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Cavendish Laboratory, Cambridge, March 23-25, 1970

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edited by:
D.H. Lord
B.W. Powell

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* * *

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The following papers were submitted but due to time limitations could not
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Bubble chamber film measurement on HPDs at CERN
W.M.R. Blair and B.W. Powell, CERN.

A system for on-line control of bubble chamber measurements
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Pattern recognition methods for Omega and SFM spark chamber experiments
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Operational experience with the Brookhaven on-line data facility*)
S.J. Lindenbaum and S. Ozaki, Brookhaven National Laboratory.

Operator intervention in the Imperial College HPD system
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Preliminary tests with pictures from Mirabelle
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* * *

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* * *

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*) These papers would have been presented if their authors had been able to
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WIRE-SPARK-CHAMBER SYSTEM WITH ON-LINE COMPUTERS*

W.T. Ford††, P.A. Piroué‡‡, R.S. Remmel,
A.J.S. Smith and P.A. Souder.

Department of Physics, Joseph Henry Laboratories,
Princeton University, Princeton, N.J. 08540, U.S.A.

1. INTRODUCTION

This paper describes an on-line wire-spark-chamber system used at the Brookhaven A.G.S. to measure the $\tau$ decay mode of $K^+$ and $K^-$ mesons ($\pi^\pm K^\pm \rightarrow \pi^\pm \pi^\pm \pi^\pm$). Slightly more than 3 million good events were detected. The data handling system, with a PDP-9 computer interfaced to the PDP-6 computer1) of the Brookhaven On-Line Data Facility (OLDF) may be of interest for the following reasons:

i.) Substantially the same method as that described here is used at present and will be used in the foreseeable future to interface on-line small computers to the OLDF.

ii.) This was the first experiment at the A.G.S. to use both small and large computers on line, and also one of two initial experiments to use the OLDF's job-swapping disk system, with which two on-line users shared both PDP-6 core and processor time with up to 4 off-line users.

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†Permanent address: Synchrotron Laboratory, California Institute of Technology, Pasadena, California 91109
‡‡Present address: CERN, 1211 Geneva 23, Switzerland
iii.) Our design might serve as a prototype or basis of comparison for outside user groups planning on-line experiments, who face as we did the problems of constructing and testing much of their apparatus and software before arriving at the accelerator.

In what follows we shall outline the experiment and the physics behind it, and then discuss the acquisition and processing of the data.

2. **THE EXPERIMENT**

2.1 Motivation

All existing data on $\tau$ decay$^{2,3)}$ are consistent with the linear approximation to the $\tau$-decay matrix element:

$$|M|^2 \, dX \, dY = \text{const} \, (1 + a_\tau \, Y) \, dX \, dY$$

where $a_\tau$ is a constant, and $X$, $Y$ are the usual Dalitz variables. A high-statistics measurement of $\tau$ decays can give new information as to the existence of higher order terms in the matrix element, e.g. $X^2$, $Y^2$, $X^2Y$ terms, as well a more precise value for the slope parameter $a_\tau$.

Such knowledge is interesting primarily for the following reasons:

i.) Test of CP invariance.

Any difference between the Dalitz plots of $\tau^+$ and $\tau^-$ would indicate a CP violation outside the neutral kaon system and hence one which could not occur via the "superweak" interaction.\textsuperscript{4)}

ii.) Test of $\Delta I = 1/2$ rule.

The comparison of the parameter $a_\tau$ for $\tau$ decay with
the corresponding parameter $a_\tau'$ for $\tau'$ decay

$$(K^\pm \rightarrow \pi^\pm \pi^0 \pi^0)$$

tests the $\Delta I = 1/2$ rule, which predicts$^{5,6}$ that

$$a_\tau'/a_\tau = -2.0$$

neglecting electromagnetic corrections.

We hope to reduce the uncertainty in $a_\tau$ by a factor

of $\sim 4$.

2.2 Experimental Arrangement

The experimental arrangement is shown in Fig. 1. $K^+$ or $K^-$ mesons in a charged 3.0 GeV/c separated beam
were identified by a differential gas Cerenkov counter
and 3 scintillation counters (only the last beam counter
is shown in the Figure). Kaons then decaying into 3
charged pions were detected with less than 2% background
by a 3-fold coincidence in an 8-counter hodoscope
octagonally symmetric about the beam. For 50% of such
coincidences, the "unlike" pion (opposite charge to the
beam) was detected by a 16-counter array behind the wide-
aperture spectrometer magnet $D_4$; wire spark chambers were
then triggered with 20 - millisecond dead-time. (All
"like" pions and beam particles missed the rear hodoscope
and spark chambers completely). The 5 chambers (each
with X and Y planes) ahead of $D_4$ measured all 3 pion
directions. Each chamber had $\sim 95\%$ 3-spark efficiency/spark
with $\sim 25\%$ probability for an extra spark. Two of the
chambers were rotated $45^\circ$ w.r.t. the other three to
resolve ambiguities. The six chambers behind $D_4$ served
to measure the unlike pion momentum.
The spark coordinates were digitized via a magnetostrictive-readout and scaler system purchased from Science Accessories Corp. Each event consisted of 90 13-bit words, including hodoscope information. Typically 10-15 events were accepted in each 400-msec A.G.S. burst.

3. DATA ACQUISITION AND ANALYSIS

3.1 Principles of Operation

The data flow is shown in Fig. 2. For on-line operation, digitized information from the experiment was fed to a PDP-9 computer, programmed in assembly language, which buffered the data and reinitialized the spark chamber read-out system. Between A.G.S. bursts the raw data in the buffer was dumped onto magnetic tape, and simultaneously transferred via an interface to the PDP-6, where complete reconstruction of a substantial fraction of the events took place. Summarized results from the PDP-6 concerning the apparatus were printed on a remote teletype in the experimental trailer. More complete results of the on-line analysis were put on magnetic tape and a line printer.

Off-line analysis was facilitated by the fact that the reconstruction program also accepted input either from the data tapes, or from Monte-Carlo-generated data. Written in Fortran, this program was source-deck-compatible among the three installations at which it was used. This made it possible for us to develop the reconstruction programs on the
Princeton 7094 or 360 computer before moving to Brookhaven, and to perform off-line analysis at the B.N.L. 6600 computer during the run. To ease the reading of tapes on these various machines, the tape-record length was fixed at 4080 6-bit characters, an integral number of words for the 7094, PDP-9, PDP-6, CDC-6600, and IBM 360.

3.2 The PDP-9 System and its Interfaces

i.) PDP-9 Performance.

The PDP-9 configuration is now summarized:

- memory: 8192 words, 18 bits, 1 µsec cycle time.
- Extended arithmetic element: hardware multiply, divide, normalize, shift instructions (fixed point only)
- Magnetic tapes: 1 TU-20 unit (36,000 characters/sec at 800 b.p.i.)
  2 TU-55 DEC tapes for storing programs.
- Data Channel Hardware: steals 3 central-processor cycles/word to transfer data between external devices and memory.
- Program interrupt: one level of priority.

As well as controlling the data flow, the PDP-9 monitored the performance of the spark chambers and hodoscopes. For the front chambers the sparks were fitted to tracks; the tracks were then tested to see how many came from a single vertex. The residuals
to the track fits were computed for the 10 wire planes (2 planes/chamber) and stored as histograms in a display scope described below. Also computed and displayed were the raw spark-frequency distributions for all 22 planes and two-dimensional illumination of any two chambers selected by the operator. These displays were used to align the chambers by software, and to expose malfunctions such as edge-breakdown, inefficiencies, etc. Serious error conditions caused error messages to be printed on the teletype. The computing speed (~ 7 events/sec) was more than adequate to process all events, even at the maximum event rate of ~ 15 events/burst.

The PDP-9 system was designed so that it could operate completely independently of the PDP-6; because of this we could take meaningful data even when the PDP-6 was not working. More importantly this independence made it possible to test the PDP-9 system and spark chambers before moving to Brookhaven. This latter feature seems to be essential for outside users, if they are to get a complex apparatus working under the pressure of accelerator schedules.

11) Display Scope

Our display scope consisted of a Nuclear Data 4096-word, 18-bit pulse-height analyzer memory unit interfaced as a multiscaler. The hardware-wired programs of this unit displayed the contents of the
memory on a Tektronix 503 oscilloscope. To the
PDP-9 this device appeared just like a teletype,
raising its flag when ready to accept another word.
Aside from the obvious saving of 4096 core locations,
this device also freed the PDP-9 from the processor-time-
consuming display function.

iii) Interface to PDP-6

An extremely simple interface was possible because
the PDP-6 data-link accepted 6-bit characters, packing
them 6 characters per 36-bit word, and was handled by
the PDP-6 similarly to a magnetic tape unit. Hence we
simply tapped the 7 data signals (6 bits + parity bit)
from the write circuits of our TU-20 tape unit, amplified
them, and sent them to the Data-Link. The data transfer
rate was thus 36,000 characters/sec) the speed of the
TU-20 tape unit. Only three additional lines were needed:

- A D.C. reference signal to eliminate
  common-mode noise.
- A line from the PDP-9 to the Data-Link
  requesting service.
- A busy/not-busy line from the Data-Link
  to the PDP-9.

Note: The Data-Link was designed originally to interface only
Data-Handler(4096-word storage memories) to the PDP-6. However,
the simplicity of interfacing small computers such as ours to it
has led to its use in all scheduled experiments with small
computers on-line to the PDP-6.
3.3 On-Line Use of the PDP-6

i.) Purpose of On-Line Reconstruction.

To operate consistently, the spark-chamber system had to be finely tuned. Chamber performance could severely deteriorate in a few minutes, in ways not discernable other than by complete on-line reconstruction of a large fraction of the data. For example, the rate of spurious sparks could only be found after all tracks had been fitted. Similarly, to determine the properties of the last 6 chambers, we had to reconstruct particle trajectories through the spectrometer magnet. On the basis of such information, adjustments of chamber parameters were made when necessary, and soon enough to prevent any accumulation of useless data.

Needless to say, a large computer with fast floating point hardware was needed for this task, as well as an efficient Fortran compiler. The PDP-6 of the OLDF fulfilled these requirements most satisfactorily.

ii.) The Job-Swapping System.

This system has been described in detail elsewhere, but a few comments from a user's point of view are perhaps in order. (The last half of our data were taken using the swapping system, it having been installed during our experiment.)

The OLDF hardware configuration as of January 1969 is shown in Fig. 3. The disk had 500k 36-bit-word
storage, 17 msec access time, and 13 µsec/word transfer time. The solid lines denote experiments in progress or completed; the dotted lines indicate off-line users testing their programs for "upcoming" experiments. We shared on-line use with the Columbia (Lederman) group, both groups having ~ 25k compute-bound programs.

The Columbia program remained in core, while ours was swapped with off-line users every 10 sec or so. The sharing of CPU time was adjusted independently to keep the computer busy. We usually received ~ 50% of the CPU time, as did Columbia. (Off-line users usually required negligible CPU time.) Because there was always a compute-bound job in core, CPU efficiency was virtually as good as when both on-line jobs resided in core. Typically we analysed ~ 30% of our data on-line, the analysis time per event being ~ 3 second. System reliability, though marginal at first, improved rapidly, till by the end of our experiment system failures were not a problem.

4. CONCLUSION

The system just described is not by any means the most efficient from a strictly instrumentalational point of view. However, its flexibility and simplicity made it extremely practical, and possibly the only system with which our relatively small group could have assembled the experiment in a reasonable time. The use of Fortran for the reconstruction programs meant we did not have to become programming specialists.
PDP-9 assembly language was relatively straightforward, and very efficient in performing the logical operation for which it was used. The PDP-9 was built into the apparatus from the beginning; by the time we got to the A.G.S., it was a familiar piece of equipment. Finally, and perhaps most important, the many components of apparatus and software could be constructed and tested independently, in our own laboratories and computer center, and then carried over to the final on-line configuration with a minimum duplication of effort.

5. ACKNOWLEDGEMENT

The authors wish to thank the many people who made this work possible. Dr. S. J. Lindenbaum, Dr. S. Ozaki, Dr. W. Love, and the staff of the OLDF worked very hard to help us. Mr. J. Gould and Mr. A. Friedman gave essential advice and support concerning the hardware and software links to the PDP-6, and were most cooperative in solving problems as they arose. At Princeton Mr. K. Wright, Mr. Fred Schwarz, Mr. Howard Edwards and their staff built much of the apparatus. Mr. Edward Card fabricated much of the digital electronics. It is with special gratitude that we acknowledge Mr. H. Meusel, who sustained a serious and unfortunate injury while working on our equipment. One of us (PAP) wishes to thank Professor B. P. Gregory and Professor G. Cocconi for their hospitality at CERN.

This work made extensive use of the Princeton University Computer Center, sponsored in part by the National Science Foundation.
REFERENCES

1) For a description of the On-Line Data Facility see the paper submitted to this conference by S. J. Lindenbaum and S. Ozaki.


Fig. 1. Experimental arrangement
Fig. 2. Data flow. A detailed explanation is given in the text. The part labelled on-line was in use during the taking of data. The same reconstruction program was used on-line and off-line.
Fig. 3. The On-Line Data Facility as of January, 1969. The PDP-6 is housed in two trailers depicted at the right of the figure. The experiments on the floor are represented at the left by solid lines. Dotted lines are used to show those experiments preparing programs off-line.
DISCUSSION

H. FAISSNER (Aachen): How many accidental tracks did you typically register in your chamber?

A.J.S. SMITH: Accidental tracks were five percent, I would say. It was a separated beam, the pion-to-K ratio being about ten to one.

H. FAISSNER (Aachen): Did you encounter any ambiguities in connecting tracks before and after the magnet?

A.J.S. SMITH: There was a small amount, we were greatly helped by one feature which is rather amusing. I mentioned that the magnetic field shape of that magnet is terrible, but it provides a significant focusing and large vertical displacements, so by matching up the vertical and horizontal position of the track there were not many ambiguities, less than one percent.

R. BAIRSTOW (RHEL): What was the resolution for two sparks?

A.J.S. SMITH: We managed to get a separation between two sparks of about six to seven clock counts, one clock count corresponded to something between one and two millimetres. The wire separation is 52 wires per inch.

R. BAIRSTOW (RHEL): What was the effect of the magnetic field?

A.J.S. SMITH: The magnetic field was an extremely serious problem to start with, and it was solved simply with brute force by sticking enough iron between the big magnet and our chambers. We put two inches of iron along all the magnetostrictive delay lines.

P. VILLEMOES (CERN): What was the data rate from the experiment?

A.J.S. SMITH: In any given AGS pulse we took about 15 events, and each event had about 90 8-bit words in it.

D. RUST (Argonne): Did you have to re-analyse all events off-line even though 20% to 40% had been analysed on-line?

A.J.S. SMITH: Unfortunately, yes. This is partly due to the Monte Carlo preparation of the events not being sufficient -- one does not know the background and other problems arise during the run. I think that especially for a small group there is not much sense in making the on-line program so elaborate that one can hope to avoid processing these events again. One has to. One should regard the on-line processing more in the spirit that it tells you what is going on.
R. ROSNER (RHET): What sort of output came back to the experimenter from the PDP-6 and how often did such output occur?

A.J.S. SMITH: The main information we got back from the PDP-6 on-line was the efficiency of each chamber and the amount of extra sparking in each chamber. This came back every ten minutes, unless there was something wrong, for example it found that the efficiency of one of the chambers dropped below 93 per cent. In this or in similar cases it would print an error message. We detected some extra sparking in this way, which we could overcome by adding alcohol to the gas.

K.M. SMITH (Glasgow): What resolution was achieved in reconstruction and how long did it take to do it?

A.J.S. SMITH: On the PDP-9, we processed about seven events per second. The reconstruction of the vertex was accurate to about half an inch. On the PDP-6, it was slightly better. Including the reconstruction through the magnet, it took about 300 msec per event.

B. POWELL (CERN): Did you feel that in general it would be useful to have more computer capacity available on-line than that provided at BNL?

A.J.S. SMITH: I would say that what we had was sufficient, but of course the experiment was not very complicated. For a larger experiment it would not have been sufficient. We needed the results of the on-line analysis of about 30 per cent of all events, and this would probably hold for other experiments as well. So, if the reconstruction takes much more time, you need more on-line capacity.

D. WEBSDALE (CERN): Which principal factor limited your event collection rate to about 15 per burst?

A.J.S. SMITH: The main limit was set by the dead time of the chambers. If we made it much less than 20 msec, they would not fire reliably, since we did not have a pulsed clearing field circuit. But the number of useful events per burst was not very much higher.
ON-LINE COMPUTER FACILITIES AT ARGONNE

D. R. Rust,
Argonne National Laboratory,
Argonne, Illinois, USA.

1. INTRODUCTION

On-line experiments have been conducted at the Argonne National Laboratory ZGS since early 1967. We have gained considerable practical experience since that time and we believe that we have been successful in making good use of the means at our disposal. In what follows, I will try to demonstrate some of the results which we regard as successes. First, I will outline our basic philosophy of on-line computing. Then a short description of the system will be given followed by some evaluation of its performance in an experiment; and, finally, there will be a short summary of future plans.

2. OUR VIEWS ON THE CONDUCT OF ON-LINE EXPERIMENTS

First of all, a simple system is desirable to avoid as many complications due to non-physics as possible. In consideration of this requirement, each on-line experiment is assigned its own computer to be used as the experimenter deems best. In this we are carefully avoiding computer links or any kind of time-shared system. We also avoid small computers because there is time available in an on-line experiment to do a great many complex calculations. We are therefore led to moderate sized computers as the heart of our on-line systems. I will presently give a short description of the ones we are using.

Many users from outside Argonne bring their own computers and I will exclude their systems from my talk. Our intention is to make somewhat more extensive systems available but that they be intimately connected with the apparatus as if they were the users' own. It is part
of the basic philosophy that the computer is part of the experimental apparatus. In practice, close contact between the computer and experimenter is necessary over an extended period of time to make this policy work, and users' groups have usually included Argonne collaborators in experiments using Argonne computers. This arrangement has worked for the benefit of all; it has been fortunate for Argonne to have the services of able programming physicists as collaborators. By now a series of programs for on-line use has been accumulated and standard hardware interface procedures have been adopted. As for the matter of scheduling computers, it is no different than the scheduling of other large pieces of equipment. At the end of an experiment a computer is no more built in than a magnet and it can be pulled out the same way.

At Argonne and at most proton synchrotrons, there is a beam cycle characterized by a long beam-off time. The beam at the ZGS is off typically for 2.5 to 3 seconds or about 5/6 of the time. A great deal of computation can be done in this time; in fact, each day contains 20 hours of computing time on the on-line computer. Our moderate sized computers, at least until now, have been able to perform all calculations on all events on-line during the beam-off time. This is the second point of our basic philosophy of on-line computing. It has been accomplished through careful programming and through certain experimental design considerations to be described later. Thus, the only operations remaining to be performed on the data are done on the distributions; for example, background must be subtracted and the acceptance function unfolded at a later time.

This mode of operation is efficient and at the same time satisfying to the experimenter in several ways. First, the computer time is used efficiently. Twenty hours a day on our computers is too much of a resource to waste. Second, the experimenter finds that he must cope with all the problems of analysis in the present rather than being able to postpone them to the time when reprocessing will occur.
Postponements often result in the growth of the complexity of the job, but complications can be avoided sometimes if a problem is recognized on-line. This leads to the third point: the effects of making changes in the apparatus are immediately visible in the final data so that attempts to reduce background, improve resolutions, etc. are considered and carried out rather than dismissed as too risky or not worthwhile. A fourth point, of course, is that any failure that occurs can be recognized before too much bad data is taken; however, this is a characteristic of all reasonable on-line systems. By way of generalization one may remark that the computer used in the manner described above effectively reduces the complexity of an experiment. The final distribution is compared to the incident beam scaler to obtain the cross-section much as early experiments obtained the same by comparing two scalers.

3. SOME DETAILS OF HARDWARE AND SOFTWARE

It is our belief that the procedures described above are not extravagantly expensive and we think that in the long run they may be cheaper than those involving extensive computation on a large machine. I want now to give a short description of the computers we own and a little about our on-line programming.

We have two EMR 6050 computers and one XDS Sigma 2. The Sigma 2 is a common machine for on-line work but the EMR machines probably are not. The first EMR machine was obtained in early 1967, the latter in early 1968. These machines are fairly expensive by modern standards but very versatile. Because the price per function of computers gradually goes down, by 1968 it was decided to get a cheaper machine, the Sigma 2. This arrived in early 1969. Table 1 gives a resume of some important features of our machines.
### Table 1

<table>
<thead>
<tr>
<th></th>
<th>EMR 6050</th>
<th>XDS Sigma 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>16K</td>
<td>16K</td>
</tr>
<tr>
<td>cycle time</td>
<td>1.9 μsec</td>
<td>1.95 μsec</td>
</tr>
<tr>
<td>word size</td>
<td>24 bit</td>
<td>16 bit</td>
</tr>
<tr>
<td>Instruction set add time</td>
<td>~ 100</td>
<td>~ 40</td>
</tr>
<tr>
<td></td>
<td>3.8 μsec</td>
<td>2.25 μsec</td>
</tr>
<tr>
<td></td>
<td>hardware floating point</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>8 priority interrupt</td>
<td>4 priority interrupt</td>
</tr>
<tr>
<td></td>
<td>16 signal lines</td>
<td>disc unit</td>
</tr>
<tr>
<td></td>
<td>64 sense lines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>display scope and standard peripherals</td>
<td>display scope and standard peripherals</td>
</tr>
<tr>
<td>Cost</td>
<td>$250K each with this configuration</td>
<td>$110K with this configuration</td>
</tr>
</tbody>
</table>

Notice that both machines have 16K words of memory. We regard this as a minimum for our purposes. At the time of purchase these machines were among the fastest available. Both speed and core capacity together allow a great deal of on-line computation. The EMR has a rather extensive instruction repertory for this class of machine plus the feature of hardware floating point instructions making it a versatile machine; therefore it is suitable for the more complex experiments. Sigma 2 is faster and more suitable to simpler experiments with high data rates.

The programming for these machines has been done almost exclusively in machine language to achieve the best speed and efficiency. Kinematics programs and other calculational programs are the only routines that are sometimes written in FORTRAN. To many people, machine language programming is distasteful. It is another instance of our good fortune...
that we have had sensible machine language programmers who have developed some very effective on-line programs.

4. PERFORMANCE SO FAR

The three computers since their arrival have been or are being used in a total of eight experiments. It is interesting to note that all eight involve the measurement of the polarization produced in some reaction. Three of these eight have been wire spark chamber experiments; the others have been purely counter experiments. By nature, the wire spark chamber experiments demand more of the computer, and since they happen to be the ones I am closely connected with, I will specialize and talk about them only.

First I would like to suggest that it is advantageous to design an experiment to lessen the amount of computation. This is, of course, not always possible but such a consideration may make a large difference in computing time. We have used the following techniques among others:

a) The use of a magnet with a good uniform field may eliminate the need for ray tracing or some other complex technique. In our experiments we have been able to use a uniform field approximation corrected by a polynomial function of a position coordinate.

b) Spurious tracks due to the long memory time of a spark chamber relative to a scintillation counter can be reduced by reducing the effective area of the spark chamber. This can be done by placing a hodoscope in the back of the chamber. All tracks are rejected which are not within the area of the counter which has a count in coincidence with the trigger.

Another important consideration is the display capability which allows the experimenter to see what is happening. Displays are of two basic types: chamber spark and fiducial displays, and distributions of
data. Chamber displays are for recognizing types of malfunctions in
the chambers and are usually important only when checking out the equip-
ment. These chamber displays are available at all times during the
experiment, however, in case something needs to be checked. The dis-
tributions contain monitoring information such as chamber efficiency and
target distribution, and also the results of the experiment such as a
missing mass plot or a distribution of events in t. Displays are selected
and controlled by the 64 sense lines of the 6050. The program operates
the display so that not much time is taken away from calculations.
Displays are operated in a background mode at a high frequency if no
calculations are being done and at a much lower frequency when calcula-
tions are going on.

The layout of apparatus used to study the reaction $\pi^+ + p \rightarrow K^+ + \Sigma^+$
as well as elastic scattering of $\pi^+$ and $K^+$ mesons on hydrogen is shown
in Fig. 1. The wire spark chambers are in groups of four gaps labelled
K1, K2, K3, K4, and $\Sigma$, 20 chambers in all. The "K" chambers measure
the momentum and angle of the forward scattered particle and the "$\Sigma$"
chambers measure the angle of the recoil particle. From this you can
judge the level of complexity of the experiments done using our system.

I will now illustrate some of the operations performed on the
data by showing slides of a few of the displays. First Fig. 2 shows a
general flow diagram of our program and indicates where displays are extracted,
Fig. 1.

Layout of a typical experiment.
A simplified flowchart of the on-line calculation programs

The display of chamber data after the final track filter is shown in Fig. 3 for the "K" series of chambers of Fig. 1. Both fiducials and sparks plus two lines of reference are displayed. The line on the far left is drawn through the center of the target parallel to the chambers. (All "K" chambers are parallel to each other as shown.) The dense part of this line is the projection of the extent of the target. The vertical line of dots near the middle of the picture indicates the center of the magnet. The horizontal views of the K1 and K2 groups of chambers are between the target and the magnet; the K3 and K4 groups are on the other side of the magnet; and on the right are the vertical views of the K1 and K4 groups. In each group you see fiducial marks at the top and bottom of the active area and sparks within the active area of the chambers.

Next a target distribution is shown in Fig. 4 as an example of a monitoring display. It always has good statistics as you can see from the error bars.
Fig. 3 Display of chamber sparks and fiducial marks.

Fig. 4 Display of distribution of points of origin of scattered particles in target.
Figure 5 shows a missing mass distribution for pp collisions at 4 GeV/c with a forward going proton momentum analyzed. The large peak is at a missing mass corresponding to the mass of the other proton. This is the data from one run only to indicate how much can be seen and checked with complete analysis on-line. I resisted the temptation to show a final sum of many runs.

Adding the criterion of a recoil particle occurring at the correct angles for elastic scattering adds two constraints and results in the elimination of background. A plot of the events satisfying these constraints as a function of \(-t\) is shown in Fig. 6. This is the data from the same run as Fig. 5. There are a total of 1276 events in this plot and the \(t\) scale runs from \(-0.5\) to \(-3.5\) (GeV/c)\(^2\). The plot is altered by the shape of the acceptance function which cuts off below \(-0.7\) and above \(-2.6\) (GeV/c)\(^2\).

There are many more displays including some two dimensional ones where histograms in one variable are displayed in slices in another variable. A description of them would take too long.

The time it takes to perform calculations is such that about twenty events are analyzed per pulse but not all go all the way through the programs. Probably around ten events going through all the programs could be calculated per pulse. This has been a satisfactory rate for the experiments done so far using this system.

I must stop here to acknowledge the contributions of some collaborators. Most of the work connected with the Argonne system was not done by myself. The extensive programming effort for wire chamber experiments was by Carl Akerlof of the University of Michigan, and John Lales, formerly of Argonne. R. A. Lundy was in charge of computer planning during most of the period of development of our system.

5. FUTURE PLANS

Future experiments will involve a more complex topology and it is unclear at the moment if there will be sufficient time for all of the
Fig. 5  Display of a (missing mass)$^2$ distribution obtained with protons of 4 GeV/c incident on protons and one outgoing proton analyzed. The scale ranges from 0.5 to 3.5 (GeV)$^2$.

Fig. 6  Display of a distribution in (momentum transfer)$^2$ for pp elastic scattering at 4 GeV/c. The scale ranges from 0.5 to 3.5 (GeV/c)$^2$. 
more complex calculations. We are trying hard to perform all calculations as we have done in the simpler experiments. One improvement in the computers themselves will be the addition of more extensive memory, since it is very cheap these days. This will probably be a necessary step in more complex experiments.

In the long run, new computers will be necessary. It appears that developments in integrated circuit technology will reduce the cost of the moderate sized computers drastically. The word "moderate" may be applied to more extensive machines in the future, but the kind of machine appropriate to on-line data collection will probably always be the kind where the logistics of interdevice communication are as simple as possible. Although we are interested in all types of computer development, we are hoping that a lower cost for more extensive and faster machines in the future will allow us to continue our basic plan of operation, because it is so satisfying and productive to do physics this way.

* * *

REFERENCES

A. WERBROUCK (Torino): Can you explain in absolute terms, for example in dollars, what you mean by inexpensive memories?

D. RUST: The memory that we bought with our EMR 6050 costs $58,000 for 16 K, we can buy the same for at most half the price now.

A.J.S. SMITH (Princeton): I would like to mention that for the Brookhaven on-line data facilities, a 64 K 36-bit memory with two microsecond cycle time was purchased for $70,000, which is really cheap.
WIRE SPARK CHAMBER DESIGN AND PERFORMANCE USING FET, CAPACITOR READOUT

T.A. Nunamaker and M. Neumann,
The Enrico Fermi Institute, University of Chicago,
Chicago, Illinois 60637, USA.

Presented by R. Winston.

1. Introduction

The continuing motivation for this readout system is its high sensitivity and its immunity to magnetic fields. Readout sensitivity is necessary for two reasons; first for good multiple spark efficiency; and second to keep the level of ionization within the spark chamber low in order to reduce the possibility of refiring on old tracks when operating at high spark rates.

We operate these chambers with high voltage driving pulses having a decay time constant of 90 n sec., and under these conditions the level of ionization in the spark is $10^{-7}$ to $10^{-6}$ coulombs. This level of ionization is considerably lower than that required by other currently used types of readouts, and corresponds to a gas gain of the order of $10^{10}$ to $10^{11}$. Gas gains of $10^{7}$ would be enough for efficient readout, however we have not obtained good chamber efficiency at this low a gas gain. Possibly shorter high voltage driving pulses or other gases would be more suitable.

2. Chamber Construction

The chambers have three electrodes; the center electrode has an aluminum foil pulse electrode 0.0005 inches thick.

*) Work supported by The National Science Foundation.
while the outside electrodes form and X and Y readout grid of 0.0004 inch diameter copper wire. The wire spacing of the readout grids is 1 mm, and the spark gap is 10 mm. The readout wires are soldered to a printed board which has a 72 pin connector for each group of 32 readout wires. The remaining connector pins are used for the readout of data. This printed board and its connectors are a permanent part of the spark chamber, while the data memory cards, which carry all the active circuit components are plug-in's.

Presently three functionally identical data memory cards are being used; they differ only in physical size. Card number 1, Figure 1, is made with standard discrete components and measures 15 cm x 13 cm and is about 1.5 cm thick. Card number 2 is also made with discrete components; however it has been made from four small boards joined to a common connection board. Its size is 9.5 cm x 8.2 cm and is 3 cm thick. Card number 3 uses a special hybrid circuit made for us by the Burroughs Corp. and a discrete RC filter network; it measures 10 cm x 9 cm and is 1.5 cm thick. We hope to design a new hybrid card that will be considerably smaller than any of our present cards.

It is worth noting that the electronic volume would be reduced considerably by reducing the wires handled per card from the present 32 wires to 16 wires, however our present design may be used with a wire spacing of 48 wires per inch provided the thickness of the data memory card is kept below 1.6 cm.
3. The Basic Circuit and its Operation

The capacitor memory FET switch circuit is shown in Figure 2. This circuit is similar to the original circuit proposed in 1968; the differences are the use of a clamp diode (for cost reasons only) instead of a zener diode, along with an additional RC network between the spark chamber wire and the memory capacitor. The function of this additional RC network is to reduce the magnitude of the transient current through the clamp diode. This in turn reduces the peak transient voltage across the FET. The gate resistor of the FET allows an N channel FET to gate negative signals and assures a fail safe situation, i.e. should a gate short occur in the FET the drive voltage to the other 31 common circuits will not be effected. The 150 ohm resistor in series with the FET discharge path improves its transient voltage tolerance from roughly 70 to 300 volts.

As with magnetic core readout a quenching agent in the gas is needed to prevent spark current ringing. We use a standard gas mixture of 90% Ne, 10% He with one half the gas passed through an ice bath of I Proponal alcohol. If more alcohol than this is used one observes widening of the discharge on the anode wires.

The data scanning is organized to readout 32 wires at a time, and scanning proceeds at a 1 MHz rate until data is found. The address of the spark and its width are
determined by the data scanner and sent to an on-line computer or buffer memory. After all the data has been transferred the scanner goes into a continuous erase mode, in order to keep all the memory capacitors completely discharged until the next event is found. The scanner is connected to the spark chambers by 6 m long cables as it is desirable to keep the readout electronics out of the magnet; however all scanner controls and indicator lamps are in a remote control box which may be located at any convenient location. All electrical connections between the spark chamber and the scanner are through transformers to assure freedom from ground currents.

4. Performance

Three 25 cm x 25 cm chambers with a total of 1,500 wires readout have been tested with cosmic rays and operated in a proton beam at the University of Chicago's Cyclotron. Spatial resolution, Figure 3, of less than one mm FWHM was observed by comparing one chamber against the other two, and we conclude that the spatial resolution of these chambers is identical to that obtainable with magnetic core read-out chambers. The spread, i.e. the number of adjacent wires that fire, varies between 2 and 5 and may be controlled by the high voltage pulse width and magnitude. The high voltage pulse used to drive the chambers is around 4.5 K.V. at the chamber and has a 90 n sec. decay time constant. Efficiencies of better than 99% are readily obtained.
During the course of these tests roughly $30 \times 10^6$ individual sparks have been produced, and during this time 4 FET's have become leaky and required replacement. Components were not pretested.

These chambers, shown in figure 4, were used to measure efficiency and spatial resolution of some of our film supported wire proportional chambers; during the course of these tests we learned to appreciate their low level of noise as our proportional chamber was only 25 cm from the spark chamber.

5. Acknowledgment

We would like to thank Professor H.L. Anderson for his interest and support of this work, and D. Jensen for his programming effort that made the final testing possible.

* * *

REFERENCES

Fig. 2 Memory circuit
FET SPARK CHAMBER
COSMIC RAY RESOLUTION

FWHM = 0.97 mm

Fig. 3 Cosmic ray resolution
DISCUSSION

P. Osman (Westfield College): How does the cost of capacitative read-out compare with the cost of core read-out?

R. Winston: It is almost identical. Right now it may be about 20% to 30% higher, but by using hybrid circuits it becomes quite comparable, about $1 per wire.

H. Grote (CERN): Do you intend to build bigger chambers, and if so which problems do you foresee?

R. Winston: That is a question of the sort of physics one wants to do with these chambers, and right now I do not know of any specific experiment for them. This method was simply developed to see if it would work.

G. Jarlskog (Lund): Your statement of needing a 1 cm plane spacing for the Charpak chamber is clearly dependent on your choice of gas mixture.

R. Winston: Yes, the statement is true for the standard He-Ne at normal pressure and temperature. Certainly one can go to a different mixture or higher pressure, but that makes life hard.

H. Faissner (Aachen): I would like to amplify on your remark about the connection between wire separation and resolution. You can do better than the value of a/2 which you quoted, if you run the chamber under the following conditions: Whenever a particle passes within ± a/4 of a wire, just that wire fires and if it passes to within ± a/4 from the centre between two wires, both wires fire. If one then assigns to one-wire events the wire position, and to two-wire events the centre position, the maximum error is clearly ± a/4. In practice things are slightly worse, mainly because of the finite extent of the discharge but we have experimentally achieved a resolution of a/3.

E. Quercigh (CERN): Are you sure that the idea of using a capacitative memory for spark chambers is only two years old?

R. Winston: The idea to use a capacitative memory is older, but how to do it practically, using a field effect transistor, is two years old. One needed a high impedance switch.
1. Introduction

The FOCUS system is a small-scale multi-access data-acquisition and file-handling system. It has been designed and implemented at CERN on a CDC 3100 computer which is connected to CERN's central computers, a CDC 6600 and CDC 6500. The 3100 is also connected by a CERN-built data link network to some remote data-acquisition computers which are on-line to spark and wire chamber experiments.

The system was developed in the face of a need at CERN to provide fast turn-around for sample calculations on data produced by such experiments. The data from these experiments is collected directly in a digital manner by small on-line process control computers. In recent years developments in particle detection techniques have lead to considerable increases in the quantity of data collected, and with it a need for fast processing of some of this data in order to check against undetected malfunctions in the detectors or the data acquisition equipment. The small on-line computer generally does not have enough power to perform these calculations, and the provision of bigger direct on-line computers is too expensive.

Up to now two solutions have been tried at CERN for providing fast processing of data samples from these experiments. The first and most common is to transfer data via magnetic tape from the data acquisition computers to the laboratory's central computer installation, where it is processed as a high priority job in the normal batch processing work load. This method known as "bicycle on-line" gives a turn-around of one hour to three hours at the cost of some inconvenience to the experimentalists. A second method of providing turn-around is to connect the remote computer directly to the central computing system by a data link. This method gives immediate processing but because of
basic limitations in the flexibility of the CERN batch processing system, it involves the permanent allocation of a significant part (≈ 20000 words) of the central computer main memory to a resident program whose central processor utilisation may be very low, due to low average mean experimental data rates.

The drawbacks in these two methods of approach lead to the development of a third method, which provides the necessary multiple access facilities to the central computer system via fast data links, but which allows the processing to be efficiently handled by the central computers as part of the general batch work load. This solution is the FOCUS system.

2. **FOCUS**

FOCUS provides multiple access I/O facilities on a CDC 3100 computer with limited disk storage. The 3100 computer is an extension of the central computer system and by means of its hardware connections to the central computers and the experimental halls, acts as an I/O buffer between the remote data acquisition machines and the main computers. As raw data is accumulated at the remote computer a sample of it is transmitted over a data link and accumulated on disk storage in the 3100. At suitable intervals a job file consisting of the experimental data file together with a processing program file is transferred at high speed from the 3100 to the central computer input job queue, where it is processed in due course as a high priority job. After execution results may be transferred from the central computer to FOCUS where they may be accessed by the experimenter.

These facilities have been provided in FOCUS within the framework of a general purpose, multi-access file handling and remote job submission system. To its users FOCUS is a file handling system allowing several users simultaneously to create accumulate and manipulate information files, be they program files, data files or sample remote data files. All users access the system from teletype consoles from which they are provided with:
i) on-line storage of active users' program and data files,

ii) a simple permanent file scheme,

iii) on-line creation manipulation and modification of users' program and data files,

iv) transmission of data between the 3100 and the remote acquisition computers via data link connections,

v) priority access to the central computer system for job input files created through FOCUS,

vi) the transmission of job output files from the central computer to remote users.

To the central computer FOCUS is an input-output station similar to a combined card reader and line printer. Job input files received through FOCUS are added to the queue of waiting job files received via the central computer's card reader. Jobs are then processed in sequence depending on the priorities assigned to each input file. Files created during job execution as remote output files are sent to the 3100 instead of the central computer's line printers.

This method of implementation was chosen so as to involve very little development directly in the central computer, with as much of the development as possible carried out in the 3100. In this way disruption of the central computer operation during development was kept to a minimum.

3. **System Hardware** (Fig. 1)

The system has been implemented on a CDC 3100 computer with 32K of 24 bit words. Three disk pack drives give a direct access capacity of 24 million characters, with 3 20Kc tape units providing back-up storage. The system has a card reader and a line printer, and the teletypes are connected via a CDC multiplexor with current provision for 12 consoles. Connection to the CDC 6600 and CDC 6500 central computers is via standard CDC channel to channel adaptors.
The remote data acquisition computers are connected to FOCUS by a network of fast data links designed and constructed at CERN. This network is controlled at the 3100 by a Data-link Synchroniser (DLS). The DLS can control four high speed data links to remote sites (up to 3 km distant) and each link is terminated by a Data-link Terminal (DLT) which in turn can be connected via a standard interface to four remote computers located at distances up to several hundred metres from the DLT. Thus one DLS can connect as many as 16 remote computers to the 3100. The data-link system transmits data and status as 12 bit parallel bytes and has a design speed of up to one million bytes per second.

The hardware thus exists to enable the 3100 to act as a node machine of a network connecting many remote computers to the central computing facility and the FOCUS software system is designed to implement this capability.

4. User Access to the System

It does not fall within the scope of this talk to give details of the internal structure of the system software. A CERN paper describing this is available (Ref. 1). I will only attempt to describe the way in which a user makes use of the system.

FOCUS facilities are accessible to users via a series of commands entered from a teletype console. The system maintains a list of authorised users identified by a name, number and group code in a way compatible with the conventions of batch users of the central computer system. To obtain access to the system a user types in the LOGIN command on his teletype, specifying his name and other identifiers, and if he is known to the system, he is logged in and his permanent files and all system facilities are made available to him. Commands are provided for system access, file management, file manipulation and editing, for job submission to the central computers and for the accumulation of sample data from remote computers via the data links.
Each command corresponds to a service program which is stored permanently on disk, and commands which can be used by several users at once, are coded re-entrantly so that only one copy is needed in core. On typing a valid command name, the appropriate service program is transferred from the disk and relocated in core if a copy is not already loaded. Commands are typed in free format and consist of the command name followed by one or more parameters which are usually file names e.g.

```
RENAME JOHN MARY
```

This command "renames" the file named JOHN by the new name MARY. Users are informed of illegal parameters and prompted for missing parameters. This makes the system very easy to use but at the moment it also makes the system extremely verbose, which can be very annoying to an experienced user. Optional reduction in teletype output is currently being provided.

There is no point here in going into details of the commands provided by the system. In general they follow a pattern fairly common in systems of this type. The command system is extremely flexible and modular and within reason there is no limit to the provision of new commands to expand system facilities.

It is of interest however to give more details in the area of remote job submission to the central computers, and to communication with remote computers.

5. **Remote Job Submission**

Remote job submission is provided by means of two FOCUS commands SEND and STATUS. By using the SEND command, a user can transfer to the central computers, a string of FOCUS files which are combined into one job file and entered in the central computer's input job queue. Such a string of FOCUS files might typically consist of a control card file, a program file and a data file, although much more complex combinations are possible within the limits of the central computer job control language. In addition the user specifies at the time he sends the job, which of the job output files he wishes trans-
ferred back to FOCUS on job completion. After the job has been sent
the user in FOCUS is free to continue with other FOCUS work while
waiting for job execution and he is notified by the system when his
output files are returned.

The command STATUS permits him to enquire as to the status
of his job in the central computer while he is waiting for job
completion.

6. Remote Computer Interface

At the moment the facilities provided in the system for
transferring data between FOCUS and the remote experimental computers
are of a very simple nature. Two FOCUS commands, DATIN and DATOUT,
are provided to respectively input and output a file between FOCUS and a
remote computer. In addition a utility command is provided for for-
matting an output file in a way suitable for displaying at remote
computers equipped with Tektronix 611 storage display tubes.

From the point of view of FOCUS the remote computers func-
tion purely as another I/O device. DATIN allows a user at a teletype
near the remote computer to accumulate data from his machine in a
specified FOCUS file, prior to sending it to the central computer for
processing. The complementary command DATOUT enables an output file
to be sent back to the remote computer.

The main complication in implementing these facilities lies
in the fact that most remote computers are data acquisition computers
operating in a stringent real time environment. Thus the FOCUS data
link software is designed to operate in conjunction with the remote
computer software in such a way that the link to FOCUS operates only
when more important activities in the remote computer permit, and the
FOCUS transfers can be interrupted and if necessary terminated, at
any time a higher priority activity at the remote site requires it.

7. Current System Status and Experience

The system has been operational for about a year and is
currently running 4 hours a day connected to the CDC 6600, for general
purpose file handling and remote-job-submission work. This availability will shortly rise to about 8 hours a day prime shift as other development work is moved off the 3100 leaving it to be dedicated entirely to FOCUS.

11 teletypes are currently available to users and some 80 users out of a CERN programming population of about 450 are entered in the system, of whom some 20 - 30 make regular use of the system.

Currently two remote computers, an IBM 1800 and a Hewlett Packard 2115 are connected via the data link and I had hoped to be able to present some details of operational experience with the data-links on-line to the wire chamber experiment operating on the IBM 1800. However various problems, including the limited availability of FOCUS due to pressure of other work on the 3100 and reorganisation of data acquisition hardware or the 1800 due to the introduction of the new CAMAC standard electronics have caused some delay. Nevertheless the data link software and hardware at both the 3100 and the 1800 are available and have been shown to be reliable at least in test runs. It is hoped that the first run on-line to the experiment will take place towards the end of April.

Reference 1. Ball D., Blackall P.M., Gerard V., Macleod G.R., Marcer P.J., Palandri E.M.  
FOCUS - A Remote Access File Handling System On-line to a CDC 6000 Series Computer.  
CERN DD/CO/69/9, November 1969.
FIGURE 1

BLOCK DIAGRAM OF HARDWARE CONFIGURATION
DISCUSSION

H. FRESE (DESY): How do you manage a 1 M byte/sec rate over a distance of 3 km?

M. PALANDRI: We send off a burst which is buffered to some extent in the DLT by a small hardware buffer. I am not sufficiently familiar with the hardware to say more.

H. FRESE (DESY): What is the actual rate you can handle with the writing speed of your disks?

M. PALANDRI: The maximum transfer rate on the disks we have is about 180,000 6-bit characters per second. You have to add access time to that, so you end up much lower than that. This link system was designed not only to run with a 3100 but as a piece of hardware that would be available for many years to come.

R. ROYSTON (SCS): What is the physical form of the connection between the DLS and the DLT?

M. PALANDRI: It is a thick cable of twisted pairs.

R. ROYSTON (SCS): Which data rates have been achieved in operation?

M. PALANDRI: It has been tested by the engineers at 1 M byte/sec, but this we cannot achieve in operation. There we run it at 150 K bytes/sec.

A. WERBROUCK (Torino): What is the priority arrangement for the remote terminals and computers?

M. PALANDRI: Basically the computers are served on a "first-ask-first-served" basis.
THE DATA HANDLING SYSTEM FOR THE
OMEGA AND THE SFM PROJECTS

H. Davies, R. Nierhaus, P. Vilemoes and P. Zanella
CERN, Geneva, Switzerland

1. Introduction

The Omega and the Split Field Magnet (SFM) projects involve
the construction and operation of two large magnets which will be used
over a number of years for a series of experiments using different
arrangements and types of electronic detector. The Omega project,
which will be used for experiments at the CERN PS, is described in
Reference (1) and a preliminary discussion of the data handling pro-
blems is given in (2). The Split Field Magnet project is described in
(3); it will be used for experiments at the CERN Intersecting Storage
Rings. Both projects will require on-line computers for data taking
from experiments and during their lifetime will generate a large amount
of data to be processed. Because the structure of this data and many
of the problems related to its processing depend on the basic apparatus
and are independent of the particular experiment being carried out, it
has been decided to incorporate a data handling system as an integral
part of each project. Because the data handling problems of the two
projects are similar, they are being solved by a single group.

This paper describes the data handling problems of the two
projects, the solutions being adopted and the proposed modes of oper-
ation to be implemented.

2. The Projects

The Omega magnet is shown in Figure 1. It will have super-
conducting coils and will be surrounded by a heavy iron shield, which
has a number of removable blocks. The field will be 18 kGauss in the
centre of a useful volume of 14 m$^3$, (2m high and 3m in diameter). It
is expected to go into the West experimental area and to begin oper-
ation in 1972, and during the first 1 to 2 years optical spark chambers
will be used as detectors, but later it is expected that filmless
detectors will be used. The initial choice of optical chambers is based on the experience gained with the CERN-ETH Zürich-Imperial College London magnet spark chambers (Reference (4)) which has a layout similar to the one planned for Omega.

The Split Field Magnet is shown in Figure 2. It is a magnet system to be placed around intersection region I4 of the Intersecting Storage Rings (ISR). It is designed such that its net effect on the circulating proton beams is 0. The bottom part of the Figure shows the SFM seen from above. On one side of the intersection the field is +12 kGauss and on the other it is -12 kGauss thus deforming the primary beam paths into an S-shape and providing momentum analysis for the interaction products. On each side of the central magnet is placed a compensator magnet which brings the beams back to their correct orbits. Electronic detectors, most probably Charpak chambers which have a very high time resolution, will be placed inside and outside the magnets but they have to be outside the beam vacuum chamber. Each arm of the magnet has an aperture 5m long, 1m high and 2m growing to 3m wide at the centre giving a volume of 25m$^3$. It will have conventional coils and is expected to be operational in 1972. Experiments without the magnet will, however, start in 1971 when the ISR will begin operation.

Estimates of the data rates and the structure of the data from the detectors are given in Table 1.

| TABLE 1 |
| Data Rate Estimates |

1 coordinate = 16 bits

<table>
<thead>
<tr>
<th>Omega</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CPS cycle</td>
<td>~1.5 sec.</td>
</tr>
<tr>
<td>Burst duration</td>
<td>~0.3 sec.</td>
</tr>
<tr>
<td>Coordinates per burst</td>
<td>10000 - 45000</td>
</tr>
<tr>
<td>Coordinate rate during burst</td>
<td>33000 - 150000 coor/sec.</td>
</tr>
<tr>
<td>Average coordinate rate</td>
<td>6700 - 30000 coor/sec.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SFM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No burst structure</td>
<td></td>
</tr>
<tr>
<td>Continuous coordinate rate</td>
<td>4000 - 20000 coor/sec.</td>
</tr>
</tbody>
</table>
The values in Table 1 are estimates based on a particular model and serve as guidelines only, however, they do not depend too much on the model used. The fact that SFM data are continuously produced means that the data buffering problems for SFM are simpler than those for Omega.

