty of time I have the impression that you can go very far; it means that you have to open a gate and have a stable oscillator.

Roberts: This question as to the ultimate accuracy is an interesting one because when you get into all sorts of problems like lead inductance from the ends of the chamber and at the 1/10th per cent level this is not trivial any more, so like in any analog measurement there is some limit.

Charpak: The only problems in lead inductance I see is that the lead has to be fixed. You can compensate for anything as long as it is constant.

Roberts: Yes and you also have the two transformers which you are using in an approximately linear mode but they aren't really linear because they contain ferromagnetic elements and they are not good to better than a fraction of a per cent.

Charpak: We have tried with a two metre chamber and had the system working easily.

Giannelli: The idea could be to make a system which is a composition of the delay line system and the system you describe.

Charpak: When we made the method with the delay line we were a little bit blind because we were getting on each side signals that were delayed, but at that same time we observed that they were of different pulse height, and we just did not react to this. It took us a long time to find out that this was in fact an information independent of the structure and for this reason more interesting because you can take a standard spark chamber and have the information.
ELECTROSTATIC PHOTOGRAPHY AS A MEANS TO OBTAIN MAGNETIC RECORDS OF SPARK CHAMBER PICTURES

G. CHARPAK, P. DUTEIL, R. MEUNIER, M. SPICHEL
and J.P. STROOT

CERN, Geneva

(presented by J.F. Stroot)

Electrostatic photography is proposed as a method for fast processing of spark chamber pictures. The eventual use of magnetic powder for the development should provide a means for fast access to the actual information contained in the photographed events.

Electrostatic photography *) is also known under the trade name of xerography. It is a process based on the production of a latent electrostatic image by light falling on a uniformly pre-charged conductor layer (usually amorphous selenium). Development to yield a visible image is done by projection of charged powder particles on the electrostatic image. The powder image can be transferred from the photoconductor surface to another surface like paper and fixed by various methods, one of them being the heat treatment of thermoplastic material associated with the powder. By a proper choice of the sign of charge carried over by the powder, either positive or negative image is obtained.

Nothing should prevent the use of magnetic but highly insulating powder as a developing agent. After having passed through a magnetizing stage, the pictures would appear as a series of black spots and stripes which can be detected by a magnetic tape reader.

The advantages of the xerographic method are:

a) the suppression of the servitudes of film and delayed processing;

b) it nevertheless gives a permanent record on a cheap substrate. Light density is also reproduced. Resolution is a question of powder particles' size; apparently it does not depend on the photoconductor.

c) The photo-sensitive layer is not consumable, it can eventually be deposited on a continuously running belt.

d) Associated with magnetic powder, xerography gives a means to use magnetic analysis. The photos can be scanned line by line being passed in front of fixed multiple magnetic heads. A suitably chosen combination of these can readily give orthogonal co-ordinates that are sent to a computer on-line or stored on magnetic tape. On-line analysis is possible. The speed of processing can at least be 20 cm/sec. A picture can be taken at every FS pulse. For simple events, decoding of multi-triggered pictures during one accelerator burst could be envisaged.

The main questions are:

a) the actual possibility of using magnetic powders in xerography;

b) the sensitivity of xerographic layers.

Contacts have recently been made with the experts from the Rank Xerox company. No definite answer has been obtained yet, but the first comments are encouraging. Sensitivity is about 10–20 ASA. If, as we expect for a photoelectric process, no reduction of sensitivity occurs in connection with the very short duration of the spark, it should be sufficient for our purpose.

If it works, this method would satisfy the requirements of fast scanning and continuous real time control of an experiment and yet present the advantages of visualisation and permanent record of film spark chambers.
DISCUSSION

ANDERSON: I didn't quite understand how much of this is still conjecture and how much has been done by way of experimental trial.

STROOT: As I told you, this was purely an idea and consideration about its feasibility. This is conjecture but we thought that as this was an informal meeting on film-less spark chambers, it would be the right time to present it to people and discuss about it.

FESSEL: I simply want to point out that there is commercially available, at least in America, apparatus to read such photographs. It is the same apparatus that is used to read magnetic numbers on bank cheques.

STROOT: Yes, as a matter of fact, this induced us to develop the proposed system to allow direct analysis.

ZACHAROV: Since the vidicon system also uses a photoconductive layer for storing the visual image as a charge pattern and since with this signal essentially you can do more conveniently anything that you claim you do with xerography, you can certainly store all the images as a permanent record on a magnetic tape and you can process the information much more readily. I am not clear what specific advantages you claim xerography will have over using a signal generating device.

STROOT: Well I am glad to hear that vidicon systems are so much more convenient then, we will see.

WISKOTT: Will you state more clearly the advantages of the xerographic system over the vidicon system? Could you say also something about the comparison between film and the xerographic paper? I have the idea that xerographic paper is much less easy to store and to handle than 35 mm perforated film.

STROOT: No that is not true because, as you have heard, the resolution which you can have with xerography is quite high and you can certainly have a substantial reduction in size. It is certainly not a definite point but with xerography you have, as we said, this easy access fast processing and then you have the permanent record, that is what I said to Zacharov.

ROBERTS: The difference between film and xerography seems to me might give a closer approach to on-line operation.

PIZER: Accepting the fact that you use xerography where do you see the particular advantage in the magnetic pick-up over an optical pick-up? After all, one could use many photo diodes or many magnetic heads. Why do you particularly want to use a magnetic pick-up?
STROCH: We can see advantages in using the magnetic recording heads. In fact you just move some sheets of paper in front of a fixed analysing head and this is certainly easy to do. You do not have the problem of a flying spot, etc., which is certainly very interesting, but we wanted to try this method.

PIER: But you could have photo diodes.

STROCH: Yes you can have many things. This is just a proposal.

CHAPMAK: To answer Zacharov's question about what would be the relative advantage over vidicon systems, I think one should say the following: in this method, if it is going to work and if it is feasible, you have the information in a visible form, it seems that storing the thing on magnetic tape is very good, but if you have the picture you can make a prescanning by eye, that is an important feature. This was in fact the main feature that attracted us. With the vidicon method you do not keep permanently a picture of the event, while here with xerography all your events are printed. It seems that in some cases it is a great advantage.

STROCH: May I repeat exactly what I said in my conclusion? This method, if it works, can provide fast access. One has on-line control of one's experiment and keeps the advantage of classical film spark chambers which is visualization and a permanent record.

ROBERTS: Opinions on this are not likely to be swayed by argument so let us not make the discussion much longer.

ZACCHAV: I would just like to point out that any signal generating device can first of all be used to store the information permanently on magnetic tape or directly in the computer if you like. At the same time it can be used to regenerate the display to be used for scanning.
DIRECT RECORDING ON MAGNETIC TAPE IN SPARK CHAMBERS

E. QUERCIGH

Istituto di Fisica dell'Università, Milano, and
Istituto Nazionale di Fisica Nucleare - Sezione di Milano

The possibility of recording directly the position of events in a spark chamber, by means of a magnetic material behind or in place of the normal electrode, has been investigated.

When a spark falls on an electrode of magnetic material (e.g. steel wire or tape) it leaves a magnetized spot which can be used to determine the position of the spark. For simplicity in scanning it is preferable to separate the magnetic material from the electrode. This can be done by laying a non-metallic magnetic tape behind a wire mesh electrode. The tape can then be moved after the recording of the events and read bidimensionally by a moving magnetic head.

A single-gap model of a spark chamber (Figs. 1 and 2) has been used to test this system. The chamber was operated with helium plus ethyl alcohol at atmospheric pressure, the applied voltage being 7 kV over a 1 cm gap. The electrodes were of stainless steel mesh*) (16 wires/mm² and wire diameter 0.03 mm), stretched over an insulating support (recording area 60 cm²). The sparks were registered on a series of 10 magnetic tapes each 1/4 inch wide, which can slide between the mesh and the support. For simplicity the tapes were scanned only longitudinally in a standard recorder unit, the signal being displayed on an oscilloscope.

The chamber was placed between two plastic scintillators and triggered by the coincidence pulse given by cosmic ray particles. Fig. 3 shows the type of signal obtained during scanning. The total length of the signal varied between values corresponding to 0.3 mm and 1 mm on the tape.

*) This mesh was chosen after trials on several types of copper, brass, bronze and stainless steel meshes. No detectable signals have been obtained with aluminium sheet electrodes (minimum thickness tried = 0.02 mm).
The precision in localization of the spark and the resolving power of the system for multi-spark events have not yet been analysed in terms of length and form of signal, nor has the influence of geometric factors and type of gas on the precision obtainable been investigated. It seems, however, definite that the sparks can be localized and resolved to within less than 1 mm. In principle, therefore, this method can be used to study high multiplicity events.

Since the magnetic tape can be used in a closed circuit of registration, scanning and erasure, this method has been considered for application in cosmic ray and space physics. It can certainly be used in balloon-borne experiments, but with difficulty in space vehicles. On the other hand, its intrinsic simplicity makes it worth considering for experiments at accelerators.

ACKNOWLEDGMENT

The author is grateful to Professor G. Occhialini for guidance and criticism during this work.
Figure captions

Fig. 1  Sketch of the apparatus.

Fig. 2  Photograph of the apparatus.

Fig. 3  Oscillogram of the signal from the magnetic tape
X axis: 1 division = 0.35 mm on the tape
Y axis: 1 division = 2 Volt.
DISCUSSION

NEUMANN: I thought it would go beautifully with aluminium foil. Could you tell me did you apply good pressure between the foil and the tape?

QUERCIGH: The possibility of recording a signal depends on the spacing between the electrode and the tape. We tried with the aluminium and we had no results.

NEUMANN: Did you try pressure or vacuum?

QUERCIGH: Yes, we had something like this. We had a cylinder on which we stretched this aluminium foil and we tried with spurious sparks. We did not have any good results.

FARLEY: Have you tried putting the magnetic tape on top of a conducting plate? It is well known that you can get sparks to an insulating surface.

QUERCIGH: It is well known that it is possible to have sparks between insulating layers and this was quickly tried, but we found that the dielectric strength of our tape was a bit low so there was a beautiful magnetic record but a hole in the tape.

FARLEY: I was already thinking about this possibility. Why not use paper tape? The sparks would make holes in the paper leaving a permanent record. Computers of course like to read holes in paper tape. More seriously, such a system might realize the advantages claimed for Xerography: a permanent record, which can be easily scanned by a photoelectric device.

MAGLIC: Suppose onto this magnetic tape - you put a layer - you evaporate the layer of aluminium or anything to make it a little bit more conductive; than can you use the magnetic tape as a ground electrode?

QUERCIGH: Yes I have tried this with something similar, instead of using a magnetic type I have used a tape of steel which is magnetic, very thin: 3/100 of millimetres, and I have some records. Of course the noise was very high when I read them because of the irregular shape maybe, but I had some signal.
A SPARK CHAMBER OF THREE-DIMENSIONAL RESOLUTION

E. GYGI and F. SCHNEIDER

CERN, Geneva

(presented by F. Schneider)

Some time before the multi-plate spark chamber was widely used in high energy physics, Charpak\(^1\) had the idea to delineate the track of a particle by means of a pulsed discharge in such a way that the initial electrons displaced over a small length excite and ionize the gas. Independently we came to the same idea and we worked out the requirements for the electrical pulse and photographic devices to realize a chamber which could be competitive with a cloud chamber in respect to spatial resolution\(^2\). We concluded that it was necessary to have an electrical pulse of some 10 kV/cm to 100 kV/cm amplitude and with at the most a duration of some nsec. Further, to obtain a reasonable depth of field, the light output of the track has to be amplified by means of an image intensifier.

In order to understand the mechanism of electron multiplication and to see what can be done to achieve a light output, as large as possible, we will rely upon the conception of Raether.

An electron ionizes the gas along its path of displacement \(x\). The total number of electrons grows like \(e^{\delta x}\) as long as the field is uniform in space. Due to diffusion a lateral expansion occurs. Most of the electrons and ions are concentrated within a sphere at the head of the avalanche. This sphere can be considered as a dielectric medium, polarized by an external field. If the dielectric constant of the sphere is much larger than that of its surroundings, that is, if the plasma density is large enough, the external uniform field will be perturbed by the dipole field of the sphere. Inside the sphere the field is weakened and at its poles the field is intensified. At a critical electron amplification of about \(10^6\) the field inside the sphere is practically zero and at the poles it has doubled its value. Photo electrons produced outside the sphere in the surroundings of the poles will develop in the larger field electron avalanches of critical size much faster than the initial one. If this process is repeated several times the original plasma sphere will be finally deformed into a plasma streak, which is then called a streamer. As the streamer grows longer, the electric field at the head and the tail will increase and the development of new avalanches will be more efficient. The propagation speed of the streamer parallel and antiparallel to
the field is at least $10^8$ cm/sec. Because the streamer propagates in two
directions, it is fruitless to try to limit the spatial extension of a dis-
charge by applying an alternating electrical field with a frequency such
that the plasma will still be polarized. The polarization effect can be
neglected only for frequencies $\geq 10^6$ Hz.