The number of events per year from Omega depends very much on the type of experiments to be performed, but the amount of pictures per year which is technically possible is estimated to be about 12 million, while the number of triggers from a filmless detector may be about 5 times higher, i.e. 60 million per year, but this number may well be smaller because of physics limitations. Averaged over the different types of experiments, the number of good events is expected to be one quarter of the pictures and triggers thus giving estimates of 3 million good film events and about 15 million good triggers.

From SFM the number of triggers could be of the same order of magnitude as for Omega but reliable estimates are very difficult to obtain at this stage of development of the project.

3. **Data Handling Requirements**

The data handling requirements of the two projects cover a very wide range from checking the performance of the experimental equipment to full analysis of the data on a production scale. Omega experiments will be carried out by outside groups as well as by CERN groups and outside groups will be expected to process their data on their own computers. Although only a small proportion of the data will be analysed at CERN and so only the computing capacity necessary for the data acquisition phase and for the analysis of this fraction of the data is required there, an important fraction of the data processing facilities will have to be provided at CERN.

The list of jobs which have to be done by the data handling system is as follows:

a) **Film Measurement** As mentioned above, about 3 million good events could be recorded during each year that optical spark chambers are used inside the Omega magnet, and FSD capacity for the CERN share of these
pictures and control programs will be needed to measure them. The film format and the type of track patterns to be measured is expected to be similar to those of the current series of CERN-ETH Zürich-Imperial College experiments (Reference (5)).

b) **Equipment Checking and Fault Finding** for on-line experiments. Diagnostic programs and programs for the determination of experimental parameters are required. The diagnostic programs must include testing facilities for the principal electronic detectors and other input devices such as counters, pattern units* and digital voltmeters and must have error tracing capabilities. The most important experimental parameters to be measured are the efficiency and resolution of the detectors and alignment checking programs would be necessary during their installation.

c) **Data Acquisition** involves control operations, read-out of digital coordinates from the experimental equipment, buffering this data and storing it on magnetic tape for processing later. The system must be able to operate flexibly and reliably for long periods and must provide samples of data for checking as described below.

d) **Sample Checking** The data handling system must be capable of providing rapid feedback of information which can be used to tell if the experiment is proceeding as planned and if the equipment is working properly, and which also enables the physicists running the experiment to make adjustments of parameters or equipment settings in order to improve the quality of the data. The data handling system will do this by carrying out checks on samples of data at two levels. Firstly, routines similar to those used in the setting up phase of the experiment will be used to check the performance of the equipment. Secondly, complete processing of a sample of events through the stages of track and event recognition and geometric and kinematic reconstruction will give intermediate information showing the quality of the raw data and give an indication of the physics conclusions to be found when all the data is processed later. It is impractical to process even a very small sample of the data simultaneously with its acquisition because

* Pattern units on registers containing information on the status of the equipment which can be interrogated by the computer.
the processing time per event on existing computers is much greater than the time between events, but the sample calculations provide a means of regularly showing how the experiment is progressing. Because the physicists will want to change their criteria of judging the experiment and to examine different parameters from time to time, the system should allow frequent changes of the sample analysis programs and distinguish clearly between these and the data acquisition programs so that the latter will continue to run and store all the available data even if an error in a sample analysis program causes it to fail.

e) **Full processing of the CERN share of the data** Programs have to be provided to carry out pattern recognition for both film and filmless events, geometrical and kinematic reconstruction and post kinematic analysis.

f) **Display of results and events** Graphic display facilities are required for showing the results of sampling calculations during data taking, for visualisation of filmless events, and for event recovery procedures in both film and filmless experiments.

Furthermore, the use of interactive graphic displays for the development, testing and assessment of new pattern recognition methods is considered indispensable for making this development sufficiently fast to cope with the requirements from different experiments.

g) **Simulation of Experiments** Programs are required for feasibility studies of possible arrangements of experimental equipment and ways of operating it. The output from these programs should have a form such that it may be used instead of the real data without requiring modifications to the processing chain for the real experiment, thus also allowing development and testing of the processing chain before real data is available.

All the requirements listed above will involve the development of a large amount of software, and this will in turn lead to demands for efficient program development facilities.
It is expected that when the projects are fully operational, data taking on a production basis will occupy about 25% of the time (taken over a period of several months). The rest of the time will be spent in equipment development and setting up new experiments.

4. Principles of Implementation

After the description of the data characteristics and the requirements of the data handling system in the previous sections, this section will describe how this information has determined the design of the system.

The fact that optical spark chambers will be used only during the first one to two years of Omega operation has lead to the abandoning of a first idea of constructing a special HPD for Omega. Instead, the more economic solution of modifying the CERN HPD 1 such that it can measure the pictures has been adopted, and the modified machine will remain connected to a CDC 6000 computer.

During experimental runs a powerful computer with a large memory must be available on-line to perform sampling calculations for up to two simultaneous experiments and to provide enough buffer space for storing the data for the entire burst from Omega at the highest data rates. However, because any experiment is expected to do production data taking during only 25% of the time and because the setting up and testing of new experiments or detectors are activities of a kind which will prevent the use of the on-line computer for other activities, it seems natural to attach a small computer to each of the Omega and SPM detectors and connect these via data links to the more powerful computer, thus freeing the latter from the interference from the setting up activities. This arrangement will lead to a more economical use of the total system. The actual locations of the two magnets, they will be about 0.5km away from each other, also supports the choice of attaching a small on-line computer to each of them.

For the more powerful computer there are essentially two possibilities, it could either be a fraction of a very large computer at the CERN central computer installation or it could be a dedicated
medium-sized computer. If it is a fraction of the central installation it may either be connected to the FOCUS network (Reference (6)), or have a private data link to the central installation.

The FOCUS solution must, however, be discarded, because FOCUS is not designed for providing the buffer space necessary for the data acquisition at the higher rates from Omega, also the amount of sampling computations required by the projects is on the limit of the FOCUS design aims.

The private link possibility does not involve the limitations of FOCUS, but has a number of disadvantages both for the projects and for the central installation. For the projects, fundamental changes to the system may have to be made when major changes are made in the central computer installation, and this may occur several times during the lifetime of the projects. The disadvantages for the central installation are that the existence of such permanent links places heavy limitations on the possibilities for modifications and development of its system, and that a large fraction of memory must be permanently assigned to the Omega and SFM sampling programs.

A dedicated machine thus seems the best solution, especially if it can compete economically with the other possibility. For the tasks required by the projects, especially the running of the pattern recognition programs, which use mainly integer arithmetic, tests have shown that a medium-sized 32 bit machine is more economic per event than the general-purpose, long word length computers at the central installation, and remembering the number of events to process estimated in section 2, it is seen that there will be a sufficient load to keep it busy full time.

There are several further advantages to be gained by using a dedicated computer, the most important of these is related to the use of displays. The envisaged use of interactive graphic displays for rescuing of failed events and for development of pattern recognition methods will represent an extensive use of the display equipment, so it is most practical to have it attached to a computer which will have a stable configuration during the lifetime of the projects,
especially when the pattern recognition programs will be run on the same computer.

We have thus arrived at a system layout as shown in Figure 3 with a small computer attached directly to the experiments and connected to a medium-sized main computer via data links.

5. Modes of Operation

In the system of Figure 3 three distinct modes of operation can be separated out. Which mode is chosen at any particular time depends on whether experiments are running or not, and on their data rates. The three modes also correspond with three phases of implementation.

Mode 1

No experiment is in progress. The on-line computers are used for setting up and check-out of new experiments, the main computer is used for processing of events written on to tape during earlier experiments, general program development, and for display activities. The off-line event processing will mostly consist of the pattern recognition stages of the processing chain for which the computer is best suited, while it is not yet clear how much of the geometric and kinematic reconstruction which contain many more floating point computations, will be shared between the main computer and those of the central installation. The programs will however be able to run on both.

Mode 2

An experiment is in progress at one or both of the magnets, and the data will be collected and stored on magnetic tape by the on-line computers. Samples of data will be stored on the disk of the on-line computers from time to time and used by the basic equipment checking programs. Other samples of data will be sent to the main computer via the data link for more complete processing; the results of these calculations will be either displayed at the main computer or sent back via the data link to be displayed in the experimental area.
Mode 3  The data rate from Omega is too high for the on-line computer to buffer the data so it will be sent from the Omega on-line computer to the main computer via the data link. The memory of the main computer provides the buffering capacity required and the main computer writes the raw data on to magnetic tape. Equipment checking can still be done by the on-line computer and sampling calculations will also continue in the main computer, though necessarily at a lower rate than in mode 2.

6. The Hardware Elements

After the general description of the system given above, we shall describe in this section the individual hardware elements in the system and give their actual status.

The expected characteristics of the modified HPD 1, renamed the HPD Omega, are given in Table 2. The main modifications are the

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Expected Characteristics of HPD Omega</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of scan line</td>
<td>66 mm.</td>
</tr>
<tr>
<td>Spot size</td>
<td>12-15 μm.</td>
</tr>
<tr>
<td>Spot least count</td>
<td>~2 μm.</td>
</tr>
<tr>
<td>Stage least count</td>
<td>2.54 μm.</td>
</tr>
<tr>
<td>Stage speed</td>
<td>5-50 mm/sec.</td>
</tr>
<tr>
<td>Stage retrace speed</td>
<td>100 mm/sec.</td>
</tr>
<tr>
<td>Film transport: Min. time to advance small numbers of pictures</td>
<td>1.5 sec.</td>
</tr>
<tr>
<td>Film speed for large numbers of pictures</td>
<td>2 m/sec.</td>
</tr>
<tr>
<td>Disk speed</td>
<td>1500 - 2200 r.p.m.</td>
</tr>
<tr>
<td>Number of fibres</td>
<td>8</td>
</tr>
<tr>
<td>Length of film scanned in a single scan</td>
<td>170 mm.</td>
</tr>
<tr>
<td>Resolution</td>
<td>~35 μm.</td>
</tr>
</tbody>
</table>
scan line length of 66 mm (which makes it possible to cover the two stereo views placed side by side on the film in one sweep), the smaller spot size, and the improved resolution required to match the Omega demagnification ratio of about 50. For a scan line separation of 50\(\mu\)m the maximum measuring speed becomes 450 2-view pictures per hour. The HPD Omega will be ready to start operation during the summer of 1970.

The configuration of the on-line computers is shown in Figure 4. They are both EMR 6130's from Electro Mechanical Research in Minneapolis, U.S.A., and will have identical configurations except that only one will have a card punch. There is 24K of 16 bit 0.775μsec. memory, two 60kb/sec. tape units, a backing disk store and a full complement of standard peripherals, such that it is a stand-alone configuration which makes development work on it independent of support from the main computer via the data link. The first computer will arrive in summer 1970 and the second about a year later.

The main computer is shown in Figure 5. It is an CII 10070 from Compagnie Internationale pour l'Informatique, France and is a French-built version of the XDS Sigma 7. It will have 64K of 32 bit words, 5 tape units of which two have a 120kb/sec. recording speed, such that it can cope with the highest data rates from Omega. Besides the standard set of peripherals, there will be 16M bytes of fixed head disk space for use by the system, for sampling data, and for permanent files. It will have a multiprogramming system developed by CII, France and it will be delivered end-1970.

The data links will be designed and produced by CERN, they will have a transfer rate of 400,000 bytes per second over a distance of 500m. They are expected to be ready during 1971.

7. Development of Programs

The program development for the data handling system is still at the design stage so this section will essentially describe the basic principles which have been adopted.
It is clear that a large number of programs will have to be provided both at the basic system level and for the applications. Some of them, particularly the applications programs, will be developed from existing routines which already work on the CERN central computers, but the major part will have to be written from scratch.

Experience from the analysis of data from both film and filmless experiments has taught us that a system of program modules, which can be assembled into entire programs, is very important for the fast production of working programs. Also flexibility of operation is a primary design goal, so that frequent ad hoc modifications can be avoided.

As much as possible of the operating systems delivered with the computers will be used, but because they will be used for a particular application and do not have to process a completely general workload, it is reasonable to remould part of the manufacturer's software to optimise it for this particular application.

A number of special problems arise from the inter-connection of the computers and the attachment of non-standard peripherals. Each of the on-line computers will have to communicate with the main computer via the data links, and the main computer, besides operating the data links simultaneously, must at the same time be able to handle a display system, which may itself contain a small computer. A multiprogramming system provides a good basis for doing all this, as it contains most of the facilities which are needed for managing the simultaneous operations.

In order to have a protected data acquisition program and a flexible means of changing between operational modes in the main computer, the data acquisition and sampling programs will operate as normal independent jobs in the multiprogramming system, transmitting data between each other by means of shared files on disk. Changes in the sampling programs may then be made without stopping the data acquisition and possible errors in the changes cannot affect the data acquisition.
8. Conclusion

This paper has described the principles which have been adopted in the provision of a data handling system for two large experimental projects. We realise that it contains mainly plans and intentions but we believe that the information is of value at this stage because our plans may affect those who want to make use of the facilities we shall provide.

As both the projects are long term ones there are many problems which cannot be attacked yet, because not enough is known about them. For example, some of the biggest uncertainties are related to the performance of the filmless detectors, which are still at the development stage.

A set of general problems arise from the changing nature of the experiments and the data to be analysed, in particular from the increasing amount of data produced by a single experiment. Solutions to the problems of changing from partially guided measurement to completely automatic measurement of pictures on the HPD and of speeding up the analysis programs to cope more efficiently with larger quantities of data are already being studied. A description of the activities in these applications-oriented areas is given in Reference (7).
References

(1) "The Omega Project", CERN internal report NP-68-11 (1968).

(2) J-C. Lassalle, P. Zanella, "Developments in the evaluation of magnetic field spark chamber pictures". Proceedings of the Int. Conf. on Advanced Data Processing for Bubble and Spark Chambers, Argonne National Laboratory, October 1968.


(6) M. Palandri, "The FOCUS remote access system", paper submitted to the Tenth Int. Conf. on Data Handling Systems in High Energy Physics, Cavendish Laboratory, Cambridge, March 1970.

Figure Captions

Figure 1  The Omega Magnet.

Figure 2  The Split Field Magnet seen in two views. The central magnet and the two compensator magnets are shown in a side view in the upper part and in a top view below. The deformation of the primary beam paths is indicated in the top view.

Figure 3  Principal layout of the data handling system with an on-line computer attached to each experiment and connected to a main computer via data links.

Figure 4  Configuration of an on-line computer, the EMR 6130.

Figure 5  Configuration of the main computer, the CII 10070. The MIOP is a multiplexed input/output channel with an individual and total transfer rate of 400,000 bytes/sec.
Fig. 3

SYSTEM LAYOUT

OMEGA
EXPERIMENT

ON-LINE
COMPUTER

DATA LINK

MAIN
COMPUTER

DATA LINK

ON-LINE
COMPUTER

SFМ
EXPERIMENT
EMR 6130 CONFIGURATION

16 EXTERNAL INTERRUPTS

CPU
19 μsec FIXED ADD

MEMORY 24K, 16 BITS
0.775 μsec CYCLE TIME

CHANNEL 1Mb/sec
CHANNEL 1Mb/sec
CHANNEL 1Mw/sec

TELETYPE
CARD READER

CARD PUNCH
LINE PRINTER
TAPE CONTROL
DISC CONTROL

DATA LINK TO CII 100/10

60kb/s
291kb/s

TO EXPERIMENT DISPLAY

Fig. 4
DISCUSSION

H. FAISSNER (Aachen): Why do you still insist on using optical chambers, now all the problems with filmless chambers have been solved?

P. VILLEMOES: CERN has a great deal of experience with optical chambers in a magnetic field. From the beginning of the Omega project one has followed quite a conservative approach, in order to get experiments started as early as possible.

H. FAISSNER (Aachen): In German this is called "Nibelungentreue".

D. WEBSDALE (CERN): Professor Faissner's suggestions for a relatively economical digitized system capable of operating in an 18 kG magnetic field and capable of handling six tracks or more, in 120 gaps, are welcome if they can be realized before 1972. Could I emphasize however that optical chambers are to be used only during the first year or two of Omega operation, and that the SPM will use Charpak chambers from the start.

P. OSMON (Westfield College): I believe that vidicon read-out is the way to digitize the Omega gaps, and that this can be done despite the stray field at the camera positions.
COST-EFFECTIVENESS OF DIFFERENT SPARK CHAMBER READ-OUT AND DIGITISING SYSTEMS

P.E. Osmond and J.A. Strong,

1. INTRODUCTION

Eight years or so ago spark chamber experiments were restricted, typically, to about 100,000 pictures each, because of the time required to scan and measure them. The interval has seen the development of a variety of automatic and semi-automatic systems for processing spark information. Inevitably the systems have a wide range of characteristics and costs, and these we will review. Some systems are capable of taking 100 "pictures" per second, and a number of experiments have been done already where millions of "pictures" were taken.

To be specific we will consider the 5 kinds of spark chamber read-out which are in use at the Rutherford Laboratory. See Table I.

TABLE I
DIFFERENT SPARK CHAMBER READ-OUT
AND DIGITISING SYSTEMS

1. Film-Flying Spot\(^1\) \) OPTICAL
2. Television (Vidicon)\(^2\) \) ELECTRICAL
3. Sonic\(^3\) \)
4. Magnetic Core\(^4\) \) WIRE
5. Magnetostrictive\(^5\) \)
2. **THE CHAMBERS**

Optical chambers have usually been constructed from glass or perspex frames with aluminium foils stretched and glued to them. Because of the "finish" and uniformity required these frames are expensive, costing, typically, about £500 per gap. Recently, aluminium clad boards made from expanded polystyrene or polyurethane foam have been substituted for the stretched foils. Very recently corrugated Mylar transparent walls, developed at Westfield College (6), have been substituted for the glass or perspex frames. This technique permits particles to pass through the walls, as well as the plates, of a chamber with very little multiple scattering. These two developments have reduced the cost of typical optical chambers to a negligible level.

The special feature of sonic chambers is the 4 microphones which are an integral part of each gap.

Wire chambers are available commercially. They have also been constructed by different groups in a variety of ways: planes of taut wires supported at the edges, a weave of conducting and insulating wires, or wires bonded to an insulating plate. Typically the cost is £500 per plane. A number of cylindrically shaped wire chambers have been made.

Typical foil or board chambers use .025 mm. aluminium. Typical wire chambers use .17 mm. copper wires at .5 mm. intervals. In general multiple scattering has proved harder to minimise with wires than with foils. Thus aluminium foils as thin as .006 mm. have been used, whereas to the best of the authors' knowledge it has so far proved impossible to work with wires of less than a thickness equivalent to .0025 mm. copper foil.

In general, wire read-out requires less energy in the spark than the other methods. Typically, wire chamber sparks dissipate about
10 m. joules, sonic and optical chamber sparks about 100 m. joules. With lower energy sparks the clearing problem is less and recovery quicker. Wire chambers can be operated conveniently with a dead-time of 1 ms, the others typically require 10 ms.

Users of wire chambers report\(^4\) that their multispark efficiency is not so good as in foil chambers, but apparently it can be improved by using wide gap chambers in a track-following mode.

An advantage of optical chambers is that the sparks are visible to the eye, and spark chamber performance can be monitored without recourse to the read-out system. This is especially useful when spark chambers are being tested, and makes development of novel construction techniques much easier.

3. **THE SYSTEMS**

The electrical systems have one important advantage over the optical ones. This is the ease with which spark co-ordinate information from remote or confined parts of the apparatus can be collected, since all that is involved is the laying of some cables. In the optical systems signals have to be transmitted and oriented by, often elaborate, arrangements of mirrors and field lenses. The problem is particularly acute for film cameras. In fact the need to present stereo views of all spark chambers in the system to one or two camera lenses is a severe restriction on experimental layout. In the case of vidicons, the problem can be eased by deploying a number of them. For example, in the current \(\tau\) -decay experiment at the Rutherford Lab 12 vidicons are used. 4 of them view remote up-stream chambers used in determining the momentum of the beam. The remaining 8 are arranged in 4 stereo pairs for viewing chambers grouped around the hydrogen target (see Figure 3).

At its present stage of development\(^2\) the vidicon system is more cumbersome to use than the others. Linearity is only good
to about one per cent and digitising have to be corrected using a fifth order calibration polynomial. There is also a frame distortion of the same order making alignment rather critical. Because of thermal drifts linearity and alignment have to be continuously monitored using a large number of fiducial lights. These shortcomings are being actively pursued.

Sonic read-out was the first of the electrical systems. Its simplicity is very attractive, but the inability to cope with more than one spark in a gap is fatal in many situations. Core read-out is at the opposite extreme and can, in principle, cope with an enormous number of sparks in a gap, but at the price of an external electrical connection to every wire in the plane.

Magnetostrictive read-out is now the most popular method, and it is easy to see why. The electrical signals come out on a single wire from each plane, and yet this one wire carries information about many sparks. Magnetostrictive read-out does have one disadvantage not shared by any of the other systems, and this is that there are severe difficulties when one tries to read out chambers inside a magnetic field.

There are some problems which are common to all systems:

(i) **Ambiguities.** To determine the co-ordinates of a spark stereo measurement is needed. When 2 or more sparks occur in a gap there are ambiguous associations of the co-ordinates. Thus for the case of 2 sparks (as is shown in Figure 2) one has the problem of distinguishing between the 2 possible sets of co-ordinates \((x_1 y_1), (x_2 y_2)\) and \((x_1 y_2), (x_2 y_1)\).

There are three ways to resolve the ambiguity.

a) By software. Sparks are associated together as tracks and then the decision is made at track level.
b) By hardware. A third digitising direction is
introduced. For optical read-out no extra gaps
are required as is shown in Figure 1 for the vidicon
case. With wire read-out an additional gap seems to
be implied, however changes, from gap-to-gap, in
digitising direction as small as ± 5° can in practice
resolve the ambiguity (e.g. CERN Missing Mass
Spectrometer Group.)

c) By digitising spark intensity. This is already done
in the Cyclops Flying-spot device and could be
done more crudely with vidicons.

(ii) Surveying. Positions of spark chambers can be determined
to about 1 mm. by conventional surveying techniques. Since
spark co-ordinates are usually required to greater accuracy
than this, corrections are made to the measured values
using digitisings of straight tracks which thread more than
one chamber. The simplest procedure is to determine the small
rotation and displacement variations from the survey numbers
such that the deviation, in a least squares sense, of the
measured track segments from collinearity is minimised.

4. DIGITISING AND TEMPORARY STORAGE

4.1 Digitising in the different systems

In every case, except magnetic cores, digitising is
effected by conversion of distance to time and then
counting clock pulses. The magnetic core method makes
direct use of the spatial digitisation provided by a
plane of parallel wires. Digitisers for the magnetostrictive
and vidicon techniques are so similar that the hardware
could probably be used interchangeably.
For this kind of digitiser, where there are to be many digitising in one plane/gap costs can be reduced by using a vertical arrangement of shift-registers, with a scaler on the top, as a 'push-down' store instead of the corresponding number of high speed scalers.

The accuracies of the different systems are given in Table 2.

**TABLE 2**

**ACCURACIES OF THE SYSTEMS**

<table>
<thead>
<tr>
<th>1. Film-Flying spot</th>
<th>1 part in 10⁴ (limited by spark width)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Vidicon</td>
<td>4 parts in 10⁴</td>
</tr>
<tr>
<td>3. Sonic</td>
<td>.25 mm</td>
</tr>
<tr>
<td>4. Cores</td>
<td>.25 mm</td>
</tr>
<tr>
<td>5. Magnetostrictive</td>
<td>.25 mm</td>
</tr>
</tbody>
</table>

Digitising rates for the different systems are given in Table 3.

**TABLE 3**

**DIGITISING RATES FOR THE SYSTEMS**

<table>
<thead>
<tr>
<th>1. Film-Flying spot</th>
<th>6 secs per picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Vidicon</td>
<td>typically 20 ms per event + 50 ms dead time</td>
</tr>
<tr>
<td>3. Sonic</td>
<td>instantaneous + 10 ms dead time</td>
</tr>
<tr>
<td>4. Cores</td>
<td>instantaneous</td>
</tr>
<tr>
<td>5. Magnetostrictive</td>
<td>instantaneous (brute force method)</td>
</tr>
</tbody>
</table>
Film-Flying spot is off-line and so can operate continuously. Its annual throughput maximum is $5 \times 10^6$ pictures. The rate for the on-line systems should be multiplied by the duty factor of the accelerator. The vidicon system is the slowest, and a duty factor of 20% would imply a maximum annual throughput of $10^8$ events. The wire systems are only limited by spark chamber recovery time and could in principle exceed $10^9$ per annum!

4.2 Buffering the information flow

Since all the spark chamber gaps in a system are fired at once, all the spark co-ordinate information becomes available simultaneously. Thus the systems have to provide for buffer storage of the information and its gradual release at a rate the system computer can absorb:-

<table>
<thead>
<tr>
<th>Buffering the information flow in the different systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Film-Flying Spot</td>
</tr>
<tr>
<td>2. Vidicon</td>
</tr>
<tr>
<td>3. Sonic</td>
</tr>
<tr>
<td>4. Magnetic Cores</td>
</tr>
<tr>
<td>5. Magnetostrictive</td>
</tr>
<tr>
<td>the film</td>
</tr>
<tr>
<td>the image is stored on the vidicon anode until scanned off.</td>
</tr>
<tr>
<td>4 scalers for each spark the cores</td>
</tr>
<tr>
<td>(a) &quot;brute force&quot; method: magnetostrictive wire per plane + 1 scaler for each spark.</td>
</tr>
<tr>
<td>(b) &quot;stacking&quot; method: long magnetostrictive wire</td>
</tr>
</tbody>
</table>
5. COMPUTERS.

The buffered information customarily flows from the digitisers into a small computer. Now the information content of the pictures is determined, by and large, by the experiment and not by the nature of the digitising system. So the operations carried out in the small computer are likely to be similar whichever system is used. The rate at which information flows in from the digitisers will determine how hard the computer has to work. It will also, together with the accelerator duty cycle, determine the size of the computer's core memory since this will have to buffer the information flow onto tape (see Figure 4). So the specifications for the computer will be fixed by the experiment rather than by the choice of any particular data acquisition system.

The small computers have often been very small e.g. 4K x 12 bit words. The trend to more complicated events is forcing up the size of data blocks and so making the smallest machines inadequate. For example, in the $\beta$-decay asymmetry experiment at the Rutherford Lab the data block (vidicon) is 1K x 12 bit words with the possibility of 8 pictures per beam burst. Also at the Rutherford Lab is an experiment on leptonic decay of $K^0$'s (flying-spot digitiser) with a data block of 4K x 24 bit words.

The data block consists of a list of spark co-ordinates. This has to be separated into lists representing distinct tracks or showers, with any "noise" sparks removed. A great deal of programming effort, throughout the world, has been expended on this problem. For example Duff et al. have studied the processor time required for various kinds of spark associating programs and find that typically $\geq$ .1 seconds of 7090 time is required for one track view of moderate complexity (see Figure 5).

Since some at least of these programs use integer arithmetic this kind of elementary pattern recognition is likely to be done increasingly on the small computer, thereby saving
appreciably in large computer time. This work could not be done on-line by the small computer in most cases, but could be done with a second pass of the data. One would expect the small computer to be able to cope with the elementary pattern recognition on \(10^7 - 10^8\) pictures per annum.

If no higher level of pattern recognition than this is required in processing the data, then the processing can proceed automatically in the large computer. This is the case, in general, if the pictures are 'clean' and 'simple' as for example when there are just two charged particles in the final state. One can certainly envisage \(10^7\) pictures of this kind being taken and processed in a year - for example in a programme of elastic scattering measurements.

If the pictures are 'complicated' for example because of superfluous tracks or gamma ray showers, any programs are likely to require human assistance. One might need to scan all the events, or just a sample so as to correct for losses, or one may use scanning to assist program development. But certainly one would think twice before taking \(10^7\) of these pictures.

Once the data is inside the computer, scanning can be done with the help of an interactive graphics terminal. The Westfield/RHEL group are connecting 2 such, via CAMAC, to our small computer (a 16k, IBM 1130). Whilst we are taking data on line (vidicons) the terminals will monitor the progress of the experiment. When digitizing is not in progress they are to be used for scanning a proportion of the pictures. One of the terminals is being mounted in the local control room of the experiment at the Rutherford Lab, the other 60 miles away in the University, being connected to the CAMAC via a telephone line.
6. **COST COMPARISON**

6.1 **Basis of the comparison**

We consider three quite different kinds of experiment:

**TABLE 5**

<table>
<thead>
<tr>
<th>THREE KINDS OF EXPERIMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Each experiment is roughly costed for $10^5$, $10^6$ and $10^7$ events. In the case of Magnetostrictive read-out the costing is for a "brute-force" system. We believe that the cost pattern for a 'stacked' magnetostrictive read-out system would be similar to vidicon costs.

We have broken down costs under the following headings: chamber cost; initial capital costs; incremental capital costs (to expand the system from its minimum size) proportional to the number of gaps, and sparks too in some cases; cost of the small computer; and running costs. Costs which have been omitted, as common to all systems, are scanners wages and time on the large computer.
6.2 Costs

i) **Chamber costs** < uncertainty in costing, and so neglected

ii) **Initial capital costs.** These are cost estimates for duplicating an existing system and take no account of development costs:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TABLE 6</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Film-Flying spot: Film cameras, 'Cyclops'</td>
<td>$30,000</td>
<td></td>
</tr>
<tr>
<td>2. Vidicon: Vidicon controller, Digitisers</td>
<td>$15,000</td>
<td></td>
</tr>
<tr>
<td>3. Sonic: Digitiser Controller</td>
<td>$4,000</td>
<td></td>
</tr>
<tr>
<td>4. Cores: Read-out controller</td>
<td>$4,000</td>
<td></td>
</tr>
<tr>
<td>5. Magnetostrictive: Digitiser Controller</td>
<td>$4,000</td>
<td></td>
</tr>
</tbody>
</table>

iii) **Incremental capital costs.**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TABLE 7</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Film-Flying spot: nil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Vidicon: camera units (typically 1 per 5 gaps)</td>
<td>$1,000</td>
<td></td>
</tr>
<tr>
<td>3. Sonic: set of 4 digitisers (per gap)</td>
<td>$600</td>
<td></td>
</tr>
<tr>
<td>4. Cores: core array, including read-out (per plane) (In quantity $800)</td>
<td>$1,500</td>
<td></td>
</tr>
<tr>
<td>5. Magnetostrictive: digitiser (1 per spark) (In quantity $100)</td>
<td>$150</td>
<td></td>
</tr>
</tbody>
</table>
iv) **Small computer (purchase).** Requirements are assumed to be the same for all systems, but depend on the complexity of the pictures.

<table>
<thead>
<tr>
<th>TABLE 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EXPERIMENT</strong></td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
</tbody>
</table>

v) **Running costs**

<table>
<thead>
<tr>
<th>TABLE 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Film-Flying spot</td>
</tr>
<tr>
<td>2. Vidicon</td>
</tr>
<tr>
<td>3. Sonic</td>
</tr>
<tr>
<td>4. Cores</td>
</tr>
<tr>
<td>5. Magnetostrictive</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
</tbody>
</table>

6.3 **Comparison**

The graphs (see Figures 6, 7, 8) show comparative costs for the various systems for our three different hypothetical experiments. The graphs are very crude, in keeping with the uncertainty in costing because of the many possible differences in system realisation at the detailed level. Costs are expressed on a logarithmic scale so that there is room for quite large
changes, for example scalers and logic generally will
certainly be cheaper in the future, without the broad
conclusions being affected.

It could be argued that it is unfair to write off the
capital costs of system and computer in just one experiment.
A different formula would not much affect the conclusions
since the real differences between the systems are in running
and incremental capital costs.

7. CONCLUSIONS ON COST-EFFECTIVENESS

I Simple events, few gaps.

All methods, except film, are equally cheap. Film
appears to be competitive only below the \(10^5\) event level.
This is not quite fair. Film is digitised off-line so that
the flying-spot digitiser could be shared between several
experiments. In these circumstances the conclusion should
perhaps be that film is only competitive below the \(2.10^5\)
level. Sonic and magnetostrictive are the easiest to use of
the on-line systems and should be first choice for this
class of experiment.

II Simple events, many gaps.

The same conclusions about the film method apply as in
the few gap situation. Core is expensive and there may be
difficulties in operating so many planes.

III Complex events, many gaps.

Vidicon is the clear first choice for this class of
experiments. Core is fairly, and magnetostrictive very,
expensive. Again film is only a reasonable choice below
\(2.10^5\) events.
The most general conclusion to emerge is that the vidicon method is the cheapest, and by a large margin for complex events.

8. SPARK CHAMBERS IN MAGNETIC FIELDS

8.1 Read-out problems.

In a magnetic field, magnetostrictive read-out, which has otherwise proved the most popular technique, gets into difficulties. What happens is that the pulses obtained from the magnetostrictive wire vary considerably in amplitude, and also in sign, according to the orientation and size of magnetic field the wire experiences.

Operation of vidicon tubes and magnetic cores also presents problems. Typically they cannot be operated reliably in fields of more than a few gauss. However, combinations of long light paths/wires, to get clear of the high field region, and local screening, seem to be effective.

The confined space between the poles of a magnet presents problems for optical systems. The number of chambers which can be packed into the space is severely restricted by the difficulty of stereo viewing and a large fraction of the useful field volume tends to be occupied by cumbersome arrangements of mirrors, unless the spark chamber arrangement is especially simple as is the case in the CERN-ETH-IC magnet or the Omega project.

8.2 Geometry and Kinematics problems

The problem of momentum determination from digitisations of curved tracks has been faced by bubble chamber groups and the small number of spark chamber groups who have operated their chambers inside a magnet. Bubble chamber geometry programs like THRESHH take
between 1/10 sec and 1 sec on a large computer to fit a momentum to a track. Spark chamber pictures have a much lower information content than bubble chamber ones, but they may well have been taken in a much less uniform magnetic field.

A number of programs have been written especially for magnetic spark chamber tracks, which work by following the track, through the field, and iterating at every digitising to optimise the fitting parameters. Like the bubble chamber programs these use a lot of computer time. It is clear that unless these fitting times can be substantially reduced, magnetic spark chamber experiments with $\gtrsim 10^6$ events are likely to be ruled out by the size of the computer bill.

Recently 9) a different approach has been suggested, and applied to the restricted case where the spark chambers are situated fore and aft of the magnet but not inside it. The principle of the method is to express a particle momentum as a function of observed spark co-ordinates and also certain parameters. These parameters are determined by a calibration procedure whereby, with the aid of a field map, a number of particles are tracked through the field using a conventional program. The method has been found to give a saving of 2 orders of magnitude in computer time.

Attempts are now being made, at the Rutherford Lab. and perhaps elsewhere, to generalise the method to the case of spark chambers inside a field. Unless this or some similar approach succeeds it seems possible that the data taking potential of automatic read-out from magnetic spark chambers will not be realised, because of the cost of processing the data.
The authors wish to thank Dr. B.G. Duff for the illustration from which Figure 5 was derived, and also many other colleagues, at the Rutherford Laboratory and elsewhere, for helpful discussions.
References


4) B.G. Duff and F.F. Heymann (private communication).


6) L. Draper (to be published).


BEAM SPARK CHAMBER
MIRROR SYSTEM
ETA EXPERIMENT

Fig. 1
AMBIGUITIES WITH MULTIPLE SPARKS

Fig. 2
INFORMATION FLOW

buffered information from digitisers

Small Computer

Simple checks on data
Conversion to more condensed format
Assembly of data block

Magnetic Tape

Pattern recognition
Kinematics
Statistics

Large Computer

Results

Fig. 4
Simulated events

Simulated events after track finding

Fig. 5
Fig. 6
Fig. 8
DISCUSSION

H. SHAYLOR (Birmingham): Two questions: 1) What difficulties would be encountered with vidicons in magnetic fields such as are expected for the Omega project? 2) Does the cost of synchrotron operation make the security of data on film important compared with the reduced cost of non-film methods?

P. OSMON: I want to answer the second question first. As far as the security is concerned, we do lose a tape of events from time to time, with 4,000 or 5,000 events on it, which is of no importance, provided one loses them in a random way. I do not know the cost of synchrotron operation, so I cannot answer that part of your question. The magnetic field in the Omega magnet at the position where one would put vidicons is about 100 Gauss, and we certainly cannot stand that. However, we believe that it is fairly easy to put our vidicons in a sufficiently big iron package.

H. GROTE (CERN): I want to mention that at CERN magnetostrictive wire chambers have worked by storing all of the pulses in one delay line and then reading them out one after the other at the end.

P. OSMON: I think that the cost of such a system would be very comparable to the vidicon one.

A. J.S. SMITH (Princeton): The vidicon dead-time might be too long to use the accelerator efficiently in high data rate experiments. As far as the computers are concerned, I think that on-line computers, even large ones, are not necessarily more expensive than off-line ones. One sometimes needs very large on-line programs to tell if the experiment is working, "small" computers cannot handle the job in many cases, especially if floating-point is needed.

P. OSMON: I think that if one has got a small or medium size computer on-line, it can tell one if things are going wrong or not. It appears to me that one should not try on-line fitting of curves through magnetic fields or similar things. This should be left for off-line processing. My personal preference is for a complete separation of the small on-line and the large off-line computer.

The dead time of the vidicon certainly is a disadvantage. One gets a maximum of about eight events per burst. We are trying to reduce the dead time.
THE HPD - IBM 360/44 SYSTEM REALIZED AT C.N.A.F.
FOR BUBBLE CHAMBER DATA ANALYSIS - I

Presented by A. Werbrouck

THE SYSTEM CONFIGURATION AND ITS PERFORMANCE IN
ROAD GUIDANCE

G. Cecchet, M. Dameri, M.L. Luvisetto, M. Masetti,
G. Misuri, U. Romagnoli, A. Sala, D. Venturi and
U. Zanotti, Istituto Nazionale di Fisica Nucleare, Bologna, Italy.

1. The FSD-IBM 360/44 System

In this paper we describe the new FSD system developed at CNAF. The
configuration is shown in Fig. 1.

The system is driven by an IBM 360 Model 44, with 128 K bytes or
storage. The computer is equipped with three channels: MPX (for slow
deVICES, such as printer, card reader/punch, single disk storage drives),
HSMPX (for fast I/O units, such as 2311 disk drives), and DDC (for real
time data transmission, at a maximum speed of 4,000 K bytes/sec).

Furthermore a special IBM feature DW (Direct Word) sends single words,
such as the FSD orders, to the external devices. To these we have added
the BCU (buffered control unit), completely designed and built at CNAF.
This unit allows the connection of several external devices (HPD, CRT
scanner, 7094) to the 360 by decoding suitable signals, which are sent
through the DW. The HPD is the usual HPD device, while the CRT scanner
is for spark chamber measurement and is like the CERN Luciole. In the
near future a second HPD is planned to work in parallel during the dead-
time of the existing one.

Therefore the programmer can choose with simple instructions the
external device to be selected. Each external device is equipped with a
"status word" which can be read by the program when required. Under
program control each device is also able to send to the computer an
interrupt for any abnormal condition.

In this way, wasting computer time is minimized (frame advancing time,
etc.). Before sending the data to the computer, they can be stored in
the BCU buffer; thus, during the HPD on-line operation, the other scanning
device can send data to the buffer. The same BCU can also be used for display purposes during the time between the scanning of two consecutive frames. An interrupt sent by an external device is decoded by the program, which can then read in the status word of the device involved. The status word enables the computer to decide upon the nature of the request.

Another interesting feature is the use of the CRT display. This device is used as a useful diagnostic tool (for FSD data, simulator files, and data reduction programs) and as a measuring device for FSD coordinates (i.e., automatic search for fiducial centres to be given as constants to the data reduction programs).

In order to use the simulator (containing FSD digitizings of a picture) the data have to be first stored on a simulator disk, containing usually 10 to 20 frames. Then the display operator can select from the disk the desired frame, suitably magnify a particular portion of a frame for examination, or measure any desired point in HPD coordinates. Some magnification is usually required in order to display the frame with better resolution, since it is not possible to have more than 10,000 points at a time on the display without flicker. The operator requests are serviced by an interrupt which informs the computer about the waiting display request; the display status word is then read in to identify the request.

Gated points, filtered points, and premeasurements can be superimposed on the CRT, by means of suitable programs (see Part II), in order to check the performance of the program chain.

The programs to process the FSD data are divided into two groups:
a) on-line processing with the FSD-IBM 360 connection for the data reduction (GATE program);
b) off-line processing for event reconstruction (FILTER program).

The former FILTER program\(^1\) working on the IBM 7094 and receiving input data on-line via the IBM 360/44 has been fully rewritten for the IBM 360/44 and is described in Part III.

The GATE processing is shown in Fig. 2. The scan cards with rough digitizings are processed by MIST, checking the data, transforming the
coordinates, computing the circle parameters for each track, finding out which track needs an abnormal scan and storing the output data onto a 2315 disk. The 360-HAZE selects and checks on-line the picture number, determines the HPD and glass fiducial centres, reduces the HPD digitizings, storing only the digitizations inside a road centred around the pre-digitized circle.

The road width is variable from 512 LCY (≈ 640 μ) to 256 LCY (≈ 320 μ), depending on how many digitizings are found inside the road and how far from the road edges they are. In this way the amount of output data is drastically reduced (≈ 5000 digitizings per picture of the 2 m CERN chamber). This is then stored on a 2311 disk and used as input for the FILTER program.

These data can also be examined using the display to check their reliability.

2. System performance

At the time of the Conference, about 16,000 events of the experiment π⁺p at 11 GeV/c in the 2 m CERN bubble chamber have been analyzed. To do this, both the old and the new program chain have been used.

The former has already been described\(^1\): the latter is reported in Part II of this paper. The HPD production rate is now about 60 events/h, partly owing to the quality of the HPD fiducials which required a double scanning of the picture (the premeasurements are referred to two glass fiducials) in about 30% of the pictures. The estimated limiting rate on pictures with good HPD fiducials is about 90 events/h.

The over-all geometry rejection rate (for THRESH error ≥ 4) of the HPD road guidance system determined on 3041 four-prong events is ≈ 14%. An additional 8–9% of the events are at present considered to be doubtful owing to track residuals greater than:

a) \[ 8 + 32 \left( 1 - \frac{P}{600} \right) \mu \text{ for } P < 600 \text{ MeV/c}; \]
b) \[ 8 \mu \text{ for } P > 600 \text{ MeV/c}. \]

We have not yet been able to determine the exact percentage of the different causes of these rejects and uncertainties. The known sources are:
a) failure of the on-line program (e.g. insufficient fiducials); 
b) filter failure; 
c) premeasurement defects not revealed by MIST; 
d) constants and apparent fiducial positions not optimized.

An analysis of THRESH errors based on 12,107 secondary tracks (of which 5.6% failed) gives the following classification of causes in percentages.

<table>
<thead>
<tr>
<th>Error</th>
<th>Percentage of track failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>34.5</td>
</tr>
<tr>
<td>1000</td>
<td>7.5</td>
</tr>
<tr>
<td>100</td>
<td>39.0</td>
</tr>
<tr>
<td>4</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>

Error 4000 is easily understood in terms of causes (a), (b), and (c). Error 1000 does not seem very important. Error 100 is due to discrepancy between internal and external errors obtained using the standard constants. Judging from the large number of tracks in this category, these deserve a careful investigation. Error 4 (helix fit with fixed vertex coordinates) involves the correspondence between the premeasured vertex and the HPD measured tracks in a rather complicated manner.

The film contrast varied considerably in this run. In fact there are differences by a factor of two in rejection rate between different rolls. For a particularly pale film not included in the above average, the event rejection rate rose to 33%.

From the GRIND results on four-constraint events, we observe a systematic distortion indicative of liquid motion in the chamber. As seen in Fig. 3, the momenta of positive tracks are underestimated and for negative tracks are overestimated by the measurements. Obviously the effect is more evident on the high-momentum tracks, especially when measured by the HPD compared to those measured by image plane digitizers (IPD). Hopefully it will be possible to introduce an average sagitta correction in GRIND.
Between the IPD and HPD measurements there are no significant differences between the percentages of 4C, 1C, and NOFIT classes, or between the percentages of events with different numbers of possible hypotheses. For all these events the number of hypotheses was minimized by using visual estimates of ionization. From the probability distribution of the 4C fits, we estimate that the GRIND constant $f_0$ for the HPD should be about 60 $\mu$, whereas it is 70 $\mu$ for the FPD*) and 80 $\mu$ for the IPD.

REFERENCE


*) Film plane digitizer.
Fig. 1 Hardware system configuration
Fig. 2 Gate processing of FSD data
\frac{P_{\text{unfitted}} - P_{\text{fitted}}}{P_{\text{fitted}}} \ vs \ P_{\text{fitted}} \ \pi^+ p \ 11.7 \ \text{GeV/c}

Fig. 3a Percent correction to the measured momenta \(P_{\text{unfitted}}\) introduced by the program GRIND on the positive tracks for events of the type \(\pi^+ p \rightarrow \pi^+ \pi^-\) as a function of the fitted momentum. Comparison between the results obtained with the image plane measuring devices (1293 tracks) and with the HPD (939 tracks).
Fig. 3b  Percent correction to the measured momenta ($P_{\text{unfitted}}$) introduced by the program GRIND on the negative track for events of the type $\pi^+ p \rightarrow \pi^+ p \pi^+\pi^-$ as a function of the fitted momentum. Comparison between the results obtained with image plane measuring devices (431 tracks) and with the HPD (313 tracks).
THE HPD - IBM 360/44 SYSTEM REALIZED AT C.N.A.F.
FOR BUBBLE CHAMBER DATA ANALYSIS - II

Presented by A. Werbrouck

SOFTWARE AND HARDWARE DEVELOPMENTS OF THE HPD 360/44
SYSTEM AT C.N.A.F. FOR BUBBLE CHAMBER DATA ANALYSIS

A. Castelvetri, L. Fonti, A. Ghiselli, M.L. Luvisetto,
M. Masetti, G. Misuri, U. Romagnoli, G.P. Sini,
D. Venturi and U. Zanotti, Istituto Nazionale di
Fisica Nucleare, Bologna, Italy.

In the flow chart presented here (Fig. 1), one can see the whole
program chain both for the 360/44 and for the 7094. Scan cards with the
rough digitizings are processed by MIST and stored on a 2315 monodisk.
The on-line program gates the picture scanned by the HPD and finds the
fiducial centres for THRESH. The gated information is then processed
by the global FILTER program, described in Part III of this paper. At
this point also the ionization is computed following the CERN method.
Both GATE and FILTER information is stored on the disk; the three views
are processed separately and stored as such.

We use a disk output both for GATE and for FILTER to take advantage
of the random access facility in the diagnostic checking program where it
is possible to have a single CRT display of all the different kinds of
digitizings. In Fig. 2 an example is shown with the predigitizings in
the HPD system indicated by large dots, GATE road contents as normal dots,
and FILTER average points brighter dots. In this way we can check the
performance of the programs (GATE and FILTER) and at the same time the
quality of the premeasured data referred to the HPD system. More than
three dots appear per track when the GATE program has interpolated the
premeasurements (e.g. when the track has been measured partly in one
scan, partly in the other).

After FILTER, a program (Fig. 1) merges the three views writing a
BCD THRESH input tape, which can then be analyzed with any computer.
At this stage the first 360/44 processing is ended and the 7094 program
chain is now entered. The first step is the tape conversion from BCD
into binary*). After THRESH, another program checks the goodness of the measurements and punches rejection cards for all rejected events. This program also processes the ionization data (this part cannot be joined to THRESH for storage reasons) and writes an input tape for GRIND.

The program chain foreseen for event recovery works as follows. From the GATE and FILTER output disk, the reject analyser program extracts all information relevant to the events selected by the rejection cards. It also transforms the gated digitizings of the track to be remeasured into the CRT format. A second program drives the CRT display where an operator tags the desired digitizings with a light-pen so that rejected tracks can be refiltered and a new BCD input tape for THRESH written. This tape is then sent to the 7094 for an update run. The recovered events pass through THRESH again and the successful ones are merged into the previous THRESH output.

We foresee the following cases:

a) Insufficient fiducials found, the event is rejected.

b) Track too far from vertex, the vertex is remeasured as an HPD digitizing.

c) Bad track points, the track is remeasured as explained above.

d) Any track with total sigma larger than a certain tolerance is remeasured. Actually our upper limit is \( \sigma(\mu) = 8 + 32 \left[ 1 - \frac{P}{600} \text{MeV/c} \right] \) for \( P \) from 0 to 600 MeV/c, and \( \sigma(\mu) = 8 \) for \( P > 600 \text{ MeV/c} \).