In order to register the position of a single electron on a photo-
graphic film with a desired resolution of 1 mm and a depth of field of some
10 cm, the amplification of the electron must be so great that at least $10^{10}$
useful photons are produced. One knows that on the average about one useful
photon is accompanied by one ionization for the conditions under question.
The multiplication factor of the electron therefore has to be also in the
order of $10^{10}$. This means that we are already in the streamer region. To
limit the streamer length to about 1 mm severe conditions on the electrical
pulse must be fulfilled; the pulse length should be one nsec or even less.
However, if the amplification is chosen $\leq 10^8$, the restrictions on the
electrical pulse are not so serious. The propagation speed of the avalanche
is of the order of $10^7$ cm/sec so that the pulse may be 10 times larger. By
means of an image intensifier the missing light intensity can be gained.
Nevertheless it is still difficult to produce an electrical pulse of some
100 kV with only a duration of some nsec.

At the moment we have succeeded in constructing a Marx-generator
with the required properties. The pulse obtained was of triangular shape
with an amplitude of about 50 kV and a base width of 10 nsec. Construction
details can be seen from Fig. 1.

About 150 nsec after the passage of an energetic particle through
the chamber, the pulse could be applied to the electrodes. The spacing of
these was 4 cm and one transparent electrode of conductive glass was used in
order to view the chamber from any direction. In different gases (N$_2$, CO$_2$,
Ar, Xe, Ne-He mixture) visible tracks have been obtained. The largest
light output was achieved in Hennagal (70% Ne, 30% He).

Because no multi-stage image intensifier tube was available at the
time, we had to work with rather light sensitive optics and films in order to
register the tracks. The figures on the last page demonstrate tracks of
cosmic ray particles, taken with a lens opening of f/1.9 on a Polaroid film
of 10,000 ASA. The chamber filling was Hennagal of 770 mm Hg.

Figure 2 is a view perpendicular to the direction of the electric
field. Owing to statistical fluctuations in the electron multiplication, the
time when an avalanche will transform into a streamer jitters appreciably.
The transformation of a certain number of avalanches into streamers would
explain the different lengths and intensities of the streaks.
In Fig. 3 the track is viewed parallel to the direction of the
electric field. It is evident that the light intensity in this direction
is larger and that the picture of an avalanche or streamer is much smaller
than in the other view.

The average streak density obtained from some 10 cm of track was
about 10 streaks/cm. This result corresponds to the primary ionization of
a minimum ionizing particle.

The quality of the picture makes it possible to determine the
direction of a track of some 10 cm in length to an accuracy of some mrad.

During this investigation it came to the authors' notice that
elsewhere\(^3\) experiments had been carried out in the same field. In this
case the chamber used was about 10 times larger than ours\(^1\). Streak density
and streak length were worse compared with our results (probably due to the
much longer electrical pulse).

Last but not least we would like to mention Gatti et al\(^4\) who
produced some years ago already visible tracks with the help of a damped
radiofrequency oscillation. Due to the fact that the pulse was rather
long, it was not possible to work with an amplification large enough to
register single electrons. It was possible, however, to make the track of
an \(\alpha\)-particle visible.

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Figure captions

Fig. 1   Marx-Generator.

Fig. 2   View of the track perpendicular to the electric field.

Fig. 3   View of the track parallel to the electric field.
fig. 1 Marx - Generator
DISCUSSION

PEREZ-MENDEZ: Which gas gave the highest light intensity?

SCHNEIDER: We succeeded with xenon (mixture of neon and helium). If one looks in tables of gas discharge one finds that pure neon would be the most preferable gas. With this gas you can work with the smallest voltage compared with other gases under the same conditions.

PEREZ-MENDEZ: Has anybody used xenon since xenon gives more light?

SCHNEIDER: First you get a much larger primary ionization but the voltage you need in order to get the amplification necessary to see something is about three times larger than in neon. If one is already in the 100 keV range one should just choose a gas which requires the smallest voltage. If one thinks about chambers which have a space of 30 cm we end up with one million volts or something like this already with neon.

CHARPAK: I wish to emphasise that for the study of complex events this chamber is extremely promising. I have seen pictures obtained in magnetic fields by Shikovanié with one metre chambers and in which one could see showers with hundreds of electrons and this was very impressive. In this case he uses pulses that are wider and the quality of the tracks is not as good as the case of Schneider. However, it is remarkable that even if you apply a pulse that is too long so that you have a discharge in space that is extended over, even going from one plate to the other, the structure of the discharge still shows more or less where the particle has been. One can extract this information with less accuracy about the third dimension but one can extract it. The author claims here to have an accuracy in the determination of the centre of a couple of millimetres. Since in this case the light output is much higher it may be that one could find a compromise.

SCHNEIDER: I think it depends on what one likes to do. In one case, perhaps just this simple solution is good enough, in another case, if you want to measure angles very accurately, one should do something like this.

CHARPAK: One should point out that even in big bubble chambers for instance, the accuracy of the determination of the depths is not that good and one still succeeds in dealing with it. So the requirement of the third dimension is not completely historic on the two others. What is the dead time of your chamber due to residual ionization of the last image?
SCHNEIDER: We never measured it but it is easy to estimate. If you have no electron negative gas in the chamber the dead time is given by the diffusion time out of the chamber. If you have a distance between the electrodes in the order of some centimetres and xenon filling, the sweeping time for thermic electrons would be, say, between 10 and 100 μsecs, something like this. But this is no serious problem limiting the application if one just puts into the chamber a little iodine or SO₂ or something like this. It is easy to bring down the sensitive time to the order of 100 nsecs.

ANDERSON: Well let me ask the other question. What is the sensitive time, and how much background are you likely to pick up?

SCHNEIDER: The sensitive time is determined by the time the electrons need to disappear out of the sensitive volume.

ANDERSON: Oh yes but I meant with these metal plates here.

SCHNEIDER: Well in the normal spark chambers where the plate distance is very small it is easy to sweep them out, but at a distance of 10 cm or something like this, if you do it with a clearing field you will end up at least with about 10 μsecs.

ANDERSON: Yes that is just the point.

SCHNEIDER: But if you put in some iodine or another electron negative gas which is very efficient, for instance SO₂ of some per cent (I cannot give exact figures) it is easy to limit the time to one hundred or some hundred nsecs.

KAPTANOV: I have two comments. First of all referring to the question of using xenon: a couple of years ago we studied the question of using pure xenon and also of adding some xenon to neon. We found that for instance about one half per cent, not more, of xenon did not change the working conditions in the chamber but did change the brightness to a large degree. We noticed, also, that the colour of the spark changed from red as a characteristic for pure neon to almost white. The second remark is that in the Institute of Theoretical and Experimental Physics, Moscow, they have studied the large gap spark chamber with a track crossing the electrode and found that the brightness of the sparks depends on the velocity of particles. They received their rough information on β particles also.

SCHNEIDER: I think the addition of xenon might be an advantage if one likes to take the picture directly onto a photographic plate, because the best films are most sensitive in the blue range. We intend, though, to employ an image intensifier tube. The main spectrum from neon radiated under our conditions is between six and seven thousand Å and it is not difficult to get a photo cathode which has its maximum sensitivity just in this range.
PROPOSAL FOR A SPARK CHAMBER OF THREE-DIMENSIONAL RESOLUTION WITH THE HELP OF A LASER

F. SCHNEIDER
CERN, Geneva

As this paper has been submitted to Nuclear Instruments and Methods, only its summary will be presented here.

SUMMARY

The feasibility of confining the gaseous discharge in space (without forming a conductive channel between the electrodes) is shown, by means of a laser of sufficiently large electric field to produce gaseous breakdown.

The required light power density is:

\[ P_{em} = 2a \frac{U_i U_e}{r^2} \sqrt{\frac{\varepsilon}{\mu}} \left( \frac{\omega}{\nu} \right)^2 \approx 10^6 \text{ [Watt cm}^{-2}\text{]}. \]

The required total energy per unit area of the light beam is:

\[ E = \alpha \frac{m}{e} U_i \sqrt{\frac{\varepsilon}{\mu}} \frac{\omega^2}{\nu} = 50 \text{ [Joule cm}^{-2}\text{]}. \]

Here, \( e \) = electron charge, \( m \) = electron mass, \( \omega \) = angular excitation frequency, \( \nu \) = collision frequency, \( E_o \) = amplitude of electric field, \( U_i \) = average energy expended per ionization, \( U_e \) = average electron energy, \( \lambda \) = mean free path for electron, \( \epsilon \) = dielectric constant, \( c \) = vel. of light. In order to obtain visible spot from one primary electron, \( \alpha = 25 \). Reasonable size of the plasma ball is 1 mm. With \( U_i = 50 \text{ V} \), \( U_e = 10 \text{ V} \), collision frequency \( \omega = 3 \times 10^{14} \text{ Hz} \) will be possible, with gas pressure of 10 atmospheres. Reflecting the laser beam up and down the chamber it should be possible if one can realise a reflection coefficient of 0.999, to sweep a volume of about 100 liters with a laser of 1 M Watt output power.
DISCUSSION

VERNON: Are you aware that people have achieved breakdowns with laser beams in gas?

SCHNEIDER: I saw something in the "Scientific American" on the front page.

VERNON: I think I have a paper, I cannot remember where it is from but people have done it.

SCHNEIDER: What I remember from "Scientific American" is one has concentrated the beam with a lens and so achieved a field strength of the order of $10^8$ volts per centimetre, just sufficient to strip an electron from a neutral molecule.

HINE: If you want a high density do you think this would work in a liquid, I mean do you think liquid hydrogen would be excited?

SCHNEIDER: If your particle passes your chamber the minimum time which will pass before you can apply the laser pulse is 100 nsec. Does one have still free charges in the liquid hydrogen - free electrons?

HINE: Supposing you did?

SCHNEIDER: Let me see, with 10 atmospheres we have a collision frequency of about $10^{14}$ cycles per sec and the density in the liquid hydrogen chamber is about two or three times larger. The exciting frequency must be within the ultraviolet range in order to fulfil the assumed conditions. If one shifts the frequency up it is possible that one can come to the minimum power requirements even in a liquid.

FORTUNE: I think that one important advantage of this type of chamber is the possibility given by its low density and fine track structure of making very precise primary ionisation measurements over an extended range of relativistic ionisation increase. Such ionisation measurements coupled with momentum measurements should enable mass identification of individual tracks to be made for values of $\gamma f = P/mc$ up to several hundred or higher. This is a technique which was being developed in Cloud Chamber work just before the the use of the Cloud Chamber with accelerators went out of fashion, and now seems to be revived by the possibilities afforded by this kind of spark chamber.

ROBERTS: That would be true of any kind of spark chamber wouldn't it?

8446/zn
FORTUNE: This one has high optical resolution and the possibility of measuring the primary ionization directly. I do not think any other spark chamber affords this possibility in this one manner.

ROBERTS: Yes there are other spark chambers that do.
COMPARATIVE STUDY OF SPARK CHAMBER
DATA RECORDING SYSTEMS

prepared by: the ad hoc Working Party

D. MILLER, Harvard University, Harvard
V. PEREZ-MENDES, Lawrence Radiation Laboratory, Berkeley
A. ROBERTS, Argonne National Laboratory, Argonne
(Chairman of the Working Party)
A.E. TAYLOR, Rutherford High Energy Laboratory, Chilton

I. PROPERTIES OF VIDICON DATA ACQUISITION SYSTEMS

V. Perez-Mendez

1. Spatial resolution

Princeton and Berkeley groups report resolution of spark location, by timing the sweep of the electron beam in the vidicon, to be as good as 1/2000. The resolution for recording two sparks separately in the same gap was measured by the Berkeley group as being 1% of full sweep.

2. Time resolution: dead time; sensitive time

The time required for processing an event depends on the sweep rate of the scan, the number of scan lines used, and the time required to erase the previous image and to recharge the photo-conductive layer. The Princeton group requires 32 ms plus 0.5 ms per spark digitized. For the Berkeley work, using a 10 plate chamber with 250 scan lines at a 20 Mc/s clock rate this time is 40 ms. Using 100 Mc/s scalers now available, this time can be cut down to 10 ms or less.