Case (b) is an event rejected by THRESH with error code 10; this means that the track in question is too far from the vertex. This error could be due to the vertex itself, since it is measured at the scan table to the same precision as the predigitizings (moreover the transformation into the HPD system is also dependent upon the accuracy of the pre-measurement of the two glass fiducials). In this case we could try to

*) This conversion is done primarily for reasons of storage space as the BCD THRESH requires more storage for input buffers. This affects the results, as some routines would have to be deleted. Furthermore, the BCD input is much more tape-consuming and causes greater tape-handling problems.
recover the event by measuring the vertex again at the CRT display, which gives the same precision as the HPD. At present we cannot use CONVEX in THRESH due to memory limitations.

In the other categories (c) and (d), we use the Brookhaven philosophy to display the rejected tracks. We transform the track digitizings into a system where the length of the CRT x-axis is the track length and the length of the CRT y-axis is the road width, so that the y-coordinates represent the distance of the points from the road edge.

To avoid the use of an interrupt for each digitizing accepted by the light-pen, we store the digitizings in the BCU memory and re-cycle them for the CRT. The hardware is such that a special control bit is added to an accepted digitizing to flag it for the refilter routine. On the screen, such points appear brighter. An interrupt is sent to the computer only when the operator has completed the track. At this point the data are converted to the HPD system again, refiltered, and sent to the 7094 for the update run.

At the end of the gating process, a diagnostic program (SCMFAF) is available to determine the level of agreement between the fiducials measured by the HPD and their expected positions given by the geometry titles after the determination of the transformation coefficients between the HPD measurements and the front glass of the chamber. This program, which essentially repeats the calculations of the GEOM subroutine in THRESH, was written to obtain an immediate survey of statistical and systematic deviations between measured and apparent fiducial mark positions.

The results were needed to understand systematic differences between HPD measured momenta and the manual measurement values. In fact we found a good agreement between measured and predicted position only for some fiducials, while for other ones this agreement was bad. The r.m.s. of the measured fiducial (using a sample of 40 fiducial marks) is several times (4–6) smaller than the distance between the measured fiducial and its predicted position. This r.m.s. deviation determines, around the fiducial, a square of 40–50 μ on a side in the plane of the front glass. We think that the disagreement mentioned above could be due to the fact that the manual measurements are referred to a single fiducial plane, while the HPD uses all detectable fiducials on both window planes.
We want to mention now in more detail the CRT display and the light-pen performance.

The light-pen scheme is shown in Fig. 3. A light is filtered by a red filter and sent through an interference dichroic mirror to the focusing lens via a flexible fibre optic guide. In this way we obtain a red spot projected on to the green phosphor of the screen (see Fig. 4). The operator thus sees exactly from where the light-pen is transmitting green light to the phototube.
Fig. 2 Display aided diagnostic program - CRT display
Fig. 3 Light-pen
Fig. 4 Light-pen and CRT display
THE HPD - IBM 360/44 SYSTEM REALIZED AT C.N.A.F. FOR BUBBLE CHAMBER DATA ANALYSIS - III

Presented by A. Werbrouck

THE NEW OFF-LINE GLOBAL FILTER PROGRAM

A. Castelvetri and M. Masetti, Istituto Nazionale di Fisica Nucleare, Bologna, Italy.

The general philosophy of this new FILTER program was suggested by the results of an analysis of gated HPD digitizations: GATE output data were displayed on a CRT on-line to the computer. The coordinates of some track points were measured manually and a second-order curve was fitted through them. Selecting from the GATE output data only those points, the distance of which from the resulting curve was less than 50 LCY (LCY = 1.6 microns) and treating them with a repeated least squares fit, it was possible to select the actual digitizings of the observed track, within 10–15 LCY. This spread depends upon the track curvature, a distance comparable to the bubble dimension and the HPD resolution.

FILTER's chief input data are:

I1) MIST premeasurements in the HPD system, to which some other track reference coordinates are geometrically added.

I2) GATE output data.

Its chief output data are:

Ø1) Track point coordinates as required by THRESH.

Ø2) Information about ionization.

The FILTER program attempts to repeat the above procedure automatically. To do so, it computes, at regular intervals along the track, guide points which substitute for the manually chosen track points.

The procedure can be summarized in the following steps:

1) At regular intervals along the premeasured track, sections of the road, 300–400 LCX (LCX = 2 microns) are selected from the gated digitizings (Fig. 1, beam track).
2) In each section (Fig. 2) all digitizings are histogrammed parallel
to the road edge using bins which are initiated by unassociated
points and which can then shift up or down by no more than 30 LCY
in order to associate subsequent digitizings.

3) Histogram peaks are retained as guide-point candidates (crosses in
Fig. 2), each being characterized by four parameters:
\( \bar{X}, \bar{Y} \) mean coordinates of the point
\( H \) mean distance from the lower edge of the sampled section
\( P \) weight (proportional to the number of associated digitizings).

4) A weighted linear fit is executed using all candidates within a
road (Fig. 3), expressed in a system having \( \bar{X} \) and \( H \) as coordinates
and retaining those for which:

\[
\frac{\Delta H}{P} < T_1 ,
\]

where \( \Delta H \) is the distance of the point from the fitted curve,
\( P \) is the weight,
\( T_1 \) is an empirically determined tolerance.

A second weighted linear fit is now executed on the accepted
points. Finally, all the original guide points of the sampled
sections are checked again with a new fit. Guide points are
accepted for which:

\[
\frac{\Delta H}{P} < T_2 ,
\]

where \( T_2 < T_1 \) is another empirically determined tolerance.

This process is illustrated in Fig. 4, where the dots are
guide-point candidates (with their weight written nearby). The
presence of a circle (cross) indicates that the candidate satisfies
the first (second) criterion. The dashed (solid) line gives the
result of the first (second) linear fit.

5) From a second-order fit of the \( \bar{X}, \bar{Y} \) coordinates of the finally
accepted guide points, a road 100 LCY wide is determined in which
all gated digitizings are accepted to enter an iterative sequence
of second-order fits repeated until not more than two points have
deviations of more than 25 LCY from the fitted curve.

6) Ionization information and average points are derived from the
selected digitizings.

From a sample of 2500 four-prong events ($\pi^+ p$, 11 GeV/c) we obtain
a THRESH rejection rate for error code $\geq 4$ due to FILTER inefficiency
which was less than 10%. A detailed description of the THRESH rejection
rate is reported in Part I of this paper.

The actual speed of the FILTER program is about 150 four-prong
events per hour. We are now working to improve this figure.

From a sample of 97 events, which were handled both with the old
FILTER and the new one, THRESH results were:

\[
\begin{align*}
\text{Old FILTER} & \quad \{ \\
& \quad \frac{1}{\rho} = 0.0004436 \text{ cm}^{-1} \\
& \quad \text{R.M.S.} = 0.0000074 \text{ cm}^{-1} \\
\text{New FILTER} & \quad \{ \\
& \quad \frac{1}{\rho} = 0.0004413 \text{ cm}^{-1} \\
& \quad \text{R.M.S.} = 0.0000079 \text{ cm}^{-1}
\end{align*}
\]

The principal advantage of this new FILTER with respect to the old
one (CERN real time track-following FILTER written in IBM 7090 FAP) is
the increased efficiency (of course, at the cost of increased computing
time).

**APPENDIX**

In Figs. 5a and 5b, a CRT output is shown of the display diagnostic
program (as explained in Part II of this paper).
Fig. 1 Road slice at regular intervals.

Fig. 2 Digitizations inside a slice. Determination of guide point candidates.
Fig. 3 Guide point candidates within a road.

Fig. 4 Weighted linear fit to select the guide points.
Fig. 5a  Display diagnostic program - CRT output.

Fig. 5b  Display diagnostic program - CRT output.
ADAM+EVA, A UNIVERSEIAL SCANNING AND MEASURING MACHINE
FOR FILM FROM THE LARGE BUBBLE CHAMBERS

J. Altaber, G. Chanel, P. Dodd, D. Eastwood, A. Fucci,
C. Mazzari, P. Stürzinger, C. Verkerk, D. Wiskott and
A.I. Vaghin*

CERN, Geneva, Switzerland.

1. Introduction

ADAM+EVA is a universal scanning and measuring machine for
film from the large European bubble chambers. It is essentially a
highly automated, manually operated film-plane digitizer, particular
attention having been given to scanning facilities. Universal should
be interpreted as meaning easily adaptable to film from BEBC, Gargamelle
and Mirabelle.

When the ADAM+EVA design was started, the aim was to have
scanning and accurate measuring equipment operational by the time the
first film would become available. Taking account of the uncertainties
existing at that time as to film quality and contrast, a classical
film-plane digitizer, operating on-line to a computer offered the
saftest approach.

On the other hand we expected the scanning to be more
difficult than for conventional chambers. Some aids in scanning were
therefore thought to be necessary and in our opinion these could best
be provided by an on-line computer communicating with the operator. If
this principle is accepted a one-pass analysis scheme is feasible and
has several further advantages : filmhandling is reduced to a minimum
and transfer of scanning information is no longer needed.

We therefore combined our original designs ¹) for separate
scanning and measuring apparatus into a design for one machine. This
was easy to do and added very little to the cost of the original
scanning machine. ADAM+EVA is thus one of the first machines specially
designed for a one-pass treatment of bubble chamber film with the

* Visitor from the Radiotechnical Institute, Academy of Sciences,
Moscow, USSR.
availability of real assistance by computer, both in scanning and in measuring.

The high degree of automation and the excellent performance in speed of operation has been obtained by having all controls for each single machine in a 4K PDP8/L computer. A number of ADAM+EVA's can then be connected via the PDP8/L's to an on-line computer, which in our case is a CDC 3200. The fact that the ADAM+EVA hardware is indirectly controlled by the 3200 computer has given us the possibility of providing active help to the operator in scanning and measuring.

Figure 1 is an outline of the configuration of the ADAM+EVA system, indicating the tasks assigned to the various components. A sufficiently large on-line computer is essential if powerful tests (e.g. spatial reconstruction) on the measured data are required, but the device could be operated under control of the PDP8/L alone if desired.

The following paragraphs will bring out in more detail some of the features of the ADAM+EVA system.

2. Projector

Figure 2 shows, at the left hand side and centre how the apparatus is being installed: the different views of a single frame are projected down onto a table located one floor below.

However, if one has no objections against using large mirrors (1.4 x 2.3 m²) the projector can be turned upside down and the table placed alongside it (see Fig. 2, right-hand side). The film-gates are fixed and the lenses (Schneider D-Claron 210 mm, f/5.6), mounted on a precision X-Y-stage, can be displaced by an amount sufficiently large (180 mm in X, 70 mm in Y) to move the images over the whole area of the scan-table (2.50 x 1.20 m²). The operator is seated at a short end of the table. For Gargamelle and Mirabelle film the projections of different views overlap by a predetermined amount in order that the beam-plane of these chambers is correctly reproduced in the projection. A reference reticle, which is rotatable, is projected onto the table at
a convenient distance from the operator. Measurements are made in the usual way by centering a point on the reticle and reading out the "scalers" (see below) associated with the encoders of the stage movement which have a 2 μm least count. The angle of rotation of the reticle is also digitized with 512 least counts per radian to a very good approximation. Stage movements over short distances are controlled by a track ball; fast movements over longer distances can be initiated by push-buttons. Each button corresponds to a zone on the frame and pressing it moves the stage to a position where the selected zone is centered around the reference reticle. This movement takes generally less than 1 second.

The lamp housings have to follow the stage movement and in order to eliminate static and dynamic loads on the measuring stage, a separate servo is used. The coordination is achieved in the FDP8/L.

The magnification from film to table is 17X, but it is our intention to display the region around the reference reticle on a TV-monitor with a variable magnification of 17 to 50 times. A TV-camera simply looks at the optical projection on the table. We are currently comparing different cameras (vidicon and plumbicon) and making further tests to obtain the best quality of the display.

The filmtransports, which are easily accessible, are very simple. The filmposition is digitized to 0.2 mm using the perforation holes. A step by step control is the main feature, the advance of one frame (380 mm of Cargamelle film, 313.5 mm for Mirabelle) being performed in 1.3 seconds. The rewinding speed will be limited to 3 m/s.

The photographs of Figure 3 and 4 shows a projector in the course of assembly, with the doors carrying the filmtransports closed and opened respectively.

3. Control by FDP8/L

The tasks of the FDP8/L are multiple. It counts all digitizer pulses, it is the basis of all servo controls (stage, lamp-housings, reticle, filmtransports), it handles all communication with the
operator and the 3200, and it reacts to the controls on the console and to alarms. All controls are entirely digital, which reduces considerably the electronics, and which allows us to elegantly merge and interlock commands coming from different sources: operator, on-line computer or PDP8/L itself.

3.1 Counting of Digitizer Pulses

The memory increment facility, which is available on the PDP8/L is used for counting digitizer pulses. Two different memory addresses are used for each encoder: in the first location forward pulses are counted, in the second all backward ones. Two more locations are required to deal with overflow conditions.

The machine contains a large number of encoders: for stage, lamp-housings, filmtransports, reticle, trackball and the reticle control, a total of 2 linear and 10 rotary encoders. Obviously one should never lose a single digitizer pulse. To cope with cases where two or more pulses arrive within the duration of the longest instruction cycle of the PDP8/L (4.8 μs) the memory increment requests have to be stacked together with the address associated to each of them. If a request causes an overflow, it is re-entered in the stack, with a modified address.

3.2 Direct Digital Control of X-stage

The principle of the digitally controlled servos will be outlined using the X-stage servo as an example. Figure 5 is a schematic of this servo. An external clock interrupts the PDP8/L program every two milliseconds. By simple arithmetic operations on the contents of the locations where the digitizer pulses are counted, the instantaneous position $X_a$ of the stage is obtained. Comparison with the desired position $X_d$ results in a value for the error $E$. The time derivative of the error, $E_d$, is approximated by subtracting the value of $E$ at the previous clock interrupt. A control function $F_u = E + KE$ is calculated where $K$ is a constant related to the damping $\gamma$. $F_u$ is quantized to a limited number of values (8 pos. and 8 neg.) with the help of a staircase function (see inset of Fig. 5). The quantized value is then
output to a register. A resistor summing network, an operational amplifier and a power amplifier produce the voltage applied to the printed circuit motor which drives the stage via recirculating ball-screws.

Figure 6 gives an idea of the performance obtained in this way from a model of the stage, which has a mass of 20 kg*. The curves, which show the acceleration and the deceleration phases of the movement are drawn from the output of the PDP8/L obtained during the tests. The total displacement was 171 mm in this test. The top speed of 170 mm/s was obtained to within 10% in 60 ms. The final position was crossed for the first time after 1.02 s. After 1.15 s the overshoots are smaller than 15 μm, and it takes not more than a further 0.2 s for vibrations to die out and for the servo to stay at the desired position to ± 2 μm. We have reason to expect that these preliminary results can be improved by adjusting program parameters.

3.3 Other Controls and General Organisation of PDP8/L Program

The various other servos are controlled in essentially the same way. The PDP8/L program looks after each of them by entering, after a clock interrupt, all active servo routines in succession. Each servo routine has the task to make and to maintain $X_a$ (the actual position) equal to $X_s$ (the desired position). When under trackball control, $X_s$ is calculated from the memory increment locations associated with the trackball. But $X_s$ can also be set directly by the program, and in this way commands received from the 3200, or from the operator via the zone buttons, are executed.

Depressing a console button in general results in an interrupt to the PDP8/L. The program, examining a number of status words, determines the exact source of the interrupt and enters the associated routine. The tasks of the interrupt routines are generally very simple. Often they consist of setting the contents of a given location to some value.

* The mass of the ADAM+EVA stage will be 40 kg, but the other parameters of the servo are such that this should make practically no difference.
For communication with the 3200 computer the operator has a keyboard and a teletype at his disposal. Messages return from the 3200 on display lights or on the teletype, depending on their complexity, but more often than not, the 3200 or the PDP8/L would exert a direct action on the ADAM+EVA hardware.

3.4 Interface PDP8/L - 3200

The interface 3200 - PDP8/L allows a number of possibilities: besides the transfer of blocks of data in both directions, loading, overlaying and dumping of PDP8/L programs can be performed. These programs will be kept in absolute code on the disks of the 3200. The data taking is buffered by the PDP8/L. The data blocks transferred can contain either measurements, or characters or requests for certain actions. Header words specify in detail the contents of each block.

For the actual transfers the data break facility of the PDP8/L is again used and interrupts to either computer initiate the required action in the computer concerned. A status register is the kernel of the interface 3).

4. Hardware Facilities for Aid in Scanning

Another paper presented to this conference 4) contains a description of a software system to provide aid in scanning and in measuring. In the present description of ADAM+EVA we will therefore not enter into details of our planned software system. Nevertheless we must point out that the ADAM+EVA hardware, due to its high degree of automation, offers a number of possibilities which can be very useful for aid in scanning and measuring:

1) The digitized reticle makes measurement of direction of tangents of tracks possible. When, during scanning, the tangents of all tracks at the vertices of interest are measured this information can be exploited at different other phases of the analysis. It allows a track matching to be performed, it facilitates communication with the operator (by centering and orienting the reticle on the track to which the program wants to draw his attention) and it provides a means of associating $\lambda$'s, $K_0$'s and $\gamma$'s.
2) The stage can be driven along any curve. In particular this curve - taking lens distortions into account - might be the projection of a lightray onto a view. Supposing the lightray originates from a measured point on view 1, the projection of it on view 2 can then be used to find the corresponding point on a track (or a number of candidates on different tracks). The stage is driven slowly along the curve and the operator is asked to stop the stage when it crosses a track. A tangent measurement made at the corresponding point can then further help to disentangle ambiguous situations in track matching.

3) When measurements are made on a track by track basis, the facility of positioning the stage and reticle can be used to indicate to the operator the continuation into a third view of a track already measured in two views. For this a 2-view reconstruction of the track must be made which can then be projected onto the third view.

5. Conclusion

We hope to have shown that even in a conventional film measuring system based on a mechanical stage movement there is still room for improvement and interesting development. It is our belief that when we succeed in implementing effective automatic fiducial measuring and track following on ADAM+EVA we will have a system which can compete in overall throughput with many automatic measuring systems which require prescanned film. This will be particularly true if scanning turns out to be the bottleneck in the analysis of Gargamelle and Mirabelle pictures. In that case a system of the ADAM+EVA type stands a fair chance of being the most economical solution.

References:


2. P. Stürzinger; Designing the ADAM+EVA stage control using MIMIC simulation language. Report CERN - DD/DH/70/1.


Figure Captions

1. Layout and tasks of the ADAM+EVA system.

2. Installation of projectors for direct projection (left-hand side and centre) and for projection via mirrors (right-hand side).

3. ADAM+EVA in the course of assembly. The projector is arranged for Mirabelle film.

4. Inside of ADAM+EVA.

5. Schematic of X-stage control.

6. Performance of X-stage servo. The table represents output obtained from the PDP6/L during tests. The acceleration and deceleration phases of the movement are plotted at the right-hand side. Note change of scale at t=1120 ms and setting accuracy at $t > 2400_8 = 1280_{10}$ ms (see table).
ADAM + EVA CONFIGURATION

3200
32 K, 24 bit

3 tapes

3 discs

to other PDP 8/L's and A+E's

PDP-8/L's
4 K, 12 bit

ADAM + EVA

projection table

TTY
operator console

3200
aid in scanning checks on measurements geometry

stages reticle film transports lamp housings

servo controls digitizations sampling of console + alarms communication with 3200 and operator

filmtransport projection system precision stage

communication with 3200 commands indicator lights message display (from 3200)

scanning measuring magn. 17 x variable magnification (≤50 x)

TV camera

Fig-1
Projection directe
Projecion par miroirs interposés
Grossissement x 17 - Focale 210 mm
Projection via mirrors
Magnification

Fig. 2
STEP RESPONSE OF STAGE
MASS 20 KG

1 LEAST COUNT = 2 MICRONS
(ALL NUMBERS ARE OCTAL!)
XA (L.C.) XS (L.C.) AT T = 0
0000 1000 0025 0000

TIME POSITION ERROR SPEED
(MS) (LEAST (L.C) (L.C/ COUNTS MS)
00 0000 1124 6654 0032
0000 0000 1554 6224 0052
00 0000 2346 5432 0064
0000 0000 3268 4528 0076
0050 0000 4256 3522 0103
0060 0000 5342 2436 0111
0070 0000 6450 1330 0112
0100 0000 7623 0155 0115
0110 0001 0776 7002 0116
0120 0001 2285 5573 0120
0130 0001 3420 4360 0121
0140 0001 4653 3125 0124
0150 0001 6105 1673 0123

1740 0024 5137 2641 0122
1750 0024 6202 1576 0076
1760 0024 7065 0713 0060
1770 0024 7685 0173 0046
2000 0025 0200 7600 0034
2010 0025 0467 7311 0022
2020 0025 0651 7127 0015
2030 0025 0753 7025 0004
2040 0025 0760 7020 7777

2357 0024 7776 0002 0000
2377 0025 0001 7777 0000
2417 0025 0000 0000 0000
2437 0025 0001 7777 0001
2457 0025 0000 0000 0000
2477 0025 0000 0000 0000

XA (L.C.) XS (L.C.) AT T=INF.
0025 0000 0025 0000
DISCUSSION

O.R. FRISCH (Cambridge): Why is it called ADAM + EVA?

C. VERKERK: This is an acronym of the French Appareil de Dépouillement et Analyse de Mirabelle et Eventuellement Autres chambres.

H. NAGEL (Bonn): Why do you allow an overshoot during stage positioning instead of reducing the speed prior to arriving at the desired position?

C. VERKERK: Figure 6 shows values of a test made before optimization. The behaviour depends on the value of the parameter K (see Fig. 5), the only constraint on this value being that we would like keep it a power of 2 in order to make the calculations simple.

H. SHAYLOR (Birmingham): What is the cost of one ADAM + EVA table?

C. VERKERK: Approximately £30,000 including the PDP-8/L and all workshop labour.

R. BAIRSTOW (RHEL): Could you tell me how much of the PDP-8/L core memory is taken by the servo-control routines?

C. VERKERK: One control routine takes about one page, i.e. 128 locations. Some space has to be added for interrupt routines, etc. We now want to combine all routines for the different servos as far as possible into one loop, taking probably two or three pages.
SCANNING AND MEASURING OF HEAVY LIQUID FILM ON-LINE

H. Burmeister, D.C. Cundy, H.I. Sletten and W. Venus,
CERN, Geneva, Switzerland.

Abstract: Towards the end of 1970 the large heavy liquid bubble chamber Gargamelle will become operational. To deal with the difficulties in scanning and measuring Gargamelle film, a highly interactive on-line system is being developed in the CERN heavy liquid bubble chamber group. It allows computer-guided scanning and measuring with complete geometrical reconstruction and also minimizes the manual book-keeping effort. It is based on a working system of seven measurement tables on-line to a CDC 3100 with full geometry.

The paper briefly reviews the present system and gives the philosophy and main features of the one planned.

1. INTRODUCTION

Despite the increasing sophistication of automatic measuring machines heavy liquid film is still measured manually. The short radiation and interaction lengths of heavy liquids generally make the events rather complex. Gamma-rays are converted to electron-pairs, secondary tracks frequently interact or stop and decay, and individual tracks deviate substantially from ideal trajectories because of the strong single and multiple scattering and, in the case of electrons, bremsstrahlung. Fig. 1 shows a 12 GeV $\nu$-event found in the CERN 1.2 m HLBC filled with heavy freon (CF$_3$Br).

On-line scanning and measuring can save time and effort by identifying background events and events that do not fulfil all criteria at an earlier stage. The computer can guide the operator and can frequently detect errors and omissions and require their immediate rectification. Machine faults can also be detected. Full three-dimensional reconstruction on-line completely eliminates later remeasurement of points and tracks rejected by the geometry.
program. The manual book-keeping effort and clerical work can be very much reduced, and film handling minimized.

Thus on-line scanning and measurement can significantly reduce the time and effort necessary to analyse an experiment and improves the quality of the results. For heavy liquid experiments with a large number of events, on-line analysis is essential.

2. THE DOLL ON-LINE SYSTEM

DOUL 1) (Decoding On-Line Logic) activities began in 1967 with two measurement tables and a simple format and measurement checking program. The system was gradually expanded to more tables and the software improved. It now has the configuration shown in Fig. 2.

The seven image-plane measurement tables are connected to the computer through a multiplexer. Communication between operator and computer is via a typewriter. The computer is a CDC 3100 with a 32 k core store of 24 bit words, a memory cycle time of 1.75 microseconds, floating point hardware, 3 I/O channels with 2 disc drives, 3 slow tape units, a line printer and a card reader.

The program now contains full geometry with a helix fit to light-rays and, for electrons, a spiral fit to space points (the SPIGAM 2) method). It also does the comparison of internal and external errors leading to GRIND error words. An optimum length method is being implemented.

The system has been used to measure events from a number of experiments in the CERN and RHEU/UCI heavy liquid bubble chambers. The measurement rate per table depends on the experiment, and generally lies between 3 and 6 events per hour.

3. THE GARGAMELLE ON-LINE SYSTEM

The Gargamelle chamber volume is a 4.5 m long cylinder, 1.9 m in diameter. The volume is photographed through 8 wide-angle, low distortion lenses in contact with the chamber liquid. The 8 lenses are arranged in two rows parallel to the chamber axis.
The optic axes in a row are parallel, but the axes of the two rows are inclined at 66 degrees to each other. The magnetic field bisects this angle. Two 70 mm wide perforated films are used to record the images, one in each row. Both camera-based and chamber-based fiducials are provided.

This unconventional chamber geometry makes scanning, measuring and geometrical reconstruction more difficult and time-consuming than in classical chambers. The multiplicity of views alone is a burden. Because the wide-angle lenses are so close to the sensitive volume, and because the lens axes are at an angle to the magnetic field, many tracks will be photographed at large angles to the axes of their helical trajectories. This can cause even perfectly smooth tracks to appear on the film with loops and cusps, and their apparent curvature may even change sign. The strange appearance of the tracks and the large stereo angles will frequently make it difficult to recognize the same event or track in different views. The large variation of the magnification will also cause some problems. Fig. 3 shows a view of a neutrino event as it would have appeared in Gargamelle.

As each of the 8 views only covers part of the chamber volume, it will often happen that electron-pairs from converted gamma-rays, and other interactions or decays of neutral particles, will not be seen in the same view as the parent interaction. This causes difficulties in correlating neutral particles with their origins. There will also be some difficulty with the "bridging" of charged tracks that cross the field of view of several cameras.

The properties of heavy liquids and the large volume of Gargamelle frequently allow the identification of particles. Characteristic decay and interaction modes, length of delta-rays, ionization estimates and locations and angles of kinks must all be recorded or measured at the appropriate stages of analysis.

The large number of events possible in a Gargamelle experiment, together with the complexities and difficulties involved in the analysis of these events, have led us to adopt an on-line system of analysis in which the operator is guided and assisted
by the computer throughout the scanning and measuring phases. Once an event is found all relevant data are collected and the geometry of the event is completely reconstructed. Ideally we should never need to look at that event again.

Thus, we want our on-line Gargamelle analysis system to:

- provide for both scanning and measurement with full geometrical reconstruction in one pass;
- guide and assist the operator throughout by keeping track of what has been done and indicating what is to be done next;
- do all the book-keeping;
- detect event candidates that need not be measured at an early stage;
- ensure that all relevant data are collected in the single pass;
- remove subjective decisions on particle identification by recording the basic information and leaving the decisions to the program;
- enable consistent criteria to be applied in all decisions;
- relieve the operator of trivial routine tasks wherever possible;
- be flexible enough to cater for the simultaneous analysis of different experiments;
- permit corrections of errors and omissions not detected by the computer with minimum loss of data;
- be simple and easy to use.

3.1 Outline of the Scan and Measurement Procedure

The actual scan and measurement procedure will obviously be experiment dependent. As an example, we describe the procedure presently foreseen for the neutrino experiment.
The first phase is a scan for primary vertex candidates as defined by the scanning rules for the experiment. The computer sends the operator through the required view sequence to ensure that the necessary chamber volume is scanned. The scanner controls the view changes with a single GO-button. He may switch on other views to help him understand what he sees, and he may repeat the whole sequence if he wishes. Primary vertex candidates are measured in all views, and if necessary a point-matching program sorts out the measurements. The fiducial marks are not yet measured, but the images are sufficiently well positioned to permit the matching and rough spatial reconstruction of the points. A first check is performed to find out whether the candidates are within the fiducial volume. If they are not they are rejected. If there are primary vertices in the fiducial volume, the computer then requests measurements of the fiducial marks.

In the next phase the computer displays the "best" view of a candidate to the operator and asks him to start a charged-track scan. The best view is normally a view where the apex is somewhere near the beam entrance side of the view, but the scanner may override this if necessary. The track scan proceeds track by track on the best view and on one or more other views as necessary to follow all tracks to their end points. The scan starts with a request to measure the end point of track 1. If it leaves the view the computer will switch to another view and again ask for the end point of the same track. For a track that ends in a given view, the computer then switches on the "pair" view, i.e. the corresponding view in the other row, and requests an end point measurement of the same track. Information is requested from the operator, for each track, whether it interacts or decays, and whether it appears to stop. Ionization estimates are requested at the beginning and at the end of each track, and the length of the longest delta-rays and the location of kinks are also asked for. If any question has a negative answer the operator simply proceeds to the next question by pressing the GO-button. If the answer is positive he responds by giving a co-ordinate pair or by typing in the required response on a keyboard. No time is wasted on useless questions such as asking
whether a particle decays when it has already been recorded that it interacts. The information collected in this phase is mainly for particle identification, but it also serves to provide a checklist and guidance for the subsequent measurement phase. Note that the matching of most tracks can be verified by checking that the interaction, decay and stopping points, and the locations of delta-rays and kinks are corresponding points.

The following phase is a scan for correlated neutral particles, in particular gamma-rays. The operator first notes all gamma-rays on all views that may come from the primary vertex by recording the co-ordinates of the vertices of the electron pairs. In a subsequent pass other correlated neutral particles are recorded by measuring their interaction or decay points. Additional information may also be requested by the computer. The operator does no point matching. The program takes care of this and asks for clarification in case of inconsistencies. Doubtful correlations are also recorded and the final decision taken after full reconstruction has been carried out.

The measurement phase is then entered. The computer is in possession of the necessary information to organize the measurements and guide the operator throughout this phase. The computer decides which views are the best for any given item, and also decides when enough views have been measured. Measurements proceed item by item. Each item is completely measured in all necessary views before the next item is started. Reconstruction is tried at once and if it fails remeasurement is immediately requested. The computer switches the views and indicates which item is to be measured by projecting a light-spot.

Only when everything has been satisfactorily measured and reconstructed does the operator start on the next frame.

3.2 The Conversion of DOLL

The DOLL system has to be partially changed, expanded and improved to handle the analysis of Gargamelle film as discussed above. New scan and measurement tables are necessary, and a faster and better means of communication between the computer and the operator is needed. This hardware is described below.
Although DOLL provides some guidance with autolabels and error messages it is mainly a reactive system in that it leaves the initiative to the operator and merely responds to his actions. In contrast the Gargamelle system software includes a group of steering routines, some of them experiment dependent, which guide and assist the operator and handle the scan phase which does not exist in DOLL.

Also DOLL uses a labelling scheme where each item is identified in all views by a label made up of two alphanumerical characters. In the Gargamelle system we use a data structure following HYDRA *) conventions which clearly define the associations between vertices and tracks in the different views. No labelling is required from the operator.

Finally, the geometrical reconstruction methods used in DOLL are not suitable for Gargamelle. For Gargamelle methods developed for LBCG 3) are used.

3.3 The new Hardware

Our scan and measurement tables are designed and built by SAAB to specifications developed in collaboration with University College of London and based on a pilot model constructed in CERN. The same type of tables will be used by groups in Aachen and Brussels. They can also be used for Mirabelle film by adding some hardware for a third film.

Each table is made up of a projector bank with film transport an overhead mirror and a projection table. The elements of the projector bank are mounted on a base-plate inclined at 40 degrees to the vertical and situated on the floor alongside the projection table. The mirror is an aluminium honeycomb sandwich construction suspended from the ceiling. It reflects the light downwards to form images on a horizontal 2.5 m by 1.0 m projection table. The table can accommodate 3 Gargamelle views side by side in the long direct-

*) HYDRA is the new, highly modular, bubble chamber analysis chain being developed at CERN.
ion at 12 times magnification. The operator will normally sit at the short end of the table looking along the beam direction.

The two Gargamelle films are moved together by two capstans, one at each end of the projector bank. The two capstans are electronically coupled, and when one capstan pulls the films by the sprocket holes in the required direction, the other maintains a suitable tension in them. Between the capstans and each reel of film there is a film buffer consisting of a spring loaded loop of film. The length of each loop is sensed and signals are sent to the corresponding reel motor that tends to keep the length constant. Since the different views of one frame are far apart on the film it is also necessary to form loops of constant length between adjacent film gates in a row. The films can be moved any number of frames at high speed, or they can be moved from one frame to the next at a single command. Both operations are possible in either direction. Permanent leaders are used in the film transport, and once the reels are loaded and the films properly connected to their leaders, a single LOAD-command will bring the first frame into the film gates for projection. At any time the films may be automatically rewound using the UNLOAD-command. During transport the films ride on aircushions above the gates. When the films are stopped for projection an indexing device near each film gate positions the views accurately in the gates to permit accurate superposition of the images on the table. The film is clamped in the gates by vacuum applied to slits extending all around each view.

Any combination of the 8 views may be projected at any one time. The images may be moved along the table by moving the lenses. Two different and independent image movements are possible. One, which we call displacement, serves to bring any view rapidly in front of the operator for close examination and measurements. All 8 lenses move together. The other, superposition, is necessary for pointing of neutrals if their origins are not seen in the same view. If the interlens distances are suitably changed while being
kept equal to one another for the four views in a row, classical pointing with a ruler is possible.

We will measure in the image plane with supermangiaspagos situated at the operator's end of the table. Since the image is 84 cm across we have made provisions for measuring it in two halves. The two positions are determined by clickstops on the lenses. The system is such that, once the fiducials have been measured, we can leave the measurement positions and later revert to them without remeasuring the fiducials. The supermangiaspagos have a least count of about 20 μ and we expect that the x and y errors will not exceed 50 μ over the working area. The operator can bring any view into a measurement position by pressing a button corresponding to the position wanted. If a single view is illuminated that view will automatically be brought to the measurement position wanted and locked in place.

To aid the operator we will add to the table an independent device capable of projecting a light-spot anywhere in the measurement area. This projector will be steered by the computer.

A frame counter in the film transport will inform the computer which frame is currently being examined. During measurement the view number and the position of measurement are picked up automatically by the computer. The computer can transport the film, switch views, and lock any view into either measurement position. However, the operator can override the computer.

The operator can communicate with the computer via a set of functional keys and separate numerical and alphabetical keyboards. The latter is for occasional use only. The functional keys which can be used at any given moment are lit. Status, messages and requests to the operator are displayed on an 8 cm by 10 cm CRT screen which can display 10 lines with 25 characters each. The CRT is driven by a cyclic memory and a character generator. It is line-wise addressable and can display lines in a flashing mode. Audible signals inform the operator whether an action is accepted or not, and whether he has to look at the display.
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Fig. 1: A 12 GeV u-event in CF$_3$H$_2$ in the CERN 1.2 m HIBC
Fig. 2 DOLL on-line system configuration
Fig. 3: A ν-event as it would appear in Gargamelle
DISCUSSION

R. BAIRSTOW (RHEL): Could you say something about the size, construction and flatness specifications of the mirror required when measuring with the super-Mangiospago?

H. SLETten (CERN): The overhead mirror is of aluminium honeycomb sandwich construction with two $\frac{1}{4}$ inch glass plates separated by about 4 inches of honeycomb. The reflecting surface is about $200 \times 70$ cm$^2$. The flatness is specified in terms of the maximum distortion introduced in the image. The actual values depend on the projection geometry.

P. van BINST (Bruxelles): Are you thinking of using the same computer system for these new tables?

H. BURMEISTER: Yes, as a first step. We do not have the time now to write a new system. Perhaps later we will re-write the whole system, making use of more modern techniques.
DATA PROCESSING FOR BUBBLE CHAMBERS
FROM THE POINT OF VIEW OF A SMALL LABORATORY

W. Gräbsch, P. Hein, H. Kirst, K. Kuhn, H. Lippold,
and K. Wattenbach
Institut für Hochenergiephysik der Deutschen Akademie
der Wissenschaften zu Berlin,
Berlin-Zeuthen, Germany.

1. BASIC IDEAS

From 1963 to 1965, two handmeasuring microscopes\textsuperscript{1, 2)} and several
scanning projectors\textsuperscript{3)} have been developed in our institute for the pro-
cessing of bubble chamber photographs. The experience obtained from this
work and from participation in several physics experiments with the
Saclay 81 cm and the CERN 2 m liquid-hydrogen bubble chambers, allowed us
to propose a data-handling system, based on a higher degree of automation,
which offers a suitable increase in measuring capacity.

At that time we had a choice of one of two alternatives: total auto-
mation of the photograph processing (FSD), and a semi-automatic manual
processing (SMF). Devices such as IEP and Frankenstein seemed to be less
effective, and systems such as Spiral Reader, PEPR, POLLY, and others,
were only being developed. A choice between the principles of FSD, SMF,
and our own variant had to be made, bearing in mind the limited possi-
bilities of our small laboratory, which could be defined as follows:

i) The laboratory does not have its own accelerator or bubble chamber.
Therefore, one should be able to handle photographs of different
quality and format. Universality is required.

ii) For technical reasons, the upper limit for the pulse frequency should
be lower than 0.5 MHz.

iii) A medium-fast small computer has to be used in the system.

iv) All the mechanical and electronic work should be carried out by our
own workshop.
Given these restrictions, automatic devices (FSD, CRT, etc.) should be avoided. The remaining possibility was therefore a relatively slow running device with modest computing requirements.

The most favourable solution seemed to be a system in which all the individual processes are well balanced so that the operator is released from the fatiguing and error-prone routine work, carrying out only the pattern recognition. These considerations led us to the following conception:

i) The films are scanned. The information obtained is used for on-line control of the measuring devices by a small computer.

ii) The measurement of events will be guided by an operator. The guidance consists of an operator-controlled rough track-following. Within the limited measuring region defined in this way, precise coordinate measurements will be taken automatically.

iii) The operator should take care that there are, if possible, only true track bubbles within the measuring region. Thus a complicated filter program can be omitted.

iv) A possibility of measuring separate points (bubbles) should be foreseen.

v) The output from the measuring devices will serve as input for the geometrical reconstruction program.

vi) During the coordinate measurement, ionization measurement can also be performed.

Thus, for the measuring devices, the SMP philosophy has been used—positioning of the "mask" by an operator, at the same time as the coordinate measurement—but still with the possibility of making point measurements when necessary. To avoid a filter procedure, the following measuring procedure was proposed: within parts of the film without background, the measurement will be carried out rapidly by the automatic system within the defined measuring region; in "dirty" regions, separate points (bubbles) on the track will be measured by hand. Simultaneously with the automatic measuring of coordinates, a gap-length measurement can be performed on the track. The width of the measuring region of about
0.6 mm diameter on the film was chosen so that in a 4 GeV/c (π⁺p) experiment the measurement of about 70% of the track segments to be measured may be done automatically. For the measurement of high-energy events, one would have to select a width of about 60 μm.

2. PERFORMANCE OF THE SYSTEM

The films are scanned on scanning tables (Fig. 1). After an independent double scanning, a paper tape is produced which serves for the control of the measuring process.

A special measuring projector (ZMP) has been developed for the coordinate and ionization measurement (Fig. 2). The film stage with three film channels is driven by the operator by means of a track-ball. The motion of the stage is digitized by two diffraction-grating systems. The choice of the film, out of three, is carried out by switching the light sources. In the projection table, on the axes of the projection systems, there is an aperture of about 6 mm diameter defining the measuring region. Through this aperture, the measuring region is projected onto a short slit with a photomultiplier (PM) by means of two oscillating mirrors, the axes of which are at 90° to one another. Thus, within the measuring region, two scan zones are obtained. When a bubble occurs in one of the scan zones, a typical track signal will be produced on the output of the PM; if one of the mirrors is deflected, the distance between the track signal and the zero position of the mirror has to be determined. The mirrors are located in such a way that the deflection of one gives a scan parallel to the X-coordinate of the film stage and the deflection of the other -- parallel to the Y-coordinate. Thus we have two orthogonal scan directions, similar to those of the HPD. Any track may be measured with either one or the other scan, depending on its orientation in the X,Y-coordinate system (Fig. 3). As the deflection of the mirrors is made by signals derived from the corresponding digitizing system of the film stage, the "road" is scanned in equidistant steps.

The coordinates of a bubble can be measured by two means:

i) Point measurement. The bubble to be measured should be put in the centre of the measuring region, using the film stage motion. For
this reason, an additional image (at about 5 times magnification) of
the measuring region is projected on to a screen. In this case the
current coordinates of the film stage \( X_0, Y_0 \) are simply the true
coordinates of the bubble centre (Fig. 4).

ii) Measurement with automatic scanning. The track to be measured should
be held within the measuring region. The coordinates of a track
signal obtained by a scan then provides a correction \( \Delta \) to the \( X_0, Y_0 \)
coordinates of the centre of the measuring region, which should be
added to either \( X_0 \) or \( Y_0 \), depending on the scan direction.

The least count is 2 \( \mu \)m for the \( X,Y \) system and 3 \( \mu \)m for each scan.

Counting the number of scans between two successive bubble signals
during the measurement with automatic scanning, one gets information
about the gap length.

The hardware of the ZMP has been developed supposing a tight on-line
computer control of the coordinate measurement, based upon the scanning
information. The conversation between computer and operator is performed
via a teletype 33 ASR.

The main functions of the computer in the on-line process are:
advancing to the frame with the next event and, if it is necessary, the
required projection; printing a "head" of the event, containing the
event number, event type, etc.; moving the film stage successively to
the vicinity of the fiducials to be measured exactly by the operator;
checking the measurements of the fiducials; moving the film stage to
the apex of the event. Then every track of the event is measured by
the operator, and the film stage is moved back to the apex by the com-
puter at the end of the track measurement. A gap-length measurement may
be carried out either by the operator (simultaneously with the coordinate
measurement), or later, by the decision of the computer, based upon the
calculated curvature of the track. There are some logical checks for
all words entering the computer. The measured coordinates are checked
by a circle-fit in the film plane. After the measurement of an event,
the completeness of the information is checked.
3. **STATUS OF THE SYSTEM**

The principle of coordinate measurement was successfully proved on a functional model of the ZMP\(^4\). Now we are testing the first ZMP in an off-line version and installing two additional ZMP's. In a few months we are going to start testing the first ZMP on-line to a small TPA computer (12 bit, 12 K, 10 µsec). The other two ZMP's will be connected also to the TPA. The data will be written onto a magnetic tape, and a data link to a BESM 6 computer is planned. Simultaneously with this hardware work we are trying to optimize the design of our whole data-handling system, i.e. all stages of the processing and the software.

In conclusion, we may continue the glossary of "On-line Measuring Devices" from the Argonne Conference as follows:

**Installation:** Institut für Hochenergiephysik der Deutschen Akademie der Wissenschaften zu Berlin, Berlin - Zeuthen, DDR

**Machine(s):** 3 ZMP's (Zeuthener Messprojektoren)

**Computer(s):** TPA - BESM 6

**Contact:** R.A. Pose

**Started:** 1965

**Current state:** ZMP-1 Testing  
ZMP-2,3 Installing

**Comments:** Three computer-controlled measuring projectors with human road-guidance. Production planned by mid-1970.

* * *

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Fig. 1 Scanning table
Fig. 2 Principle of the measuring projector ZMP
Ionization Measuring $x_o, y_o = 8\mu m$
Coordinate Measuring $x_o, y_o = 16\mu m$

Fig. 3 The ZMP-Scan

Fig. 4 Principle of ZMP coordinate measuring
H. SCHNEIDER (Heidelberg): What is the cost of one ZMP?

R. POSE: We worked on the ZMP for several years with 10 to 12 people but we have not yet made a price estimate.

R.M. BROWN (Illinois): Could you describe the control computer you are using?

R. POSE: The control computer is a Hungarian product, called TPA, with 12 bit word length, 4 K basic memory and 10 µsec cycle time; it can be compared to the PDP-8.

R.M. BROWN (Illinois): Will 12 bits be enough for your coordinates or will you use double precision?

R. POSE: Yes, we have to do double precision arithmetic. The computer is a little small but we have no other possibility at present.
CONTROL OF MANUAL MEASUREMENTS OF
BUBBLE CHAMBER FILM BY A SMALL COMPUTER

E.C. West,
University of Toronto,
Toronto, Canada

ABSTRACT*

A Control Data 1700 controls the manual measurement of bubble
chamber film by analysing and organizing coordinate data and communicating
with the operators through Input/Output typewriters. Data analysis and
operator communication will be described.

In addition our work on a POLLY system will be described. This
will include some discussion of DNA molecules and fluid flow measure-
ments using photochromic dye traces.

* The text of Dr. West's paper was not received in time for inclusion
in the proceedings.
DISCUSSION

C. OUANNES (IPN, Paris): What is the percentage of time requested by your associates on the POLLY project?

E. WEST: Mechanical engineers have a vast amount of data; they have something like 10,000 feet of 16 mm film stored, which they cannot handle because they do not have an automatic system to measure it. The medical use would be much less. It would take a lot more effort, and maybe only a few thousand molecules of any given type are enough to supply the kind of information they want. Once the technique is developed, there will be many other applications. One possible application is the study of chromosomes, but I am not familiar with that.

H. SHAYLOR (Birmingham): The Birmingham HEP group has investigated the possibility of using a film scanning machine for scanning cervical cancer smear slides. Generally, the magnification of our scan tables is too small. An interesting difference with smear tests is that the "reward factor", i.e. the percentage of interesting (cancerous) slides is very low (≈ 0.1% or less) and this gives rise to psychological difficulties in holding the operator's attention to the job. Missing an incipient cancer indication can have very serious consequences of course!

E. WEST: Similar to the problem you just mentioned, if you are looking for abnormal chromosomes then you first look through thousands which are not abnormal. The technicians who are doing this apparently go to sleep when they try it. So there is a need for an automatic way of handling them.

R.T. Van de WALLE (Nijmegen): Regarding the possibility of using CRT-type devices for other things besides HEP, I would like to point out that Professor Grasselli at Pisa has been working for several years now on the problems of fingerprint reading and scanning of chromosome spreads.

A.G. KLEIN (Melbourne): In connection with non-HEP uses of HEP apparatus, we too have had interest expressed by researchers in Genetics (chromosome outline tracing) and Fluid Mechanics (tracing of buoyant particles for flow visualization and turbulence studies).
We at the University of Melbourne are currently constructing a Sweepnik - type device and I would remark that this kind of machine appears to be, a priori, more suitable for the detection and measurement of such irregular and tortuous lines, often of poor contrast.
RESULTS ON THE USE OF A SIMPLE GEOMETRY PROGRAM FOR FILTERING HPD DATA

Ch. de La Vaissière and A. Leguey,
Institut de Physique Nucléaire, Paris, France.

B. Ton That,
Collège de France, Paris, France.

1. INTRODUCTION

We report here results on the use of a simple geometry program for filtering data from the Paris off-line HPD.

This HPD (Fig. 1) is connected to a small computer (CDC 160 A) which performs all real time operations, including a rough gating and the writing of digital images on magnetic tapes.

These tapes enter as input for the "Filtering", performed off-line on a big computer, now a CDC 6600.

Filtering was based on "road guidance", obtained by predigitizing the apex and two points/track during scanning.

Experience with processing 70 000 $\bar{p}p \rightarrow$ four-prong events demonstrated that such premeasurement was a very heavy load.

It seems essential that, in order to maintain the value of our system, we must reduce the level of predigitizing. Such a reduction implies forsaking road guidance, and a complete rewriting of the track processing.

We use a small geometry program to make up for this lack of guidance. In this way we achieve a 50% reduction in predigitizing, while increasing filtering speed by about 30%.

Fig. 1 Block diagram of the HPD system at Collège de France
2. **PRINCIPLES INVOLVED IN THE USE OF GEOMETRY FOR TRACK FILTERING**

It is well known that geometrical relations exist between the images of a track seen by the cameras looking into the bubble chamber. These relations are simple as long as great accuracy is not required. However, they can easily give useful information for finding tracks (often more precise than approximate points coming from premeasurements). Furthermore, it gives automatic track-matching between views.

Geometrical relations must be used in a restrained way to save time. Our method relies upon two important properties of the CERN 2 m bubble chamber's geometry.

a) Images \((m_1, m_2, m_3, m_4)\), as seen by the cameras, of a point \(M\) in the chamber are obtained by conical projections from the optical centres \((O_1, O_2, O_3, O_4)\), on to an arbitrary plane perpendicular to the optical axis (Fig. 2).

![Fig. 2 Principle of geometrical reconstruction in CERN 2 m bubble chamber](image)

We choose the plane of the back window. This means that corresponding fiducials must be superimposed.

The quadrilateral \(m_1, m_2, m_3, m_4\) is a square homothetical to the one constituted by \(O_1, O_2, O_3, O_4\).

Typical dimensions, such as \(m_1m_2\), called parallaxes, are proportional to \(h\) (distance of \(M\) to plane). Connecting lines \((m_1m_2, m_1m_3, \ldots)\)

Make \(0^\circ, \pm 45^\circ, 90^\circ\) angles with the chamber's longitudinal axis.
b) The magnetic field $B$ being perpendicular to the windows, the dip of the tracks is constant. We have therefore, in projection, the approximate linear relation

$$\Delta z = \alpha \Delta s,$$

when $z$ is the parallax, and $s$ the curvilinear abscissa of corresponding points. How one combines these two properties depends upon the amount of information available at the time of the processing.

We take (Fig. 3) the example of one track found already on two views, the problem being to locate this track on the third view.

![Diagram of track on first and second views](image)

**Fig. 3** Use of corresponding points to find an approximate location of a track, already found on two previous views.

By superposition of the back window fiducials, curves corresponding to the two first views are calculated for the plane of the digital image.

Then a pair of corresponding points are easily obtained. Each pair gives an approximate point. This set of points defines with fairly good accuracy a narrow road where actual digitizations are situated.

Our results show that 90% of tracks lie within a width of ±30 least counts (HPD length unit), and this is far less than the road width of ±250 L.C. used with our former road guidance program.

The background level is small with such narrow roads; and, if one is not interested in ionization data, one can get accurate information on the position of the track very quickly by only sampling digitizations within the road.

3. **EFFICIENCY OF GEOMETRICAL RECONSTRUCTION**

The following example, involving the second property, gives an illustration of the geometrical reconstruction's efficiency for filtering.
We shall suppose that the following data are available in the image plane (second view):

- apex position (given by premeasurements, or other tracks)
- accurate position of one track found on the first view.

(In HPD slang: minimum guidance.)

Finding the track requires three steps (Fig. 4):

a) Sample digitizations inside the area of corresponding points. Boundaries are obtained from two limits of spatial slope $\alpha$ according to whether the track reaches the front or back window.

Sampling is made along narrow strips following several reconstruction lines. Here, reconstruction and scan lines are parallel.

b) Coordinates of each digitization are computed in the $(s, z)$ plane. One can see that several points are fitted by a straight line on Fig. 4B.

c) The conjugate curve in the HPD plane gives an accurate approximation of the track. Figure 4C shows the neighbourhood of this curve. The exact localization is then easy to perform.

Systematic use of the method allows one to reduce the premeasurement to:

- some road guidance on the first view,
- apex or nothing on the second view.

A limitation can come into our system from the greater number of digitizings one has to store. With predigitizing the apex and one point/track on the second view it is possible to obtain a good reduction of the number of digitizings (the same as with road guidance). We choose this intermediate solution as a first step which already gives a 50% reduction in the amount of predigitizing.

Comparison of the time necessary for track processing on the CDC 3600 between the three views shows no strong influence due to the geometrical reconstruction:

<table>
<thead>
<tr>
<th>View</th>
<th>Time (sec)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.84</td>
<td>apex + 2 points/track guidance</td>
</tr>
<tr>
<td>2</td>
<td>2.81</td>
<td>apex + 1 point/track guidance + geometry</td>
</tr>
<tr>
<td>3</td>
<td>2.55</td>
<td>geometry</td>
</tr>
</tbody>
</table>

Total 8.20 sec
Fig. 4 Searching a track on second view in a HPD plane if the track on first view and apex on second view are given. Lengths in HPD least counts: 1 LC = 1.6 μ on the film.
(The time for the same four-prong event with the old program: 14 sec).

We still do not have much information on the rejection rate. We hope that it will be smaller than the present rate when the debugging is finished.

4. CONCLUSION

We intend to put an operational program into service in the next few months. This new program will be designed to allow a further reduction of the predigitized information.

It seems to us that simple geometry can be efficiently used to save time in HPD minimum guidance filtering. We think that it can also give good results in processing data from devices other than an off-line HPD.

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6) C. de La Vaissière, Thèse (Chap. V), to be published (mai 1970).
DISCUSSION

A.J. OXLEY (RHEL): Have you tried out this method on multi-prong events? If so, at what energy?

C. de La VAISSIERE: Yes, on 4 prong events at 2.3 GeV/c.
THE BRUSH SYSTEM FOR AUTOMATIC PROCESSING OF BUBBLE CHAMBER PICTURES (Status Report March 1970)

H. Billing, A. Rüdiger, R. Schilling,
L. Schnupp, R. Kaufhold and F. Gandini.

Max-Planck-Institut für Physik und Astrophysik,
Munich, Germany.

ABSTRACT

The BRUSH system is intended for automatic track detection, track following, and 3D track reconstruction of bubble chamber pictures. Track detection and track following are done in the special purpose BRUSH computer, on line with the HPD. A special geometry program for the IBM 360/91 is being written to reconstruct the tracks from the track elements found by the BRUSH computer. The special hardware used for detection of track elements from the individual digitizings (Track Detection Unit) has been completed and has been attached to a general purpose computer to speed up the simulations of the BRUSH computer.

The use of an active program memory and the addition of a magnetic drum will result in more program flexibility in the BRUSH computer. Modifications of the BRUSH program result in improved track following and allow detection and flagging of beam tracks to speed up the subsequent geometry program.

The general concept of the geometry program is discussed. A significant feature is the direct 3D approach. First results of this geometry program are quoted.
INTRODUCTION

The BRUSH method of automatic processing of bubble chamber pictures was first proposed at the Argonne Conference [1]. The operation of BRUSH can only briefly be described in this status report. Some more details are given in the literature [1,2,3,4].

BRUSH is intended for zero-guidance on-line processing of HPD data. Our concept consists of four distinct phases which are listed in Table I. These phases are: (1) the detection and (2) the subsequent precise calculation of individual track elements, and (3) track following. The first three phases will be performed by the BRUSH computer, on-line with the HPD. The final phase (4) of reconstruction in chamber space will be done off-line on a general purpose computer (360/91).

I. HARDWARE

I.1. BRUSH Configuration

Figure 1 shows the overall BRUSH configuration. The BRUSH computer (inside the dotted lines) receives the digitizations from our HPD via its small buffer memory of 64 words. The output, the track elements of one picture, is accumulated on a magnetic drum. After completion of one picture, these data are transferred to the large disc of the IBM 360/91. After accumulating there the data of, say, one roll of film, these data are transferred to a magnetic tape for later processing in a geometry program. Some parts of BRUSH form a more or less conventional computer: a very fast CPU, a set of 64 fast flipflop registers (FFR), and 2 separate 8K core memories (CM) of about 1/ us cycle time. The core memories and the components for registers and CPU have been delivered and tested. With the help of computer simulations to verify the internal logic, the design of the fast arithmetic unit has been completed, and construction is now under way.
I.2. Program Memory

Because of the on-line real-time requirements, the BRUSH program must be stored in a separate memory (PRS), about 10 times as fast as the core memories.

Our design of this program memory has undergone perhaps the most drastic change. Instead of the rigid read-only diode matrix, we will now use read-write MOS memories (Texas Instruments). With almost no penalty in speed and price, we now have an active memory, and thus full program flexibility.

With addition of the magnetic drum, we can now even swap programs during the processing of one picture, to change, say, from recognition of the picture number to the main program for track recognition, and, at the end of the picture, switch to a program to calculate the optical transformations for all track elements, before sending these data to the disc. The MOS-circuits for the program memory have already been delivered, the design of the printed circuit boards is nearly completed.

Also under construction are a CRT display and a small input-output console for testing and maintenance.

I.3. Track Detection Unit

Of the core memory, 4k words are reserved for buffering the HPD digitizings, allowing only a short section of the picture to reside in this buffer. Track detection and track following can, therefore, only be done locally. The phase of track detection is done by special hardware, in the Track Detection Unit.

This Track Detection Unit, consisting of a shift register array (SRA) and 48 local processing units (LPU), was completed and successfully tested. In 1969, it was attached to our G3 computer which is used to simulate the overall operation for the BRUSH computer. The resulting gain in speed allowed us to establish more quickly the appropriate strategies for track element calculation and track following. Such strategies must be carefully chosen, as the HPD allows only a single sweep across the picture.
Fig. 2 shows a schematic picture of the Track Detection Unit. Track detection is done in slices of 16 scan-lines (only 8 are indicated in Fig. 2). The principal idea is to map the digitizing of one slice onto a two-dimensional array of shift register flipflops. This array is crossed by 48 narrow linear search strips at closely spaced angles to search for strings of aligned bubbles. The image of the digitized bubbles is shifted vertically down this array of flipflops, and at each height step, representing 20 μ on film, the hit counts in all 48 search strips are simultaneously determined by 48 local processing units (LPU).

A conspicuously high hit count represents what we call a track element candidate. The necessary comparisons between neighbouring hit counts are also performed in the 48 local processing units.

These processing units are fast enough to allow shifting at a 1 MHz rate. Thus it takes only 2.5 ms to shift a total slice through the shift-register array, whereas the HPD takes 40 ms to digitize one slice.

II. SOFTWARE
II.1. Track Element Calculation

In the phase of track element calculation, a straight line is fitted to those digitizings which gave rise to the candidate. Along with precise position and slope, the rms scatter of these digitizings is calculated. This scatter in general has low values in the case of genuine track elements, and relatively high values in the case of ghosts, that is in the case of only accidentally aligned bubbles.

By introducing a hit-count-dependent threshold for this scatter, a surprisingly reliable discrimination of genuine track elements from ghosts can be made [1,4].

Dense electron spirals can give rise to a large number of track element candidates. The CPU is, however, fast enough to calculate the fits of up to 500 such candidates in one slice, a number never reached in reasonable pictures.
The phases of detection and precise calculation of track elements serve the purpose of picking up or initiating tracks. The goal is, of course, to follow the tracks once they are initiated. Nevertheless, these initiation phases have to be re-peated in each slice of the picture, as the beginnings of tracks are not known beforehand in a zero-guidance system. Furthermore, tracks may have to be re-initiated, if track following has failed over a few slices.

II.2 Track Following

In preparation for track following, corresponding track elements in successive slices are linked (Fig. 3). A parabola is fitted to a series of such linked track elements. Such a parabola is accepted as part of a genuine track if the rms deviation of the track elements from this parabola is reasonably low. These parabolas are used for track following.

In the linking of track elements and in the parabola fits we only have to deal with the relatively few accepted track elements. This allows the use of more flexible procedures than in the detection and calculation phases [4].

After the HPD has finished digitizing the next slice, first a direct search for digitizings is made in narrow roads along the extrapolation of the parabolas. Again, a linear least squares fit is made with the digitizings thus found, this time however, in the curved coordinates of the parabola.

Track following by such a "preview" finds the continuation of a track much more reliably than the shift register search. This is so because the preview road is adjusted in position, slope, and curvature to the track element to be found. Also, interference by neighbouring or crossing tracks is greatly reduced, due to the small road width of about 40 \mu. Furthermore, as the track has already been confirmed by the previous track elements, the acceptance criteria can be relaxed considerably. Crossing of tracks can be detected ahead of time, and measures can be taken to make up for the disturbed digitizings in such regions [4].
II.3. Erasing

After the previews have been completed, the digitizings of this slice are entered into the shift register array of the track detection unit in an attempt to pick up additional track elements.

The track elements found in the previews need, of course, not to be found again by the track detection unit. Digitizings found in successful previews and in good agreement with the preview parabola are, therefore, not entered into the shift register array. By this "erasing" of preview digitizings, regions of close tracks become less confused, and in the subsequent shift register search the remaining tracks are more easily found. The erasing criteria are made subject to the quality of the parabola, the presence of a crossing and the beam status of the parabola.

II.4. Beam Recognition

The track elements found in the BRUSH computer are transferred to the drum, and eventually to tapes for later processing in a special geometry program.

This geometry program has to perform a few additional tasks beyond the tasks of a full guidance geometry program. The most important of these are also listed in Table I. They are, in reverse order: (D) the recognition of the events, which should preferably be done in space. This stage must, of course, be preceded by (C) the matching of tracks of the individual views. These tracks have (B) to be constructed out of the linked track elements of the individual views, with the linkage information already supplied by BRUSH.

In our geometry program the tasks (B) and (C) will be combined, by initiating the tracks in space from the linked track elements and then simultaneously following this track in all three views, carrying along a helix fit.

Such additional tasks can only be performed in a reasonable computer time if we can, in this track reconstruc-
tion, disregard the majority of non-essential tracks, such as
beam tracks, scratches and ghost elements (A).

Therefore, a beam recognition is performed on-line
in BRUSH [4]. A beam status is assigned to each track element
and to each parabola, according to slope, curvature, and past
history. In Fig. 4, the widely spaced dots represent beam track
elements (B), the intermediate pattern elements of undecided
status (U), and the non-beam elements (N) are indicated by
the dense string of dots. These dot patterns are no longer re-
solved in the compressed representations in Figs. 5 and 6,
but there the heavy N-elements are still clearly distinguished
from the faint B-elements.

The local beam recognition works quite reliably in
track following, with an accuracy of about a quarter of a de-
gree ($\approx 5$ mrad).

In general, the geometry program will not have to re-
construct the beam tracks. Track elements not used in accep-
ted parabolas or not even linked are also indicated by a widely
spaced dot pattern. Perhaps such isolated elements can be
ignored by the geometry program. Only in the vicinity of an
event, in an attempt to find short stubs, will such isolated
elements be used in 3D track initiation.

II.5. Film Demonstration

To give an impression of how BRUSH is working its way
through the digitizings of one picture with the interlacing
techniques of previews and shift register search, a movie
film was produced from the simulation runs.

Going in slow motion through the complete length of
a bubble chamber picture, the operation of BRUSH was demonstra-
ted by superimposing in different colors the digitizings,
the candidates detected, the accepted track elements, and the
digitizings erased after the previews.
II.6 BRUSH Output

The output of the BRUSH simulations on the 03 computer was written on magnetic tape and used as input of the geometry program. Table II contains a list of the items of information which characterize one track element, the column "Length" indicates the minimum requirements for the individual items.

III. GEOMETRY PROGRAM

The peculiarities of the BRUSH method (zero-guidance; individual track elements) require a new approach to the geometry program.

This geometry program has been written and tested on the 360/91, many refinements, however, still have to be added. This program consists - roughly - of a linear chain of separate stages, some of which are treated below.

Fig. 7 shows schematic flow diagrams of the present status of the BRUSH system and of the planned final BRUSH configuration.

It is probable that BRUSH can become operational already at an intermediate stage.

III.1. Optics

From the fiducials found in the BRUSH on-line processing, the transformation coefficients to the reference frame are calculated. Subsequently, the track elements are transformed into corresponding light rays. As this transformation requires only information of single views, this part will later be performed by the BRUSH computer during stage retrace and film transport.

III.2 3D Track Initiation and 3D Track Following

A basic feature of the BRUSH geometry program is the direct 3D approach. A possible intermediate step of linking the BRUSH track elements into 2D track segments is not performed. A track in space is initiated by track element matching.
A non-beam track element in view 3 is combined with a non-beam element of the corresponding slice of view 1 which is within a certain height range ("window") to insure intersection inside the chamber. The resulting space point is projected into view 2 in search of a confirming track element there. If there is no confirmation, a combination with the next track element of view 1 must be tried.

In case of a confirmation, one proceeds in all three views to the track elements of the preceding slice with the aid of the BRUSH linkage information. After having obtained at least three confirmed space points in, say, 6 successive slices, the track is considered initiated. One continues following this track in all three views, but space points are now calculated only every four slices.

A helix fit, updated with each new space point, helps to extrapolate across gaps or regions of confusion. All track elements successfully used are flagged as "checked off". These track elements will not again be used in track initiation, thus further reducing the number of possible combinations.

In the few geometry runs made so far, this concept has been quite successful. The non-beam tracks of Fig. 6 were reconstructed over their entire length, despite some gaps in the BRUSH data and ambiguity in the BRUSH linkage.

In the present state of the program, still heavily burdened with diagnostics, and with no attempt to optimize efficiency, the CPU time to find and reconstruct all non-beam tracks of Fig. 6 was about 2 sec on the 360/§1. This CPU time can certainly be reduced considerably.

III.3 Event Recognition

An event recognition part has also been written and tested. This first links segments of interrupted 3D tracks into full length tracks.
A search for vertices is then made in space using as criterion the shortest distance between helices in the neighborhood of the last space points on these helices. Each new vertex is compared with those found previously. In case of good agreement, vertices are merged, and the position of the vertex is updated.

A search for the incoming beam track has yet to be added, also a search for secondary tracks that may have been masked by beam tracks.

The assignment of a charged secondary interaction to its primary vertex is made with the help of the interconnecting track. Possible assignment of neutral events to primary events is tested.

The exact location of stopping points can be derived from the hit distribution (16 bit "hit word") edited with each BRUSH track element.

Very short tracks will require special attention. Appropriate strategies have yet to be developed.

III.4. Input for Kinematics

The standard method for ionization measurement is also included in the geometry program.

The mass dependent fit has yet to be added to produce an output compatible with GRIND. In the mean-time, to compare our results with full guidance, geometry is actually done twice, using as master points for THRESH the track elements of the already reconstructed events. The THRESH residuals showed no significant differences between full guidance and BRUSH.
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II. Software (A. Rüdiger)
III. Geometry Program (R. Kaufhold)
Internal Reports, Max-Planck-Institut für Physik und
Astrophysik, Munich, Germany.
### Table I

<table>
<thead>
<tr>
<th>PHASE</th>
<th>PROCEDURE</th>
<th>IMPLEMENTATION</th>
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<tbody>
<tr>
<td>(1) DETECT</td>
<td>Map digitizations onto flipflop array</td>
<td>hardware, special memory organization</td>
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<tr>
<td></td>
<td>Determine hit counts Tmn</td>
<td>hardware</td>
</tr>
<tr>
<td></td>
<td>Compare Tmn → Candidates Yn, tg αn</td>
<td>hardware, (20 μ, ~2°)</td>
</tr>
<tr>
<td>(2) CALCULATE</td>
<td>Line fitted to dig. of candidate</td>
<td>fast arithmetic unit, special memory organization</td>
</tr>
<tr>
<td></td>
<td>→ Y, tg α, T: Q</td>
<td>conventional, (1.5 μ, 0.2°)</td>
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<td></td>
<td>Scatter criterion Q(T, tg α, ...)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>→ Track Element Y, tg α</td>
<td></td>
</tr>
<tr>
<td>(3) FOLLOW</td>
<td>Link with predecessors</td>
<td>conv.</td>
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<tr>
<td></td>
<td>Fit parabola to series of track elements</td>
<td>conv.</td>
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<td>Preview: as in (2) calculate</td>
<td>as in (2)</td>
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<td></td>
<td>→ Track Element</td>
<td></td>
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<tr>
<td></td>
<td>Global features: Beam</td>
<td>conv.</td>
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<tr>
<td></td>
<td>Scratches</td>
<td></td>
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<tr>
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<td>Crossing</td>
<td></td>
</tr>
<tr>
<td>(4) RECONSTRUCT in space</td>
<td>additional tasks:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(A) Eliminate non-essential tracks (beam, scratches, ghosts)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(B) Form tracks out of tentatively linked track elements of individual views</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(C) Match tracks from individual views</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(D) Recognize event (3D)</td>
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### Table II

<table>
<thead>
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<th>Length (bits)</th>
<th>Remarks</th>
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<td>Position (at right slice boundary)</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Slope</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Curvature (of preview)</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Hit count</td>
<td>4</td>
<td>0,1, ... 14, &gt;15</td>
</tr>
<tr>
<td>TW</td>
<td>&quot;Hit word&quot; (distribution of dig. in 16 scan lines)</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>Addresses of 2 direct predecessors</td>
<td>12</td>
<td>2 x 6</td>
</tr>
<tr>
<td>NP</td>
<td>Total number of direct predecessors</td>
<td>2</td>
<td>0,1,2, &gt;3</td>
</tr>
<tr>
<td>Q</td>
<td>Scatter of fit</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>Length of successful past linkages</td>
<td>5</td>
<td>0,1, ... 30, &gt;31</td>
</tr>
<tr>
<td>ST</td>
<td>Status bits, including:</td>
<td>16</td>
<td></td>
</tr>
<tr>
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<td>Beam status</td>
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<td>Multiple beam</td>
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<td>Preview element</td>
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<td>Review element</td>
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<tr>
<td></td>
<td>Used in parabola</td>
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</tr>
<tr>
<td></td>
<td>Used in linkage</td>
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Fig. 1 Configuration of BRUSH System

Fig. 2 Schematic picture of Track Detection Unit
Fig. 3 Linking of track elements, preview parabolas

Fig. 4 Digitizings, track elements in part of bubble chamber picture
Fig. 5 Digitizings, track elements of picture 754, view 2, total length, height 10 mm. Compressed in x-direction.
Fig. 6 Track elements in all 3 views of picture 754, compressed as Fig. 5.
Fig. 7 Schematic flow diagrams of total BRUSH System: Present status and final configuration
DISCUSSION

D. HOLTHUIZEN (Amsterdam): How many orthogonal scans do you intend to make per frame?

A. RUDIGER: This has not been decided yet. To be sure to get all tracks on the 2 m chamber format naturally 3 orthogonal scans would be needed per picture. It might, however, be more reasonable to make a simple pre-scan in which the operator just states which orthogonal scans should be executed.

J. BURREN (RHEL): What CRT system did you use to make your movie?

A. RUDIGER: Our home built G3 computer has a CRT display with a white phosphor. We attached photographic equipment which included a set of colour filters selected under computer control. Multiple exposure then allowed the production of this colour movie of the display.

M. FERRAN (CERN): At which stage do you measure fiducials?

A. RUDIGER: We search for fiducials in the normal track detection and track following process. Fiducials would cover at least two of the 1 mm wide slices. For well digitized marks no trouble is anticipated but it might be useful in more difficult cases to have more elaborate routines available. An advantage will be that one knows in which region of the picture these routines have to be used, i.e. where to search for fiducials.

C. OUANNES (IPN, Paris): Could you calculate your parabola on more than 3 consecutive slices?

A. RUDIGER: At present we construct the parabolas from data on four successive slices. If one retained track elements from more slices better fits could be made on longer parts of the tracks. This would naturally improve the quality of the curvature information.

In the "preview" calculations the curvature is taken into account; a least squares fit is made over the digitizings within the (curved) coordinate system of the preview parabola.

J. HARRIS (Oxford): How well does your parabolic model perform on very curved tracks?
A. RUDIGER: The method still works fairly well for tracks with a radius of curvature of half the film width. In the case of stronger curvature more refined methods than parabolic extrapolation have to be used. This has been tried in simulation studies but not much work has been put into it as the computer used is very limited in memory space. It is fortunate that the highly curved tracks are usually also heavily ionizing so that they can be found easily.

E.M. PALANDRI (CERN): Do you have any estimates of the cost of the BRUSH computer?

A. RUDIGER: Yes, adding hardware costs including drum and core memory, CRT display etc. gives a sum of about £25,000. This figure, however, does not include labour costs.
THE HPD - CDC 3200 SYSTEM AT AMSTERDAM

Zeeman-Laboratorium, Universiteit van Amsterdam, Holland.

1. INTRODUCTION

In this paper we want to present results obtained with an HPD system, with the special feature that an abnormal scan is not required. After a short discussion of the hardware configuration and of the digitizing method the main features of the Minimum Guidance program will be described and some figures on the performance will be given. Preliminary results of the ionization measurements and future developments like BEBC and Zero Guidance will be discussed.

2. MAIN FEATURES OF THE HARDWARE

The main features of the system are summarized in Fig. 1. The HPD is on-line to a medium size computer (CDC 3200, 32 K of 24 bit words, cycle time of 1.25 μs). The external equipment consists of 4 magnetic tape units, a diskfile (capacity 33 M words), a card reader, a line printer and a console typewriter. Part of the system is a Tektronix 611 storage scope of which the 'write thru' mode is used to measure points on the displayed picture directly in HPD coordinates.

The advantages and disadvantages of not using an abnormal scan have been extensively discussed by Harting in Argonne 1). We will therefore give only a short description of the digitizing method, which is illustrated in Fig. 2. Instead of finding along each scanline the centre of the dark spots encountered, a sampling technique is used. Only a normal scan is made with a scanline distance of 25 μm and the track signal is sampled with the grating pulses, occurring at intervals corresponding to 12.5 μm on the film. Sample pulses are defined as the 'and' of the track pulses and the grating pulses. The number of sample pulses in the "track pulse" is sent to a
buffer memory together with the y coordinate of the centre of the spot. In this way a 50 x 120 mm$^2$ picture is covered by 4000 x 4800 measuring points, the position of each point being known with an accuracy of ± 2 μm.

3. **MINIMUM GUIDANCE**

3.1 **The program chain**

The program chain consists of the programs MIST - GATE - FILTER - THRESH.

The program MIST controls the premeasurement of the vertex, which is done on three on-line Enetra film plane digitizers, that are normally used for hand measurements. In each frame three fiducials and the vertices are measured in 2 views and the third view is computed. If the error in the spatial reconstruction of the point is too large MIST asks the operator to measure the third view. The final accuracy is 5 - 10 μ on the film. The output is written on a tape in a blocked format, as proposed by the CERN MG group.

This tape is used as input tape for the program GATE, which controls the HPD and transfers the digitizations from the HPD to the disk. Immediately after the scan is finished the picture number is decoded, the fiducials are found and FILTER is executed. The masterpoints and the ionization information are written on the output tape together with the information from the input tape. We therefore do not need a merge program like SMOG.

Our version of FILTER has been adapted from the CERN Minimum Guidance FILTER. The techniques used for track finding and following have been described elsewhere $^2$, we therefore report only on the main changes necessary to adapt the program to our HPD and computer.

1. The abnormal scan is simulated in the program: the original information on the black grid points is obtained from the y coordinate of the centre of the black spot and the number of sample points along the y direction. For abnormal tracks the points are grouped together in the x direction and represented by the x coordinate of the centre and the number of points in the x direction (Fig. 3).
2. The search for outgoing tracks (subroutine WEDGE) is done over the full 360° at one time.

3. Due to the limited core size the program had to be split into overlays and segments.

4. The digitizings cannot be stored in core memory all at the same time. Only those digitizings required by the program for the next section of the followed track are read in from the disk. This transfer is done in parallel with the execution of the FILTER program.

5. In clear regions of the picture a fast track following routine is used.

The geometry program is a combination of a THRESH version already in use on our computer and a rather old CERN version of MATCH, which has been put into THRESH as an independent overlay. Failures of MATCH are corrected afterwards in THRESH by trying all combinations of track-views, which did not already give a good 3 dimensional fit. THRESH does not get information about the expected number of tracks.

The THRESH output tape also contains ionization information, corrected for geometrical effects. This information will be used in GRIND for automatic decision making.

3.2 Results of geometry and kinematics

With this program chain we are now measuring 15 hours a week on a sample of 1600 4-prongs and V⁰’s from a 4.2 GeV/c K⁻p experiment in the 2 m CERN HBC. The results of this sample will mainly be used to optimize the program chain. Until now 1000 events have been measured and processed through GRIND. As measurement and analysis are still in progress we are not able to give accurate figures about success and failure rates. The results obtained so far indicate that 55% of the events have a GRIND error < 100 and give a fit or a missing mass fit in GRIND.

In Fig. 4 the THRESH residuals for the helix fit are shown. To study the effect of the absence of the abnormal scan we grouped the tracks into three categories according to the angle between track and x-direction (0° - 30°, 30° - 60°, 60° - 90°). The peak values of the residues are 2.5 µ, 3.5 µ and 3.5 µ respectively.
3.3 Speed

The speeds of the different programs are listed in Table 1. The speed of FILTER depends very strongly on the event type, the film quality and the number of beamtracks, which is reflected in the number of digitizings. The speed of 20 events/hour is obtained for 4-prongs on a picture with 20 incoming tracks, giving 150 000 digitizings. The time for the display is needed because we want to save the digitizings of 1 cm$^2$ around the vertex for debugging purposes. Time can be gained by decoding the picture number and finding the fiducials during the scan.

3.4 Ionization

The $V^0$'s in the sample are used to test the ionization measurements. For each track segment the ratio of the number of hits along the track and the corresponding number of scanlines is measured. These ratios are corrected for the angle between track and scanline. From the resulting numbers the bubble density and the error are calculated.

Table 1

<table>
<thead>
<tr>
<th>Program</th>
<th>Time per event</th>
<th>Time per frame</th>
<th>Time per event</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIST</td>
<td></td>
<td></td>
<td>150 s</td>
</tr>
<tr>
<td>GATE</td>
<td>scan</td>
<td>16 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>picture number</td>
<td>7 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>decoding fiducial</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>finding</td>
<td>3 s</td>
<td></td>
</tr>
<tr>
<td>FILTER</td>
<td>computations</td>
<td>24 s</td>
<td>87 s</td>
</tr>
<tr>
<td></td>
<td>waiting time for disk</td>
<td>5 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td>display</td>
<td>8 s</td>
<td>24 s</td>
</tr>
<tr>
<td>THRESH</td>
<td></td>
<td></td>
<td>20 s</td>
</tr>
<tr>
<td>GRIND</td>
<td></td>
<td></td>
<td>20 s</td>
</tr>
</tbody>
</table>
The average of the bubble densities in the three views - after geometrical corrections - is taken as the ionization density of the track. In Fig. 5 the ratio of the bubble densities of the 2 tracks of the $V^0$ is compared with the same quantity as computed in GRIND. In 80% of the events the agreement is within 20%.

In future the information on the track width will be used to correct for differences in the apparent bubble size in the three views.

4. FUTURE DEVELOPMENTS

4.1 BEBC
Some effort has been made to digitize pictures from the BEBC model at CERN 3). As in these pictures the particle tracks show up light against a dark background, AC coupling was used instead of DC coupling and the signal was passed through a high pass filter with a cut-off of 200 kHz to eliminate background variations. It was proved that good digitizings can be obtained from these pictures and that the tracks can be followed by our MG FILTER.

4.2 Zero Guidance
The HPD system at Amsterdam is intended eventually to operate in the Zero Guidance mode. A vertex finding routine based on picking up and following all beamtracks simultaneously has been written. This program will be used to scan small angle scattering of $K^+$ in hydrogen.

Acknowledgements
We wish to thank Drs. R. Pfeijffers for helpful discussions, F.G. Hartjes, F.E. van 't Hul, P. Snitker and A.P. Slootweg for maintaining and developing the HPD hardware and J.C. van den Berg, J.G.H. de Groot, C.J.H. Nijman, H.F. Weesing and J. van Zanten for writing parts of the programs. The expert help of the staff of the electronic and mechanical workshops of the Zeeman-Laboratorium is greatly appreciated.

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3. L.O. Hertzberger.
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FIG. 1

HPD-CDC 3200 system

CDC 3200
32K 24 bits
cycle 125 μs

HPP without abnormal scan

TEKTRONIX 611
WRITE THRU

CR PR

DISK (33M)

3 ENETRA'S

CERN/HELE MINIMUM GUIDANCE
FIG. 2  DIGITIZING METHOD
FIG. 4 THRESH RESIDUALS
RATIO = \frac{BD \text{ of Pos. Track}}{BD \text{ of Neg. Track}}

FIG. 5 IONIZATION OF $V^0$'s
DISCUSSION

W. BLAIR (CERN): Do you need the accuracy of the ENETRA in pre-digitizing the vertex?

W. van LEEUWEN: The ENETRA are there and also they are on-line. At present their accuracy is needed but later we might do with lower precision.

D. HOLTHUIZEN (Amsterdam): An accurate vertex measurement is not strictly necessary. However, it saves computer time because one can recognize passing tracks as not belonging to the vertex in less time.
EXPERIENCES WITH COUPLED COMPUTERS TO CONTROL AN HPD

H.J. Mück, H.-H. Nagel and F. Selonke,
Physikalisches Institut, Bonn, Germany.

V. Blobel, B. Hellwig, D. Mönkemeyer and E. Raubold,
DESY and II. Institut für Experimentalphysik, Hamburg, Germany.

Usually one of the following three modes to operate an HPD is encountered:
- The HPD is directly connected to a dedicated medium-size computer
- The HPD is directly connected to a shared large computer which gates
  in real-time but filters off-line
- The HPD is connected to a small computer which gates the digitising
  onto magnetic tapes later to be filtered at another, larger computer.

The BONN-HAMBURG collaboration chose a different approach. The HPD is
controlled by a small computer§ which is directly connected to the large
central computer§§ at DESY via a 1.2 Mbyte/sec data channel and a separate
Direct Control Feature (DCF). The DCF enables both computers to interrupt
each other in order to transmit an 8-bit Byte of control information.

The satellite computer serves a threefold purpose:

1. **DIGITISING BUFFER**
   The small latency of 1-4 μsec and the high transfer rate of up to
   1 Mword/sec of the Direct Memory Access to the satellite computer made
   a separate thin-film memory buffer unnecessary. A fast 8-word shift-
   register constructed of ICs is sufficient as buffer between the track
detection circuit and the satellite computer memory even for 8-10
   parallel tracks separated by not more than a bubble size.

2. **PROCESS CONTROLLER**
   The large computer transmits to the satellite information completely
   specifying the next scan. Film transport, carriage positioning and start
   of the digitising scan are then performed by the satellite computer
   which also routinely checks all incoming HPD-data for consistency.

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§DPF-9 with 16K (18 bits) 1 μsec memory, Automatic Priority Interrupt
System and Extended Arithmetic Element

§§IBM/360-75 with 1 Mbyte (8 bits) 750 nsec main core memory, 2 Mbyte
8 μsec Large Core Storage, 16 disc drives capable of storing
25 Mbyte each, etc.
These data are sent to the large computer in blocks of approximately 1000 words where they are transformed into the format required by the FORTRAN programs and stored into the Large Core Storage (LCS). No gating or filtering take place in the central computer during the scan. Carriage positioning and film transport by the satellite computer, however, are overlapped with filtering the digitisings of the preceding scan in the central computer.

The hardware design of the satellite computer and the negligible systems overhead allow it to react more rapidly than a large or even a medium size computer. Therefore the entire decision logic necessary to control the HPD was transferred to the satellite programs. This approach reduced the interface hardware considerably with the additional bonus of more flexibility. Special hardware-testing and trouble-shooting routines in the satellite computer substitute for the test- and simulation electronics required whenever an HPD is directly connected to a complex large computer. Thus program-supported trouble-shooting is possible without interfering with other users of the large central computer.

3. OPERATOR TERMINAL

The satellite computer uses a teletype and a fast, random access display with character generator, increment mode, vector mode and light pen in conjunction with 6K of satellite memory to support the communication between the operator and the programs in the large computer. Utility routines in the satellite computer allow one to display and modify text, display digitisings, select and enlarge areas of interest in the digitisings display, move symbols of rough digitiser measurements relative to the simultaneously displayed HPD-digitisings and to delete Master Points superimposed on the displayed road plot. The operator communication routines in the central computer are all written in Fortran, to a large extent according to standardised rules.

The final control concerning all HPD operations rests within the central computer programs. The HPD-operator cannot directly influence the HPD-routines in the satellite computer. He has to communicate his intentions to the central computer programs using the light pen to select one of several options offered to him in clear text on the display. Through this
feature the operator may guide the programs in all major decisions. During production, however, logical flags changeable at execution time can be set to suppress most or all of the decision requests. The central computer programs then branch according to a standard choice.

The decision requests - if offered to the operator - are supplemented by the optional display of information necessary for a proper analysis of the situation. This includes a complete survey of the input to a program step: the display of all relevant program parameters by Fortran name and value, the scan and rough digitiser information, the HPD-digitising as decimal numbers or as pictorial display. In addition the operator may request or suppress at execution time a varying amount of intermediate and final results for each program step. The speed and ease of information presentation on a display is essential for this kind of approach. The linkage editor used to build the overlay structure of the central computer programs allows the definition of more than one "region" - the overlays in one region being completely independent of those in another region. This feature was used to pack a large number of routines all in parallel into a small second region. Most of these routines display a section of a COMMON block containing parameters, data or working variables. The operator may request displays by these routines without modifying the program status in the main working region. The possibility to request displays of the same working variables at successive stop points in the program logic reduced the necessity for voluminous and usually not very intelligibly formatted on-line diagnostics encountered in lineprinter oriented program tracing.

Direct access to datasets residing on disks and the use of the new CERN geometry input format simplify the data management. A normal off-line batchprocessed job copies the filter results of a finished roll of film onto magnetic tape and then transfers the scan- and premeasurement information of a new roll onto the same permanent dataset. The amount of physical records in this dataset reserved for each event is determined from the number of tracks to be measured. There are actually two of these datasets which are used alternatively. The HPD-programs are fully controlled by the HPD-operator and need no special intervention by the central computer operators since no tape units are used by the on-line programs. To
measure an event, the corresponding records of the direct access dataset are read by the on-line program, the fiducial and filter results are appended to the existing information and the combined data are written back onto the same place within the direct access dataset. This approach adapted from RHEL renders a separate SMOG-run unnecessary. In addition it allows repeat measurements of random events without any organisational difficulties and offers a good security against loss of events due to incorrect operator intervention, malfunction of hardware or central computer stops and restarts.

Adapting the CERN and RHEL Full Guidance Programs we attempted to implement the following concepts:
- Everything that depends on HPD-parameters is run on-line to the HPD. One common set of parameters is accessible to all routines. Conflicting parameter assignments in the course of hardware or software modifications should thus be avoidable.
- At every stage tests check the consistency of the results transmitted to the next step. Difficulties should be identified at the earliest possible stage before they accumulate and intermix at later stages rendering a proper error analysis time consuming if not impossible.
- The operator is able to immediately correct as far as possible any troubles detected by the program checks. This should reduce the book-keeping and other data management efforts necessary to bring recoverable events back into the main stream of processing. Unrecoverable errors are identified and flagged in order to pass them through all following members of the processing chain. This facilitates the easy accumulation of statistics about how many events are lost, for which reasons and in which part of the chain.

To realise this goal we incorporated the MIST, GATE, FILTER and SMOG programs into one overlay structure utilising the 120 Kbyte (12%) main core storage permanently allotted to the HPD-programs. In addition we use about 370 Kbyte (18.5%) of LCS for I/O-buffers and for saving the stage coordinates, the pointers to the digitising and all digitisings for the normal and up to one abnormal scan.

As an example some of the tests are given that are applied in HAZE on top of the usual processing after a segment is filtered:
- Make sure a large fraction of the road is covered with Master Points
- Check the distance between the first or the last Master Point and the corresponding rough digitised point
- Check the distance between successive Master Points and its variance to insure an approximately even spacing of Master Points along the segment
- Check for subsidiaries in the roads of low momentum tracks for which larger tolerances must be admitted. Under these conditions incorrect subsidiaries are occasionally accepted by the program.

If the segment fails any of these tests the road plot together with superimposed symbols for Master Points and rough digitiser measurements is displayed. Depending upon the quality of the premeasurements about 5-8 % of the track segments are presented to the operator. About 2/3 of these are nevertheless acceptable and the operator chooses 'NORMAL CONTINUE'. Otherwise the operator may modify the road width, change the position of critical premeasurement points or shorten the road in case of discernible scatters. Since all digitisings are kept in the LCS, he may even correct completely wrong premeasurements where the track of interest leaves the road. Then the filter process is repeated. The operator may also force the acceptance of a subsidiary if the program choice is unsatisfactory or he may force filtering of the road in the opposite direction. Incorrect Master Points e.g. in the vicinity of small angle crossing tracks or confused regions may be deleted by the operator.

Under these conditions about 88-89 % of the events (12 GeV/c pp exposure in the CERN 200 HBC, all event types are measured) are successfully reconstructed by THRESH in the first pass. On a sample roll we redigitised those events that did not pass THRESH and scrutinised all tracks on the display that were not successfully reconstructed after the first pass. A number of small-angle kinks, rough digitiser errors and incorrect filter results could be identified and corrected that were not detected by the post-filter tests of the first pass. About 95 % of the 430 events on this sample roll were successfully reconstructed in THRESH after the second pass through the HPD.
One roll was processed by the HPD without any operator intervention. 82% of the events passed THRESH. Thus the on-line operator intervention seems to gain us 6-8% of the events. We are currently installing the following system: during the first pass no operator intervention is requested by the programs. As soon as all three views are measured on the HPD, THRESH will be run on a first direct access dataset containing both the premeasurements and the filter results. The THRESH-results will be written onto a second direct access dataset. In a separate step following the THRESH-run the geometry output on the second dataset will be inspected and the premeasurements of all tracks that failed in THRESH will be flagged in the first dataset. Only events with failed tracks will then be redigitised during another HPD-pass and the failed tracks presented to the operator. In a second pass through THRESH these remeasured events will be reconstructed and the THRESH output inserted in the proper place of the second direct access dataset. Only then will both direct access datasets be copied onto magnetic tapes for further processing.

Based on our experience this approach is expected to yield well over 90% of the events successfully reconstructed for GRIND without a second pass on the rough digitiser tables which constitute the bottleneck within our system. The number of tapes and the corresponding book-keeping problems should be kept to a minimum. The geometry program is only run once on the good events which represent over 80% of the sample. Since all segments are filtered by the same routines the recovery procedure should not introduce any bias with respect to precision or ionisation information.

We are just starting to adapt the CERN Minimum Guidance programs to our installation. Within our framework no large amounts of digitising tapes will have to be handled since all digitisings of a scan are retained in the LCS, immediately processed by the Minimum Guidance routines and then discarded. The organisation developed to cope with the Full Guidance rejects is equally well applicable to Minimum Guidance rejects. Finally the methods developed to keep a complex program under close operator or physicist control are expected to be advantageous during the transfer and adaptation of the Minimum Guidance system to our HPD and our experiments.
DISCUSSION

J. RUSHBROOKE (Cambridge): Did tracks with small-angle kinks not detected previously show up as tracks with large helix-fit errors in geometry, or at the filtering stage?

H. NAGEL: These small angle kinks were usually rejected by THRESH as having too large an error (> 17 μm THRESH residual). The kink, however, was not large enough to be detected by the FILTER test and was therefore not presented to the operator at the first pass.

J. RUSHBROOKE (Cambridge): Down to what angle could an angle-change be detected by your FILTER program, with a view to segmenting long tracks having small angle changes in direction (Coulomb Scatters) on BEBC film?

H. NAGEL: We have not made any investigation as to whether we could be able to find small kinks automatically, (as is intended at Amsterdam, for instance) using the well known feature that a road plot compresses a track in its length and expands it in its width. So I cannot give you an exact figure.

J. RUSHBROOKE (Cambridge): May I therefore put this question to Dr. van Leeuwen?

W. van LEEUWEN (Amsterdam): The minimum angle, which can be detected during track following by MG FILTER is about 1°.

J.W. BURREN (RHEL): Suppose that you compress the length of the track to fit it onto your display and then you blow it up sideways so that the width of the screen corresponds to say 300 to 400 microns. Then, you know that you can detect by eye a kink of a few degrees - certainly less than 5. When the track is non-circular the sensitivity of the eye of course will be lower. Even so one comes to remarkably small detectable angles (~ 0.05°) for a manual system using HPD digitizings.
USE OF IBM DATA MANAGEMENT TO
CONTROL BUBBLE CHAMBER DATA FLOW

E. Raubold,
DESY, Hamburg, Germany.

1. INTRODUCTION

The cataloging facilities of the IBM 360 Operating System offer the following possibilities to the user:

i) Identification and retrieval of data in a device and volume independent manner by data set names.

ii) Automatic generation of sequences of data set names for data sets belonging to a predefined group of data.

iii) Run-independent retrieval of input data by symbolically referring to the last or all of the members of a pre-defined group of data sets.

These features are considered useful since

i) the user need not care about tape volume labels and volume capacities when generating data or working on already existing data,

ii) the user has to change less or even no job control cards to specify input and/or output data for sequentially repeated standard steps of the program chain,

iii) the book-keeping task is considerably reduced.

In the following the available facilities will be briefly described and the use we make of these facilities at our laboratory will be demonstrated.

2. DESCRIPTION OF THE CATALOGING FACILITIES

The systems catalog is basically a list kept on a direct access device which contains for each cataloged data set name (DSN) the kind and name of the physical volume or volumes carrying the data set. Catalog entries can be
generated, changed or deleted by means of the DISP-
 disposition-) parameter required for every data set in the
 users job control cards.
 Once a data set has been cataloged, the DSN alone allows the
 system to retrieve the data set via the catalog.
 A necessary implication of using the catalog is that DSN's
 must be unique in the system (which is enforced also by the way
 OS 360 interlocks simultaneous access to the same data set).
 The catalog can be structured into several levels of sub-
 indices, thus speeding up the catalog search procedure.
 Reference to sub-indices is made by symbolic names which
 form, linked together by periods, the complete data set name.
 E.g., BLAKA, PPEXP, GTIT is a legal name belonging to master
 index BLAKA and sub-index PPEXP with last level identifier
 GTIT (which could be for instance a data set containing GRIND
 titles for a pp-experiment).
 Special sub-indices called generation data group indices can
 be generated providing additional service by the system. All
 data sets having all sub-index names except the last level
 identifier in common are said to belong to the same generation
 data group (GDG). The last level identifier has a certain
 standard form in this case:

 Gnnnn Vmm

 which can be read as "generation no.nnnn, version no.m".

 The system provides the following facilities for such GDG's:

 i) all members of a generation data group may be re-
     ferred to virtually as one data set by simply
     specifying the index names without last level
     identifier (automatic concatenation).

 ii) new data sets may be added to the GDG by specifying
     index names (+1), which results in generating a DSN
     for the new data set with nnnn in the last level
     identifier being one greater than the highest nnnn
     before.
iii) individual members of a GDG may be retrieved by

index names (1) with

\[ l = 0 \] addressing the data set with the
  highest nnnn

\[ l = -1 \] addressing the data set with the second
  highest nnnn

... currently in the GDG.

It should be pointed out that every member of a GDG can
be referred to and manipulated like any other data set by
specifying its full DSN explicitly.

3. USE OF ABOVE FACILITIES

3.1 Managing a tape library and data set retrieval.
When the user desires to create a new data set he defines
a DSN and requests a private volume on his data set
definition card without specifying a volume name.
The operator will then be advised by the system to
mount as many scratch tapes from a pool of free tapes
as are needed to keep the whole data set. Since all
tapes carry labels, the system recognizes which volumes
have been used in which sequence and stores this infor-
mation in the catalog. The operator marks all these
volumes as "in use" removing them in this way from the
pool of free tapes. Subsequent retrieval of this data
can be done by specifying the DSN only.
When the user no longer needs the data set, he
simply has to remove his DSN-entry from the catalog
by specifying DELETE as disposition in a data set
definition card for this data set.
Every 14 days the present contents of the catalog is
compared with the tapes being marked "in use". Per
definition only those volumes appearing in the catalog
are really in use, so the rest of them are returned to
the pool of free tapes by removing the "in use" indication.
3.2 Automatic generation of new data set names.
Output data from each step in the chain of bubble chamber programs are collected in one specific GDG.
A new DSN for each run of the program step is automatically generated by specifying \( DSN = \text{index names}(+1) \).

This feature, together with the non-specific volume request described under 1., allows one to use a standard data set definition card for the output data set which need not be changed from run to run.

3.3 Automatic transfer of data between jobs.
Two applications should be noted: One is the accumulation of several data sets in one GDG and subsequent simultaneous processing of all members of the GDG. This is done for instance for the data going from \text{THRESH} into \text{GRIND} (see fig. 1). \text{THRESH} is normally run on a roll by roll

![Diagram showing data flow and DSN's for HPD-THRESH-GRIND](image_url)

\( n \) measurements
\( n + 1 \) measurements
\( n + 2 \) measurements

Fig. 1 Data Flow and DSN's for HPD-THRESH-GRIND
basis to give feedback of error information to the
HPD-people. The output of THRESH is collected in a GDG
called THRESH by specifying DSN=THRESH(+1). GRIND-runs
however will normally be scheduled weekly and accept all
THRESH output available so far by specifying DSN=THRESH.
All THRESH data sets are deleted from the catalog after
successful completion of GRIND.
A second example shows a combination of the above
described method and an update procedure in the case of
maintaining the master index of an experiment (see fig. 2).

![Data Flow Diagram](image)

---

*Fig. 2 Data Flow and DSN's for Typical INDEX UPDATE*

All index update information is collected in a GDG
called INDEX,NEWS by specifying DSN=INDEX,NEWS(+1).
The index update program accepts two input streams: One
stream contains the last master index identified by
INDEX.MASTER(∅). The other stream consists of all index update information available so far identified by DSN=INDEX.NEWS. The output is a new master index entered into the master index GDG by DSN=INDEX.MASTER(+1). All INDEX.NEWS data sets are deleted after successful completion of the update run. Both examples demonstrate how data can be automatically transferred between different jobs in the program chain without having ever to change any data set definition card or to take care of physical volumes.