3. Number of tracks per gap that can be handled: spark intensity and intensity information

The number of tracks per gap is limited only by the capacity of the electronics to handle the information, provided the sparks are further
apart than the minimum distance quoted above. The spark intensity is readily recorded; although the current output versus light intensity of vidicons is logarithmic, a light intensity scale of 8 (3) bits is quite feasible.

4. Feasible range of chamber size

Any convenient size that can be imaged by lenses and mirrors on to the vidicon anode. Two-spark resolution and spatial resolution and accuracy will vary inversely with chamber size. This can be avoided by using more than one vidicon to look at the spark chamber.

5. Ease of construction: flexibility

Any chamber array that can be handled by optical recording methods using film can be handled by a sufficient number of vidicons. Appropriate fiducial marks have to be placed on the chambers to satisfy the detailed requirements of the particular vidicon digitizer which is used.

6. Use of commercial components

Three of the 5 groups reporting on vidicon methods used commercially manufactured cameras with home-made (minor) modifications. The Berkeley group assembled their camera and control circuits at its own laboratory.

7. Cost: required manpower to build

Commercial cameras costing from $750 to $3000 have been used. The major cost of these systems is in the electronic equipment for recording and storing the digitized information, also required for other "film-less" methods. The work required to assemble any one of these systems using commercial components has been done — at Princeton — by one physicist and one technician.

8. Types of data storage

Vidicons can use any of the electronic techniques used for data storage, including paper tape, core storage, magnetic tape, etc.

9. Special computer and programme requirements

None; analysis of tracks etc., as required by any spark chamber experiment.
10. Optical requirements

Similar to those for photographic chambers. Vidicon digitizing systems discussed here require a format in which the spark chamber plates in each view of all chambers appear parallel to each other on vidicon anode. For different sets of plates more than one vidicon can be used in place of complicated mirror arrangements.

11. Present status

Late development stage.

II. SONIC LOCATION OF SPARKS

A.E. Taylor

1. Spatial resolution

a) One spark in each gap: Accuracy of location \( \pm 0.3 \) mm but depends a little on size of chamber.

b) Two sparks in each gap: Spatial resolution is governed by the transducers of detectors to \( \frac{1}{2} \) cm for damped detectors. Another solution is \( 3n + 1 \) undamped detectors per gap, where \( n \) = number of sparks, but can only be used up to \( n \leq 3 \) (never used yet for \( n > 1 \)).

2. Distinguishable elements

With 4 to 6 detectors per gap, the distinguishable elements, i.e., the number of gaps is limited by the number of separate channels available for storage. For optimum accuracy using 10 Mc/s clock frequency, 14 binary bits are needed for a chamber 1 m on the side.

3. Time resolution

Dead time. With a sound velocity of 1 cm per 20 \( \mu \)s, there is a dead time or time for all the signals to be received which depends on the size of the chamber. For a large chamber this might be \( 1 - 3 \) ms.

4. Data storage

With 60 scalers decimal readout (CERN systems) directly onto magnetic tape (120" per second 200 bits per inch) the write time is \( \sim 80 \) ms. With ferrite core buffer store, the readin time cannot
be less than the dead time, but the readout time directly to a computer or onto magnetic tape is a few milliseconds for a reasonable number of channels.

5. **Number of tracks per gap that can be handled**

So far all measurements have been made with one track per gap. This is not regarded as the limit for the future given sufficient storage channels. The main limitation is probably governed by the dynamic range of spark intensities which can be handled by the detectors and the complexity of the circuitry. In principle, any number of sparks/gap can be handled by using damped transducers; up to \( n = 3 \) sparks/gap can be handled with \( 3n + 1 \) transducers/gap. It is generally agreed that no difficulties are expected in handling 2 to 3 sparks/gap.

6. **Size of chambers**

Chambers have been operated with sensitive area of 50 \( \times \) 100 cm.

7. **Intensity information**

The strength of the sound signal depends directly on the spark energy and the distance away from the spark. The dependence on distance has been overcome by making the sensitivity of electrostatic microphones increase with time from the time of occurrence of the spark. However, for one spark per gap the spark intensity is not dependent on the ionization.

8. **Ease of construction**

The chambers are no more complicated than optical chambers except that the fiducial marks are now the position of the detectors.

9. **Cost and use of commercial components**

Most components are commercially available and the cost lies in the data handling system.

10. **Type of storage possible**

a) Many scaler readout coupled to paper or magnetic tape.

b) Fast carry scaler coupled to ferrite buffer store with readout to magnetic tape or directly to a computer on-line.
11. **Optical requirements**

None. The event can be reconstructed on the face of a scope for visual observation of the more complicated events.

12. **Features**

a) Automatic digitization of information.

b) Chambers are not limited to a planar geometry and can be put into conventional magnets.

c) There is usually a minimum time, ~300 µs, before any sound signal arrives at the detectors. This time interval could be used by a computer on-line to digest other information, and, for instance, provide a go-no-go gating of a somewhat more complicated nature than the usual counter trigger. Thus some selection and filtering can be made before the need to record and store the same information and so reduce the storage requirements.

13. **Present status**

One experiment completed, several in progress.

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**III. COMPARISON CHART FOR DIGITIZED DISCHARGE PLANES**

(Wire Array)

D. Miller

1. **Spatial resolution**

Error in locating centre of discharge \( \leq \) half the spacing between wires - error typically 0.5 mm.

2. **Present maximum size**

65 x 65 cm (512 elements).

3. **Construction methods**

for plane

a) Wind wires over frame using lathe - 2 man-hours/ plane

b) Stretch foils over frame - 6 man-hours/ plane

c) Etch electrodes - commercial
for memory
a) Dip solder write lines - 1 man-hour/plane
b) Memory plane - commercial $1/2$ Sf/bit

4. **Multiple track capability**

10 per gap observed.

5. **Sensitivity to specific ionization**

Given by number of adjacent cores set.

6. **Sensitive time**

0.2 to 0.5 μs.

7. **Recovery time (discharge planes)**

0.2 to 0.5 ms (smaller in the three electrode unit)

8. **Reading time**

Can clear memory of several hundred spark locations during the recovery time.

9. **Optical requirements**

None.

10. **Electronic requirements**

Scaler-decoder-read current sources - commercial modules parallel to series converter. $\$15,000 - \$20,000$ significant design time

11. **Permanent data storage**

Magnetic tape.

12. **Computer requirements**

Programme interrupt feature is useful for on-line analysis.

13. **Special programme requirements**

Must locate spark centre in each gap.
14. Special features

Short recovery time, mechanical flexibility, simple analogue display, can be used as a logical element.