4. Safety Considerations

All the cataloging facilities have the important property of providing a highly usable service without restricting the basic data manipulation possibilities of the 360 OS. For instance if it is necessary or desirable to refer to a specific volume the user can still do so even if the volume carries a catalogued data set. So it is always possible to go back to the "conventional" method of data organisation. Nevertheless since the present state of the tape library is documented in the catalog we copy and list the current contents of the catalog every day. An IBM utility program allows one to restore the catalog from the copy if necessary. We have had the catalog feature now for about 6 months, but a restoration has never been necessary.
THE STATUS OF THE HPD MINIMUM GUIDANCE PROGRAMS AT CERN

CERN, Geneva, Switzerland.

1. INTRODUCTION

The Minimum Guidance chain of programs has measured one experiment of 9,000 events from the CERN 81 cm Hydrogen Bubble Chamber and is at present being used to measure a 30,000 event experiment from the CERN 2 m HBC. One can say therefore that the programs have achieved production status.

This paper describes some recent developments in the program chain and gives the present characteristics of the programs.

2. THE PROGRAM CHAIN

The chain has been described already\textsuperscript{1,2,3} but as a framework for the present paper this section contains a brief summary of the programs.

2.1 Principles

Minimum Guidance requires events to be located and identified by an operator. The events are marked by a rough measurement of the vertex or vertices and a fiducial mark. Any frame which contains an event is scanned by HPD and the tracks of the event are found and followed by program using the HPD digitizings. When images of the tracks in all views have been measured, these are matched together and the tracks reconstructed in space.

2.2 Implementation

Figure 1 shows the program chain. Film is scanned and premeasured at a Milady table. The premeasurements are punched on cards which are checked for mispunches by the program MIST I. The program MIST II puts all premeasurement information on to the "scan tape". This scan tape thus contains a job list for the GATE program. GATE controls the HPD, directing it to scan the chosen frames, measures the fiducials thereon and writes all the digitizings from the scan on to the "digitizings tape", together with the original scan tape data. The FILTER program, guided by the Milady points, finds and follows the vertex tracks among the HPD digitizings. The found
master points on the tracks are then written on to a "tracks tape". When
a batch of events has been measured on all views the program SLOG puts
views of the same event together for input to THRESH. THRESH is a modi-
fication of the standard CERN geometry program with a special input sec-
tion to accept the MG "linked block" format\textsuperscript{6}) tapes. It also contains an
improved Track Match section which identifies the three views of a track
prior to reconstruction and attempts to reject images or tracks which do
not belong to the event.

3. RECENT DEVELOPMENTS IN THE PROGRAMS

Although the existing descriptions of the programs are still valid,
some refinements have been made.

3.1 Vertex check by MIST

The MIST program now checks the validity of the premeasurements by
doing a rough reconstruction of the vertex. This tells, to an accuracy
of $\approx 400 \mu m$, whether a given vertex has been well measured on all views
or not. Since even a very poor measurement would not be out by such an
amount, this test can only indicate a completely wrong measurement. The
roughness of the reconstruction and the lack of redundant information
makes it unwise to replace a measurement which has been classed as bad,
by coordinates derived from the good measurements. At present work is
in progress to extend the existing on-line Milady system, using an
IBM 1130, to cater for MG premeasurements. This will replace card handl-
ing and associated errors and hence the program MIST I.

3.2 Digitizing level control by GATE\textsuperscript{6})

GATE, the control program for the HPD, now needs only a few plug-in
program units to convert from FG to MG. Knowing, more or less, the beam
parameters in each view, GATE constructs a rough "road" leading to the
expected position of the vertex. In this road a stringing process asso-
ciates beam-like sets of digitizings together to form "streams". Simple
hits-per-scanline values distinguish single-beam streams from multiple-
beam streams. The values from good, single-beam streams indicate whether
the digitizing level is too high, too low or good. To keep the CM size
of the GATE program as small as possible the digitizings are written out
on to tape during the scan, only the fiducial boxes and beam road being
kept in the CM for inspection.
3.3 Bubble density estimation in FILTER

The FILTER program has been adapted to provide bubble density information from the track elements it has used in following. The program simply uses the hits per scanline for each element, neglecting the hits which are necessarily at each end of the element.

The events which had been studied to test the bubble density information given by the Full Guidance chain were measured again by MG and gave practically the same results\(^*\). Figure 2 shows a plot of the normalized ionization against \( \log_{10} (\text{momentum}) \) for \( \pi s \). This plot follows a \( 1/\beta^2 \) law, the solid curve, quite well, with R.M.S. errors of 15\%-20\% above 300 MeV/c whereas the human eye cannot do much better than distinguish 40\% difference in ionization.

3.4 Vertex measurement "repositioning" by FILTER

FILTER now considers the region around the MILADY premeasurement of the vertex and, if possible, will calculate the coordinates of the vertex more accurately. The routine fixes the y-position of the vertex by finding a suitable beam in the region and the x-position by finding a point of convergence on the chosen beam of all the "strings" in the region. Only if there is no doubt about the correctness of the new vertex will the Milady measurement be replaced. The program will also try to estimate accurately the size of the error in the vertex measurement, even if it has not been changed. A more accurate vertex makes it easier to find weak tracks coming from the vertex and, by reducing the number of unrelated tracks found saves time in FILTER and THRESH and makes the track matching problem simpler.

3.5 Gear changing in track following

Before this change FILTER was finding 40 or 50 master points on long tracks, particularly beam tracks, and these were having to be thinned out before being input to THRESH which can accept only 25. Thus computations were being thrown away. To avoid this, FILTER is now allowed to simulate an increase in scanline separation once track following is well under way. Every scanline is used to detect and establish the tracks but once, say, 8 average points have been found on a track then only every other scanline is used in track following. After a further, say, 6 points are
found, only 1 in every 3 scanlines is used. This method has been called "changing gear". The curvature of each track is checked and if it is sufficiently curved then the program will stay in a lower gear to cater for non-circularity.

Gear changing saves $\sim 20\%$ of CPU time in FILTER and does not noticeably affect the bubble density information or track-following success. Figure 3 gives a breakdown of how CPU time is spent in FILTER.

3.6 Choice of tracks by MATCH

It was thought better to select the tracks which belong to a vertex on the basis of their nearness of approach to the vertex, accurately defined in space by the convergence of all reconstructed tracks, rather than the original method of preferring tracks which were well reconstructed. This "closeness to vertex" test is now done by MATCH and gives more good events than before. Further, the contamination of apparently successful events with foreign tracks has been reduced almost to zero.

It is currently required that secondaries pass within 1 mm of the vertex in the beam plane and within 7 mm in a direction perpendicular to the beam plane. At present beams must have a mass-dependent fit residual of $< 6 \, \mu m$ and secondaries a mass-dependent fit residual of $< 10 \, \mu m$ unless they are of too low energy to be considered "good". Since $\sim 5\%$ of tracks, in 4-prong events, are reconstructed from only 2 views, a test is being made to determine whether there was any physics bias due to the use of such tracks.

4. PERFORMANCE OF THE CHAIN

An experiment of 9,000 6-prongs from a 700 MeV/c antiproton beam has already been measured by MG $^5)$. In this experiment, where about 80% of the events were good after remeasurement, performance was to some extent limited by the resolution of HPD 1, the film quality, and the poor collimation of the incident beam. This interpretation is confirmed by the improvement now obtained using HPD 2 on film from the CERN 2m HBC.

4.1 The present experiment

An experiment of 30,000 4-prong events is now being measured by MG. These are from an antiproton beam at 5.7 GeV/c.
Figures 4 and 5 show typical frames from the experiment. All pre-
measurements have been made at the rate of 20 events/hour.

4.2 Program characteristics

Table 1 gives some characteristics of the programs when measuring
the present experiment.

4.3 Quality of measurement

Figures 6 and 7 show plots of the residuals of helix fits to beam
tracks and secondary tracks for a sample of events from the present
experiment.

4.4 Results

So far 1400 events have been passed through to GRIND. Table 2 shows
a breakdown of this sample. No study has yet been done to classify the
main causes of failure, but the impression from looking at failed events
on the film is that some events are extremely difficult.

5. LIGHT-PEN RECOVERY OF FAILED TRACKS

Preliminary results indicated that a recovery system will not be
needed for this experiment. However, such a system is being developed
and will be tested on a sample of several thousand events from the experi-
ment. This will facilitate a search for physics biases in the rejects
and program deficiencies in the basic chain.

5.1 The recovery system with the present chain

Figure 8 shows a sketch of the recovery system. The main chain is
as before except that from FILTER to THRESH a sample of 4,000 digitizings
from around each vertex is transmitted with the track information for the
event. There is virtually a one to one correspondence between THRESH
rejects and GRIND rejects, so any event which fails in THRESH is written
out on to a "RESCUE" tape with track matching information, THRESH errors,
and the attendant digitizings. At the display the operator sees the
digitizings from the vertex region and the superimposed THRESH informa-
tion. Figures 9 and 10 show the operator's display. He indicates with
a light pen what action should be taken: delete tracks, move vertex, meas-
ure crutch points etc. This information, together with the information
for the "good" tracks is output on to a "tracks points" tape. FILTER, with access to the total digitizings, will remeasure only those tracks indicated and the new track images are written out with the old "valid" images to be matched and reconstructed. Recovered events are then merged with the other events.

* * *

REFERENCES


6) "HPD Digitizings Tape Format", W.G. Moorhead and A. Sambles, CERN Internal Report CERN/DD/DP/66/6 (Revision 3).


8) The Method for estimating the Beam Ionization from HPD digitizings in the FGGATE program, and the use of this value to control automatically the digitizing level of the HPD, A.E. Head, CERN Internal Report CERN/DD/DH/69/10.
Table 1

Characteristics of MG programs in CDC 6600, for exp 01.
Scanning and premeasuring 20 events/hour

<table>
<thead>
<tr>
<th>Program</th>
<th>CM size</th>
<th>CPU time ev/sec</th>
<th>Real time rate ev/hour</th>
<th>Tape units</th>
<th>Other characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIST I</td>
<td>16 K</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>MIST II</td>
<td>18 K</td>
<td>0.2</td>
<td>5,000</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>GATE</td>
<td>18 K</td>
<td>5.0</td>
<td>110</td>
<td>2</td>
<td>Uses program overlays writes 130 frames/1&quot; tape</td>
</tr>
<tr>
<td>FILTER</td>
<td>37 K</td>
<td>7.8</td>
<td>180</td>
<td>2</td>
<td>Uses program and data overlays</td>
</tr>
<tr>
<td>SLOG</td>
<td>26 K</td>
<td>0.2</td>
<td>5,000</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>THRESH</td>
<td>36.5 K</td>
<td>1.5</td>
<td>2,000</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2
1400 events from exp 01
GRIND verdict

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Verdict</th>
<th>Fate</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>Good</td>
<td>To GRIND library tape</td>
</tr>
<tr>
<td>12</td>
<td>Bad</td>
<td>Remeasure (normally)</td>
</tr>
<tr>
<td>7</td>
<td>Check</td>
<td>Found good: - low probability fit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- poor ionization information</td>
</tr>
<tr>
<td>2</td>
<td>Check</td>
<td>Good after recomputation:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- beam from titles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- reject extra tracks</td>
</tr>
</tbody>
</table>
Fig. 1 Block diagram of the Minimum Guidance program chain
Fig. 2 Plot of the normalized ionization against the logarithm of momentum for π⁺s (from CERN Internal Report DD/INT/DP/69/21)
Fig. 3 Breakdown of the CPU time spent by FILTER
(from CERN Internal Report DD/DR/69/19)
Figs. 4 and 5 Typical frames from the present experiment
Fig. 6 Helix fit residuals on beams from the present experiment

Fig. 7 Helix fit residuals on secondaries from the present experiment
Fig. 8 Block diagram of the light-pen recovery system
Figs. 9 and 10  The recovery system display screen
DISCUSSION

H. FAISSNER (Aachen): How many events do you measure per hour?

M. FERRAN: On the HPD we run at a peak of 138 and a mean rate of 110 events per hour.
Some information on the bubble and spark chamber picture processing system at JINR has been presented at previous conferences\(^1,^2\). The present configuration of the system and plans for development are given in this report. During the next 2–3 years, the main sources of film at the Joint Institute for Nuclear Research will be:

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**from the JINR synchrophasotron:**

- the 1 m hydrogen bubble chamber with two 50 mm films,
- the 1 m propane bubble chamber with two 80 mm films,
- film from spark chambers.

**from the Serpukhov accelerator:**

- the 2 m hydrogen bubble chamber with 3 or 4 50 mm films,
- the 2 m propane bubble chamber with six 50 mm films,
- the 5 m magnet spark chamber spectrometer with one 35 mm film,
- some large streamer chambers in a magnetic field.

A part of these films will be analysed by physics groups from the laboratories of the JINR member countries or will be processed in large collaborations, but because of the limited possibilities of these laboratories the major part of this film will probably be processed on the JINR devices. A processing system is being developed which will be able to handle these various films effectively.

A brief survey of the data processing system status is given below.
1. STATUS OF THE TRACK CHAMBER PICTURE PROCESSING SYSTEM

1.1 Semi-automatic measuring devices (PUOS) on-line to the BESM-4 and MINSK-22 computers (Fig. 1)

At present, the work of attaching 11 PUOS's on-line to a BESM-4 computer is in the last stages of completion\(^3\)\(^,\)\(^4\). Production measurement has already started with 5 GeV/c (πp) interactions in the 1 m hydrogen bubble chamber. Measurements are carried out by operators in accordance with the scanning information provided. The BESM-4 computer reads in and checks the data from the measuring devices, and those measurements which satisfy all criteria are recorded on magnetic tape. The operators communicate with the computer via switches and indicator lamps. The system operates for six hours per day, with the operators working 3.5 hours on the scan-tables and 3.5 hours on the measuring devices. To achieve maximum efficiency these PUOS's will be divided into three subgroups: one for processing hydrogen bubble chamber pictures, one for processing propane bubble chamber pictures, and the third one for various work with spark chamber pictures and for tests.

The PUOS's now in use for measuring the pictures from the 1 m propane chamber which are on-line to the MINSK-22, will be taken out of service. These devices will then be connected to the BESM-4 computer. Thus finally the number of PUOS's on-line to the BESM-4 computer will be increased to 16.

1.2 HPD on-line to the CDC-1604A computer

The Road Guidance programs for measuring hydrogen bubble chamber pictures on HPD are near completion\(^5\)\(^,\)\(^6\). It is expected that processing real events for the purpose of checking out the entire system can be started in the second part of the year.

Scanning and pre-measurement of events will be done on scanning-measuring tables of the type BPC-1 and BPC-2 connected to a small TPA computer (8 K, 12 bit, 8 μsec). Two tables are presently being connected on-line. Next year there will probably be six tables on-line. Measured data will be stored on magnetic tape and will serve as input to the normal sequence of film processing programs MIST, GATE, FILTER, SMOG and THRESH on the CDC-1604A.
In future, the pictures from the JINR 2 m hydrogen bubble chamber will be processed on the BESM-6 by a geometry program which takes into account both energy loss as a function of a particle’s mass and the inhomogeneity of the magnetic field. Work on the use of HPD to analyse film from the ITEP 6 m magnet spark chamber spectrometer operating at the 40–60 GeV Serpukhov accelerator is going on simultaneously with the work of getting the HPD to run. It seems that it will be the first experiment to be processed using the HPD. It is planned to define the approximate position of the event by measurement on the BPC-2 scanning tables; the remainder of the processing will then be automatic. At the same time this work will serve to develop the processing methods for the pictures from the JINR 5 m magnet spark chamber spectrometer.

1.3 CRT automatic scanner on-line to the BESM-4 computer

The scanner is intended for the measurement of spark chamber pictures. In 1969, 100,000 events were measured to investigate the polarization of secondary protons in the reactions $pp \rightarrow pn\pi^+$ and $pp \rightarrow pp\pi^0$ (the energy of the secondary protons being about 380 MeV). The pictures were of a 32-gap spark chamber $36 \times 36 \times 83 \text{ cm}^3$ on a frame of $18 \times 22 \text{ mm}^2$. After 3 months of operation we have obtained the following breakdown of the scheduled time:

- measuring: 75%
- input of programs
  - (adjustments of the CRT-BESM-4 and change of films): 9%
- computer malfunction: 8%
- device malfunction
  - (defocusing of the light spot, instability of discrimination levels for photo-multiplier signals and others): 5%
- accidental failures: 3%

1.4 Bubble and spark chamber picture processing programs

BESM-6, CDC-1604A, BESM-4, MINSK-22 and TPA computers are all used by the bubble and spark chamber picture processing system in the JINR. Of these the BESM-4, MINSK-22, TPA and to some extent the CDC-1604A are involved in the measurement systems. The data processing programs are
run on the CDC-1604A and BESM-6. One must also mention that these computers are used for the off-line processing of experimental data received by data links from remotely located computers in the Institute; BESM-4, BESM-3M, and MINSK-2 computers are used for these purposes. Altogether these computers make up the measuring-computing complex of the JINR which is intended to handle both bubble and spark chamber picture processing and also data from filmless experiments).

The 1 m hydrogen bubble chamber data processing is done on the CDC-1604A by the PRIT, THRESH, GRIND programs. The PRIT program is used for preparing magnetic tape in the format which is necessary for THRESH. THRESH, GRIND, SLICE and SUMX programs have been modified to the JINR requirements (computer, chamber, measuring system) from the well-known CERN programs with similar titles).

The geometry and kinematics programs are ready for processing the 2 m propane bubble chamber data on the BESM-6. The geometry program is based on algorithms developed for the program on the BESM-4 for heavy-liquid chambers. In that program multiple scattering, kinks, and inhomogeneity of the magnetic field are taken into account. The kinematics program for heavy liquids has been developed from and uses the same general organization as the GRIND program.

The 2 m hydrogen bubble chamber data processing programs on the BESM-6 are based upon the corresponding geometry and kinematics programs developed in CERN (including the mass-dependent treatment of energy loss).

Versions of such programs developed in the JINR have to include the possibility of measuring film from large magnet spark chamber spectrometers (ITEP, JINR). At the end of 1970 it is also planned to start using the SLICE and SUMX programs on the BESM-6.

2. DEVELOPMENT OF THE BUBBLE AND SPARK CHAMBER PICTURE PROCESSING SYSTEM

Within the next few years most attention will be given to the HPD. There will be both hydrogen bubble chamber pictures and large streamer chamber pictures to be processed on it. The development of this device will be in two directions:
- overcoming limitations affecting device efficiency arising from the CDC-1604A computer, and
- the use of a display with a light-pen for the recovery of rejected events (possibly in real time).

The PUOS's on-line to the BESM-4 will be used for propane bubble chamber picture processing once the HPD device is in operation and the system will be developed to increase efficiency.

At present the CRT is being used for the processing of cylindrical spark chamber pictures. Much attention is being given to the use of a display with a light-pen to provide effective man-machine interaction in the process of recognizing and measuring events.

A device of the "SPIRAL READER" (SR) type is being developed in the JINR in collaboration with some other laboratories. It is planned to put it into operation in 1971. Together with the High Energy Physics Institute in Zeuthen we are studying the possibility of using the SR, possibly in modified form for processing pictures from the large chambers. Also, one would like to be able, with such a machine, to measure ionization in the region of the relativistic rise if that should prove feasible.
REFERENCES


DISCUSSION

W. BLAIR (CERN): You have not said anything about measuring film from large bubble chambers, for example, Mirabelle. Would you like to comment on this?

R. POSE: We are just tackling this problem but we have not yet put very much work into it.

W. SLATER (UCLA): What are the main characteristics of your computers?

R. POSE: The BESM 4 is a 3 address computer with a core memory of 8 K 45-bit words and a 600 K word drum. It operates at about 20,000 instructions per second.

The MINSK 22 is a two-address machine, with a core memory of 8 K 37-bit words and a memory cycle time of 24 μsec.

The BESM 6 computer works at a speed of one million one-address instructions per second, has a 32 K word core memory of 48-bit word length and a 512 K word drum.

For the small TPA computer I gave some information in the morning session.

M. THOMPSON (Wisconsin): Can you run FORTRAN of the BESM 6?

R. POSE: Yes.

K. SMITH (Glasgow): Have you made any attempts to analyse streamer chamber film?

R. POSE: No, not yet. We are, however, building streamer chambers in Dubna, therefore at the beginning of 1971 we have to do something for them.

H. NAGEL (Bonn): The Bonn-Hamburg HPD measured about 300 events from the DESY 1 m streamer chamber (set up by Dr. Ladage and co-workers) as a test using the Full Guidance system. 90% of the tracks were successfully reconstructed by THRESH. The track residuals peak at 6-7 μ.
PERFORMANCE OF THE DAPR SYSTEM

H.S. White and D. Hall,
Lawrence Radiation Laboratory,
University of California,
Berkeley, California, U.S.A.

INTRODUCTION

The Digital Automatic Pattern Recognition (DAPR) System for the unassisted discovery and measurement of events in bubble chamber film has been described at previous conferences of this series \(^1-3\). The objective of the DAPR process is to produce on magnetic tape a concise abstract of the usable information contained in each film image, and then, by means of a digital computer, to perform all further analysis procedures from the information stored on this data abstract tape.

The hardware for the DAPR System consists of a Flying Spot Digitizer (FSD) of the Hough-Powell type, attached to an IBM 7094-II computer. This hardware configuration has been used for physics measurements at Berkeley since 1963 as part of the HAZE system. HAZE performs automatic measurement of bubble chamber events under the guidance of manual scanning. DAPR makes use of this hardware without significant modification, and thus takes advantage of the reliability and precision which have been established during the measurement of nearly two million events in the HAZE mode of operation. A Tandem FSD which is now being fabricated to augment the measurement capacity will strongly resemble the original unit, differing only in those components most affected by the gains in laser and integrated circuit technology made since 1961 when the first FSD was designed.

Fundamental to the DAPR system is the process by which information on film is converted to a digital abstract on magnetic tape. Digitizations from the FSD are associated into track segments. Segments from the sweeps necessary to cover the image in both normal and orthogonal mode are then linked into tracks. Each track of each view is represented on the Data Abstract Tape (DAT) by a set of average points uniformly distributed over the length of the track, and by a measure of bubble density in clear regions away from other tracks. This
ionization information is contained in the counts of digitizings and of
total intersections of the scanning spot with the track locus. Fiducials
are recognized, and their measured locations are preserved. Other lines
which are digitized at fixed locations in repeated views are deleted,
along with tracklike point sets originating from marks exterior to the
chamber image. What is preserved on the DAT is therefore a precision
measurement of ionization and track locus with respect to reference
fiducials, exactly corresponding to the measurements made by HAZE, except
that every track in every abstracted image is so recorded.

In order that the scanning programs which make use of the DAT
can readily perceive events, further information describing the associa-
tion of tracks is stored on the tape at the time of image abstraction.
Vertices are detected in each view as being the clustering of track ends,
confirmed by the determination that all associated tracks intersect at
a common point. Coincidences due to viewing point are resolved by inter-
view comparison. Final association of tracks in each view with a spatial
vertex is made for tracks which can be matched in space. A table which
summarizes this association of tracks and vertices in the three views
is contained on the DAT, in addition to the track measurements.

Generation of the DAT is performed at a rate established by the
FSD measurement speed. Film of small chambers, such as the LRL 25" HEC,
requires about two seconds per normal or orthogonal view measurement, so
that when stage retrace and film motion is included, an elapsed time of
about 24 seconds is required to measure the three views on one bubble
chamber exposure. Thus the one FSD unit yields a measurement rate of
about 150 triads abstracted per hour. The central processor of the
IBM 7094-11 computer is occupied somewhat less than half time in
controlling the FSD and achieving the data abstraction. A second or
tandem FSD unit is expected to increase the measurement rate by about
1.8. Part of the computer capacity will remain available for background
computations even when both FSD units are active.

The DAFFR scanning process operates without further reference
to the bubble chamber film. Events are selected by applying scanning
criteria to the detected vertices listed on the DAT, and the track
measurements are edited into the HAZE library format for subsequent
processing through geometry and kinematics programs. Because the vertices
are stored on the DAT in a form readily perceived by the digital scanning process, comparison of scanning criteria with measured data to recognize desired events proceeds at a very rapid rate. Depending upon the number of events to be written out to the HAZE library tape, the rate of scanning is from 12,000 to 15,000 triads per hour.

**COMPARISON EXPERIMENT**

The best determination of the performance of a new system is obtained by comparison of its results for a substantial number of events with those obtained from some other well understood system. Film from a 1.53 GeV/c $\pi^+$ exposure of the IRL 25'' Hydrogen Bubble Chamber was chosen for this comparison. This film had recently been analyzed for 2-prong events by use of the HAZE system, and for $k$-prong events by use of the COBWEB system of online Franckensteins, so that a three-way comparison seemed possible. Furthermore, the IRL 25'' EBC is optically clean, having two glass sides which allow images uncluttered by side effects of the illumination. The low momentum pion beam produces simple event types with a minimum of scanning ambiguities. And finally, there remains a sizable quantity of unmeasured film of this type and momentum region. However, the film chosen was not as good as we might have wished. In particular, the beam tracks are too closely spaced for best results. It was also discovered in the course of the DAPR measurement that static electric discharges in the camera produced images which caused serious problems for positioning views on the PSD. These positioning errors also lowered the completion ratio of the HAZE measurement.

**COMPARISON PROCEDURE**

Eight contiguous rolls were selected for comparison. All 13,005 frames were processed to form a DAT. Although prescanning in the form of HAZE roads existed, we chose to operate DAPR in the entirely unassisted mode. Only after the scanning program had selected vertices for assignment was it made aware of the HAZE scanning information, so that appropriate error codes could be assigned for bookkeeping purposes to unselected vertices which had been found by the HAZE scan.

Because comparison of the measurements on a track-by-track basis was desired, it was necessary to ensure that the track labeling be
done in the same manner for both DAPR and HAZE measurements. The HAZE labels initially had been assigned by the scanners, and experience has shown that some inconsistencies of labeling are characteristically present. Therefore, the HAZE measurements were converted to the format of the DAT, and the tracks were relabeled by the DAPR scanning process. This procedure guaranteed identical labeling while causing only minute differences to the event throughput; we observed 84.6% throughput for the 2-prong events as a direct result of the HAZE measurement, and 84.4% throughput for the same data with the DAPR relabeling. It is of interest to compare these values with the normal throughput value of 92% for what is considered typically good film, giving evidence that the film selected for the comparison was below the usual quality.

The chamber volume in which vertices were accepted was limited for both the DAPR and HAZE scans. For DAPR, the limit at the entrance side of the chamber was set by the requirement in the scanning criteria that the incident track be measured over a sufficient length to establish that it was a beam track, while the limit at the exit side was set only by the need for outgoing tracks to be unambiguously matched. On the other hand, the HAZE scanners were instructed to accept events in which the incident track, even though short, appeared to follow the orbit of a beam track, allowing a much earlier acceptance region than for DAPR. Similarly, the HAZE criteria at the exit side took into account the requirement for kinematical uniqueness, and forced the acceptance volume to be more restricted that would have been required for track matching alone. The intersection of these two volumes, which is illustrated in Figure 1, will be referred to as the "joint fiducial volume" (JFV).

There are only 462 4-prong events within the joint fiducial volume. These yielded results similar to those derived from the comparison of the 2-prong events between DAPR and HAZE. On the other hand, the small number of events and the different basis of comparison (COSWEB rather than HAZE), makes the 4-prong data difficult to quantitatively relate to the larger data set. Therefore, we shall restrict the detailed discussion to the 2-prong data.

A simple set of scanning criteria was formulated to identify the 2- and 4-prong events to the DAPR scanning program. These criteria were intentionally conservative, so that any residual track match or vertex
association ambiguity would cause the vertex to remain unselected as a desired event. The scanning criteria imposed the following requirements: The measured parameters for the incident track were required to be consistent with the defined beam orbit. Charge conservation was imposed. The vertex was required to have at least one track associated with it in each view. At least two view measurements with suitable geometry for reconstruction were required for each track.

**COMPARISON RESULTS: THROUGHPUT**

One basis for comparison of measurements is the number of events which are available to the kinematics programs. Of interest is not only the ratio of geometry completions to total events, but so also is the nature of the events which fail to be satisfactorily measured.

A total of 3140 2-prong events was found within the joint fiducial volume in the 13,005 frame sample of film. This total includes 2957 events found by the HAZE scanner, as well as 183 events newly found by DAPR. After a very painstaking scan of part of the film, we believe that it is unlikely that more than 2% of the total 2-prong beam event sample is not counted within this total number.

The distribution of these events according to whether their measurements passed or failed geometry is shown in Figure 2. Somewhat more than half of the events (1752 = 55.8%) had both HAZE and DAPR measurements pass satisfactorily through the geometric reconstruction. These events will form the basis for a detailed comparison of track parameters to be discussed below. The remaining 1388 events had no geometric output from one of the HAZE or DAPR sources, or both. Note that in the case of HAZE measurements, most of these events were found by the HAZE scanner, but had their measurement rejected for some reason. In like manner, most vertices were found by the DAPR process, but the track measurements were such that the DAPR event selection criteria were not met. This distribution therefore addresses the throughput efficiency, not the finding efficiency. These categories will be discussed in more detail in the following sections.

**DAPR RESULTS MISSING**

Results from geometric reconstruction are not present for the DAPR measurements described in Figure 2 under the categories "HAZE ONLY"
and "NEITHER". The 722 events (23.0%) included in the "HAZE ONLY" category are those found by the HAZE scanner, and satisfactorily measured by HAZE, but either undetected or unselected by DAPR. The 252 events (8.0%) marked "NEITHER" include 17 which were unseen by the HAZE scanner, but were selected by the DAPR scanning program and then failed in the geometric reconstruction. The 974 events in these categories were inspected at the scanning table, and each event was classified according to the apparent cause of its failure. This classification was based upon the coded comment supplied by DAPR and upon the appearance of the event and its surroundings as viewed at the scanning table. Figure 3 shows the distribution of these assigned causes.

Film format problems which prevented one or more views from being properly positioned by the FSD caused the rejection at abstraction time of frames containing 5.0% of the JFV sample. Nearly all of these are due to static discharges made in the camera which introduced confusion in the area of the edge markings by which the view is positioned. This is not a common problem in 25' HBC film, and undoubtedly contributed to the lower HAZE throughput observed for this film. If we correct the throughput ratio for these events, we obtain a DAPR throughput of 72.6%, which indeed was exceeded for the first six of the eight rolls.

Many of the events which could not be selected were victims of their surroundings. These are shown in the next major division of Figure 3. Although the events are well distributed across the chamber in the total sample, the tracks of any one beam pulse are rather tightly clustered. The most significant result of such overlaid beam tracks was the addition of a track or tracks which could not be excluded from the vertex, which therefore produced geometric ambiguities that prevented the clear choice necessary for event selection. This class is indicated as "Close Beam Tracks" in the distribution. An example of such an event is shown in Figure 4, where the forward outgoing track was confused with the nearby beam track enough to produce a poor vertex point, thereby excluding the backward track.

In some cases, two events were sufficiently close to confuse the vertex generating algorithms of DAPR. This caused all of the tracks of both vertices to be gathered into a single vertex producing the logical "OR" of the tracks. The class is so named.
Some events are made ambiguous by the presence of an unrelated, but spatially coincident track which ends nearby. We call these tracks "interlopers", and the class is named accordingly. An example of this is shown in Figure 5, where a track produced at a vertex near the entrance ends quite near a 2-prong event in the lower half of the picture.

The following of an electron spiral of a few centimeters radius is generally quite incomplete, giving rise to several short segments which represent part of the total spiral. When one of these passes through a vertex, it usually produces an ambiguity which the program cannot presently resolve. An example of this "Electron Spiral" class is shown in Figure 6.

For a considerable fraction of the DAPR measurements not output through geometry, there is an apparent dependence upon configuration. These are shown in another major division of Figure 3. Most of these configuration dependent selection failures are in the category of "Vertex Algorithm" failures. The only algorithm presently incorporated in the DAPR vertex search routine depends upon the presence of two or more track endpoints near each other, with at least one endpoint being quite near the intersection point of the two tracks. One large subset of 2-prong events is guaranteed to fail this search algorithm: those events in which one outgoing track departs from the vertex in a direction essentially parallel to the incident track. Small angle elastic scatters and inelastic events are both observed in the "Vertex Algorithm" failure category. The present algorithm is by no means the only one feasible, and it soon will be augmented by another algorithm especially tailored to pick up these events. An example of "Vertex Algorithm" failure is shown in Figure 7, where the elastic scattering produced by the beam track nearest the right side of the picture is followed as a continuation of the incident track. In Figure 8, the inelastic event is most obvious as a change of bubble density fairly early in the chamber, and no significant deviation of the beam track is seen for some distance. The presence of a number of close beam tracks makes this picture difficult for visual inspection as well.

The DAPR program is conditioned to retain only tracks on which a minimum of twelve hits have been made. This minimum requires that the track be at least 720 microns in projected length along the direction of
the stage travel. Tracks in the bubble chamber shorter than 1.5 centimeters generally are not found by DAPR because of this requirement, giving rise to the selection failure class "Short Stub". An example of this is shown in Figure 9, where the shorter of the two elastic recoil tracks is approximately at the limit of being seen by DAPR track following.

A short track outgoing from a primary event which leads to a nearby secondary event is similar to the category of "Vertex OR" previously discussed, except that of course this class is produced by the event configuration. An example of "Short Secondary" is shown in Figure 10, where the left-most beam track produces a 2-prong event with a secondary 2-prong about 1 centimeter away.

Some event configurations have tracks obscured by other tracks of the event, as in the 4-prong event shown in Figure 11. Others have tracks so placed that the three-view geometric reconstruction cannot produce a unique match of the track-views, as is illustrated in Figure 12 by the 2-prong event with coincident tracks at the bottom of the picture. These classes are indicated in Figure 3 by the legends "Configuration Precludes Track Following" and "Ambiguous Tracks".

A few of the events detected by the DAPR vertex search, and selected by the DAPR scanner, failed the three-view geometry program FOG. However, for a number of events, no apparent reason for failure was seen when they were viewed at the scanning table; these were assigned to the category "Reason Unclear". They have since been studied in detail by use of various diagnostic procedures. Some are found to result from frame positioning errors undetected by DAPR, errors which caused one view of some other triad to be measured in place of the correct one.

Some events have tracks which extend beyond the usual region of chamber illumination, so that the track was rejected as unwanted noise. The latter can be corrected merely by changing a constant within the program. The event in Figure 13 that is produced by the right-most beam track contains such a track, extending out beyond the chamber image to the left of the picture.

Not all of the events which remained unselected by the DAPR scanning program failed to have a detected vertex. Figure 14 shows the distribution of undetected vertices among the 974 events not output by DAPR which have just been discussed. It should be noted that correction
of the causes yielding "Film Format" and "Vertex Algorithm" failures will reduce to only 3% the fraction of vertices unperceived by DAPR, with half of these due to close beam tracks. This compares, as we shall see, to nearly twice this number of events missed by the HAZE scanner.

**DAPR EVENTS NOT OUTPUT BY HAZE**

Each event output by the geometry program from the DAPR measurement, but not from the HAZE measurement was carefully reviewed at the scanning table. The 414 valid 2-prong events are distributed between those which were found, and those which were missed by the HAZE scanner in the manner shown in Figure 15. Allowance has been made to credit the HAZE scanner with finding the event when procedural or scanning hardware errors prevented the HAZE measurement from being successful. Even so, 166 events, or 5.3% of the total sample were not detected by the manual scanning process. There were no obvious features to distinguish any of these events from the total distribution, except that the HAZE scanner missed events invisible in the one view which he scanned.

An additional 43 vertices from the 13,005 frame JFW sample successfully met the criteria which were given to the DAPR scanning program, but proved upon inspection not to be valid 2-prong events. The distribution of these 43 "fake" events as determined by scanning table inspection is shown in Figure 16.

The eight secondary events were selected by the DAPR scanner only because of an oversight in writing the scanning criteria, which neglected to require that "beam events" must have an incident track that actually enters the chamber.

The classes of "Short Sigma" and "Short Secondary" are due to DAPR's inability to see short tracks. Their frequency can be reduced by tightening the tolerance by which tracks are allowed to miss the common intersection point. Some of the 4-prong events have one very faint track, which digitizes so poorly that it is not followed. If this track is caused by the negative particle, and if the forward positive sufficiently resembles a beam track, the track match routines delete the "outgoing beam" track, leaving an apparently valid 2-prong event. This happened in nine cases. On the other hand, the deletion of an
apparently "out-going beam" track allowed the selection of perhaps 10% more 2-prong events which were very close to a neighboring beam track. Finally, some adjacent track endings meet all present criteria for both vertices and selected events.

We believe that the problem caused by these fakes is not serious. Many can be eliminated by small changes in the DAPR procedures and scanning criteria. Fakes which then survive will represent only a small increment to the set of fakes found by manual scanning, and can be guarded against in the kinematic analysis by the same means now used to eliminate scanning ambiguities and mistakes.

**DAPR Measurement Quality**

We now turn to the 1752 events for which geometry output (kinematic input) from both the HAZE and DAPR sources was available. In order to achieve a valid comparison of the two measurements, all tracks were fitted as pions in the geometry program FOG 5). This procedure was chosen since the orbital error introduced by fitting a proton track to a pion mass hypothesis is negligible whereas fitting a pion track to a proton mass hypothesis produces serious discrepancies in the orbit at low values of momentum. Differences between the HAZE measurement and the DAPR measurement were computed for the dip angle, the azimuth angle, and the momentum at the vertex for each track. These differences were then normalized by dividing by the combined a priori error estimates for the two measurements. The difference between track length measurements was also computed but no normalization factor was applied. For all parameters the DAPR value was subtracted from the HAZE value so that a positive difference implies that the HAZE value was greater than the DAPR value and vice versa. Thus, for each track in the sample, comparison parameters were computed for the dip angle, the azimuth angle, the momentum, and the track length.

Qualitatively we would expect independent measurements of the same track to produce symmetric distributions centered at zero. Further, the standard deviation of these distributions should be somewhat smaller than unity, since the normalization factors include a term which accounts for multiple scattering. Figure 20 shows the distribution of the normalized differences in dip angle summed over all three tracks. We
notice that the observed distribution is entirely compatible with our a priori assumptions. Furthermore, there are very few tracks with large departures. The source of the few large departures has not been completely determined at the present time, although a number of these events have been studied. Improper vertex correlation by the event comparison program is certainly one source. Small angle scatters which were detected by the HAZE scanner, but not by DAPR have some contribution. There is some evidence that a priori errors may be underestimated for low momentum tracks. Whatever the source, these events are not believed to represent a serious contamination of the data, since their frequency is low.

Figure 21 shows the distribution of the normalized differences in azimuth angle summed over all three tracks. In this case we observe a somewhat wider distribution with a mean of -0.2 standard deviations. The increased width is probably due to a slight miscalculation in the error coefficient which was used for normalization, and does not reflect a basic error in either HAZE or DAPR. The shift in the mean represents an angular discrepancy of only .016 degrees on the average, or one minute of arc.

Figure 22 shows the distribution of normalized differences in momentum, and again, the two measurements are seen to be in excellent agreement. Thus the HAZE and DAPR systems are seen to be equivalent in their measurement of the three basic track descriptors.

In the case of track length, a somewhat more surprising result was obtained. We had assumed that the length of track measured by DAPR would be somewhat smaller than the length measured by HAZE on the average. In fact just the opposite was observed. Figure 23 shows the distribution of track length differences between HAZE and DAPR. Notice that this distribution is skewed even though it peaks at zero and has a standard deviation of about .75 centimeters in space. The number of events in which the HAZE measurement exceeded the DAPR measurement by more than 2 centimeters is negligible. However, there is a significant contribution of events in which the DAPR measurement was more than 2 centimeters longer than the corresponding HAZE measurement. A small fraction of these events are indeed due to kinks and other small angle departures detected by the HAZE scanner but not by DAPR. However, the
The majority of these events are due to the HAZE scanners ending the road prematurely. This unfortunate habit went unnoticed until the comparison experiment was performed. Since the ability to resolve kinematical ambiguities is strongly related to the length of track measurements, DAPR represents a significant improvement over our operating experience with a full guidance system.

A related question concerns what is the shortest track that can be measured by DAPR. Figure 24 shows the track length distribution for the proton track of elastic events. Tracks longer than 1.4 centimeters in space are seen to be consistently detected. This corresponds to 1 millimeter on film, or 17 hits if no angle projections are assumed. When a correction is applied for the average projection angle this value agrees exactly with the 12 hit cutoff in the DAPR track following process. A new procedure which accepts dense tracks with fewer hits is planned for the future.

Finally, Figure 25 shows the distribution of \( \cos \theta^* \) in the center of mass system for the proton track of the elastic events. The HAZE data was derived from the entire HAZE fiducial volume and normalized to the eight roll JFV sample. The normalized HAZE data is represented by the dotted line, and the DAPR data is represented by the solid line. The depletion of DAPR data in the first two cells, and in the last cell is due to the predicted bias from the as yet incomplete vertex algorithm and short stub procedures of DAPR. When the data in the central 37 cells were compared, a \( \chi^2 \) value of 8.0 was calculated for a 20 degree-of-freedom fit. Thus, except for predictable biases, the DAPR measurements are seen to be in excellent agreement with the HAZE measurements.

UNSELECTED VERTICES

An investigation of all vertices detected by DAPR but not noted by the HAZE scanner was undertaken for one roll of the eight roll study. Obviously, not all event types in the film had been considered by the HAZE scanner; the distribution is presented here for two reasons. First, there is the practical consideration of how many frames per roll must be manually reviewed in order to be certain that no desired events were overlooked. Secondly, the distribution gives an indication of the DAPR finding efficiency for all event types in the film. Unfortunately,
no comparison data for event types other than beam 2- and 4-prong events was available. Thus finding efficiencies can not be reported for event types other than these. However, there is good indication that 2-prong events are the most difficult for DAPR to detect, and that the finding efficiency for other event types is excellent.

DAPR produced in the entire roll of 1663 frames a total of 108 vertices which were not recorded by the HAZE scanner. Figure 26 shows the distribution of these vertices by event type. Most (68) of these resulted from 2-prong events. Of these, 32 were valid beam events, with 20 selected by the DAPR scanner and 12 detected but unselected. In addition, there were 15 2-prong events produced by degraded beam particles, as well as 16 secondary scatters. The five fake events were among those already discussed.

The second largest category contains 22 events of all other types, consisting of 4 4-prong events, 5 events in the glass, 5 kinks, 5 electron pairs, 2 $\pi \mu \beta$ decays, and one $\nu^0$ from the chamber wall. The 5 events in the glass can be eliminated by applying a fiducial volume cut in the Z direction.

The final category consists of 12 vertices formed from unrelated tracks which happened to end near each other in space, together with 6 "vertices" which were not apparent when inspected at the scan table. Thus in 1663 frames, the DAPR procedure yielded only 18 vertices which were not the result of some sort of interaction.

The DAPR scanning program can be instructed to identify events of a given type without including them on the HAZE library tape for further analysis. Use of this procedure greatly reduces the number of frames which require manual review. Such identification is analogous to describing the signature of unwanted events in the manual scanning instructions so that they will not continually be brought to the attention of the experimenter. In this comparison experiment, for example, a description of the non-beam and secondary 2-prong events, and events in the glass would identify approximately 26 undesired events among the 108 vertices shown in Figure 24. The number of vertices remaining after selection or identification is therefore 57, or about 4% of the frames in the roll. Using these procedures, the DAPR scanning program can extract most desired events from the film without
manual assistance, and can produce a concise list of frames outside its scanning criteria for manual review.

PHYSICS PRODUCTION

The use of DAPR for physics measurements has now begun. The first film measured was from a 1.29 GeV/c π⁺ exposure of the 25" HEC, which allowed the experience gained in the comparison experiment to be most directly applied. Because the bulk of the 2-prong events in this film had not previously been measured, manual scanning was used to provide a bookkeeping entry for each event found by the scanner. This prescan was most important in giving confidence to the experimenter that DAPR can indeed find his events adequately. However, since the events occur in about every third frame, by using the prescan information to select frames to be abstracted, the cost of the scanning is balanced by the saving in abstraction cost. The DAPR processing makes no use of the prescan information except for frame control. About 14,000 events were measured during the first week of operation in February, 1970. Pre-scanning has operated at a rate averaging 100 frames per hour or more. Measurement of frames selected has averaged 150 frames per hour with the DAPR system.

SUMMARY OF PRESENT STATUS

The comparison experiment provides a firm basis for confidence in the DAPR process as it now stands. We have shown that the tracks and vertices contained on the DAT are a high fidelity abstraction of the film information. Almost all events are perceived by DAPR. Nearly three-fourths are available to kinematic analysis without any manual assistance, and this fraction is increasing as gaps in program completeness are filled in. The list of vertices containing desired events that are perceived but unselectable contains but few extra entries. The measurement precision is equivalent to HAZE, our present standard of excellence. DAPR has now become a practical tool for high energy physics measurements.

Some parts of the system remain to be completed. Additional vertex algorithms are being implemented, as is the ability to follow shorter tracks. The art of writing scanning criteria has only begun to be explored. We hope that the impediments caused by format and close beam track difficulties will influence the design of future experiments.
DAFR is already superior to manual scanning systems in some ways. The full abstraction of all tracks allows calibration of ionization and of beam cross section on a frame-by-frame basis. Consistent adherance to desired standards can be more readily achieved with an automatic system than with a manual system employing many persons. The cost of discovering and measuring events is considerably reduced in comparison to HAZE and other systems.

THE FUTURE

We expect that DAFR can be operated with little change in chambers of the two-meter class, and steps to measure data from the SLAC 82" HRC are now being taken. Extension to the large scale chambers being designed will depend primarily upon the ability of the digitizing hardware to produce good representations of the information from the film. The procedures of DAFR, perhaps implemented on a larger computer, would seemingly perform as well for large chambers as small.

We believe that DAFR has already moved very close to the goal of totally unassisted analysis of bubble chamber data. Its achievement of this goal seems assured. With human reaction times no longer included in the system, it would be possible with suitable hardware to operate without film, online to the bubble chamber. This would allow for bubble chambers the same advantages of immediate, online data analysis which have been so useful in many spark chamber experiments, while retaining the precision and resolution of the bubble chamber. Only a system which operates without manual assistance can go online in this manner. We believe that the attainment of operational status by DAFR is a significant step toward these goals.

ACKNOWLEDGEMENTS

The development of the DAFR system has resulted from the efforts of many persons including several former members of the Data Handling Group who now have gone elsewhere. The hardware owes its fine design and performance to groups at LRL headed by Jack Franck and Gene Binnall. The continued interest, encouragement and firm support given to the project by LRL Director Edwin McMillan and Physics Division Leader David Judd have made it all possible.

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Figure captions

1. Joint fiducial volume for the comparison experiment.
2. Distribution of 3140 two-prong events within the joint fiducial volume.
3. Distribution of 974 events not output by DAPR.
4. Example of the class "Close Beam Tracks".
5. Example of the class "Interloper".
6. Example of the class "Electron Spiral".
7. Example of the class "Vertex Algorithm" (elastic event).
8. Example of the class "Vertex Algorithm" (inelastic event).
9. Example of the class "Short Stub".
10. Example of the class "Short Secondary".
11. Example of the class "Configuration Precludes Track Following".
12. Example of the class "Ambiguous Match".
13. Example of the class "Reason Unclear".
14. Distribution of 974 events not output by DAPR showing undetected vertices.
15. Distribution of 414 two-prong events output by DAPR only.
16. Distribution of 43 fake two-prong events found by DAPR in the joint fiducial volume for 13,005 frames scanned.
17. Example of a DAPR fake due to a forward track to the secondary vertex.
18. Example of a DAPR fake due to a short Σ decay.
19. Example of a DAPR fake due to a non-beam event coincident with a beam track.
20. Comparison of HAZE and DAPR measurements of dip angle.
21. Comparison of HAZE and DAPR measurements of azimuth angle.
22. Comparison of HAZE and DAPR measurements of momentum.
23. Comparison of HAZE and DAPR measurements of track length.
24. Distribution of CMS proton recoil lengths for elastic events.
25. Distribution of CMS proton recoil angle for elastic events.
26. Distribution of 108 vertices received by DAPR but not seen by the HAZE scanner.
DISTRIBUTION OF 3140 TWO-PRONG EVENTS
WITHIN JOINT FIDUCIAL VOLUME

Fig. 2
DISTRIBUTION OF 974 EVENTS NOT OUTPUT BY DAPR

31.0 % OF 3140 EVENT JFV SAMPLE

Fig. 3
Fig. 10
DISTRIBUTION OF 974 EVENTS NOT OUTPUT BY DAPR
UNDETECTED VERTICES SHADED

Fig. 14
DISTRIBUTION OF 414 TWO-PRONG EVENTS
DAPR ONLY (13.2% OF 3140 JFV SAMPLE)

Fig. 15
DISTRIBUTION OF 43 FAKE TWO-PRONG EVENTS
FOUND BY DAPR IN JFV OF 13,005 FRAMES SCANNED

Fig. 16
DIP ANGLE COMPARISON
HAZE-DAPR (NORMALIZED)

Fig. 20
25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 053593 DATE 700219 ASN.GP AA03
LEVEL G4 HIST NO 8
U60 CELLS 0.2 5241 POINTS

AZIMUTH ANGLE COMPARISON
HAZE-DAPR (NORMALIZED)

Fig. 21
25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 053593 DATE 700219 ASN.GP AA03
LEVEL G4 HIST NO 4
U60 CELLS .200 5241 POINTS

MOMENTUM COMPARISON
HAZE-DAPR (NORMALIZED)

Fig. 22
25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 053593 DATE 700219 ASN.GP AA03
LEVEL G4 HIST NO 1
U40 CELLS .5 3494 POINTS

TRACK LENGTH COMPARISON
HAZE-DAPR (CENTIMETERS)

Fig. 23
25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 049715 DATE 700130 ASN.GP AA03
LEVEL A0F2E1 HIST NO 9
N40 CELLS .2 956 POINTS
LTOT FOR DAPR ELAST

LENGTH OF PROTON TRACK
FOR ELASTIC EVENTS (DAPR)

Fig. 24
25 INCH HYDROGEN CHAMBER FAIR OUTPUT
RUN 049113 DATE 700128 ASN.GP AA03
LEVEL A0F2E1 HIST NO 1
U40 CELLS .050 954 POINTS
CSTHCM FOR DAPR ELAST

COMPARISON OF COS $\theta$ DISTRIBUTIONS

HAZE — DAPR

Fig. 25
DISTRIBUTION OF 108 VERTICES
FOUND BY DAPR BUT NOT HAZE SCAN
ROLL 6160 JOINT FIDUCIAL VOL

Fig. 26
DISCUSSION

A. WERBROUCK (Torino): How do you determine the number of abnormal scans on large chambers like the 82" chamber?

H. WHITE: We make as many abnormal scans as are needed to cover the area fully. On the 82" SLAC chamber one needs one normal scan covering the whole chamber and two abnormal ones that cover half the chamber each, and overlap about 8 mm.

A. WERBROUCK (Torino): On these chambers what would the digitizing rate be?

H. WHITE: The digitizing rate is not so much dependent on this. It only goes down to 95 triads per hour instead of 115 as film move time, stage retrace etc. stay the same. With the tandem FSD we will thus reach 180 to 190 triads per hour.

M. PALANDRI (cern): Are you anywhere near the CPU capacity of the 7094 with this system?

H. WHITE: We have a 7094 mod. II and would not be able to tandem operate on a 7094 mod. I. These programs use about 40 to 45% of the CP time for one FSD, so two units operating together would leave about 20% CPU time for other use. So the 7094 mod. II will keep up with the requirements for the foreseeable future but there will not be much CP time left.

W. SLATER (UCLA): What physics biases might be introduced as a result of events being missed by DAPR?

H. WHITE: The worst bias in the comparison experiment will be the vertex algorithm failure. The degree of bias will be most sensitively shown in the recoil angle plot that I have shown. This was not very bad except in the very extreme boxes and this almost gives an upper limit on the biases in that experiment.

The current experiment — which we are running at about 14,000 events per week — does not have this problem of vertex algorithm failure and therefore there will be less bias. I believe that the biases will arise for very short tracks and for small angle scatters.
CONCLUDING REMARKS

L. Kowarski,
CERN, Geneva, Switzerland

First a few words concerning the place of our meeting. Since 1960
these conferences have brought many of us to a wide variety of places,
ranging from Berkeley to Munich, and we may hope that one day they will
bring us even further East. From a more personal point of view I might
say that this series has, so-to-speak, track-followed some of my own
career with such master points as the Collège de France in 1963 or the
Cavendish today. It was also here that Frisch and I had a memorable
conversation which started at the computer conference (held here in
December 1955) and continued on a train to London. His very precise
suggestions about the role of computers in bubble chamber processing,
coupled with my more vague ideas about installing a computer at CERN,
have set in motion a long series of events; a direct link could thus
be traced to many of the activities which have been reported here in
these last few days. Finally, it is here that Sweepnik has been de-
veloped into one of the most successful achievements of our art; in
terms of performance per unit of cost and effort, quite possibly the most
successful. It is nice to have a Sweepnik here as a locally presiding deity.

Well, here we are: many of us, rather more numerous than at Munich
or Argonne, but decorously so, no population explosion. Some noticeable
absences; in particular Paul Hough, and there is even no one from his
school in Brookhaven. PEPR and Spiral Reader are well represented here,
but not by their originators. Conversely the original authors of Polly
are nearly all here, but not as a voice from Polly.

On the whole, the present-day working level is represented here
rather than the pioneers or the bosses (two concepts which sometimes do
not entirely coincide).

At Argonne I had remarked on the preponderance of papers on HPD
(or FSD as Howard White calls it) and its derivatives. They added up to
well over one-half of all papers presented in Argonne. Here it is about
one-third, if we count all the papers which will appear in the Proceedings, and rather less if we count the papers presented in session. This may have been due to the composition of the Organizing Committee and the tendency of some of its members to lean over backwards, or possibly also to the fact that Spiral Reader, Sweepnik and, particularly, the CRT devices chose to be more vocal at this meeting than in Argonne. This may be an interesting pointer about the evolution of the art in the 17 months which separate us from the Argonne meeting. Another interesting remark concerns the shift of attention among the manual or partly manual devices. A luxury manual system, the Cobweb, was presented at Argonne. This time we heard rather more on SMP which again confirms its locally entrenched vitality and, of course, we witnessed the triumphant entry of Sweepnik which I think is likely to appeal to the same category of customers as Cobweb or SMP did in the past. On the other hand, manual systems may have a renewed life in connection with the large chambers -- we will return to that.

We may turn now to what I might call together the "Great Automatized Systems", which have been presented at this meeting in their full diversity. One has a vague impression of a converging path of development. They all started with their widely different ways of collecting coordinates from the film and accordingly with widely different fundamental hardwares. But the accent is now on the ways of using the software and the co-operation between machine and operator. And here there are unexpected bridges between one system and another; thus, for instance, the Heidelberg PEPR has features which are compatible with data from HPD-BRUSH; RIPPLE, which claims to be a branch on the PEPR tree, could almost be described as a cathode-ray Sweepnik, and there is a whole CRT family, comprising POLLY, PATR, COCCINELLE, LUCY, PANGLOSS, which present a lot of common features in spite of their different starting points. All this confirms that certain feeling of convergence. It may be too sweeping a statement, but it seems to me that this converging evolution can be seen as following a path which has brought us past the peak of the insistence on the man-machine symbiosis and is now leading us to a gradually decreasing role both of the human preparation, such as crutch points or road-making, and of human operators on-line.
In POLLY and in PEPR, as we have heard, the operator now seems to have to help in only a minority of cases. In HPD the minimum guidance has come into its own, as we have heard from CERN and Amsterdam. New successes of zero guidance have been achieved at Columbia and, as we just have heard, at Berkeley, and there is a promise of zero guidance, or at least a good hope of it, in the Oxford PEPR and in the ambitions announced by COCCINELLE. Full bubble automation now seems to be at last in sight, really. And here an interesting feature is provided by new types of hardware which contribute to some stages of the data flow previously treated by software. Well there is BRUSH, SATR, RIPPLE, COCCINELLE, PANGLOSS, POLLY III; we have no time to discuss this particular contribution in detail.

The ultimate goal of course, as has been pointed out both by Howard White and by Harris, is a much increased speed. Harris wishfully was thinking of 700 events per hour, which is rather faster than what any bubble system is doing now. But even in the present, far from Utopian stage, POLLY and Sweepnik, and also FSD and PEPR, report a continuing increase in hourly rates. There is a noticeable progress since the days of the Argonne meeting.

At this meeting -- for the first time, I think -- there has been resolute tackling of new problems arising from the use of big bubble chambers, and since some of the problems were quite awesome, one can feel some regression toward simpler processing methods and therefore there is a renewal, I think, in interest in manual systems. This probably will not go on for ever.

Quality of film has been mentioned somewhat wistfully, and also the signal-to-noise ratio. For this latter reason, I suspect that maybe lasers will become finally necessary; this of course puts Sweepnik in an exceptional position already and HPD potentially, even at the cost of renouncing some of the flexibility features offered at present by cathode-ray tubes.

So far I have spoken mainly of bubble chambers. Optical spark chambers, of course, have solved their main problems some time ago, so they hardly need to be mentioned. But we also had a nearly whole afternoon on wire chambers. Their problems seem to be very different from
those of bubble chambers; many of them arise on the borderline between
detection and data handling, so that their discussion often is centred on
the wire chambers themselves rather than on the processing of data.
Another set of problems deals with how to combine already working devices
in complete and complex set-ups ready for experimentation. No doubt
bubble experimenters will experience similar preoccupations in the future;
for example, when the fully automated and speeded-up processing will be
ready for the replacement of film cameras by vidicons. And here spark
chambers may again show the way to bubble chambers, as they have already
shown it in the past for various degrees of automation.

Well, a few disjointed remarks remain, as usual. One: it seems
that the main emphasis is still on processing by separate views and then
one proceeds to spatial reconstruction out of master points certified
on the flat, so-to-speak. The efforts to produce master points already
in space are still in progress, as in SATR, in three-view PEPR, and so
on, but they are by no means dominant. This is, perhaps, another in-
novation we may expect from the future.

Another remark is that one talks less and less of small computers.
I have noticed this evolution in previous meetings; in the meantime, of
course, small computers have grown bigger and bigger, but even so there
is less insistence on them. Several papers did assume that each ex-
periment should rely on its own computer; it is, however, interesting
to notice that even in the PEPR camp which started with PDP 1 and con-
sidered this modest computer requirement as one of its main features, a
today's user of PDP 6 is dreaming of two PDP 6's. It can be said that
the physicists have definitely conquered their fear of big computers.
On the other hand, the Columbia experience with the 360/91 and even, I
would say, CERN's experience with HPD directly on 6600 may have shown
that some of these fears were not entirely unjustified.

And again, as in previous meetings, where are the other users of
all these devices for processing of visual data? They have been de-
veloped by high-energy physicists, or for high-energy physicists, but
after all they might be used in other sciences and again we are asking
where are all these other users? There have been some brief mentions
at this meeting to the effect that some other fields, in particular the
bio-medical field, are at last paying some attention to what we are doing and that the example originally set by CHLOE may be followed more consistently in the future. This will provide an additional justification for our hard efforts and our pleasant meetings.
Introduction

The main ideas of the HPD system originated at CERN in 1959-60\textsuperscript{1}). Since then, HPDs have been installed in many laboratories, and at CERN two (HPD 1 and HPD 2) have been built and put into regular operation. The Full Guidance system for bubble chamber film measurement has now been developed to the point where it has gone on to a maintenance basis. It is the purpose of this paper to review the current status of the system and to look a little into the future.

The successive stages of development of the Full Guidance system (based on "roads" derived from three points per track-view taken at the scan table) have been described in reports to previous conferences\textsuperscript{2)3)4)5)6}), and the main activity since 1968 has been consolidation. Detailed reports on operation\textsuperscript{7}), programming\textsuperscript{8}), and ionisation\textsuperscript{9}), were given at an informal meeting in Amsterdam in 1969.

At CERN the three flying spot digitisers, HPD 1, HPD 2, and Luciole are operated on-line to the central computing installation. HPD 2 is on-line to the CDC 6600, and HPD 1 and Luciole now share a channel on the CDC 6500 (following the recent upgrading of this computer from a CDC 6400). HPD 2, which is essentially similar to those in general use, has been in regular production since late 1967. It can cope with 50mm or 35mm film, but to date all production has been with 50mm film. HPD 1, which was also the prototype HPD, was taken out of service in January 1970 for extensive modifications, which will improve the accuracy to that of HPD 2, and will also extend the scan line to cope with 70mm film. It will be used extensively to
measure film from the Omega project\textsuperscript{10}), but will be available, if needed, to measure 35mm, 50mm, or 70mm film. In future this will be referred to as HPD $\Omega$.

**Performance**

Figure 1 shows the annual totals for bubble chamber event measurement on the CERN HPDs, and further details are given in Table 1. Since the end of 1968 the HPD 2 system (Full Guidance) has been running satisfactorily, both as regards hardware and the on-line program. During the first three months of 1969, the HPD was in full operation (20 hours per day) and some 70,000 events from three different experiments were measured. Since then the system has run at only half capacity due to a bottleneck at the scanning stage (see below).

The mean rate of measurement on HPD 2 is 75 events per hour ($\geq 300,000$ events per year), and the scan table rate is $\sim 10$ events per hour per table for Full Guidance (with the current staff recently increased - this is $\geq 200,000$ events per year). The scanning and measuring bottleneck will be reduced further by increasing the number of operators, but the main improvement is expected to come from the progressive introduction of the Minimum Guidance system\textsuperscript{11}). With this system the scan table rate is doubled by digitising only the vertices.

The quality of the measurements is rather satisfactory, in terms of both precision and ionisation. Indeed HPD has become the standard against which other machines are compared.

Concerning accuracy, the reproducibility of the machine is at the micron level. The mean residual for the three view helix fit, reprojected on the film plane, peaks at 3-5$\mu$, according to the experiment, and the anomalous behaviour reported at Argonne\textsuperscript{5}) is no more (caused by inadequate film clamping at HPD 2 during its early months in production). Pass rates are somewhat experiment-dependent, but a general figure for THRESH is 85-90%.
Ionisation has received particular attention. The net result is that scan table checking of ionisation is reduced by almost an order of magnitude, and typically two thirds of the events go on the Data Summary Tape automatically (there are reasons other than ionisation for looking at events on the scan table). Figure 2 shows mean values of normalised bubble density for a sample of pions and protons, plotted against momentum. The errors are based on the spread shown by different tracks in each momentum interval. The $1/\beta^2$ curves are plotted, together with the function actually used in the fitting. $\sigma$ is a normalisation factor, and $\nu$ a saturation parameter. It is found that pions and protons are resolved to 1.6 GeV/c, pions and kaons to 0.8 GeV/c.

At various levels in the system a number of checks are made to ensure that the measurements remain of the required standard. Many of these checks are listed in see also. These enable the system to operate without the day-to-day participation of engineers, physicists, or programmers.

Consolidation

As indicated above, the bottleneck during the last year was the event preparation phase. It has been agreed to increase the Milady scan table facilities to a total of 8 tables all on-line to an IBM 1130 computer. Of these, three have been on-line for some time, and the complex should be complete during the summer of 1970. With the appropriate number of operators it should be possible to achieve 300,000 events per year using Full Guidance, and the increasing use of Minimum Guidance will allow greater margins of safety and flexibility in feeding the HPDs.

During this time, a number of significant improvements have been made to the on-line program GATE. As a result of using extensive overlays, the program size has been reduced by about one third, to less than 19K words. Since this program remains in the central memory at all times, this is rather important (see below). The main ideas have been to keep the resident as small as possible (no input/
output), to overwrite during the scan the routines for decoding the picture number bits, and to store input/output till the end of the scan. A new procedure has been introduced for the program control of the digitising level \(^{13}\). This is based on the stringing technique used in the Minimum Guidance Filter program, and attempts to link together neighbouring digitisations for elements of track whose direction is along the beam track road. About 95% of the events give useful information, which is used as before in the five frame average to adjust the digitising level. Other improvements to GATE include the method used to introduce constants into the program, the determination of the slopes of the fiducial arms \(^{14}\), and diagnostic information on machine performance. A fuller discussion of these improvements is given by Messerli \(^{8}\).

The effect of the HPDs on 6600 throughput has been investigated \(^{15}\), and the conclusion was that there is an approximately linear relation between the loss in throughput and the memory space taken by the HPD programs. One HPD with an 18K program degrades throughput by \( \sim 17\% \). It has also been shown \(^{16}\) that during actual measuring the effect of the 6600 workload on the throughput of the HPD is at most a few percent.

A CRT recovery scheme \(^{17}\) to handle failing events is now in operation, and is being used initially to rescue events of Experiment 112 (see Table 1) which fail remeasurement. This is being done to investigate both the recovery scheme and the overall performance for physics. First results, based on an original sample of \( \sim 1000 \) events, indicate an overall success rate at GRIND of 97%. The system uses a CDC 250 display on a CDC 3100 computer, and in its implementation it differs little from those in use elsewhere. During the next year or so it is intended to use the recovery system instead of a second pass through the HPD system, but this can be implemented only for the more recent experiments where the digitisations tapes have been kept. (In this case the overall GRIND success rate is likely to be around 90%). A CRT recovery facility for the MG System is under development \(^{18}\).
During the last year some of the spare time on HPD 2 has been used to perform tests where, for reasons both of measurement accuracy and number of measurements, hand measurements would have been unsuitable. One such test was to verify that the distortions in reverse developed film are comparable with those in normally developed film \(^{19}\). Another test was to check for distortions arising from double pulsing the two metre chamber - on the basis of measurements of fiducials and full-length beam tracks on several hundred frames it was possible to show that no significant additional distortion is present in pictures taken on the second expansion. Measurements have also been made of beam tracks as part of a systematic study of distortions of high energy tracks in the chamber.

With the modified layout of the fiducials in the two metre chamber the HPD can now measure a sufficient number for the optical constants to be determined solely from HPD data. It is intended to use HPD 2 to make such measurements on all film from this chamber.

Returning to normal production, a significant change in the last year has been that there are now at any time three or four experiments active. This has led to rationalisation - at the Miladies, of scanning criteria, comment facilities, etc., in GATE, of the title structure, in SMOG, of the label structure, etc. The system has handled everything from stopping antiprotons to kaons of 16 GeV/c, and probably the only major problem so far unattempted is that of interactions in deuterium. For the recoil proton the Brookhaven short track measuring technique in use at the Milady should be particularly useful.

**Future work**

The completion of HPD \(\Omega\) (due in mid-1970) will mark the end of the development of HPD hardware at CERN. There are no plans to use HPD for the measurement of film from the large bubble chambers since equipment specifically for that purpose is being built. It is expected that the Minimum Guidance system \(^{11}\), which is now being used for its second experiment (01), will progressively take over from Full Guidance, though the detailed timescale for this is not yet clear. It
is expected that HPD Ω will be used to measure film from spark chamber experiments until late 1973, though, depending on the time available, it may also be used for bubble chamber work. The two HPDs are tentatively foreseen to continue in operation at least until 1975 (when the computers to which they are attached may be withdrawn from service).

Conclusion

A wide variety of experiments is now being handled by the Full Guidance system. In addition HPD 2 has been used successfully for a number of tests which otherwise would have been difficult to perform. The performance in production has proved to be very satisfactory in terms of the rate of measurement, the reliability of the hardware, and the quality of the results obtained. The precision of measurement is better than that of other machines currently used in bubble chamber film analysis, and reliable ionisation information is obtained with a satisfactory level of performance. Apart from the wider use of Minimum Guidance, development of the HPD system is now essentially ended, and extension to the target of 300,000 events per year with HPD 2 is considered to be within reach.
Acknowledgements

A great many people have contributed to the work of building and then bringing into operation the HPD system at CERN. If the list is so long that it is not possible to acknowledge them all by name here, it should nevertheless be remembered that without everyone's efforts, the system would not have reached satisfactory operational status.

Finally, since this is probably the last paper describing the evolution of the CERN Full Guidance System, we would like to express our appreciation of the help and encouragement which Paul Hough and Lew Kowarski have provided over the years. Moreover, it was due to them that the project was first initiated.
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<table>
<thead>
<tr>
<th>Experiment code</th>
<th>Beam momentum</th>
<th>Chamber</th>
<th>Main event type</th>
<th>Number of events</th>
<th>When measured</th>
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<th>Comments</th>
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Bubble Chamber experiments completed or in progress on CERN HPDs.

**TABLE 1**
Bubble Chamber Events Measured Each Year on CERN HPDs

Figure 1
A SYSTEM FOR ON-LINE CONTROL OF BUBBLE CHAMBER MEASUREMENTS

G. Blomqvist, S.O. Holmgren, P.O. Hult and U. Svedin
Institute of Physics, University of Stockholm, Stockholm, Sweden.

ABSTRACT

A hardware system that connects a measuring device for bubble chamber pictures, "Enetra", on-line to a CDC 8090 computer has been constructed by the Stockholm group. The software is under development. The measurements will be performed using a measurement list. Auxiliary data such as event type and ionization will be entered through a set of thumbwheel-switches, and demands will be given by the operator through push-buttons each with a specific function. The operator will be guided in the measurements by a label display and a set of message lamps. No typewriter is necessary in the system. The data from the measurements will be stored on magnetic tape. The on-line system will be used as a complement to a future Spiral Reader System.

1. SYSTEM CONFIGURATION

The device constructed for on-line measurement of bubble chamber film is shown in Fig. 1. Components of the CDC 8090 computer system used are also indicated. Figure 2 shows details of the operator control system.

In the on-line system, the typewriter of the off-line system has been replaced by a set of thumbwheel switches, the Databox, and a number of "Demand" push-buttons. The computer communicates with the operator via the Label display and the signal lights (the OK, Wait, and Error signals), which are placed in front of him, and via the specific messages (Fig. 2).

The counting equipment of the measuring device and the operator's console are connected via the interface to the 8090 system.
2. MEASUREMENT ON THE ON-LINE SYSTEM

Measurements on the new device will proceed as follows:

To start the measurement of a new event, the operator must load the Databox with information on the event from a measurement list (placed just below the Databox).

The operator initiates the measurement by pushing the New Event button. The wait signal (yellow lamp) is immediately turned on. This informs the operator that measurements may not proceed until this signal has been turned off.

If everything is in order, the operator receives the label of the first measurement to be made together with an OK signal (green lamp). The wait signal is turned off. It is possible, on the basis of the event type specified in the Databox, to provide the operator successively with labels, at least for those events with standard topologies.

On receiving a positive message, the operator positions the point to be measured on the Enetra's cross-hair, presses the coordinate pedal and waits for the next message. From the operator's point of view this usually arrives almost immediately. If everything is still in order, the operator receives a new positive signal together with a new label (if appropriate), and so on.

If measurement data for some reason should not be accepted -- for example, when an error has occurred in the counting equipment or as a result of an illegal operator action -- the operator receives an error signal (red lamp), which informs him that something is wrong, together with a specific error message informing him of the type of failure and the necessary action to be taken, e.g. "coordinate error, reset counters, and remeasure the view".

When the operator deems the measurements of a track to be complete, he presses the End-of-Track button. This command causes the data for the particular track to be examined.

In a similar way, the End-of-View button is pressed when the operator has completed measurement of a view, and the data from the whole view is then checked.
Should the operator find it impossible to measure some particular view, the Unmeasurable button may be used. In this case, the label for the next object to be measured is displayed.

When the topology of an event to be measured has not been anticipated by the event type, e.g. an associated secondary interaction, the label may be changed manually with the aid of the New Label button and the Step controls (Fig. 2). Using these controls, the two characters of the label may be changed to any desired combination of letters and digits. Any such changes are registered by the computer.

By making use of the four Erase buttons, the operator can delete measurements which have already been stored in the computer. These buttons delete last event, last view, last label, or last point, respectively.

When measurement of a complete event has been finished and accepted, the measurement data, which is temporarily stored in the computer, is transmitted to a magnetic tape which is used as input to the bigger computer (CDC 3600) where the events will be reconstructed geometrically by the program THRESH.

3. **COMPARISON OF THE ON-LINE AND OFF-LINE SYSTEMS**

The system constructed has several advantages over the off-line system. Simplicity has been a primary goal.

a) The typewriter used earlier is replaced by a Databox and Interrupt buttons. A typewriter is often considered more flexible, but here it was found that this greater flexibility was not necessary. The new system is simpler with respect to both the necessary electronics and the operator interface. Most of the information in the Databox is not changed from event to event, and much time spent in typing is saved. In addition, the Databox, being built of thumbwheel-switches, reduces the risk of the operator loading erroneous information.

b) Signals from the control logic of the counting equipment are transmitted to the interface and then on to the computer. The operator is given a message immediately if some error occurs.
c) On completion of each track or view, the data is checked, and the operator is informed whether the measurement was in order, whether it has to be completed, or whether some error has occurred.

d) The on-line system will be particularly useful for "operator training", and many systematic errors that otherwise occur frequently can be detected and corrected almost immediately.

e) Because of the greater reliability of the measurements, expensive computer time otherwise used for reconstruction of erroneous events will be saved.

f) As the measurement data are stored directly on magnetic tape, the conversion from paper tape to magnetic tape is eliminated.

g) Based on the experience of other groups, it seems reasonable to expect that the on-line system will increase the measurement speed by a factor of two.
Fig. 1
The On-line system and its connection
to the 8090 system
1. "Enable"
2. "Erase last event"
3. "Erase last view"
4. "Erase last label"
5. "Erase last coordinate"
6. "Not measurable"
7. "New label"
8. "Change of label, left character"
9. "Change of label, right character"
10. "End of view"
11. "End of track"
12. "Read coordinate"
13. "New event"

Fig. 2

The Console
1. Introduction

The problems posed by the new experimental facilities of the Omega and the Split Field Magnet (SFM) projects\(^1\) have led to the development of new pattern recognition methods adapted to experiments which are characterised by the production of a large volume of data and a wide variety of event topologies.

In this report we shall present the basic ideas of the pattern recognition programs being developed at CERN for the different types of particle detector that are likely to be used in these projects. Since Omega experiments with optical spark chambers will be the first to run in a magnetic field and as a detailed specification of this detection system already exists, the emphasis in the report will be on data handling programs for optical spark chambers.

2. Optical Spark Chambers Operated Inside the Omega Magnet

The experience obtained during the last few years with the CERN-ETH-Imperial College spark chambers shown in Figure 1 has led to the adoption of a similar arrangement of optical spark chambers\(^2\) for the Omega project except that plates are not parallel but have a fan-like arrangement as shown in Figure 2. This solution avoids the use of precisely machined prisms placed over the gaps, an arrangement which would be necessary for parallel plate chambers in order to direct the light emitted by the sparks into the camera. In addition, the larger visible volume allows a longer maximum track length in the beam direction. The main characteristics of this equipment are listed in Figure 3 with the CERN-ETH-Imperial College figures given
for comparison. Despite the similarities of the two layouts, new data handling problems might arise from the non-uniform spark length and from the varying gap separation in the beam direction.

The CERN HPD 1 has successfully measured more than 600,000 pictures from magnetic field spark chamber experiments and an improved version of this device will be used for the measurement of the Omega pictures. It is intended to measure the CERN share of the expected total of 3 million events per year on the rebuilt HPD 1, while the rest of the film will be measured in other European centres. The HPD will be connected to a CDC 6000 series computer at CERN and its on-line control program will be essentially the same as the existing one. The most important change will be the measurement in a single scan of the two stereo views that are recorded side by side on the 70 mm film. Simultaneously with this operation the first stage of the pattern recognition will be performed by the reduction of the digitising into master points corresponding to spark and fiducial mark positions. This information will be stored on tape and used as input for the event recognition programs to be executed off-line on a CII 10070 computer.

To perform the classification of events we have at CERN a set of pattern recognition programs\(^3\) which have allowed us to process different types of track topologies successfully. However, as the number of events per experiment increases, the programs become inadequate in several ways:

- the prescanning requirement may introduce a limiting factor in measuring speed,
- the processing time, although low enough in the past may result in the use of too much computer time when required for larger numbers of events,
- the program structure needs to be more flexible to reduce the reprogramming effort from experiment to experiment.

We have to improve these points and consequently we are developing a new pattern recognition program with the following features:
- no scanning information is used except for a list of numbers of the pictures containing good events,
- the track following methods are faster,
- the program is modular.

Let us now describe the principles of each of these developments. In the past, the films were prescanned in order to select good events, saving both HPD and computer time. Other information such as the number and nature of accidental beam tracks, the number of prongs or the position of the gap nearest to the decay apexes of neutral Vs were also given. As a first step all this extra information will be suppressed.

We do not intend for the moment to develop a general purpose program capable of distinguishing between pictures which contain good events and those which do not, but have limited ourselves to the problem of distinguishing between 3-prong and 5-prong events; as soon as possible we will attack the problem of distinguishing between other types of event such as for example one or two neutral Vs etc ...

At a later stage, the prescanning operation will be suppressed altogether. The search for good events will start at the measurement stage on the basis of quantitative criteria which will eliminate empty pictures and those without sufficient information. The rest will go through the different stages of the pattern recognition program and if they do not contain an event, will be rejected as soon as possible.

3. Faster Track Following Methods

By taking advantage of the spark displacements which occur in spark chambers working inside a magnetic field we have developed a faster track following method. Let us briefly recall how this displacement is produced by the forces acting on the column of electrons:
- the force due to the electric clearing field,
- the force due to the movement in magnetic field,
- the friction force.

This causes two displacements of the center of gravity of the column of electrons, one in the longitudinal direction, and the other in the transverse direction. As the chamber plates are at alternate voltages, sparks in consecutive gaps will be shifted in opposite directions. As shown in Figure 4, for a given angle between the trajectory and the normal to the plates these displacements will not be the same in magnitude for event tracks and accidental beam tracks, because the ionising particles do not arrive at the same time. This fact previously introduced a serious difficulty for the pattern recognition programs.

In the past the beam tracks were removed in a first pass by being followed separately first in the two sets of gaps with the same displacements. Then the positions of the other sparks were corrected by adding or subtracting an average displacement and the tracks were followed in a second pass. Although efficient, this process is time consuming, so we have now adopted the following method:

In a first stage we consider only the gaps in which the transverse deviation of the sparks is, for example, to the right. Possible tracks are then followed in this way:

a) For each track already recognised, a prediction is computed for the following gaps of the same displacement type by using linear, parabolic or circular extrapolation curves plus a tolerance around the curve.

b) Then a search is performed to find the sparks which fall within the roads defined by the predictions and the tolerances.

c) The sparks not associated with any track are then used to initialise possible new tracks.
A set of sparks is considered to be the start of a track when at least 3 sparks are found in at most five consecutive gaps of the same displacement type. Sparks used in starting trials which do not satisfy these criteria are thrown away.

In the second stage, the remaining gaps, i.e. those with a displacement in the opposite direction, are investigated in a different way. Using the followed half of a track as a guide and the displacement value that corresponds to the age of an event, a road is computed in which the other sparks must lie. This step is much faster than the first one because the prediction mechanism is so much simpler. The technique also acts as a filter on many of the beam tracks because the width of the road is such that the second set of sparks from most of the beam tracks will lie outside it. The other beam tracks are removed by applying such criteria as position in the chambers, entrance angle and curvature.

This method involves a substantial gain in processing speed. Firstly, the number of gaps to be investigated is reduced by a factor of 2; secondly, the prediction formulae are simpler because the spark displacement corrections are eliminated. The total gain in speed is about a factor of 4.

While the track following procedure can be applied to any type of experiment as long as the spark chamber arrangement is unchanged, the event recognition is experiment dependent and will in future have to be performed without any scanning information. As mentioned above, special programs for a given class of topology will be developed in the form of blocks written in a modular way which will be interchanged between one experiment and another. For the time being our experience in this field is limited to the recognition of 3 and 5 prong events of which the vertex is outside the chamber in a non-homogeneous magnetic field area. As the vertex position cannot be computed in a simple way, the track match is performed on all the tracks of the two views. In most of the cases 3 or 5 pairs of tracks are found immediately. When more than 5 pairs are found a trial is done to eliminate either a non-collimated beam track or a track which has interacted with an aluminum plate.
If 4 pairs are found two cases are possible; it may be a 5 prong event found incompletely or a 3 prong event with an extra track. If 5 tracks are found in one view and only 4 in the other, a recovery procedure is entered to look for a possible track not found by the track following program. The residual sparks of the incomplete view are associated with the non-correlated track sparks of the correct view to form a third view in a vertical plane parallel to the beam direction. In this view the tracks are supposed to be linear and a global method is applied. If this procedure fails the second hypothesis of a 3 prong event is assumed. In the same way a trial is done when 2 pairs are found with 3 and 2 tracks in the two views.

Finally, we should add that the Track Match program consists of two parts. In the first part, the track correlating values of the two stereo views are computed using simple functions such as curvature sign, length, missing sparks, coincidence and linearity in the third plane. The second part is an assignment program working on rectangular matrices which returns the best correlation solution.

4. Results of New Method

As the different devices of the Omega project are not yet available we have tested our programs using a sample of events from a diffraction experiment run at CERN last year. The events have either 3 or 5 prongs and Figure 5 shows a typical one. The results obtained with the earlier methods and those obtained with the new methods described above are compared in Figure 6.

The shorter processing time is mainly due to the much faster track following program and the higher efficiency is due in particular to the simple method of beam track elimination, and to the recovery procedure during the track matching phase.
5. **Filmless Methods, Split Field Magnet System**

In the SFM project, optical chambers will probably not be used at all. The main tool for particle detection will be large multi-wire proportional chambers. The reasons for choosing these chambers are:

1) their good efficiency (almost 100%),

2) their good performance even in strong magnetic fields (prototypes have worked without failure in fields of 45 kGauss),

3) their high time resolution (a typical value is 50 nsec),

4) their ability to serve as a trigger at the same time (a fast hardware logic decides according to the output of the chambers whether to keep it or not).

A chamber has the dimensions 50cm x 150cm and consists of three planes of wires, inclined at +60°, 0° and -60° with respect to the horizontal plane. The wire spacing is 2mm and the distance between the planes is 16mm. Each track therefore gives three wire addresses per chamber which correspond to the projections of the intersection point on three planes.

The first chambers of the proportional type will be installed in mid-1971 and will work for about one year without magnetic field. They will be used to study diffraction processes such as elastic pp scattering or N* production. Figure 7 shows an arrangement of wire chambers for the study of N* production in the reaction \( p p \rightarrow p N \rightarrow p \pi^+ n \).

A track finding program for this case of linear tracks has been written and has been tested using simulated events of the above type. The program has to deal with the following arrangement. There are four separated regions in space into which a particle may go, namely to the left, above the beam tube; to the left, below the beam tube; and in a similar manner to the right. Each of these regions
may contain a block of chambers, although in Figure 7 there are only two blocks below the tubes (and a neutron chamber above the tube). The track finding procedure consists of three stages:

1) point reconstruction in space,
2) track finding in each block,
3) vertex fit.

Stage one: the point reconstruction starts from the addresses of those wires which have given a signal. Each chamber delivers three addresses for any point, from which the two unknown cartesian coordinates are calculated. The redundancy in the information allows the rejection of wrong combinations of coordinates and at the same time of almost all spurious background pulses.

Stage two: in the case of two chambers per block there is no redundant information on a linear track, that is, each combination of two points forms a track candidate. The tracks found in this way which come from the interaction region of the two beams are kept for stage three.

Stage three: the final test consists of the reconstruction of the possible vertex inside the intersection region. This point is found by computing the minimum distance between each possible pair of tracks, taking one from each side. Then, after the rejection of tracks which are too far apart, the mean value of all minimum distance points defines the vertex. All tracks which do not pass within a certain weighted distance of this point are rejected.

This geometrical reconstruction is an essential feature of the program. It allows the detection of tracks coming from other parts of the system (e.g. interactions in the walls of the vacuum pipe or in air) as well as tracks caused by wrong combinations during stage two.
During an experimental run, it is planned to perform a large variety of sample calculations in parallel with the simple acquisition of the data. Using CRT display facilities, it will be possible to give various plots of chamber efficiencies, track finding efficiencies or even mass distributions from a simple kinematical reconstruction.

In mid-1972, after the installation of the Split Field Magnet, the chambers will be put into the magnetic field. Figure 8 shows a side and top view of the magnet; Figure 9 shows a proposed arrangement of the chambers. As can be seen from Figure 8, the magnetic field will be very inhomogeneous, changing its sign at the intersection point and between the SFW and the compensator magnets (the small magnets at the bottom of the picture). Therefore, for the arrangement of the chambers shown in Figure 9, the particles going to the left will follow S-shaped curves in the chamber region.

Another difficulty arises from the necessity of detecting the tracks of more than ten charged particles. Although there will be more or less equal numbers of these particles in the four separated space regions, yielding about three to four particles per chamber block as an upper limit, the problem is still complicated. As in the linear case, the vertex reconstruction will probably play an important rôle. A study of possible solutions has just been started.

6. **Filmless Methods for the Omega Project**

Inside the Omega magnet, filmless chambers are to be installed in 1973 to 1974. From the point of view of the track finding, the Omega magnet is a classical device with an almost homogeneous field in the region of the chambers. Therefore, it is hoped that existing methods of track finding can be modified to match the requirements of the new device. Although a decision on the type and number of chambers has not yet been taken and in spite of the long time scale, the track finding problems are already being
studied now. This is mainly due to the large number of tracks to be expected. A preliminary program\(^4\) has already been used for a set of magnetostrictive wire chambers within a magnetic field. In this program, tracks are found within predicted roads in space. It is, however, still possible that the tracks will finally be looked for in different projections and matched afterwards.

According to the complicated event structure, CRT devices for an optical presentation of the sparks as well as for the recovery of rejected events will certainly be essential\(^6\). As already mentioned in the case of the SFM, a large variety of on-line facilities will help to study the events and the overall performance in statu nascendi.
References


2) The Omega Project.
Proposal for a large magnet and spark chamber system - NP Division - Internal Report 68-11.

3) Analysis with the HPD of Neutral $V^0$ decays occurring in a large magnet spark chamber - J.-C. Lassalle and P. Zanella.

4) A track finding program for wire chamber detectors in a magnetic field - H. Grote.


6) Developments in the evaluation of magnetic field spark chamber pictures - J.-C. Lassalle and P. Zanella.
MAGNET SPARK CHAMBER
SECTION ALONG BEAM DIRECTION

FIG. 1
<table>
<thead>
<tr>
<th>CERN - ETH Spark Chamber</th>
<th>OMEGA Spark Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 twelve gap units</td>
<td>11 ten gap units</td>
</tr>
<tr>
<td>Vertical gap</td>
<td>Inlined gap</td>
</tr>
<tr>
<td>Parallel frames</td>
<td>Wedge-shaped frames</td>
</tr>
<tr>
<td>8 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>60 x 67 cm²</td>
<td>125 x 130 cm²</td>
</tr>
<tr>
<td>160 cm</td>
<td>325 cm</td>
</tr>
<tr>
<td>σy = 0.2 mm</td>
<td>of the same order</td>
</tr>
<tr>
<td>σz = 0.6 mm</td>
<td>55</td>
</tr>
<tr>
<td>24.2</td>
<td>12°</td>
</tr>
<tr>
<td>70 mm</td>
<td>15°</td>
</tr>
<tr>
<td>30.5 x 90.5 mm²</td>
<td>70 mm</td>
</tr>
<tr>
<td>Picture size</td>
<td>32 x 85 mm²</td>
</tr>
</tbody>
</table>

CERN-ETH AND OMEGA OPTICAL SPARK CHAMBER CHARACTERISTICS

FIG. 3
Diagram of the transverse deviation $\Delta Y$ of sparks from the particle trajectory (for 9 GeV/c beam tracks with 10 kG magnetic field and 60 V/cm electric field).

**Fig. 4**
RESULTS FROM A DIFFRACTION DISSOCIATION EXPERIMENT GIVING 3 AND 5 PRONGS IN THE CERN-ETH MAGNET SPARK CHAMBER (300,000 EVTS.)

<table>
<thead>
<tr>
<th></th>
<th>CERN-ETH PROGRAM</th>
<th>OMEGA PROGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO. OF EVTS. IN THE SAMPLE</td>
<td>13 227</td>
<td>13 227</td>
</tr>
<tr>
<td>EXTRA SCANNING INFORMATION</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>PROGRAM EFFICIENCY</td>
<td>89%</td>
<td>94% (93.4%)</td>
</tr>
<tr>
<td>CP TIME PER EVENT ON A CDC 6600 COMPUTER</td>
<td>1.0 sec</td>
<td>0.25 sec</td>
</tr>
</tbody>
</table>

COMPARISON OF OMEGA PROGRAM WITH MANUAL SCAN

<table>
<thead>
<tr>
<th></th>
<th>MANUAL SCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROGRAM</strong></td>
<td></td>
</tr>
<tr>
<td>3 PRONGS</td>
<td>11 334</td>
</tr>
<tr>
<td>5 PRONGS</td>
<td>80</td>
</tr>
<tr>
<td>5 PRONGS</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>973</td>
</tr>
</tbody>
</table>

Fig. 6
THE DIGITIZED MICROSCOPE (or DM) - A MEASURING DEVICE FOR THE EVALUATION OF PHOTO EMULSIONS IN HIGH-ENERGY PHYSICS AT MPI IN MUNICH, GERMANY

H. Brettel, C. Carathanassis and L. Kollmeder,
Max-Planck Institut für Physik und Astrophysik, Munich, Germany.

1. INTRODUCTION

The scanning and measuring of photo emulsions with a microscope is a time-consuming job. Carathanassis therefore made a proposal for a device which allows a fully automatic evaluation on-line to a large digital computer. A prototype has been constructed, measurements have been carried out, and data written on magnetic tapes. In the meantime, computer programs for the geometric reconstruction have been written and carefully checked.

2. SYSTEM (see Fig. 1)

The system as planned for on-line use consists of a microscope and its associated electronics, parts of the HPD electronics and data connections, a Digital Equipment PDP-8 computer, and an IBM 360/91.

The program in the 360/91 receives digitizations from the microscope, detects track elements, and follows tracks by giving commands to the stage control via the PDP-8.

Because a direct data connection to the 360/91 does not yet exist, data are transmitted via the DDC to the IBM 7090 where they are written onto magnetic tapes which are then used as input to the 360/91 program. For the same reason, computer-controlled track-following is not possible at present.

3. LAYOUT

The microscope was specially constructed by W. Süß, Munich. The precision-measuring stage and the optics were delivered by Leitz, Wetzlar. Motion of the stage and microscope tube is achieved by spindles driven from Slo-syn stepmotors. Motor-drives were manufactured by Omni Ray, Zürich. Displacements in the directions $X_m$, $Y_m$, and $Z_m$ are sensed to an
accuracy of 1 μm, by linear Heidenhain gratings and associated electronics. The television system is an Image-Orthikon-Camera System Televisor from Fernseh G.m.b.H., Darmstadt. The electronics are home-made and use Digital Equipment M-Series modules and circuits, which we designed ourselves. (It was not considered necessary to describe the HPD electronics in this paper.)

4. OPERATION

The photo emulsion lies on the measuring stage which can be moved in X_\text{m} and Y_\text{m} directions under computer control. The television camera observes, through the microscope, dark points on a bright area of 93 × 77 μm (magnification of the microscope ≈ 1000). The depth of focus is in the region of some microns. The tube of the microscope is raised by a motor-driven spindle until the top surface of the emulsion is in focus. The spindle rotates quickly back to its original position and the microscope follows slowly, its motion controlled by a hydraulic brake (see Fig. 2). During this motion the TV makes a raster scan, using the CCIR standard: the camera takes 50 pictures every second, each with 312 lines. Every second picture and every second scan line are suppressed later in the digital circuits in order to avoid getting more information than is needed. The time corresponding to several lines is needed for the retrace; thus the effective raster becomes 144 lines/picture. The time needed for one picture scan is 20 msec; this is followed by a pause of at least 20 msec. The analogue signals being picked up are filtered, amplified, and squared. The filters had to be carefully designed to avoid distortion of the signals, because noise and signal frequencies are near together and the signal-to-noise ratio is very poor. We found that a TBT-Filter (Transitional-Butterworth-Thomson) suited best. The dark period of the TV and low frequency distortions are eliminated by a special clamp circuit with an adjustable time constant. The squaring is done by a Schmitt-Trigger. Its level is controlled by computer program. The squared signals are compared with reference pulses from a crystal clock to determine the position in the TV picture (X_\text{t}, Y_\text{t}). These data are transmitted, together with the stage and tube coordinates (X_\text{m}, Y_\text{m}, Z_\text{m}), to a fast intermediate buffer in the HPD which has a capacity of 64 18-bit words and a cycle time of about 850 nsec. The data flow is under control of the 7090 and PDP-8 programs, enabling
transmission of a TV picture when a specified \( Z \) position has been reached by the microscope tube. Usually a picture is taken every 3 \( \mu m \), but a minimum distance of 1 \( \mu m \) can be programmed. The 7090 reads the content of the intermediate buffer at regular intervals and writes the data onto magnetic tapes to be used by the 360/91. (Figure 3 shows a plot of one TV picture from this tape.) As soon as the DDC between the HPD and the 360/91 is complete, all calculations will be done during the time the microscope is scanning and the generation of data tapes will not be necessary. The program will determine the direction of tracks and give commands via the PDP-8 to the stage control for track-following.

The measuring time is about 10 seconds for a volume of \( 93 \times 77 \times 400 \mu m \) including stage motion between measurements.

5. **PROGRAMS**

For each volume element of emulsion scanned, the \((X,Y,Z)\) coordinates for each grain (digitization) are measured and stored. \( X \) is the line number of the television picture, \( Y \) is the distance along the line, and \( Z \) is the \( Z \) of the microscope stage. The tracks are to be followed in roughly the \( X \)-direction.

The following procedure is used to find a track. First, the desired slice of the scanned volume is made by selecting all grains having \((X,Z)\) coordinates lying within a given distance \( \Delta Z \) of the plane

\[
Z = B + N \cdot X.
\]

(See Fig. 4.) (Which slice is "desired", i.e. which parameters \( B, N \), and \( \Delta Z \) are used, is defined by the physics involved.) Then, the \((X,Y)\) coordinates of the selected grains are considered.

A track will consist of a constellation of grains lying along a straight line of the form

\[
X = A + M \cdot Y.
\]

A matrix of all possible \( A \) and \( M \) values is set up, whereby the rows correspond to the \( A \) values and the columns correspond to the \( M \) values.
Naturally, the possible A and M values are accumulated, the number of A values being equal to the number of lines of the TV picture, and the number and magnitude of the M values being given by the physics of the situation. At the start of each slice, all matrix elements are zero. Then the \((X_i,Y_i)\) coordinates for the \(i^{th}\) grain are used to calculate the possible values of \(A = A_j\) for this grain from

\[
A_j = X_i - M_j \cdot Y_i,
\]

where all possible values of \(M = M_j\) are substituted sequentially. The corresponding matrix element for each \(A_j\) and \(M_j\) thus computed is increased by one. This procedure is repeated for all grains of the slice. The resulting matrix is then examined for maxima among the matrix elements. A matrix element which exceeds a given minimum value (given by the physics, the density of background grains, the quality of the emulsion, etc.) and which is greater than its eight immediately neighbouring elements, represents a track. The digitizations (grains) used to form this element are collected and a straight line is fitted to their \((X,Y,Z)\) coordinates. Provided this fit fulfils certain criteria, the track is accepted. This fit is used to follow the track to the next scanned volume element.

6. CONCLUSION

The DM can be said to fulfil the special purpose for which it was designed. In our opinion it would be possible, with some trivial changes in the electronic circuits, to use this system in other fields, e.g. biology, cancer research, etc.

Remark

More detailed information about the DM will be given soon in an MPI internal report.
FIGURE 1

FIGURE 2
Figure 4
ARIANE II - AN AUTOMATIC DEVICE FOR THE ANALYSIS OF SPARK CHAMBER PHOTOGRAPHS

A. Dillet, M. Goldwasser, J.C. Michau, J. Mullié, B. Pichard and G. Riols,
Département de Physique des Particules Elémentaires, Saclay, France.

1. INTRODUCTION

ARIANE II is an automatic device for the analysis of spark chamber photographs, and was developed by the Electronics Group of the department headed by Prof. Berthelot (DPh. PE), at Saclay.

As to its principles, it is similar to ARIANE I (cf. "Conference on Instrumentation for High-Energy Physics", Purdue, 1965), but is much more accurate and flexible.

ARIANE II has now successfully processed the whole of its first physics experiment, which consists of 180,000 events from the $\pi^0\pi^0$ experiment, making use of wide-gap cylindrical chambers.

Just now, we are beginning to process the $\pi^0n$ experiment, which uses a plane chamber.

ARIANE basically is a flying-spot CRT controlled by a small on-line computer, here a CDC 8090.

In order to analyse a frame, the spot is made to follow very accurately some guide lines, unique to the experiment, e.g. straight lines in the middle of the gaps for narrow-gap plane chambers, or concentric circles for cylindrical chambers.

These guide lines which may be either photographed on the same frame as the chamber (like a data-box), or on a separate slide, are used throughout the experiment.

This analogue control, along with the digital control of the spot, allows a good performance at a low price.
2. **MAIN FEATURES**

Figure 1 shows a very simplified schematic of the device. The CRT is a 5E 29/Q4 Ferranti tube, 5" in diameter, of which a square area of approximately 10 × 10 cm is used. The optical enlargement ratio being around 1/3 rd, a square of 3 cm × 3 cm on the film may be scanned with a spot of 20 microns.