15. Special problems

Can only resolve multiple track ambiguity with a third discharge plane or a three electrode unit.

16. Present status

Final development stages; operating in test beams.

Addendum to III by M.J. Neumann

The secondary discharge spark chamber should have a recovery time in the order of microseconds or better, because of the very low current discharges, the increased role of surface recombination and the fact that the distributed and isolated charge-storage principle (every wire has its own storage capacitor and bleeder) - permits triggering of the spark chamber immediately after breakdown, and only the wires involved in the previous discharge are incapacitated within their own dead time.

IV. PROPERTIES OF CONVENTIONAL CAMERA–FILM DATA ACQUISITION SYSTEMS WITH NARROW-GAP SPARK CHAMBERS

A. Roberts

1. Spatial resolution

Limited only by the structure of the spark itself. The estimated range of resolution is about 0.25 to 2 mm.

2. Distinguishable elements

Again limited only by the spark structure.

3. Time resolution

Dead time from 1 to 10 ms, depending on the conditions of operation; even shorter recovery times can be obtained if desired. Data storage
time: the interval between successive frames is usually limited by the film advance time in the camera, 25 to 60 ms in the best present cameras. A camera with 10 ms frame advance time has been tested and will soon be available.

4. Number of simultaneous tracks that can be handled practically unlimited. Up to 100 have been recorded in one event.

5. Range of size feasible

No limits known; up to 240 cm × 240 cm made.

6. Intensity information

Relative ionization measurable when more than one track present. Ionization measurements may be possible for single tracks with short pulses.

7. Ease of construction flexibility

Very many methods of construction possible, limited by need for optical access.

8. Use of commercial components

For electronics, optics.

9. Cost, manpower requirement determined by size of system. Need for film scanning may require manpower (womanpower).

10. Special computer requirements

None. On-line computer data analysis is not possible, but operation with a short delay to scanning (1 - 2 hours) and subsequent automatic measuring may cut overall feedback delay to several hours.

11. Types of data storage

At present, film; in future, other photo-sensitive processes may be usable - e.g., xerography, thermoplastics.
12. **Special features**

Chambers require optical access. Alignment of mirrors for multiple chamber set-ups is tedious, if several chamber images are collected on one film. Use of human pattern-recognition ability gives great advantage for complex event recognition.

13. **Present status**

Many completed experiments.
CONCLUDING REMARKS

M.C.N. HINE
CERN, Geneva

The job of summarising this meeting ought to be shared between Cassandra and Kowarski; Kowarski because it is intimately concerned with data handling, and Cassandra because she was fated to say unpleasant things that people would not believe until it was too late. As it is, I will do my best, but since I am neither, you need not take what I say very seriously.

I shall split what I think one can conclude from this meeting in two general headings: "Present Situation" and "Future Prospects" and for each of these two, one can in first approximation discuss on the one hand, the detectors and the immediate data acquisition method used with them and, on the other, the general system problems and the computing aspects. Of course in the design of any particular experiment you have to think of the whole thing at one time. For the present situation of what I will call "detectors", you have got the Report of the Working Party and I do not think there is much that I should say in detail. The three types of detector considered as now working are the acoustic system, the vidicon system and the wire system. All these have run in experiments or at least in serious test experiments and they have fairly similar potentialities, at least in simple systems. They seem to go up to sizes of the order \( \frac{1}{2} - 1 \) metre, with spatial resolution in the region of \( 10^{-5} \) of the size of the chamber, sensitive time about 1 \( \mu \)sec, dead time a few milliseconds, perhaps a bit shorter in some cases. All of them in their present way of use seem to suffer from rather serious problems of stereo ambiguity, if you get more than one spark. In some cases you cannot even tell whether you have got more than one spark and you do not know where it is; even if you can tell if you have got more than one spark, it is difficult to associate two stereo views. This is no trouble in low counting rate experiments but I think as time moves on one will find that people will want to have two or three sparks in every chamber or at least will be forced to accept two or three sparks in every chamber, and therefore must be able either to measure or to reject the sparks that they do not want, and the present systems do not look very clever at doing this at the moment.

As well as these established techniques, we have heard also something about a number of new ideas which have not yet reached the same degree of development. Yesterday we heard about the possible use of magnetostrictive propagation to determine where on a wire a spark had landed. This morning
we have heard about the current distribution method, which is in some ways rather similar, and also about chambers with somewhat unconventional ways of generating sparks, and finally the possibility of using bubbles in place of sparks. I think it is too early to make any predictions as to which of them is going to turn into a technique for general use by a large number of groups and which will have rather specialised field of applications. If I had to pick out one I would think that the magnetostriction wire at the moment looks very attractive because it seems to be one of the few which may be able to get round the ambiguity problem rather directly. The other ways of getting round the ambiguity all look rather tricky: in acoustic chambers I think one would say it is impossible. You can make theoretical ways of doing it but I don't think anybody who wasn't already committed to that kind of detector would launch out into an experiment in which he was using acoustic chambers and relying on multiple spark detection.

The present state of the systems which use these fairly well established techniques is not so advanced as the individual pieces of hardware. Only one or two experiments have actually been done with acoustic chambers and only one or two experiments have actually used on-line computers. Nobody has done more than test runs with either wire chambers or with the vidicon system in a complete experimental set-up, though they are coming along fast. Even so I think one can already see in the experimental set-ups using these digitized spark chambers some common features on the computer and data handling side. Everyone needs a buffer. This is surrounded by a certain amount of logical control circuitry. Everybody seems to store raw data on magnetic tape, and I think everybody gives the impression that they would like to store their data as raw as possible. Everybody wants to get at least quick service for his magnetic tapes on a large computer. Almost everybody has some form of display of his data, a quick display in a form which looks like a pattern of sparks in a chamber, perhaps transformed a little, but a display which enables them to use their visual imagination to detect whether the system is working properly and whether the events are the kind of events they are expecting or no.

In fact, everybody has a small computer on-line (even if they disguise the fact from their budget authorities) and they mostly seem to have paid for this between 100 and 300 thousand francs, or more in some cases, excluding the chambers themselves and excluding magnetic tape units.