The spot is split into two beams of equal intensity, one of which scans the film to be measured, the other being directed onto the guidelines slide (when used). This is mounted on an X-Y movable, servo-controlled clamp.

The film-transport is usable with 35 mm sprocketed film, and two control-modes may be selected:

a) fast drive, manual control (off-line) -- forward or backward, any distance;

b) step drive, computer control (on-line) -- forward or backward, 1 to 16 steps at each command, one step being 18 mm. The step drive may also be controlled off-line from the ARIANE operator's console (same conditions).

The computer is a CDC 8090; its main features are:

- word length: 12 bits
- cycle time: 6.4 μsec
- core storage: 2 × 4096 words; memory cycle: 12.8 μsec
- two external interrupt lines, "30" and "40"
- one "normal" channel (IN and OUT), program-controlled operation
- one "buffered" channel (IN and OUT), cycle-stealing operation.

The two channels operate on full-length words.

The spot motion has two control modes:

a) an open-loop mode under computer control: the computer issues coded command words which make the spot describe certain simple curves (e.g. straight lines, circles);

b) a closed-loop mode under analogue control from information on the film itself, e.g. the spot can follow a curve on the film by accurately centring itself on this curve.
3. ANALYSIS OF A FRAME

The analysis of a frame is performed by means of a series of "sequences", each of which defines an elementary path for the spot. These sequences are made up of a number (up to 12) of command words issued by the computer and stored in ARIANE's buffer registers. These words allow one to select the numerous possibilities for moving and stopping the spot, the parameters relative to the measuring conditions, etc.

Let us mention particularly that the spot may be sent to any point $M(x,y)$ of a $1024 \times 1024$ raster, or may describe a straight line at any angle in steps of $1.4^\circ$, or describe a circle defined by its centre and any point of this circle; the spot may be stopped when it has reached a point $M(x,y)$, or after a given time (up to 328 msec in steps of 320 $\mu$sec), or when it reaches a line perpendicular to its trajectory, or by combinations of these conditions (e.g. reaching a line, but only after a given time, etc.).

Figure 2A shows, as an example, the principle used to scan a simple grid (plane chambers).

In step one, the spot is sent from its stand-by position to a point near, but always outside, one side of the grid. This is due to the fact that the position of the grid with reference to the CRT is not known very precisely owing to the unavoidable positioning errors within the camera and the film transport.

N.B.: the spot may be moved at several linear speeds (three in ARIANE II), hence the subscripts "FAST"... The slowest speed would generally be used only for measuring, when the highest precision is necessary.

- In step two, the spot searches for the first line of the grid, and stops on it.
- In step three, the spot searches for the first corner of the grid, and stops on it.
- In step four, the spot follows one line of the grid, centring on this line, and the measurement takes place. The end of this step could be finding a line after a given time (last line of the grid).
- All the other lines of the grid are scanned by a succession of sequences similar to steps two, three, and four.
Figure 2B shows the spot path (as seen on a scope monitor) used to scan a frame with several plane chambers. The brighter points show where fiducial lines, sparks, etc., have been detected.

As a further example, we shall now study the case of wide-gap cylindrical chambers ($\pi^0\pi^0$ experiment). There are seven concentric chambers, and the physicists asked for seven measurements in each chamber. So, the guide-lines had to be 49 concentric circles. An eighth outer chamber needed only four lines.

Figure 3A shows (in negative) the whole guidance structure. The 36 radii, $10^\circ$ apart, will be used for interpolation (cf. "Measuring").

Another problem arose: the chambers are about 2 feet deep, and their bottom is lined with tilted mirrors, to be able to compute the depth of the track from the distance between the track and its reflected image. Under these conditions, it was impossible to photograph the guide-lines onto every frame: their reflected images would have ruined the frames. So, we had the guide-lines photographed onto a separate slide, scanned by the second beam (cf. "Main Features"). Of course, this guidance structure has to be centred very accurately relative to the frame before the measurement can start. Hence the small circle and the cross at the centre of the structure; only this circle and cross exist on every frame, and the centring is made on them by a succession of computer-controlled "sequences" which position the servo-controlled slide holder.

Figure 3B shows on a scope-monitor (coupled to the CRT) the path of the spot to scan a whole frame (centring included).

Figure 3C shows the detection of the interpolation radii ("fiducial marks") under the same conditions (the monitor is lit only when a measurement is made on the "second-beam channel").

4. **CENTRING THE SPOT ON A LINE**

It was already mentioned (cf. "Main Features") that the spot had two control-modes: computer controlled and self-centring on the film. Actually, these two modes are complementary: the computer-controlled mode switches-in function generators which ensure the coarse guidance of the spot on a
given curve (straight, circle), and when a line has to be followed accurately, a command bit from the computer switches in the self-centring mode which ensures the fine guidance.

The self-centring mode works as follows: a symmetrical sawtooth oscillation is superimposed perpendicularly to the mean spot path, giving the spot the aspect of a segment perpendicular to the line to be followed. The frequency of this oscillation is 100 kHz, and its amplitude is computer controlled in 64 values (up to 0.8 mm on the film, with 0.1 mm steps).

Figure 4 shows how this sort of "spot wobble" associated with a fast detection circuit, a phase discriminator, and a feedback loop, ensures a very accurate centring of the mean path of the spot on the line to be followed on the film (or the guide-line slide).

It should be noted here that, owing to the split-beam operation, all the detection, centring, and measuring circuits are dual, one for each beam, with separate command bits.

5. MEASURING

With the segment system, the detection of a line or a spark perpendicular to the mean spot path is rather straightforward: when only centring, the detected signals come out as short fast pulses each time the spot crosses the guide-line. When detecting a spark, the spot is masked during several oscillations (typically 5 to 30); thus, a simple low-pass filter on the detection circuit transmits the pulses to be measured. These pulses are then digitized to one of 16 amplitude levels (only 10 of which are in use up to now), and their length and position are also transmitted to the computer. The length of the pulse is measured on the last but one triggered amplitude level, by counting 100 kHz clock pulses during the triggered state of this level (8 bits).

As to the position measurement, it is given by reference to the starting point of the spot at the beginning of each measuring "sequence": as soon as the spot begins to move, another counter (16 bits) receives the 100 kHz clock pulses, and whenever a detected pulse occurs, this counter is read "in flight" and transmitted to the computer together with the length and amplitude of the pulse.
Any measured point is transmitted to the computer in a two-word (24 bits) format, coded as follows:

Word 1 - bit 1 : if 0: this is a measure from the "film channel" (first beam).
if 1: this is a measure from the "guiding slide channel" (second beam).

-bits 2, 3, 4, 5: These bits can be, by hardware option, either the amplitude of the pulse, or the four high-order bits of the position. For instance, in the π^0π^0 experiment, these bits were the amplitude on the "film channel", and the high-order bits of the position on the "guide channel".

-bits 6 to 12 : These are the seven high-order bits of the length counter; the latter being 8-bits long, this is actually the half-length of the pulse.

Word 2 - bits 1 to 12 : These are the twelve low-order bits of the position counter.

N.B.: The position counter being read at the time when the length counter is stopped, the position of the centre of the pulse is easily computed by subtracting the half-length from the position.

From what has been said of the measurement method, it should be clear that all the space measurements are transformed into time measurements with a basic frequency of 100 kHz. The speed of the spot along its mean path being computer-controlled (three speeds for ARIANE II), the space value of the least-count may be chosen in accordance with the necessary precision, down to approximately 2 microns on the film/least-count for the slowest speed. As to the centring precision on the guide-line, it is of the order of one-tenth of the guide-line width.

The position in space along a guide-line is given by the product of the time read on the position counter and the speed of the spot along this line. Actually, the time is measured with a very good precision (the clock is stable to 5 x 10^-6 and the least count is 10 μsec) and the main uncertainty is on the spot speed (stable to about 10^-4). To reach the
necessary precision over a long path within the same "sequence", use is made of "fiducial marks" on the guiding structure. These marks are measured just as ordinary sparks, but on the "guide channel".

As the exact spacing of these marks is known (when the guiding structure is engraved, e.g. \(10^\circ\) for the radii in the \(\pi^0\pi^0\) experiment), they are considered as "fixed points" in space, and the position of the sparks is computed by simple interpolation between the two closest fiducial marks. If the fiducial marks are close enough to one another, the ultimate measuring precision is no longer due to the spot-speed stability, but rather to spot-size, optical defects, phosphor grain, and afterglow, etc. With ARIANE II, this ultimate precision is of the order of \(\pm 2\) microns on the film, quite obtainable with a fiducial every \(10^\circ\) in the case of a circle described with a constant angular speed.

6. OPERATIONAL DEVICE

After the description of ARIANE II's fundamental principles, we would like to give a brief description of the operational device, which has been working satisfactorily for over a year by now.

6.1 Hardware

All the optics and film-transport mechanics are contained in a light-tight main frame, labelled A on Fig. 6. Figure 5 shows the optical schematic of the device. It is very close to the theoretical schematic of Fig. 1 except for two points:

a) The light-regulation PM (labelled 3 in Fig. 5) ensures, via a closed-loop system, that the light output from the CRT remains constant regardless of the state of wear of the phosphor, and of the irregularities of this phosphor.

b) A projector (labelled 9 on Fig. 5) has been added to allow a normal projection of the film on a transmission screen (17, Fig. 5) for operators' control purposes. Of course this projector is not used during normal operation (it is attached to a sliding mount, together with the "film" PM, which takes its place during normal operation), and the screen is covered by a sliding shutter. The projector is brought into use by means of a lever on the front of the main frame,
and several safety circuits (switches) prevent any trouble with the PM's.

All the electronics are housed in standard 19" racks, and consist of:

a) All the necessary power supplies for the CRT, film-transport, and so on.

b) The analogue electronics which assume the tasks of spot control, detection, scope monitoring, "guide" clamp control, film transport control.

c) The digital part which is devoted to the functions of computer-interface, spot-control command buffer registers (12 words = 144 bits), part of the spot stop-conditions, measuring, film-transport logic.

Three more elements complete the ARIANE II system:

a) The CDC 8090 computer (labelled A on Fig. 7) with its paper-tape system, card reader, line printer, and two tape units with their controller.

b) A control console (labelled B on Fig. 6) connected to the digital electronics, and which allows direct operator interaction with the computer program, without stopping the computer or ARIANE's operation. In addition, provision is made on this console to manually control the film-transport step-by-step, and to display a four-figure number in octal written by the computer (generally the number of the view being measured).

c) A digital display unit (labelled C on Fig. 6) equipped with a 59 cm CRT, and able to display points addressed on a 1024 × 1024 raster, with four light-levels. The unit which is computer controlled, must be refreshed at least 20 times/second.

Besides the display itself, the unit is provided with a precision co-ordinatograph. This is a hand-operated pointer, driving two precision encoders (in X and Y) with a range of 1024 × 1024. The coordinates of the pointer may be read by the computer (generally at the end of each frame).

Moreover, a small console on which one can set up, bit by bit, two 12-bit words, may also be read by the computer.
6.2 Software

The ARIANE system may operate in three separate modes: input tape generation, ARIANE operation, and digital display operation. The 8090 computer is neither large enough nor fast enough to store and operate these three modes together. Thus the three systems are separately stored on paper tape, and loaded by the operators when requested.

6.2.1 Input tape generation

Before being handed over to the ARIANE team, the films are visually examined by projection ("scanning") to select the frames to be measured. The results of this inspection are punched cards, one card per frame, with a certain amount of data punched on the card: number of the film, number of the frame, plus some physical data about the event.

During its normal operation ARIANE will have to use these data to select the frame to be measured, and also to transfer these data on the output tape for the further treatment with a powerful computer (CDC 6600).

It was found much more practical to pack as a first step, several thousand cards on an input tape, to be read later on by ARIANE. The input tape generation program performs this packing, and, at the same time, checks that the data transferred onto the tape meet the correct specifications. If a wrongly punched card is detected, it is not transferred to the tape, and its contents are listed on the line printer with a diagnostic.

6.2.2 ARIANE operation

The ARIANE operating program is now rather complex, and occupies, with its output buffers and command tables, the whole 8 K memory of the computer.

After a film, an input and an output tape have been loaded, the program runs first through an initialization routine, which in certain cases needs the operator to enter some data manually (number of film, frame etc.) at the computer console.

Then the program enters its normal cycle to measure a frame which, in a simplified way, runs as follows:
The input tape is read to get the parameters of the next frame to be measured. With these is made the "title" of the next frame, and this is stored at the beginning of the output buffer.

Knowing on which frame the film is stopped, either by the initialization steps or by the title of the last measured frame (kept in another buffer), the program computes the film transport motion (direction and number of steps).

The film-transport command word is sent to the logic on the normal channel.

When the film transport has finished its motion, the logic sends an interrupt 40, followed, on the normal channel, by an identification word indicating "film-transport executed".

Now the data-box must be read on the film to check the film position, and to acquire the physical data (unique to this frame) to be written on the output tape. The reading of the data-box is made using the flying spot and a special measuring logic which transfers the decoded data direct to the computer, over the buffered channel.

The flying-spot control, the principle of which has already been discussed earlier, reduces itself, at the computer level, to sending several command words to the logic over the normal channel. The flying-spot control executes the commands, and if the order "measure" was given, the measurements are sent "in flight" to the computer over the buffered channel. When the "stop conditions" are met, the spot halts and the logic sends an interrupt 30 to the computer. This interrupt causes the program to send the next command sequence to ARIANE, and so on.

The data-box readings are checked. If wrong, another "read" attempt is made, or the film is repositioned, or even the operator is called for, depending on the case. If right, the data are stored in the output buffer.

Then, the picture itself is measured. This is made by a succession of sequences, as explained earlier. The command sequences are stored in a special table, whose organization is such that the program knows at any time which part of the guiding structure the spot is following (for instance, on which circle the spot is, for the π₀π₀ film). This
allows one to store in the output buffer the measured points packed in groups corresponding to a physical part of the guiding structure (usually one guide-line), and thus to have the second coordinate of every point (the first coordinate is the value measured from the beginning of the guide-line, as explained in "measuring").

When the output buffer is almost full, the program transfers it onto the output tape between an interrupt 30 and issuing the next sequence.

Finally, when the picture is completely measured, the program performs a few simple checks, and if no "halt" or diagnostic condition appears, the cycle begins again to call for a new frame.

Of course the above is a simplified "from the outside" description of the operating program, but it would be far too long for this paper to go deeper in its possibilities and routines. Anyway, we should like to emphasize one particular point relative to the spot command tables. The main program provides for four different tables, called for by certain switches in the main cycle. These tables are treated as three-dimensional tables. It is by the triple index of a sequence that its correlation with the guide-lines is established.

In addition, any sequence with a first word of zeroes is not issued to ARIANE. This allows one to keep the tables at constant addresses.

All the "sequence" tables are written for a unique experiment, but are practically the only part of the program to be modified when another experiment is processed. This results in a very flexible operation, and allows one, for instance, to rewrite the entire tables for a new experiment in a few hours. If the tables are written on punched cards, their replacement in the program is made by a subroutine of the main ARIANE program; it is also possible, and it is usually made so, to write the tables directly into the operating program by means of the operators' console.

The coded parameters and a sort of symbolic address of any word in the command tables is set on the console with keyboards and switches, and a pushbutton is depressed; an interrupt 40 is sent, and the computer reads in, on the normal channel, the contents of the keyboard and switches, and then performs the change in the command table.
6.3 Digital display operation

As already explained, the size of the computer prevents the use of the digital display at the same time as ARIANE. In the present configuration, the normal use of the display would be to save events rejected at the large computer level, by adding some data ("crutch points", separation of tracks, etc.) given by the operator. This system has been tested, but, due to ARIANE's full-time operation (24 hours a day, 6 days per week) it has not yet been put into production.

On the whole, the program runs as follows:

- the points of an event are read from the input tape (which is an ARIANE output tape), and stored in a large buffer.

- All the points of the frame are sent, one after the other, to the display unit, over the buffered channel.

- At the end of the refresh cycle, the coordinatograph and the display console are read.

- From the values of the coordinatograph, the display "pointer" is computed and stored with the image. In accordance with the coded instructions of the console, some simple additions or changes are made in the stored image, in the vicinity of the pointer position.

- Another image is sent to the display, and so on.

The refresh frequency should not be less than 16-20 per second.

- When the operator has finished with the frame, a code sent from the console causes the modified image to be written on the output tape, and the next frame is called for.

7. Measurement Results

After six months of continuous operation on the $\pi^0\pi^0$ experiment, the following results can be stated:

- measuring precision: $\pm 2$ microns on the film;

- mean measuring time:
  
  30 sec/frame, film-transport operation included, for the cylindrical chambers.
Some test runs made on the π⁺n experiment gave the results:

- same precision of ±2 microns;
- mean measuring time:
  5 sec/frame, including film-transport, for plane chambers.

8. FUTURE DEVELOPMENTS

From what has been said above, it should be clear that the main drawback of the system is the small size of the computer, especially since, in most of its parts, ARIANE itself could work faster. For instance, the logic for receiving the command sequences and for sending the measured values could easily operate at least twice as fast.

Thus it was decided to change over from the 8090 to a CII 10020 at the end of May 1970. The 10020 is a medium-sized computer with 16-bit words, a 16 K memory, and several fast channels and external interrupt lines.

ARIANE itself will undergo few changes (except, perhaps, a faster film-transport). The interface logic is already being built.

This computer changeover will result in two main advantages:

- The control by the computer will be faster and more accurate, and still more complete and flexible.

- The digital display will operate on a time-shared basis with ARIANE, maybe opening the way in the distant future to some sort of on-line scanning and pre-treatment.

* * *

Acknowledgements

We wish to express our gratitude to Prof. A. Berthelot, Head of the department, who allowed the construction of this device.

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Fig. 1 Block diagram
Fig. 2A Path to analyse a grid (principle)

Fig. 2B Plane chambers: path of the spot
Fig. 3A Cylindrical chambers: guiding structure
Fig. 4 Centring on a guiding line (principle)

Fig. 5 ARIANE II optical schematic
Fig. 6 Main frame, digital display and control console

Fig. 7 Computer and electronics
AN EVALUATION OF REVERSE DEVELOPED FILM
MEASURED ON HPD 2

D. Eastwood,
CERN, Geneva, Switzerland.

1. Introduction

Track chamber film in which there are transparent fiducial and track images on a dark background, as opposed to dark images on a transparent background, has two advantages for the users of FSDs.

The random noise in the photomultiplier circuit of an FSD is proportional to the square root of the photon flux arriving at the photomultiplier tube, and is therefore proportional to the square root of the current flowing in the circuit. When transparent film with dark tracks is being digitised, the base level of the photomultiplier output is high since the photon flux is high. When information is detected on the film the photon flux diminishes and the photomultiplier current drops. Conversely for transparent tracks on a dark background, the base level of the photomultiplier signal is low and when information on the film is detected the current rises. In the former case the random fluctuations about the high light level are larger and the discrimination of real digitisations is more difficult. Figures 1 (a) and (b) illustrate the point by showing the photomultiplier output for a single scan-line on transparent background and dark background film. The improved signal to noise ratio for dark background film is particularly useful for CRT measuring devices, where the light intensity may be low, and where the signal to noise ratio is therefore worse than for a device with a mechanically generated flying spot. Figures 1 (c) and (d) show similar results obtained with a CRT device LUCY 6, for both types of film.

The second advantage is that dirt on the film which absorbs light, and faint scratches which do not penetrate the emulsion, but which scatter light falling on to transparent background film, are not digitised when the FSD is measuring dark background film. Figures
2 (a) and (b) show examples of two typical frames from a CERN 2 Metre Bubble Chamber experiment. The first frame has been normally developed and the second one has been reverse developed to reverse the contrast. If the discrimination level on the photomultiplier output of the CERN HPD 2 is adjusted so that the percentage of scan-lines with "hits" on the beam tracks is 60%, it is found that the average number of digitisings per frame for the reverse developed film is about 40% of the number on the normally developed film. Figure 11 shows two examples chosen at random of on-line teletype output from the measurement of normally and reverse developed film. Here the ratio of the average number of digitisings per frame is 3 : 1. The data handling problem is thus reduced, a consequence of particular importance for HPD Minimum Guidance 7) where there are difficulties due to the large numbers of digitisings which need to be stored.

There are two ways in which dark background film can be obtained: (a) by the normal development of film exposed in a bubble chamber with bright field illumination, which however often produces a grey background, and (b) by the reverse development of film from a chamber with dark field illumination. This paper describes the evaluation of reverse developed film exposed in the CERN 2 Metre Bubble Chamber and measured on the CERN HPD 2. The film used was standard track chamber recording film with a tri-acetate base.

Extra chemical processes are required for reverse development and the development time is about 25% longer. It is possible therefore that additional film shrinkages and distortions could be introduced which would adversely affect the measurement and geometrical reconstruction of events on the film. Furthermore the profiles of track signals on an FSD will tend to be more irregular for dark background film, since a track signal corresponds to a large photon flux with large random fluctuations at the photomultiplier tube. The track centring circuit may consequently be less accurate.

To investigate these possibilities a roll of 700 frames of film exposed in the CERN 2 Metre Hydrogen Bubble Chamber was reverse

* This is the percentage usually required in HPD 2 production measurements.
developed at the Rutherford Laboratory, and a similar quantity of film from the same spool was normally developed at CERN. Both rolls of film were measured with the CERN HPD 2 Full Guidance System \(^1\), and the measurements were compared in three different ways. The variations of the distances between pairs of fiducials were computed to find relative linear and non-linear film shrinkages. The results of the THRESH reconstruction for a large number of beam tracks were compared, and finally the GRIND kinematics and ionisation fits to measured events in each sample of film were examined.

2. Scanning and Measuring

The two rolls of film were scanned and pre-digitised on a Milady table. The film was from a 100 GeV/c K\(^-\) hydrogen exposure, and two clearly identifiable beam tracks per frame, together with any events, were measured in all three views. This resulted in 1085 and 1653 beam tracks in the normal and reverse developed film respectively, of which about 20\% in each case had measured interactions. The film was of very good quality with almost no background from flares or local boiling, and had typically about 15 reasonably spaced beam tracks per picture. The three Milady operators involved agreed that the reverse film was easier to scan because of its greater clarity and better contrast, but it should be remembered that their conclusions could be different for average or poor quality film. It is also necessary that the background illumination be fairly low in the scanning room.

Some modifications to the HPD electronics were necessary in order to measure reverse developed film. The Brenner Mark detector signal lines were inverted and an inverter was included before the track centring circuit in order to have the same polarity of the signal as for transparent background film.

Since the average number of digitisations per frame was reduced by about 60\% for reverse developed film, there was some saving in computer CP time per picture used by the GATE \(^1\) program. The saving
was difficult to estimate precisely but was thought to be about 20%.
After GATE, the information from the two rolls of film was essentially
the same from the point of view of the Full Guidance computer programs.
For Minimum Guidance, however, there would also be a saving in MGPILT
CP time per frame.

3. Film Shrinkage Comparisons

If two pairs of fiducials are chosen so that the lines joining
each pair are parallel or nearly parallel, a scatter plot of the dis-
tance between one pair versus the distance between the other pair, for a
large number of frames, indicates the variations of linear and non-
linear film distortions within the locality of those fiducials. The
spread of points along a line which has a tangent equal to the ratio
of the two inter-fiducial distances is related to the variation of the
linear film distortion. The spread about the line is related to the
variation of the non-linear distortion. The amount of linear film
distortion is unimportant since it can be accounted for in geometrical
reconstruction, but the presence of any large non-linear distortions
would be serious. Although this method does not provide direct esti-
mates of the distortions present, it is a reasonable assumption that
the variation of non-linear film distortion over many frames gives a
good guide to its magnitude. The assumption implies that there is no
periodic non-linear distortion from frame to frame along the length
of the film, nor any component of non-linear distortion, which is
constant from frame to frame, along the breadth of the film.

The fiducial pattern and numbering system is shown in Figure
2 (a) on normally developed film. Scatter plots for various combina-
tions of fiducials in 2 or 3 views are shown for reverse and normally
developed film for comparison in Figures 3, 4, 5, 6 and 7. The points
in each plot would lie along the tangent if there were no non-linear
film distortions and the HPD had infinite measuring accuracy. For
some fiducial combinations only 2 views are shown because one or more
of the fiducials has not been detected by the HPD in the third view.
The number of points per plot also varies when the detection of one or more of the fiducials involved is intermittent. The plot scales are shifted so that the mean inter-fiducial distances over the number of frames considered correspond to 0.0 microns on the axis.

The most striking feature of all the plots is the similarity between reverse and normally developed film. It is a good indication that there are no gross differences in the types of distortion introduced during the two development processes.

The values measured for the mean absolute distances between fiducials are given in Table I. S is the distance between a fiducial pair and the abbreviations R.D. and N.D. refer to reverse and normal development respectively. Distances on the reverse developed film are in all cases larger than the corresponding ones on normal film. The fractional differences are shown in columns 4, 7 and 10, and for views 1, 2 and 3 are on average about 1/6000, 1/12000, and 1/8000. The differences between the two types of film are of the same order as the width of the distribution of the individual inter-fiducial distances in Figures 3, 4, 5, 6 and 7. It is not unreasonable that these variations should occur from roll to roll, especially since the film was developed differently in different laboratories. The maximum observed deviation from the mean fiducial distance for a frame in either sample of film represented a fractional increase of about 1 part in 2000.

The plots involving fiducial pairs 2,6 and 2,8, and 1,5 and 1,7 give some idea of the scatter of points about the tangent on the plot due to the measurement uncertainty of the HPD, since the intervals between 2,6 and 2,8 for example cover approximately the same area of film, and the ratio of the distances should be nearly constant. The scatter or r.m.s. deviations of the points from the tangent are shown for each plot in Table II. It is true that plots 2,6 - 2,8 and 1,5 - 1,7 do in general have the smallest scatter of points. However, it is not true that in views 1 and 2 the scatter of points about the tangent for 2,6 - 2,8 represents the scatter to be expected from HPD measurement alone, because in view 3 the scatter is somewhat smaller. This
is presumably the effect of some non-linear distortion in this region on views 1 and 2. The largest r.m.s. non-linear distortion observed in either sample of film is in the plot involving fiducials 2, 4 – 6, 8 in view 2 of the normally developed film. Here the r.m.s. distortion is approximately 3 parts in 7000 if the HPD is assumed be be infinitely accurate, or approximately 2 parts in 7000 if the measurement uncertainty is taken to be 1.5 microns as indicated in column 7 of Table II. These numbers are upper limits and may be considerably overestimated, since from Table II the spread of points about the tangent on the plot involving fiducials 2, 4 and 6, 8 is fairly typical. However, the effect appears worse because the distance between fiducials 6 and 8 is comparatively small, moreover fiducials 2 and 6 are on the front glass and 4 and 8 are on the back glass of the bubble chamber. This would be responsible for a larger spread on the plots if the bubble chamber liquid were turbulent in the region.

In Table II there are 17 cases out of 24 where the reverse developed film plots have a smaller scatter of points than the normally developed film, although the scatter in all cases is rather similar and of negligible size. It can therefore be said that gross non-linear film distortions present over distances of about 1 centimetre and greater on the film, which are introduced in reverse development, are no greater than those introduced in normal development. Holthuizen 2) has made a similar study with normally developed film from the CERN 2 Metre Bubble Chamber and the data indicate that linear distortions of up to 1 part in 1700 and non-linear distortions of up to 1 part in 3000 are present in his sample of film. The results are similar to those presented here.

4. THRESH Results

The failure rate for tracks in Mass Dependent THRESH is approximately the same for reverse and normally developed film, being 5.4% and 5.8% in 3000 and 2000 tracks respectively. Most of the failures are beam tracks where the Milady operator has measured the wrong track in a view because of the difficulty of identification.
The largest fiducial residual for each frame and view is found by THRESH following the fiducial fit to find the transformation coefficients. This quantity has been histogrammed in Figures 8 (a)-(f) for reverse and normally developed film. The largest residuals for reverse developed film peak at a lower value in all three views, the difference on average being about 20 microns in space. The interpretation of this result is not completely straightforward since nothing is known of the other fiducial residuals. However, if the non-linear film distortions were smaller for reverse developed film, the largest fiducial residual from the fit would certainly be smaller. This is consistent with the results of section 3.

The track residuals are plotted in Figures 9 (a), (b), (c) and (d) for beam and secondary tracks, which have been reconstructed in three views. For beams the distributions are very similar, whereas for secondaries the residuals peak at a value about 1.5 microns lower for reverse developed film. The relative fractions of tracks with residuals greater than 20 microns are fortuitous, since residuals of this size normally occur only on confused or slow tracks.

The inverse momentum and dip of beam tracks (with and without interactions) have been plotted for normally and reverse developed film. The momentum of a beam track is defined at the vertex of an event or at the downstream end of the track if it does not interact. The results are shown in Figures 10 (a), (b), (c) and (d) where a value has been histogrammed if the track residual is lower than 12 microns. The inverse momentum distributions are asymmetric, both having a low momentum tail, but a mean value of 1/beam momentum has been calculated assuming that the distributions are Gaussian, and disregarding events outside the region 0.084 to 0.114 (GeV/c)^{-1} on the plots. The mean values and standard deviations are given in Table III. The dip distributions are Gaussian-like and very similar to each other in shape. The mean values and standard deviations are also given in Table III.

The agreement between the parameters of beam tracks in the two types of film is good. About 20% of the beam tracks have inter-
actions and this causes a spread of their momentum distribution of about 40MeV/c. This spread should be the same for both distributions and does not affect a comparison of the mean values. The beam momentum defined at the RF separator for this experiment was $10.10 \pm 0.04$ GeV/c, which agrees well with the values found here for both types of film after a correction of about 40 - 50MeV/c is made in swimming the measured beam momentum back to the beam entry window.

These results show that there are no observable film distortions introduced by reverse development, which are localised in the region of individual bubbles on the film, otherwise the track residuals would be higher than for normally developed film. Comparison of the beam track parameters and largest fiducial residuals tends to confirm the previous conclusion of Section 3 that large scale non-linear film distortions are no greater for reverse development film.

5. Ionisation Measurements in GRIND

A version of GRIND for 10GeV/c $K^-$ interactions in the CERN 2 Metre Bubble Chamber (Experiment 112) measured on HPD 2 was already in existence, complete with ionisation fitting \(^3\) and decision making routines. This was used for both samples of events with no modifications whatsoever, and gave the results shown in Table IV (a). A comparison of fits automatically selected using kinematic and ionisation information can be made with the fits automatically selected from a test sample of events from Experiment 112 which are shown in Table IV (b). There exist some differences in the reverse and normally developed film between the fractions of no fits, ambiguous fits and check events, but none of these are very significant.

Each decision in GRIND was checked on the scanning table by estimating visually the relative ionisation densities of the tracks and eliminating fits which were inconsistent. In all cases the ionisation fits for events input to GRIND from the normally developed film were consistent with the visual estimates of ionisation densities.
However, there were 2 cases where wrong decisions arose as a result of difficulties in the kinematical fit. For the reverse developed film all automatic decisions except 5 were in agreement with visual decisions. For 4 of these the ionisation fits were consistent and the kinematical fitting was wrong, but in the other case the ionisation measurement in 2 views of a stopping 5 centimetre long proton was too low (2.5x and 1.5x minimum) and the ionisation fit favoured a pion track. On inspection, this track looked heavily ionising, but had a large dip angle and there were several gaps along it in all 3 views.

The ionisation measurements with reverse developed film are satisfactory since for only 1 track in 339 events was there any disagreement with the visual estimate of ionisation. It may be possible to eliminate more ambiguous fits and reduce the number of check events by optimising the ionisation fitting routines for reverse developed film.

6. Measurement of Reverse Developed Film on a Conventional Measuring Machine

Since the film is black in overall appearance, most of the radiation falling on it in the film gate of a measuring machine will be absorbed. The coefficient of thermal expansion for this film is about 1 micron per centimetre per °C and it is therefore worth establishing whether the film heats up significantly during measurement. However, a bad arrangement of the film gate with respect to the light source can always cause difficulties with any type of film due to convection currents.

Raaijmakers \(^4\) has investigated whether there was any observable thermal expansion when reverse developed film was measured on an BNETRA II measuring machine fitted with a standard colloidal heat filter. A set of fiducials was measured several times over a period of 10 minutes and no observable difference in the positions of the fiducial centres were found as a result of the film warming up.
The effect poses no problem with automatic measuring machines, where the energy absorbed from a moving light spot or slit during a scan lasting a few seconds is comparatively low.

7. The Cost of Reverse Development

The extra cost of reverse developed film to CERN if a processing plant were installed is difficult to estimate, however some figures are presented below as a rough guide. Anders and Stumpe \textsuperscript{5}) state that a private photographic company charges 50\% more for processing track chamber film to reversal than it does for normal development. The overall cost to CERN of normally developing its own film is estimated to be about .30 Swiss Francs per metre, thus the extra cost of reverse development will probably be close to .15 Swiss Francs per metre.

There are 6\frac{1}{2} frames of CERN 2 Metre Bubble Chamber film per metre i.e. the equivalent of approximately 2 stereo triads. The extra cost of reverse development per triad is therefore .07 Swiss Francs. An average triad requires about 5 seconds of CDC 6600 CP time in the GATE program. This is charged at 2000 Swiss Francs per hour.

Assuming a 20\% saving of CP time in GATE (see Section 2) for reverse developed film, and an average event density of 1 per 2 frames, the saving per frame of reverse developed film is .27 Swiss Francs. The potential saving is nearly four times larger than the estimated extra cost.

This is clearly a simplified calculation, but it is intended to show that, even with a large margin of error, the extra cost of reverse development can be justified by the saving of computer CP time spent in GATE, let alone the benefits elsewhere in the measurement-analysis chain.
8. **Summary and Conclusions**

Reverse developed film from the CERN 2 Metre Bubble Chamber offers two definite advantages for automatic measuring machines. The signal to noise ratio is improved for track detection and the average number of digitisings per frame is considerably reduced.

The possible disadvantages have been investigated and found to be non-existent or very small. In particular non-linear film distortions found from scatter plots of inter-fiducial distances are no greater, the track and largest fiducial residuals from THRESH are smaller, the track parameters from both types of film are essentially identical, and ionisation measurements may be relied upon for reverse developed film. The scatter plot, fiducial residual and beam track parameter comparisons, which would indicate the presence of large scale non-linear film distortions, are complementary to the track residual comparisons which are more sensitive to small local film distortions in the region of individual bubbles. The track residual comparisons and the ionisation results show that there are no harmful consequences of the track profiles being more irregular for reverse developed film.

There appears to be no objection to measuring reverse developed film on a conventional measuring machine if this is necessary for remeasures, for example.

The extra cost involved in reverse development is very small compared with the total budget for analysing an experiment and can be justified by a saving of computer time alone.
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<td>56294</td>
<td>1/11600</td>
<td>4.3</td>
<td>56516</td>
<td>1/13000</td>
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<td>70070</td>
<td>1/6300</td>
<td>5.2</td>
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<td>1/12300</td>
<td>5.9</td>
<td>70105</td>
<td>1/12000</td>
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<td>56642</td>
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<td>56301</td>
<td>1/6600</td>
</tr>
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<td>1 7</td>
<td>15.6</td>
<td>70215</td>
<td>1/4500</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>11.3</td>
<td>69798</td>
<td>1/6000</td>
</tr>
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<td>2 4</td>
<td>3.0</td>
<td>21720</td>
<td>1/7200</td>
<td>0.5</td>
<td>15073</td>
<td>1/31000</td>
<td>1.4</td>
<td>21747</td>
<td>1/15000</td>
</tr>
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<td>6 8</td>
<td>1.7</td>
<td>14486</td>
<td>1/3300</td>
<td>0.1</td>
<td>7414</td>
<td>1/74000</td>
<td>1.7</td>
<td>13658</td>
<td>1/8200</td>
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<td>4.6</td>
<td>21799</td>
<td>1/4300</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.4</td>
<td>21647</td>
<td>1/15000</td>
</tr>
<tr>
<td>5 7</td>
<td>3.4</td>
<td>14051</td>
<td>1/4200</td>
<td>0.5</td>
<td>7266</td>
<td>1/15800</td>
<td>2.5</td>
<td>13933</td>
<td>1/5600</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>5.6</td>
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<td>6.7</td>
<td>44960</td>
<td>1/6700</td>
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<tr>
<td>8 9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.4</td>
<td>45301</td>
<td>1/8500</td>
<td>6.2</td>
<td>37352</td>
<td>1/6000</td>
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<td>1 4</td>
<td>5.6</td>
<td>42222</td>
<td>1/7500</td>
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<td>-</td>
<td>-</td>
<td>5.7</td>
<td>35298</td>
<td>1/6000</td>
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<td>5.6</td>
<td>36404</td>
<td>1/6300</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.5</td>
<td>28999</td>
<td>1/6400</td>
</tr>
<tr>
<td>3 4</td>
<td>3.2</td>
<td>32228</td>
<td>1/10000</td>
<td>2.1</td>
<td>31927</td>
<td>1/15600</td>
<td>4.4</td>
<td>32032</td>
<td>1/8000</td>
</tr>
<tr>
<td>7 8</td>
<td>4.1</td>
<td>29746</td>
<td>1/7200</td>
<td>1.5</td>
<td>29546</td>
<td>1/20000</td>
<td>4.3</td>
<td>29556</td>
<td>1/7000</td>
</tr>
<tr>
<td>1 2</td>
<td>4.3</td>
<td>32673</td>
<td>1/7500</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.5</td>
<td>32469</td>
<td>1/5000</td>
</tr>
<tr>
<td>5 6</td>
<td>5.3</td>
<td>28440</td>
<td>1/5300</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.9</td>
<td>28247</td>
<td>1/5800</td>
</tr>
</tbody>
</table>

$\Delta S = S_{n,d} - S_{n,d}$

Table I
Comparison of mean inter-fiducial distances on reverse and normally developed film.
<table>
<thead>
<tr>
<th>fiducial set</th>
<th>V1</th>
<th>V2</th>
<th>V3</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.D.</td>
<td>R.D.</td>
<td>N.D.</td>
<td>R.D.</td>
</tr>
<tr>
<td>2 6 2 8</td>
<td>2.38</td>
<td>2.49</td>
<td>2.23</td>
</tr>
<tr>
<td>1 5 1 7</td>
<td>1.70</td>
<td>1.69</td>
<td>-</td>
</tr>
<tr>
<td>2 4 6 8</td>
<td>3.78</td>
<td>3.72</td>
<td>3.22</td>
</tr>
<tr>
<td>1 3 5 7</td>
<td>2.81</td>
<td>2.74</td>
<td>-</td>
</tr>
<tr>
<td>2 4 5 7</td>
<td>2.75</td>
<td>2.72</td>
<td>2.38</td>
</tr>
<tr>
<td>4 5 8 9</td>
<td>-</td>
<td>-</td>
<td>3.26</td>
</tr>
<tr>
<td>1 3 6 8</td>
<td>3.53</td>
<td>3.69</td>
<td>-</td>
</tr>
<tr>
<td>1 4 5 8</td>
<td>3.76</td>
<td>3.43</td>
<td>-</td>
</tr>
<tr>
<td>3 4 7 8</td>
<td>3.84</td>
<td>3.74</td>
<td>3.11</td>
</tr>
<tr>
<td>1 2 5 6</td>
<td>2.14</td>
<td>2.34</td>
<td>-</td>
</tr>
</tbody>
</table>

Table II
R.m.s. deviation of points about the tangents on the scatter plots.

<table>
<thead>
<tr>
<th>mean 1/mom. (Gev/c⁻¹)</th>
<th>standard dev. of mean mom. (Gev/c⁻¹)</th>
<th>mean dip (Gev/c)</th>
<th>mean dip rads.</th>
<th>standard dev. of mean dip rads.</th>
</tr>
</thead>
<tbody>
<tr>
<td>normally developed</td>
<td>0.09951</td>
<td>0.00005</td>
<td>10.05</td>
<td>-0.0015</td>
</tr>
<tr>
<td>reverse developed</td>
<td>0.09940</td>
<td>0.00005</td>
<td>10.06</td>
<td>-0.0014</td>
</tr>
</tbody>
</table>

Table III
Mean beam momentum and dip.
<table>
<thead>
<tr>
<th></th>
<th>normally developed</th>
<th>reverse developed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>total sample of events.</strong></td>
<td>203</td>
<td>339</td>
</tr>
<tr>
<td><strong>automatic decisions taken</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total events fits.</td>
<td>145 (72%)</td>
<td>233 (69%)</td>
</tr>
<tr>
<td>nofits.</td>
<td>47 (23%)</td>
<td>83 (24%)</td>
</tr>
<tr>
<td>ambiguous fits.</td>
<td>178 (89%)</td>
<td>255 (75%)</td>
</tr>
<tr>
<td></td>
<td>7 (3%)</td>
<td>20 (6%)</td>
</tr>
<tr>
<td><strong>check events</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total.</td>
<td>20 (10%)</td>
<td>54 (16%)</td>
</tr>
<tr>
<td>check ionisation on scanning table.</td>
<td>5 (2%)</td>
<td>17 (5%)</td>
</tr>
<tr>
<td>other reasons.</td>
<td>15 (7%)</td>
<td>41 (12%)</td>
</tr>
<tr>
<td>remeasurement after GRIIND</td>
<td>38 (19%)</td>
<td>52 (15%)</td>
</tr>
</tbody>
</table>

Table IV (a)

Results after GRIIND and automatic decision making.

<table>
<thead>
<tr>
<th>topology</th>
<th>4c fits</th>
<th>1c fits</th>
<th>4c fits</th>
<th>1c fits</th>
<th>4c fits</th>
<th>1c fits</th>
<th>4c fits</th>
<th>1c fits</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>14</td>
<td>12</td>
<td>13</td>
<td>7</td>
<td>75</td>
<td>36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>201</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>6</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td>23</td>
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<tr>
<td>401</td>
<td>2</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>2</td>
<td>-</td>
<td>4</td>
<td>13</td>
<td>1</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>601</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>total events measured</strong></td>
<td>203</td>
<td>339</td>
<td>1001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table IV (b)

Distribution of fits by topology.
Fig. 1  Photomultiplier output signal for one scan-line of normally developed film (a) and (c), and reverse developed film (b) and (d) from the CERN 2 Metre Bubble Chamber. (a) and (b) are from the HPD 2 scan, and (c) and (d) are from a LUCY scan.
Fig. 2  A typical normally (a) and reverse developed (b) frame from the CERN 2 Metre Bubble Chamber.
Figure 4
Figure 5

- 899 -
Figure 6
Fig. 8 Fiducial residuals from THRESH.
Fig. 9 Track residuals from THRESH.
Fig. 10 Track parameters from THRESH.
<table>
<thead>
<tr>
<th>Frame Number</th>
<th>Fiducial Code</th>
<th>Digitizing Buffer (K-words)</th>
<th>% Hits on Beam Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>1835</td>
<td>777</td>
<td>76</td>
<td>54</td>
</tr>
<tr>
<td>1836</td>
<td>777</td>
<td>80</td>
<td>53</td>
</tr>
<tr>
<td>1836</td>
<td>777</td>
<td>76</td>
<td>0</td>
</tr>
<tr>
<td>1837</td>
<td>777</td>
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<td>1838</td>
<td>777</td>
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<td>84</td>
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<td>68</td>
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<td>777</td>
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<td>57</td>
</tr>
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<td>1842</td>
<td>777</td>
<td>93</td>
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</tr>
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<td>1843</td>
<td>777</td>
<td>88</td>
<td>52</td>
</tr>
<tr>
<td>1843</td>
<td>777</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>1844</td>
<td>777</td>
<td>84</td>
<td>54</td>
</tr>
<tr>
<td>63</td>
<td>53</td>
<td>17H43M04S</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frame Number</th>
<th>Fiducial Code</th>
<th>Digitizing Buffer (K-words)</th>
<th>% Hits on Beam Track</th>
</tr>
</thead>
<tbody>
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<td>777</td>
<td>28</td>
<td>55</td>
</tr>
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<td>777</td>
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<td>53</td>
</tr>
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<td>777</td>
<td>16</td>
<td>53</td>
</tr>
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<td>2550</td>
<td>777</td>
<td>24</td>
<td>52</td>
</tr>
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<td>2551</td>
<td>777</td>
<td>32</td>
<td>54</td>
</tr>
<tr>
<td>2552</td>
<td>777</td>
<td>28</td>
<td>55</td>
</tr>
<tr>
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<td>777</td>
<td>25</td>
<td>56</td>
</tr>
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<td>777</td>
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</tr>
<tr>
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<td>53</td>
<td>11H11M01S</td>
<td></td>
</tr>
</tbody>
</table>

Average % hits on beam track (10 frames)

Fig. 11 On-line output from GATE program showing relative numbers of digitizings on typical frames.
THE PRESENT DATA ANALYSIS SYSTEM OF THE
BUBBLE CHAMBER GROUP AT THE MPI MUNICH

P. Freund and J. Seyerlein,
Max-Planck-Institut für Physik und Astrophysik,
Munich, Germany.

The present film-measuring system at the MPI Munich consists of one
SOM ENETRA and two Vanguard film-plane digitizers, six home-made scanning
and image-plane measuring tables equipped with modified DMAC-pencil fol-
lowers, and one HPD flying spot digitizer. One PDP-8 (8 K 12-bit Memory;
1 IBM compatible, semiautomatic magnetic tape unit, and one DF 32 Diskfile)
is used to collect the data from the film-plane and image-plane digitizers.
The data handling and checking programs resident in the PDP-8 are used by
all machines quasi-simultaneously. The program package consists of an
automatic sequencing program, a fiducial-separation checking program, a
routine which fits a circle to each track in each view, a sagitta test,
and a control of the number of points to be measured on each track. A
program which makes a simple spatial consistency check is going to be in-
serted into the package.

The film-plane digitizers have been used under on-line control since
June 1967. As a result, the measuring speed was increased, by a factor
of 2 to 2.5, and the rejection rate decreased from 30% to 10%. A total
of 82,147 events from five different experiments was measured on the film-
plane digitizers in 16,225 hours during the past year. These experiments
have been treated with THRESH and GRIND on an IBM 7090.

The image-plane digitizers are used as road makers for the HPD on
film from the CERN 2 m HBC (pp interactions at 12 and 24 GeV/c). The
measuring rate at present is about 7.5 events per hour with a peak rate
of 11 events/hour.

The HPD-MK II operates on-line to an IBM 7090 using a PDP-8 as an in-
tegral part of the HPD electronics. The IBM 7090 has been used as a
dedicated machine since April 1969. With this system, production of
pp events at 12 and 24 GeV/c of film from the 2 m CERN HBC was started in
July 1969. To date 40,000 events (all topologies) have been measured.
We use a modified version of the CERN 7090 HAZE, which is a real-time filter program, integrated with a data-test and calibration program in one overlay chain. Ninety per cent of the test- and calibration-program is written in FORTRAN IV, and 95% of the production program is written in machine language.

To start a production run, the operator is forced to carry out some tests and to do the calibration. The program checks all data paths from the IBM 7090 to the HPD and vice versa. Random numbers are sent from the IBM 7090 through the command lines to the PDP-8 and through the thin-film memory along the data lines back to the IBM 7090, where they are compared with the original pattern. Now one frame of the film to be measured is scanned with one normal and three orthogonal scans. The data are tested in real time for the constancy of full grating count, scanline separation, etc., and are written on to magnetic tape. Then the program calculates the transformation constants and inserts the mean values of these determinations together with the mean values of the full grating count, and the spot coordinate of the lowest picture number bit, directly into the data field of the HAZE program. Furthermore, the program reads a title-tape containing mean values of the bit spacing, the relative positions of all fiducial centres, and the tangents of all fiducial arms. This tape is generated with a separate program for each bubble chamber run.

Apart from rewriting the control part of HAZE, the following major programming changes have been made.

The number of average points per track has been increased to fifty, because of the danger when discarding average points during the filtering of long tracks.

For lack of memory space, the ionization information is now being treated off-line in a program MINISMOG, which is used to merge the three views on to one THRESH 360/91 input tape. It is also very useful to have detailed ionization information on the HAZE-output tape.

In FILTER, in the track-finding procedure, we are more careful in controlling the tangent changes in order to get a better following accuracy.

Furthermore, there is the possibility to have two different least-count ratios for the normal and the orthogonal scan direction.
For certain error flags and error conditions the program performs an automatic rescan with changed digitizing-level if necessary to minimize operator intervention. About 60% of the rescans are successful.

Another modification is being tested now: if there is more than one event on one frame, the program filters the first event and writes the digitizings simultaneously onto tape. The next events of the same frame are processed off-line from the tape, unless filter difficulties call for a new scan with altered digitizing level.

From the point of view of HPD operation, we include the mean hit sum per beam slice in the on-line summary and the operator adjusts the main amplifier to 50% - 60% hit probability. In practice, about 80% of the scans lie between 50% and 60%, and 90% between 45% and 65% hit probability.

After changing the hydraulic system from the original open-loop system to proportional valves, there was an appreciable gain in speed. The measuring rate is very sensitive to the film quality due to necessary rescans, and the maximum rate is about 75 events per hour of measuring time.