Whether this implies that a general purpose computer as opposed to special purpose hardware is going to become universal in the near future for everybody, depends partly on how fast the system is expected to be and on whether there are other advantages that can be gained from on-line operation of a general purpose computer, as opposed to on-line operation of the special purpose computers which most people have now.
Up to now almost all the systems in use have been rather slow, either because they have been used for essentially low counting rate experiments, or because of accelerator burst characteristics or other technical reasons. I say almost all have been slow, because of course Lindenbaum's system is very big and fast and expensive, mainly because he designed it from the start to work with scintillator hodoscopes where there are essentially no dead time problems. His potential data acquisition rates are enormous compared with any set-up using a spark chamber with a dead time of milliseconds. However, the spark chamber systems are creeping down towards dead times in the millisecond region and people are beginning to talk about using this rate to take 10-20 events in the course of a typical synchrotron burst. These fast systems all need large buffer capacity and a considerable amount of logic, whereas the slow systems can afford to put one event at a time directly on to tape with pretty simple hardware logic; thus the fast systems particularly look like general purpose computers.

The other advantages of having a general purpose computer on-line, which were brought out in the various papers and discussions, are difficult to describe quantitatively, but I think that those who have used a general purpose computer, however small, on-line are unanimous that there are a lot of such advantages. They seem to be associated with the question of quick turn round of information, and perhaps, with the ability to alter the discrimination logic in an experiment by changing programmes rather than by having to modify the hardware. The quick turn round aspect has also been described by the phrase "sample calculations", as sometimes this has meant doing the complete calculations leading up to the final answer on, say, 10% of the events as the principal use of a small computer on-line apart from data acquisition. But it seemed from the discussion by the people who have actually been doing such experiments that the kinds of calculations change quite a lot from the early stage of the experiment when they were used for a wide range of checks like checking beam profiles and dead times in counters and background, to the data taking period when a certain amount of sample computation was done to get physics results, but accompanied by a lot of specially designed and quite complicated checks as to how the individual parts of the equipment were running.

The conclusion which I come to from the discussions in this meeting is that there is a big advantage for everybody having his data acquisition done very largely by means of a small general purpose computer, and not by special purpose electronics if it can possibly be afforded. There is a big advantage of having the general purpose computing ability as well as just the buffering and input-output facilities, and this looks more and more essential for the faster data rates.

Of course there are difficulties which can be summarised under the headings of money and man-power. Rather to my surprise the man-power aspects of this turned out to be less serious than we in CERN have been fearing, at
least a little while ago. If you buy yourself a small computer rather than building yourself a buffer, you actually save an electronic engineer and a technician and this is not to be sneezed at. In addition, whereas we in CERN had been rather frightened by the prospects of adding the labour of programming a small computer on top of all the other jobs, this does not seem to have caused the groups who have actually been using on-line computers any worry at all. It appears that about 10% of a group's labour has been used in programming in the sense of writing programmes that have been blocked out already. So far these have been fairly straightforward simple pieces of mathematical programming. The design of the programmes has quite properly occupied most of the physicists in the groups concerned as this is nowadays really another name for the design of the experiment itself. Once this has been settled, one man in a group seems to be enough to write the actual routines. If he cannot write the programmes there is something wrong with the logic of the experiment and that had better be cleared up first before worrying about how to get the programmes coded. I suspect that this situation will change in the future in going from the rather simple events which have been worked on so far to more complicated ones, but this belongs to the second half of my talk.

The other difficulty, of course, is about money, and there have been many comparisons between the "rich" and the "poor" with everybody casting everybody else in the role of the devil. I think here that what is "rich" and what is "poor" is not a question of what your departmental budget is. A big accelerator like the FS has direct running costs in the region of 25 million francs a year, and if you pro rate this between six experiments done in the course of the year that is about 4 million francs a year of direct operating costs. Clearly anything which increases the operating efficiency is going to save very much more than the extra cost of converting a special purpose hardware buffer into a small general purpose computer; three or four small general purpose computers spread over the experimental floor, if they do increase operating efficiency and cut down wasted time, will certainly pay for themselves. It is another case I think, a rather general rule in physics with big machines that you cannot afford to be poor. Bernard Shaw said "poverty is the worst of crimes" and he would have been a very good high-energy physicist with that philosophy.

In looking at the future, I can cease to try and report on the conference but merely air my own prejudices about how things are tending to move and what they might look like in a few years' time. On the detectors, obviously all types are going to go on being used for some time to come, but there may emerge what you could call a dominant technique as a survival of the fittest. After listening to the discussions and thinking about it I do not put my money on the acoustic chamber. I think it is too like the bubble chamber in having a 19th century steam-age feel about it. Especially I think that, apart from this esthetic disadvantage, its inability to cope with multiple tracks is going to be a practical reason why it will not
be able to keep its present predominance. I would also vote against any photographic system or any vidicon system mainly because I think the difficulty of actually optically looking into a spark chamber is going to become more and more of a nuisance as time goes on. The present photographic systems with acres of front surface mirror mounted on steel scaffolding are very clumsy and difficult to realise. Vidicons are put forward as having the advantage that you can put one vidicon camera per spark chamber, but the cameras are not negligibly cheap. There will be difficulties of fitting vidicons to chambers in conjunction with magnets and there remains the problem of stereo reconstruction. We have heard that it is apparently possible by complicated computer programmes to correlate one spark with another using the brightness and other properties of the spark, but if it can be avoided, I think everybody will feel happier.

This leaves of the methods that have been talked about during the conference, the wire chamber and the ideas that have been discussed this morning by Charpak. Maybe these look attractive merely because we know less about them. This is a rather usual state of affairs and perhaps we will end up in another year's time by saying that the whole race of digitized spark chambers is going to die out because hodoscopes made of solid state detectors will in fact take over completely. For the time being it seems to me that the wire chambers and, possibly, for the simpler kinds of detector, the current distribution method seem to have the greatest technical attractiveness and the minimum number of serious difficulties.

On the development of systems and computing needs, I think the biggest question was the total amount of computing. It is such a big question that quite a lot of people didn't even seem to notice it hanging over their heads, but to me it looks as though we are going to run into very serious trouble in five years from now if present trends continue. It is not, I think the problem of the very high counting rate experiments as such; even Lindenbaum with $10^5 - 10^6$ fairly simple events per hour can manage on a conventional sized computer. The difficulty is that when you start trying to deal with more complicated events you have really to face problems like stereo reconstructions and recognizing tracks in three dimensions; then the total amount of computing per event goes up very considerably. If the future of this technique really involves combining the data taking rate of Lindenbaum with the amount of calculation per event which the bubble chamber people are accustomed to, then the load would be too large for all the computers in the world put together. Long before we reach this impossible situation, obviously a great deal more effort will have to go on to planning systems which cut down the amount of computing to the bare minimum with careful thinking and clever programming, and perhaps the problem of scheduling the accelerator will disappear and be replaced by a weekly battle to schedule the computer. At that stage, or rather before that stage is reached people will begin to ask "Why have we got in a laboratory like CERN 200 million francs worth of hardware and only 20 million francs
of computer. Clearly we must put all the spare money for the next five years into giving everyone his own 6600 - which would still not put more money on to the data handling side than is in the data generation side." With this flight of fancy I had better stop.

A. ROBERTS (Chairman)

Since these are the concluding remarks and since Dr. Hine has managed to insult practically everybody I will rule that this talk is not open for discussion. Before closing I would like to voice the thanks of the conference to some of the people who made it possible and who helped so much in making it run so well. Among these I would like to mention Miss E.W.D. Steel and Miss Y. Henry of the Conference Secretariat, Mr. E. Bissa and his assistants who have been operating the projectors and the recording machines and so on, the Scientific Secretaries for all the sessions and Mrs. G. Andrássy and her assistants who have done all the rapid and very difficult typing far into the night in order to get the texts of the discussions back to us and who will be working very hard for the next two months in preparing the final version of the proceedings. And finally to the Directorate of CERN for their hospitality and Dr. G.R. Macleod and Dr. B. Maglić for their work in preparing the conference so excellently. The conference is closed.
LIST OF PARTICIPANTS

Argonne National Laboratory, Argonne

R. CLARK
A. MELMED
W. MILLER
A. ROBERTS

Atomic Energy Research Establishment, Harwell

C. WHITEHEAD

"Boris Kidric" Nuclear Energy Institute, Belgrade

S. BINGULAC

Brookhaven National Laboratory, Upton L.I., N.Y.

G.B. COLLINS
S. LINDENBAUM

California Institute of Technology, Pasadena

A.V. TOLLESTRUP


R. FESSEL

Centre d'Etudes Nucléaires, Saclay

B. AGRINIER
Y. AMRAM
M. BANNER
C. BRICMAN
J.F. DETOUBEUF
M. GOLDWASSER
J.C. MICHAU
J. COSTENS
E. PARLIER

Collège de France, Paris

M. CROZON
N. RABANY
P. SOUVETON

8446/ga
Columbia University, Nevis Cyclotron Laboratory, Irvington-on-Hudson

M. BARDON

Deutsches Elektronen Synchroton (DESY), Hamburg

B. ELSNER
K. HOHNE

Euratom, (C.E.T.I.S.), Ispra

P. GUTMAN

The Enrico Fermi Institute for Nuclear Research, Chicago

H.L. ANDERSON

Harvard University, Cyclotron Laboratory, Cambridge, Mass.

D. MILLER

Imperial College of Science and Technology, London

D.M. BINNIE
A. DIANNE
M. IDBOTSON

Instituut voor Kernphysisch Onderzoek, Amsterdam

C. DAUM

Istituto di Fisica dell'Università, Bari

G. GIANVELLI

Istituto di Fisica dell'Università, Bologna

L. MONARI

Institute for Computer Research, Chicago

K.G. MILLER
N.J. NEUMANN

Institute of Theoretical Physics, Copenhagen

E. LIEGE
Institut für Experimentelle Kernphysik der TH, Karlsruhe

S. GALTER

Institute for Numerical Analysis, Lund

K. JOHNSON

Istituto di Fisica, Milan

E. QUERCIGH

Institute for Theoretical and Experimental Physics, Moscow

V. KAPTANOV

Istituto Superiore di Sanità, Rome

U. ALMADI, Jr.

Istituto di Fisica, Trieste

G. BRAUTTI

Instituut voor Kernphysica, Trondheim

K. BUDAL

Laboratoire de Physique Corpusculaire de l'Université, Caen

J.L.D. DUCHON
F. LE MEILLEUR
M. SCHERER
J.L. SEQUINOT

Laboratori Nazionali del Sincrotono, Frascati

P. GORENSTEIN
S. TAZZARI

Laboratoire de Physique Corpusculaire, Orsay

P. SCHARFF
C. VICTOR

J.C. BIZOT
J. JEANJEAN
Laboratoire de Physique Cosmique, Paris

Ph. CATZ

Lawrence Radiation Laboratory, Berkeley

F. KIRSTEN
V. PEREZ-MENDEZ

Lund University, Lund

S. von FRIESEN
G. JARIKOG

Manchester University, Manchester

R.J. ELLISON
R. MARSHALL

Max-Planck-Institut für Physik und Astrophysik, München

H. GOING
W. SCHORSCH
J. TIJTSB

New-York University, Institute for Mathematical Sciences, New York

R. SHEVLIN

Northeastern University, Boston

R. WEINSTEIN

Nuclear Physics Research Laboratory, Liverpool

P.T. ANDREWS
C.D. WEST

Pennsylvania University, Philadelphia

H. BRODY
S. FRANKEL
J. HALPERN

Physikalisches Institut, Erlangen

H.J. TREBST
Princeton University, Palmer Physical Laboratory, Princeton

C.W. VERNON

"Ruder Boskovic" Nuclear Energy Institute, Zagreb

D. DENGZI

Rutherford High Energy Laboratory, Chilton

C.J. COLLIE
N. LIPMAN
G. MANNING
J.D. PRENTICE
A.E. TAYLOR
T.G. WALKER

Smithsonian Astrophysical Observatory,

G.G. FAZIO

Stanford Linear Accelerator Center, Stanford

A. BOYARSKI

Technische Hochschule, Stuttgart

E. EPPLE

Westfield College, London

C. COOKE

H.H. Wills Physics Laboratory, Bristol

B.D. JONES
W.A. VENUS

and

Visitors, Fellows and CERN Staff
The following commercial firms were also represented

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C.S.F., France

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L. HAMET

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General Electric Research Laboratory, Switzerland

P. KIRSTEIN

I.R.M. Research Center, Yorktown Heights, N.Y., United States

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H.A. NOSSBAUM

Olivetti (Ing.), Italy
R. FAIONI
A. PIZZARELLO

Société d'Applications Industrielles de la Physique, France
L. KALUSZYNER
J. SAVILLE

Société Electronique et Automatisme, France
R. DELEGLISE

Telefunken GmbH, German Federal Republic
R. STARK

8446/mm