The HPD measurements are further analysed on the IBM 360/91 using mass dependent THRESH and GRIND. The THRESH track residuals for HPD measured tracks have a peak varying from 3.5 μ to 4.5 μ according to film quality and particle momentum. The HAZE reject rate is about 5% and the THRESH reject rate, including the HAZE errors, is about 30%, splitting up into 15% due to residuals > 17 μ and 15% due to THRESH fault number > 1000, half of which have been shown to be premeasurement errors. No selection has been made to exclude very closely spaced beam tracks.
THE IBM 1130 COMPUTER ON-LINE SYSTEM AT TORINO

D. Gamba and A. Werbrouck,
Istituto Nazionale di Fisica Nucleare,
Via Pietro Giuria 1, Torino, Italy 10125.

1. Introduction

We are developing an on-line system to satisfy the measurement requirements of our bubble chamber group. These requirements vary from the reconstruction of complex multi-gamma events to the premeasurement of single vertex interactions. Much flexibility is thus necessary in the design of hardware and software. Our approach has been to consider each measuring station as a two-way terminal of which certain or all features are utilized by programming according to the necessities of the different experiments.

Explicitly the present design aims are: 1) to acquire and format-control data with general, practically experiment-independent routines written in assembler language and resident in memory, 2) to analyze all measurements as thoroughly as computing and programming capacity and memory space (including frequent disk overlays) allow while conserving the accepted coordinates for any later offline analysis, 3) to audibly and visually respond to every operator interrupt by typing at least one character, and 4) to allow the measurer much freedom of procedure and judgment. We have chosen to keep all coordinates in memory to facilitate spatial reconstruction and to keep most analysis programs in the form of Fortran overlays on disk. At present, the multi-gamma \( V^0 \) events with up to six gammas and 15
tracks have a 1280 word buffer while normal PD events fit into 640 words. As we add additional digitizers we intend to introduce dynamic storage both to relax these limits and to utilize better the central memory.

2. Hardware Configuration

Our online computer is an IBM 1130 with 16K words of 16-bit 3.6 microsec core memory and 512,000 words of auxiliary memory on an interchangeable disk cartridge. Input and output are effected by a card reader-punch and a console typewriter. A storage access channel (SAC) connects the 1130 to our home-made interface unit to which each device is directly connected by separate cables. A terminal consists of two separately-addressable devices, the digitizer (either film FPD or image plane IPD), and the associated teletypewriter TTY (IBM 721 I/O writer). Each device is assigned a line leading to a program interrupt on the lowest priority (level 5) which can support seven terminals.

To the measurer a terminal appears as the conventional digitizer plus an interrupt button, a sixteen-position rotary selector of the type of interrupt to effect, the electric typewriter, and a bank of descriptors. The interrupt button and selector are mounted on the digitizer for rapid access. A standard rack beside the digitizer carries the typewriter, the descriptors, and the terminal electronics. A digitizer interrupt leads to the reading of 8 words, each addressed as a subdevice. Word 1 contains the type of interrupt and the view in measurement; words 2 and
3, the x-y coordinates transferred directly from 16-stage binary reversible counters; words 4-8, the descriptors. Descriptor word 4 consists of 4 sixteen position rotary switches which contain auxiliary information necessary to serve various interrupts. For event initialization word 4 contains the topology i.e. number of charged vertices, neutral vertices, gamma vertices and charged tracks. Words 5, 6, 7 and 8 are each composed of 4 decimal thumbswitches in 4-2-2-1 code for setting roll, frame, zone, measurer identity, measurement number, and experiment number. While we use the term teletypewriter to designate the electric typewriter in the terminal, it communicates in parallel, not in series, with the computer. The digital hardware, executed in Texas and Philips dual-in-line TTL micrologic integrated circuits, has proven very reliable. Parity checking on transmission is not necessary and no point is ever remeasured as a control on the reversible counters. On the FPD's we are planning computer stage control.

At present measured events are stored on the disk and punched onto cards at the end of the shift. When the connection of the Precision Instrument 1207/RW magnetic tape unit is finished, we intend to transfer the events to magnetic tape at the end of each shift. If we ever need more computing or storage capacity we can connect the 1130 to the nearby (100 meters) central time-sharing computer facility of the university by private telephone line.
3. Actual Measurement Procedure

Our measurement procedure is purely passive. Each interrupt is first conditioned by the 16-position selector mounted on the digitizer. The defined positions are:

0 - measurement of fiducial mark
1 - " of charged vertex
2 - " of neutral vertex ($V^0$)
3 - " of gamma vertex
4 - " of last point of stopping track (range)
5 - " of track point (not last point)
6 - " of last point of non-stopping track (ultimate)
7 - " of curvature for highly curved or irregular tracks (curvature)
8 - " of projected initial direction for irregular tracks (tangent)

10 - initiate the banks for a new series of measurements
11 - change the fiducial mark measuring sequence
13 - write the coordinates in decimal on the teletypewriter.

Initialization is based presently on measurement requests extracted from scan cards and given to the measurer. Fiducial measurements in selected views must begin with the reset coordinate values (8000 in hexadecimal) to avoid counter overflow and permit digitizer and film gate checking. Measurements can proceed all views together or view-by-view. The sequence of arrival establishes for all tracks and corresponding points an implicit label used for sequence control and for operator messages. For example, the first neutral vertex measured is called 2 if one charged vertex
was measured before, as both are assigned point banks. Each track is assumed to begin from the corresponding point measured most recently in this view. This scheme works for all except a double $V_+$ event in which case a recall point message needs to be issued before beginning the track of the second $V_+$. Quantities, such as range, ultimate, curvature, and tangent are tagged with the number of the track with which they are associated. Curvature is a single point measured with the aid of a curvature template on the measuring head (where mounted). Together with the initial direction (gamma line of flight, tangent estimate, etc.) one can determine the spatial curvature by the parameter reconstruction method described elsewhere (1). Explicit labels are assigned when necessary by describing the quantity in word 4 and then typing the label followed by an equals sign on the keyboard of the TTY.

When our planned computer-controlled film advance is working, we will write measurement request cards onto the disk from which the program will prepare a guide transmitted to the measurer via the TTY.


Data acquisition is programmed so that a typed response begins in a time characteristic of the TTY (15 characters/sec). All format control is carried out as part of the response to the level 5 interrupt, which can be interrupted only by a higher level interrupt. Thus the measurer has the impression that the computer is continually listening and responding, and therefore develops a good measuring rhythm.
In most cases a rejected measurement leads to a different number of typed characters than expected for an accepted one, so that the measurer is informed audibly of a rejection and can then examine visually the typewritten text, if necessary, to understand the reason. Most rejection codes are two characters long while "accept" responses are of different lengths. Remeasurement request messages arriving from the background analysis programs are longer and more detailed as they don't arrive synchronized with the interrupts. Accepted coordinates are stored in memory and the indices necessary to relocate them are stored in event, point, and track banks. Since each x-y coordinate pair occupies two words and the 1130 load and store double word instructions (LDD and STD) require even addresses, we assign an even index to each x-y pair. We then use the classification of the index to indicate the state of measurement according to the scheme in Fig. 1.

The index of a quantity not yet considered is zero due to the event initialization. The normal procedure is to measure the quantity which assigns it a positive index N. If the control by the background analysis program indicates failure, the measurement is cancelled by making its index, negative while leaving intact the coordinates. Normal procedure is to remeasure the quantity in all views. If the measurement in one view is suspected to be the cause of the failure, the measurer can remeasure in only the suspected view and reinstate the others by the accept
Fig. 1. States of quantities as indicated by the states of the relative indices and as transformed by the various operations.

operation. If instead the measurer reaches the conclusion that a quantity is unmeasurable, he can declare it so by the giveup operation (after measurement) or the jump operation (before attempting measurement). Both operations yield a negative odd index (-N-1). Even if jumped, a quantity has an index so that it can be remeasured in case one erred by putting it in the unmeasurable class. All operations except measure and remeasure are effected by coding statically the request in descriptor word 4 and then typing a
semicolon. An event is considered finished when all quantities expected from the initialization procedure are either measured and controlled or declared unmeasurable. At this point the event is transferred in block to the disk and the terminal message "OKGO" typed.

There is available as part of the interrupt response the track measurement control subroutine TRCON (1) which applies the requirement of local second order smoothness \( y = a + b \cdot x + c \cdot x \cdot x \) to the fourth measurement and beyond along a track. If the previous points, extrapolate outside the track, one can restart the track with the restart operation. This control requires 10 floating point (FP) operations (about 10 ms) on the 1130, a delay not noticeable to the measurer. Since TRCON responds as part of a level 5 interrupt and the 1130 FP simulation subroutines are not re-entraible, we have duplicated the necessary ones with different names for use by TRCON. Under study is a hardware floating point operation simulator.

5. Background analysis.

The form of the background analysis depends upon many factors which vary with experiment. In all chambers we measure four fiducial marks in each view and fit them to their apparent positions to find the coefficients of the transformation from measurement to projected bubble chamber space.

Generally we also reconstruct in space all corresponding points. The treatment of tracks varies somewhat. In a heavy
liquid we control each track measurement with TRCON and then reconstruct in space. In hydrogen and deuterium we skip this control and require that the entire projected track measurement fit well an arc of a circle. There are available Fortran routines which determine the spatial parameters of straight tracks (dip, azimuth, and length) by least squares means (TNOPS and STEEP), and the spatial curvatures of tracks resulting from the estimates of projected curvature (REPAR). This software flexibility is obtained by adjusting the main program (in Fortran) so that it deduces from the coordinate indices the proper analysis routines to transfer from the disk to the overlay area. Constants are inserted where needed as DATA statements and a part of COMMON contains some intermediate results passed from one overlay to another. Other results are stored in the point and track banks. Intermediate results of the background analysis can be printed on the corresponding TTY by raising appropriate sense switches on the computer console. A diagnostic overlay serves to print the contents of the event banks on the console typewriter (WRITBC). One overlay is called to transfer the event from memory to the disk (EVOUD). Another is called at the beginning of a run to initialize the hardware system (BEGIN). A group of utility routines are being prepared to utilize the computer's unoccupied peripheral units and computing capacity during on-line measurement shifts. One is the report generator REGEN that edited this text.
6. Results

The system has been operating on heavy liquids since the summer 1969 with good results. The more stringent requirements of deuterium measurements have not yet been tested as these on-line events have not yet passed THRESH. Our book-keeping system is still rudimentary and mostly based on the offline analysis.

Acknowledgements

The actual hardware was developed by our former colleagues, G. Bairati and R. Felisio. M. Spedini has helped immensely in debugging the programs and training the measurers. Much valuable on-line experience gained at CERN has been generously shared with us, especially by A. Fucci, C. Verkerk, and P. De Meo.

References

OPERATIONAL EXPERIENCE WITH THE
BROOKHAVEN ON-LINE DATA FACILITY

S.J. Lindenbaum and S. Ozaki
Brookhaven National Laboratory,
Upton, New York, USA.

A general background description of the Brookhaven On-Line Data Facility (OLDF) and its development since 1964 has been described in a number of prior references.

The Facility was organized in 1964 as a research support group for on-line experiments utilizing electronic digitized detectors such as counters, counter and spark chamber hodoscopes, etc.

The PDP-6 computer, which was the basic core of the Facility, was, after delivery in January, 1965, debugged to the point where later in 1965 time-sharing was adopted as the operational mode, and multi-user operations have expanded ever since.

Figure 1 shows a typical configuration of users utilizing the PDP-6 system during the previous year or so (prior to the summer of 1969 AGS shutdown). By this time the PDP-6 had been expanded to include 80-96K of 2.0 μsec core (36 bit words), a 450,000 word disc, five high performance magnetic tapes, 8-10 DECTapes, and two printers. It also included a remote I/O user station which contained a printer and DECTapes.

During this period, the OLDF was simultaneously servicing about five different research user groups. Typically two were on-line via data links simultaneously, with three groups off-line. The disc system was used to swap

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† This work was performed under the auspices of the U. S. Atomic Energy Commission.

* With numerous teletypes and CRT displays distributed over the AGS floor in the user experimental trailers.
users in and out so that typically two large users were in core at any one
time. In the swapping mode, each user is assigned a small portion of core
continuously (~5-10K) to accept his data link transmissions until they can
be transferred to the disc and to do simple necessary monitoring jobs, etc.
The bulk of his program is, of course, swapped in and out typically in time
intervals which were a few seconds to a minute.

We find that allowing the on-line user program to run locked in core is
more convenient for the user (almost instantaneous response time) and allows
more efficient use of the processor. However, obviously considerably more
memory is required. The system can, of course, accommodate up to 265K of directly
addressable memory.

Each user group was provided with its own teletypes and remote scope
displays in its experimental trailer. DECTapes and high performance magnetic tape
units were assigned to each user. Line printers were shared and a remote I/O
station was installed for user convenience and efficiency.

In general, the execution times of a typical computational program are
similar to those obtained with the IBM 7094 and about eight to ten times larger
than the execution times on a CDC 6600. The time-sharing system allows each user
to obtain his own hardware protected core, and monitor protected I/O device allo-
cations, as well as shared I/O devices as desired. The processor is assignable
by a scheduling algorithm in rotation for a large number of jobs. A selected
number of one-sixtieth of a second time intervals are allocated to a particular
job according to the nature of the job and the job load on the system. The proc-
essor then works on that job for the assigned time interval and then switches to
the next job in the scheduling algorithm automatically and works on that job for
the assigned time interval and so on. Thus, provided there are sufficient compute
bound jobs in the mix, the processor can be used quite efficiently.
Each user is generally assigned his own teletypes. He can then ask for and obtain (if available) his own hardware protected core, DECTapes (low speed tapes which are primarily used for loading and dumping), his own high performance tapes, and a scope display. The printers are usually shared in rotation, although a user can be assigned a printer. A data link is assigned to each on-line user and allows him to transmit his data to the computer on a priority interrupt basis.

Local Data Handling Equipment and Satellite Computers

The data readout from either counter or (wire) spark chamber hodoscope systems has been predominantly handled by the standard OLDF digital data handling equipment, which is a general purpose system useful for handling mixed information from several different digitized detectors. These units have been provided with 4096 words of 36 bit, 72 bit, and 108 bit word lengths.

The system stacks the bit information from an event received during an AGS pulse sequentially in several consecutive words of its memory. When the buffer store is full, or an AGS pulse ends, after a specified minimum number of words is recorded, the buffer is read out automatically six bits at a time, which are recorded on a high performance tape drive together with a parity bit, and simultaneously a selected fraction of the data is transmitted to the on-line computer over an on-line data link.

A 36 bit unit costs under $15,000 (including the interfaces to experiment and tape drive). The high performance tape units cost about $10,000.

Satellite Computers for Data Handling and Local Diagnostics

With the recent rapid growth of the capacity of small computers, coupled with their rapidly decreasing prices, it has become economically attractive to consider small computers such as PDP-8, PDP-9 and Σ2, etc. for the data handling
function. These computers could then be considered a peripheral processor for the main computer.

The Princeton group has used a PDP-9 in this fashion for data handling and some preliminary local diagnostic work.

The Yale group is similarly using a PDP-8 in this fashion. In both cases, one-way transmission is being utilized from small to large computer. The OLDF is developing two-way transmission devices based on standard interface. These and other groups have found that using small computers at their home institution facilitates preparation for the experiment.

The PDP-15 has been selected as a typical local satellite to be provided to users in the future. A PDP-15/20 system has been ordered and is expected shortly. However, the data link and transmission systems are general enough so that almost any small computer can be interfaced.

The PDP-10 System

The growth in the use of these facilities by the research user community has been such that approximately three quarters of the spark chamber-counter community have or will be utilizing them. Furthermore, the computer requirements of individual user groups have also escalated rapidly as they become familiar with and realize the inherent capabilities of the on-line computer techniques. Thus the OLDF required sufficient expansion to order a PDP-10 system.

The PDP-10 system includes a PDP-10 processor, 16K of 1.0 µsec core and 64K of 1.7 µsec core (Ampex), several high performance magnetic tapes, several DECTapes, and a printer.

The PDP-10 is about twice as fast as the PDP-6 (typical program execution times are about four times CDC 6600 times), but very similar and program compatible so that all PDP-6 programs can be run on the PDP-10. With some minor restrictions on programs, we have been able to maintain the capability of using a program
interchangeably on the PDP-6 or the PDP-10. The PDP-10 and PDP-6 systems have been integrated as shown in Figure 2 so that a common pool of I/O and memory equipment can be utilized as desired for either computer. We typically schedule two on-line users on the PDP-6, several off-line users via disc swapping, and two on-line users on the PDP-10 and have found that our newly expanded facilities are already experiencing the threat of overcommitment. In this regard, it is of interest to note that user program memory core requirements vary from \( \approx 20-40\)K. Typically, on-line user requests range between 25% of and 100% of a PDP-6 processor capacity.

The software includes a macro-assembler, an efficient Fortran IV compiler, and a series of debugging, editing, and associated programs. The conversational time-sharing feature allows almost continuous access to the computers simultaneously by a number of programmers. Assistance for user programming problems has been provided by the Facility staff and W.A. Love who has had considerable experience in user research programming problems. At least a sample of the data (and in some cases all of it) is processed on-line. Almost immediate feedback of information is provided by user scope displays and printouts.

In a number of cases, the entire program processing job was done using OLDF computer equipment to complete the off-line processing when spare capacity existed.

The OLDF staff consists of two engineers and five technical specialists. Although we are understaffed due to obvious financial reasons, operational experience has been rather smooth with an overall up-time (during AGS operational periods) of 90%. A major innovation which has kept staff requirements down, is to treat the OLDF as a self-service facility. There are no operators. Each user helps himself in accordance with schedules and equipment and core assignments set-up by the staff. Except for the normal day shift, staff assistance is on an on-call basis. We find that this self-service system has worked reasonably well and that by mutual negotiation between users and OLDF staff, both efficient operations and
a generally amicable relationship have been developed. This, of course, has only been made possible by the exercise of good judgment and a high degree of cooperative spirit by both users and staff.

In the year or so before shutdown, experiments (completely or partially) performed on-line include the following:

1) A Princeton group's search for CP violation in $\pi^+$ decay. This work was described at the Conference by S. Smith.

2) A study of polarization in $K^+p$ by a Yale group.

3) A Columbia group's search for muon pairs in the mass range $\sim 1.5-6 \ (\text{GeV}/c)^2$.

4) A BNL group's investigation of $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ decays for CP test, and $K_{\mu 3}$ decay and polarization.

5) Successful tests of the Double Vee Magnetic Spectrometer system by a BNL group.

Figure 2 shows the user load and mode of operation in the present and projected near future AGS experimental operations.
REFERENCES


FIGURE CAPTIONS

Figure 1: The general typical use of the PDP-6 facility during the prior AGS schedule period until the May 1969 shutdown. Two groups were put on-line at a time via the patch panel and two or more groups prepare programs, etc. off-line simultaneously. Memory protection and relocation hardware make this time-sharing operation, which has been in use for more than two years, efficient and routine. The two trailers shown are 40' long x 10' wide truck trailers with air conditioning. They are located just outside the east experimental building of the AGS.

Figure 2: The arrangement for the combined PDP-6 and PDP-10 facility. Each computer system is shown in a 40' long x 10' wide trailer with the average minimum memory and I/O equipment usually committed to its use. The trailer in the middle contains a common pool of memory and I/O equipment which can be easily switched to either computer as desired. Even the memory and I/O in the outside trailers can be switched to either computer if desired. The solid line boxes indicate equipment in use now. The dotted line boxes indicate the major additional items expected to be incorporated shortly.
OPERATOR INTERVENTION IN
THE IMPERIAL COLLEGE HPD SYSTEM

B.K. Penney,
Department of Physics,
Imperial College,

1. INTRODUCTION

Measurement on the Imperial College HPD employs a road guidance system based on the C.E.R.N. Filter program.

To improve the pass rate a facility has been introduced enabling an operator to remeasure, with a light pen and CRT, tracks which have been inadequately filtered.

2. METHOD

2.1 Introduction

At I.C. for reasons primarily concerned with the facilities available the filtering is done on-line immediately after the HPD scan. The raw digitisations and road contents are then no longer stored, and so the operator assistance is inserted immediately after a track has been filtered on the basis of a series of diagnostic tests which the program applies to the filtered master points.

2.2 HAZE diagnostics

The HAZE program inspects the FILTER results for any sign of failure. At first the criteria for failure were set very loosely so that only about 20% of the tracks flagged as failing required light penning. These have now been refined so that a majority of flagged tracks need correction.
The checks for failure are currently:

a) FILTER error word set
b) Number of master points < 5
c) Master points cover < 75% of road length
d) Postfilter subroutines refiltered > 3 slices
e) More than 2 points are too far from a circle fitted through the master points.

2.3 Display of data

If a track fails, the road contents and master points are displayed on the CRT in a coordinate system that removes the road curvature.

The operator may then accept the track, remeasure the track or request a display of all digitisings near the road. This display is in a rectangular coordinate system and also shows the three road points.

If the operator does request this display, he may move any of the three road points continuously in the \( y \) direction with the light pen. This display is also used for resolving ambiguous track candidates. When the operator is satisfied with the positions of the road points the track is refiltered.

2.4 Measurement

To measure a track, the operator runs the light pen along the relevant track and onto the 'measure' button. The program then recalculates the master points and ionisation and displays the new master points on the road contents display for approval or further remeasurement.

2.5 Remeasurement program

The program proceeds by dividing the track into equal length slices and calculating a master point and ionisation for each slice.
To calculate master points the following information is needed for each slice:

a) $\Sigma x_i$, sum of $x$ coordinates of digitisations
b) $\Sigma y_i$, sum of $y$ coordinates of digitisations
c) $N$, number of digitisations.

To calculate ionisation the following information is needed for each slice:

a) Slice length (number of scan lines)
b) Number of 'hits' (number of bubbles seen by HPD)
c) Tangent.

Except for very short or very long tracks, the slice length on the CRT was made equivalent to 16 or 32 scan lines. The program extracts all light penned digitisations from the display file and fits the curve

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$

in the display coordinate system, i.e. with the road curvature removed. If less than 6 points were tagged the straight line

$$y = b_1 x + b_2$$

is fitted instead.

This curve is then used to define a narrow road with a width equivalent to about 10 HPD spot least counts (16 microns), and all digitisations in the display file within this road are gated out. The $x$ limits of the road are the limits of the LPM*. The contents of the road are divided into slices, and for each slice a master point $(x_m, y_m)$ is calculated as

$$x_m = \frac{\Sigma x_i}{N}; \quad y_m = \frac{\Sigma y_i}{N}.$$

* Light pen measurements
The tangents are taken to be those of the power series at the points \( x = x_m \), and the hits to be the number of digitising gated out within the slice.

This information is then transformed into the HPD coordinate system and the FILTER ionisation subroutine IONZ is called to recalculate the ionisation. Finally, the new master points and the road contents are displayed on the CRT for checking by the operator. (See Figs. 5-7)

3. RESULTS

3.1 Speed

The current production program on film from a 10 GeV/c \( K^+p \) exposure in the CERN 2 metre chamber takes about 25 seconds per event/view without light penning. For this experiment there are an average 5 tracks per event and about 10% of these require light penning. It takes roughly 30 seconds to light pen one track and so this increases the event/view time to 35 seconds, i.e. the speed of 48 events/hr is reduced to 30 events/hr. Most of this 30 seconds/track is occupied by the operator transferring his attention to the CRT.

This presents a very good case for off-line processing where the operator is always busy and wastes no time transferring his attention to the CRT.

3.2 Geometry results

The geometry pass rate has increased from 60% to 90% for film from a 2-3 GeV/c \( K^+p \) exposure in the 1.5 metre B.N.H.B.C.

3.3 Ionisation

No systematic comparison has yet been made but a study of a few tracks showed that most tracks had the two
measurements agreeing within errors, and that where they did not agree the light pen measurement looked more reliable.

4. DEVELOPMENTS

We are now writing a new version of the program which will do the LPM off-line. HAZE will write road contents for failing tracks to IBM 2311 discs, and a separate program will light pen these roads at a later time. This will be done in time sharing mode on the PDP6 computer while the HPD is running.

For this off-line LPM we plan to use a D.E.C. VT15 display unit which has 4K of 18 bit core store and a PDP15 arithmetic processor.

5. CONCLUSIONS

Light pen remeasurement is desirable as it finally gives us a 1 pass HPD system although there is a certain time penalty. As soon as it is off-line, the HPD will be able to run at full speed again.
Fig. 1a Schematic diagram of road contents display.

Fig. 1b Schematic diagram of HPD data + road points display.
Fig. 2 Flow chart of HAZE with light pen measurement.
Fig. 3 Flow chart of light pen measurement procedure.
Fig. 4 Photograph of typical data + road points display.

Fig. 5 Failing track road contents + master points display.
Fig. 6 Same track after light pen remeasurement.

Fig. 7 A typical track after light pen measurement.
PRELIMINARY TESTS WITH PICTURES FROM MIRABELLE

G. Seïte and J.C. Sellier
Département de Physique des Particules Elémentaires, CEN, Saclay, France.

1. GENERALITIES

The analysis of bubble chamber pictures with dark background introduces difficulties quite different from those for pictures with light background.

We have designed a circuit to follow the photomultiplier which regulates the potential corresponding to the film background and amplifies the signals coming from tracks in order to detect them.

When looking at pictures from MIRABELLE, we have observed that the background varies very much and that the signals coming from certain fiducials represent a modulation of only 6% of the total light flux.

Furthermore, when observing track signals in different regions with varying backgrounds, no relationship between the amplitude of useful signals and the opacity of the background could be found. The amplitude of useful signals in certain parts of the chamber is comparable to that of noise in other parts.

2. PRINCIPLE OF REGULATION

The block diagram is shown in Fig. 1. All circuits were made with operational amplifiers.

The variation of the photomultiplier anode current is 100 microamps when going from black to white. For this the amplifier A1 outputs a potential variation of 3 volts.

The peak detector suppresses the pulses due to tracks and keeps only the slow variations. By comparing in C1 the signals from the peak detector and the amplifier A1, we get track pulses and a d.c. component. These pulses are then amplified, the gain of the amplifier A2 depending on the light flux.
3. TESTS

The picture used for tests was taken on camera 8 of MIRABELLE and is shown in Fig. 2. The track widths vary between 12 and 20 microns. They are wider in the lighter regions of the picture. Tracks in some regions have small black dots on them and it is often difficult to see the bubbles.

In these pictures the large fiducials with circles around them in the lower part are 14 microns wide, and the background around them has a density of 3. In the upper part of the right, the background has a density of 0.6. On each side of the tracks and at a variable distance, there is a shadow which will be digitized given its contrast.

In order to analyze such a picture we had to amplify greatly the pulses due to tracks and fiducials. It is then possible to decrease the amplifier gain in light regions (large noise), which diminishes the number of digitizings due to noise. The main disadvantage of this procedure is that noise signals, although less amplified than track signals, still have large amplitudes. The possibility of only amplifying useful signals was considered, but given their small amplitude, this is difficult to implement. Suppressing track signals in the peak detector diminishes the amplitude of the useful signal at the output of the comparator Cl. This is so, because during the useful signal, a capacitor is charged which gives at the output of the detector a small potential variation. We are obliged to choose a large enough time constant for charging this capacitor so as not to distort the track pulses, even of low amplitude, and low enough to follow the slow variations of the light flux.

4. CONCLUSIONS AND RESULTS

Figures 3, 4, and 5 show digitizings from the H.P.D. of the picture shown in Fig. 2, at different levels.

The variable gain of the output amplifier allows us to diminish the amplitude of noise signals versus that of track signals, although this does not seem sufficient because digitizings due to noise are still numerous.
A filtering of the signals, is being considered because we observe that there is little variation in the shape of useful signals (in particular their width at half-height). The modification of the level during the measurement should yield fewer noise digitizings.
Fig. 1 Automatic gain control for H.P.D.
THE BIRMINGHAM TRACK ANALYSIS SYSTEM

J. Simmons

Physics Department, University of Birmingham, P.O. Box 363, Birmingham 15, England.

Introduction

The system is based on a conventional H.P.D. attached online, via a 2701, 16 bit parallel data adapter, to a semi-dedicated IBM 360/44 computer. It is semi-dedicated in that we are able to run a batch stream, composed mainly of statistics or Monte-Carlo programs at the same time as running the H.P.D. online program. The geometry and kinematics programs are too large to fit into core with the H.P.D. program and so must be run in non-measuring hours. The computer has a memory of 256K bytes, 2 high speed channels and a multiplexor channel. The 2701 is attached to one of the high speed channels and the 2 system disks (IBM 2311 with 7M bytes capacity each) and 4 1600 b.p.i. tape drives to the other. The low speed multiplexor services the usual low speed devices, card reader, printer and console typewriter, together with a single disk drive (1M bytes capacity), a channel to channel link to an IBM 1800 computer and an IBM 2250 display unit. A multiprogramming system developed by Perdue University, is used. The H.P.D. is currently measuring 2 and 4 prong interactions at 16 GeV/c in the C.E.R.N. 2 metre chamber.

The Manual Measuring System

The IBM 1800 computer is used to control 2 National measuring machines, 4 Duff measuring machines, and 3 double Shiva scanning tables fitted with Mangia Spago road makers.

The data from these machines is stored on disk (1M bytes) on the 1800 and when a number of these disks are full (at a rate
of about 2 a day) the data is sorted and written to tape on the 360/44 via the link. The program in the 1800 computer is used not only for data acquisition but also to help the operator where possible. Firstly the fiducial positions on each view are fed into the program for a particular experiment. After the operator has measured the first fiducial, the program positions the stage to approximately the position of each of the other fiducials, leaving the operator to make the fine setting. Return to vertex positioning is used at the end of each track. Current modifications to the program will enable a rudimentary track following scheme. The program will position the stage to approximately the position of the next point to be measured, allowing the operator to make the fine setting. After the first point has been measured, this positioning is done by linear extrapolation, and for the later points by using a circle fit. This will enable the program to control the spacing of the points. A speed ball is used for stage positioning - the ball is used in 2 modes, a fine setting mode in which it works as a normal speed ball, except that if the ball is rotated faster than a certain speed, a "higher gear" is engaged to give faster motion across the film, and a positioning mode (obtained by depressing the ball) when it works as a joystick. Program-operator communication is via push-buttons and signal lights. At the end of each track a circle fit is made to the measured points and the operator asked, by flashing a light, to remeasure it if any points lie more than a certain amount from the fitted curve. The system, used full-time, measures approximately 1000 events per week (5 ½ days). The road makers produce approximately 1500 events per week, though they are not used full-time.

The H.P.D. Measurement System

The measurement of events on the H.P.D. is carried out in two main stages - the online measurement of the film and the offline filtering within the defined roads. The usual
geometric reconstruction and kinematics stages follow this latter stage. The effective event rate at the online stage (this includes film changing and other unscheduled hold-ups) is approximately 50 events per hour (used about 6 hours per day at present). The subsequent offline processing runs at a rate of approximately 70 events per hour.

The online program is based on the program in use at the Rutherford Laboratory. Operator intervention, via the computer console typewriter is reduced to a minimum and is only required when the program has trouble with the picture number bits or is unable to find sufficient fiducials. In these cases, the operator is able to check the quality of the film by using a small Tektronix 611 storage display. The display is driven directly from the H.P.D. hardware and shows, on one half of the screen, the normal scan as it is being measured; if there is an abnormal scan for this event, it is shown in the other half of the display, rotated, scaled and positioned so that it matches the previously displayed normal scan, but displaced to one side. From this display it is easy to see if the trouble is due to scratches on the film, or fiducials obscured by tracks, and the appropriate action taken. The 2250 display, available under computer control, has proved extremely valuable for hardware diagnostics. In this case, a portion of the digitisations stored in the computer memory, may be displayed, with a variable scale, on the 2250 display. If a grid is measured, it is possible to see errors, if any, in the digitising electronics very easily.

The subsequent road filtering is done offline. All the measured events are run through a filtering program written at R.H.E.L. This program uses a stringing technique (as in C.E.R.N. minimum guidance) within the defined roads, to find the tracks. The processed events are then checked by the geometry program and the failures, about 30-40%, are input to the more conventional C.E.R.N. Filter program. Filter is
able to save about 25-30% of the previous failures, bringing the effective pass rate up to 70-80%. The final rejects, as indicated by another pass with the geometry program, are input to the patch-up system.

The patch-up system is based on the Filter program and the 2250 display. The input to the program is now the original scan tape containing the digitisings, a list of failed events and the output tape from the previous Filter run. Only those tracks failed by the geometry program are re-processed. The operator corrects the bad tracks by use of the light pen and the function keyboard and is able to indicate the correct track in the case of multiple beam tracks, or can insert or delete master points where the program got into trouble with small angle crossing tracks. The updated tracks are inserted into the previous geometry record, which is written onto the output tape. The patch-up system brings the final pass rate to about 95%. The residual failed events will probably be measured on the manual machines.

The H.P.D. has been in full production on the $K^p$ experiment for a few months and some 12000 events have been measured. It is found that the helix fit statistics peak at about 3.5$\mu$ on film (taking only 3 view tracks), compared with about 8$\mu$ obtained with the manual machines. It is expected that improvements in the Filter program will push up the pass rate (before the patch-up system) thus lessening the computer load.
THE WEIZMANN INSTITUTE SPIRAL READER SYSTEM

E.E. Ronat, H. Bresman, Y. Eisenberg, B. Reuter,
A. Shapira, R. Yaari and G. Yekutieli,
Department of Nuclear Physics,
Weizmann Institute of Science,
Rehovot, Israel.

1. INTRODUCTION

The high energy group of the Weizmann Institute decided to build a Spiral Reader in March 1968, in order to increase the event processing capability of the group to about 500,000 events per year. The mechanical and optical part of our Spiral Reader is identical to the Berkeley SR II, and the on-line computer is a PDP-9. The control electronics and the PDP-9 software were designed and built by our group at the Weizmann Institute. The Spiral Reader is undergoing test production running since February 1970 and has measured to date about 5000 events.

2. THE MECHANICAL-OPTICAL HARDWARE

The mechanical-optical hardware, consisting of the periscope and rotating cone assembly, the x-y stage, the film transport and the projection system has been built for us by the Lawrence Radiation Laboratory and is identical to the Berkeley Spiral Reader II. Thus it has a scanning radius of 80 cm in space (or 5 cm in the film plane), and its film transport is for 46 mm single strip format.

We have designed ourselves a film cage for 35 mm 3 strip film format. This new cage mounts simply on the present stage assembly, and the conversion from one film format to the other should take only a few
hours. The 35 mm film cage is presently being built in our shop and will be tested in a few months.

3. COMPUTER

The on-line computer is a Digital Equipment Corp PDP-9. The computer configuration includes 2 DECTape transports, and 1 IBM compatible magnetic tape transport, Automatic Priority Interrupt (API), and a memoscope.

The reason for getting the 2 DECTape transports was to give us the option of making use of the DEC provided Keyboard Monitor system for the PDP-9. This turned out to be of very great help in the writing, debugging and testing of the on-line programs. It will be described in more detail in section 5. During production running, one DECTape holds the system and the program, the second DECTape contains the input information while the output is written on the IBM compatible magnetic tape. In order to facilitate fast listing of programs on the line printer of our computation center, service routines were written to convert ASCII code on DECTape to BCD on magnetic tape in appropriate formats; similarly another program did conversions from card images onto DECTape.

In order to help on the debugging of the Spiral Reader and the filtering programs, a direct data link was constructed between the PDP-9 and our off line computer (a home built GOLEM, roughly equivalent to an IBM 7094).

4. THE CONTROL ELECTRONICS

The control electronics was completely designed and built at the Weizmann Institute. We made our own cards, based upon TTL type integrated circuits and thus achieved a high amount of compactness. The whole
electronics only partially fills one standard cabinet, while all the power 
supplies are in a second cabinet.

The control electronics operates through the use of a command-
and-status register (CSR) for each active device. These registers have a 
uniform general structure for the x and y stage drive, the periscope 
drive, the film drive and the Q channel (data input). The structure of 
these command-and-status registers is as follows:

```
Bits 0 - 5 : Velocity register
Bits 6 - 11: Command register
Bits 12 - 17: Status register
```

While the general structure is similar for all active devices the specific 
function of the various bits is somewhat different for the different devices.

As an example we shall describe in somewhat more detail the 
stage drive register.

The velocity registers contain the sign (bit 0) and magnitude 
(bits 1-5) of the velocity with which it is desired to drive the stage. The 
command register controls the mode of operation of the device. Thus bit 6 
specifies whether operation is automatic (under computer control) or 
manual (via the speed ball); bit 7 specifies whether counting is 
enabled or not; bit 8 specifies whether the reference signal is enabled 
or not; and bit 9 controls whether the raising of certain flags causes 
an interrupt in the PDP-9 API device. The status register (bits 12-17) 
consists of a number of flags that are raised when certain operating 
conditions occur. In particular, flags are raised when the inner or 
outer limit switch is hit, a reference mark is crossed or the scaling 
register overflows. When some of these flags are raised, an interrupt
signal is also sent to the computer which subsequently suspends its normal processing sequence and handles the interrupting condition.

The scaling registers are internal in-memory locations in the PDP-9. They are incremented or decremented by the Add-to-Memory capability of the PDP-9 computer via the data channel facility. In order to avoid loss of counts due to timing conflicts, an external scaler of 3 bits is incorporated in the electronics. When the internal scaler overflows (or underflows) an Add-Overflow flag is raised, which is also connected to the interrupt line. Thus by presetting the internal scalers a specified number of counts away from overflow, the stage can be driven that distance while the computer handles other work; when the overflow interrupt occurs the computer can either stop the stage or preset it to move another specified distance before interrupting again.

The Heidenhain grating system which provides the digitizations of the xy stage contains a reference mark. This reference mark causes the raising of a flag whenever this mark is being crossed, if the appropriate bit of the command registered is enabled. The reference mark is used for the original setting of the scalers as well as for periodic checks that no counts were lost.

The Spiral Reader I/O instructions control the devices by writing into the Command-and-Status register (CSR) from corresponding AC positions in the computer. Both jam transfer, as well as ANDing and ORing from the AC into the CSR can be executed. Thus single command bits or any desirable combinations thereof can be changed without modifying the rest. The velocity register can be written independently of the command register. The CSR can be read into the AC, and skip instructions are provided to test the status of the different flags.
The CSR of the other active devices have a similar structure to the stage drive described above, but are different in some of the details. The periscope drive has an additional homing command (in the Command register). This homing command drives the periscope at top speed to a home position, specified by a helipot mounted on the periscope lead screw. (This command is used to return the periscope to its "zero-position" after the completion of a scan). In the film drive there is a leader flag instead of limit switches, and there is a flag that is raised when the film gate is down and vacuum is on. The Q channel (data input) is connected to 2 Data channels, corresponding to 2 buffers in the computer memory being used. When one buffer has been filled, the electronics automatically switches the data input to the other channel, a flag is raised and an interrupt occurs. At this time appropriate action is taken to write the filled buffer on the magnetic tape. Furthermore, in the Q channel the velocity register is replaced by the discriminator level which specifies the acceptance criteria of a pulse.

The output of the Spiral Reader comprises of 5 pieces of data, packed into 4 PDP-9 words, for each hit. They include the radius, pulse height, leading angle ($\theta_L$), trailing angle ($\theta_T$) - where from the hit angle is $\theta = 0.5 (\theta_T + \theta_L)$. In addition we output the angle $\theta_{1/2}$ at which the pulse reaches half its maximum height. We expect this additional piece of data to be of help in an improved calculation of the track ionization.

A more complete description of our SR Instruction List and Command Register Structure, and details of our electronics is found in several Weizmann Institute Internal Reports\(^{(1-2)}\).
5. **ON-LINE SOFTWARE**

A new on-line program (ZOO) was written for the PDP-9 to control the Spiral Reader through our new electronics. The program initializes the SR operation, reads the ID information from DECTape, positions the film, controls the fiducial measurement, handles the data input in a vertex scan and outputs it on magnetic tape, allows for crutch point measurements, and performs view changing. In addition it has branches for treating cases where unexpected things occur such as hitting of limit switches, and it allows for operator intervention to remeasure an event, reject it, etc. The program performs simultaneous parallel operations whenever a reasonable saving of time can be achieved.

Our PDP-9 configuration included 2 DECTapes and 1 standard magnetic tape unit. Thus before beginning the measurements the SR input tape (containing the ID information of the events to be measured) - is copied from a magnetic tape onto one of the DECTapes (it takes about 2-3 minutes to copy 500 events). Then during the measurement proper the input is read from the DECTape and output data is written on the magnetic tape. As the DECTape is inherently slow a buffering scheme is used to avoid loss of time. When a new ID is to be read, it is already found in a 40-word buffer in the PDP-9 memory. Thus it takes only the time to transfer it from the buffer to the regular location in memory. Subsequently the next record is read into the buffer and the DECTape is repositioned; obviously this operation is done simultaneously with the measuring of the Spiral Reader and thus no time is lost.

During the collection of data at the time of the periscope scan, the data input (Q channel) is alternately connected to 2 PDP-9 data
channels corresponding to 2 buffers. While the Q channel fills one buffer, the other buffer is being written on tape; in addition the data is being displayed on the scope at the same time and various checks are also performed on the input data as it comes in to ascertain that no malfunction of the equipment occurred. When the buffer is filled the Q channel is automatically switched via hardware to the second buffer and an interrupt occurs. As the tape writing is considerably faster than the data input, by the time this switch occurs the contents of the buffer were always already written on tape, and the new buffer is ready to accept data.

As was mentioned already, it was decided to make use of the DEC supplied PDP-9 Keyboard Monitor System, in writing the on-line programs. Thus the programs were written on the PDP-9 teletype using the Editor-9, assembled by the MACRO-9 assembler and loaded by the Linking Loader. The binary programs produced by the assembler were stored, of course, on DECTape. Changes in the program could be effected in a few minutes by going through the sequence Editor-9, MACRO-9, and Linking Loader. It should be emphasized that the Monitor system was used only in the pre-execution phases of the program, as described above. Once execution started the on-line program was completely stand-alone. Thus we wrote our own special purpose and compact handlers for DECTape, Magnetic tape and teletype. Furthermore during execution the resident monitor area (about 900 locations) could be overlaid by storage space, e.g. the data buffers, and thus no serious loss of storage resulted from use of the monitor system.

A new routine which is being written at present will perform a semi-automatic measurement of the fiducials with the periscope scan.
According to this scheme the first fiducial is measured manually. Then one can accurately calculate the correction factor due to film stopping uncertainty. Subsequently the stage is driven to the second fiducial, and it is found that we can stop it well within a third of a leg from the center of the fiducial. At this point about 5 revolutions of the cone are performed at slowly increasing radii of the periscope, thus obtaining about 5 hits on each of the 4 legs of each fiducial. Then the procedure is repeated on the other fiducials. The total time it takes is the time to drive the stage to all fiducials plus about 300 msec per fiducial. Actually, this method significantly decreases the strain on the operators and potentially increases the accuracy of measurement of the fiducials. The data from the periscope scan is being subsequently analyzed in the filter program POOH by a method very similar to that employed in the calibration program. Thus a best straight line is passed through each combination of legs in a local xy coordinate system and the intersection determines the fiducial location.

6. CHECKOUT AND PERFORMANCE

The separate components of the electronic system were tested operationally as they were completed, by specially written PDP-9 programs.

The complete Spiral Reader System entered into a shake-down production run during February 1970. As of now about 5000 events were already measured on it of \( \pi^+ p \) interaction at 5.0 GeV/c (46 mm single strip film of the 82" SLAC Bubble Chamber).

The present measurement rate on our Spiral Reader is typically about 50 events/hour averaged over a two hour shift. This includes the measurement of 4 fiducials manually, and the printing on the Teletype of some ID information to which the measurer must react.
The measurement rate of the Spiral Reader will be increased in coming few months by the following means.

(1) The fiducial measurement procedure will be modified in two ways:

(a) Only 2 fiducials will be measured on each view, while several times on each roll 4 fiducials will be measured for checking purposes. This procedure will be fully implemented only after performing extensive testing to ascertain that no loss of accuracy results.

(b) Semi-automatic fiducial mode will be introduced where one fiducial is measured manually and the others are measured by making spirals around them as described in section 5. This mode is obviously equally applicable to the measurement of 2 fiducials or 4 fiducials, and is also independent of the location of the pertinent fiducials.

(2) The ID information will be displayed on the scope instead of on the Teletype, thus speeding up the response of the measurer.

(3) The improvement of the mechanics of communication between the operator and the computer, such as in verification of events, rejects or remeasurements.

The measurements already made on our Spiral Reader have gone through the analysis programs of filtering (POOH), geometry (TVGP) and kinematics (SQUAW). The success rate through POOH is at present about 70% and the least squares deviation of tracks in TVGP is of the same general magnitude as the results of our manual measuring machines.
Our main effort now is concentrated in improving the filtering to get a higher success rate, and in the determination of the best calibration procedures in order to reduce the track deviations.

It is our great pleasure to acknowledge the assistance we received from the Lawrence Radiation Laboratory throughout the entire project. In particular we are grateful to Professor Louis W. Alvarez, Mr. N.R. Andersen, Dr. J. Llyod, Dr. G.R. Lynch, Mr. W. Nolan and Dr. Frank T. Solmitz for their help and encouragement. We are also indebted to SLAC Group B and in particular to Professors J. Ballam and D.W.F.S. Leith and Mr. M. Hu for their kind support. We wish to thank our engineers J. Sokolowsky, J. Wolowelsky and our technicians A. Jacob, H. Feldman and Y. Gal for their devotion and high quality of work.

The Project was made possible through the enthusiastic support of the late Professor Amos de-Shalit.

REFERENCES


Glossary of on-line measuring devices

This glossary, like that published in the proceedings of the 1968 Argonne Conference, covers manual, semi-automatic and automatic measuring machines attached to computers. It was obtained by circulating questionnaires to attendees at the Cambridge Conference and contributors to the previous glossary, and one or two entries were gathered by personal contact. An asterisk following an entry means that it has not been updated since 1968.

The glossary is probably neither complete nor absolutely correct, though I have, of course, tried to make it so. I shall welcome errata for the correction of a subsequent edition.

My thanks are due to Pat McDonald who did the large amount of clerical work involved.

F. Beck
Argonne National Laboratory
<table>
<thead>
<tr>
<th>Installation</th>
<th>Machine(s)</th>
<th>Computer(s)</th>
<th>Contact</th>
<th>Started</th>
<th>Current State</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aachen, Germany SEE: Technische Hochschule Aachen</td>
<td>POLLY II</td>
<td>Sigma 7</td>
<td>F. Beck</td>
<td>1967</td>
<td>5-12K events/wk production.</td>
<td>Scanning and measuring possible. Computer also used for TVGP off-line.</td>
</tr>
<tr>
<td>Argonne National Laboratory</td>
<td>POLLY III</td>
<td></td>
<td></td>
<td>1970</td>
<td></td>
<td>Under construction. Will use same computer as POLLY II but not simultaneously. Four film strips as for ANL 12 ft Bubble Chamber.</td>
</tr>
<tr>
<td>Berkeley SEE: California, University of Lawrence Radiation Laboratory</td>
<td>HPD</td>
<td>IBM 360/44 + 1800</td>
<td>J. Simmons (software) H. R. Shaylor (hardware) D. C. Colley (physics)</td>
<td>1967</td>
<td>1000 events/wk production.</td>
<td>Patch up of failed events using 2250 display on 360/44. Two experiments currently in progress.</td>
</tr>
<tr>
<td></td>
<td>Film plane measuring machines (6)</td>
<td></td>
<td></td>
<td></td>
<td>1500 events/wk on manual machines.</td>
<td>Tracker ball operated.</td>
</tr>
<tr>
<td></td>
<td>Double Shiva scanning tables with mangiaspago road makers (3)</td>
<td></td>
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<tr>
<td>Birmingham, University of U.K.</td>
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<tr>
<td>Bologna, Italy SEE: CNAF</td>
<td>SOM (3) HERMES Predigitising tables (4)</td>
<td>PDP 6 and PDP 10</td>
<td>H. H. Nagel</td>
<td>1965</td>
<td>Operational (except two tables on order)</td>
<td>The predigitising tables are used to scan and rough digitise film for the HPD jointly set up by a Bonn and a Hamburg group at DESY, Hamburg. See there for details.</td>
</tr>
<tr>
<td></td>
<td>35 mm FSD 70 mm FSD Data terminal network</td>
<td>IBM 7094</td>
<td>P. V. C. Hough</td>
<td>1968</td>
<td>Production</td>
<td>430 K events calendar 1969, road guidance. Minimum guidance under test.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1961</td>
<td></td>
<td>14 image-plane rough-digitizers and 8 remote graphical terminals interfaced to Sigma 7 connected to 6600.</td>
</tr>
<tr>
<td>Bonn University Physikalisches Institut Germany</td>
<td></td>
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<tr>
<td>Brokhhaven National Laboratory (Bubble Chamber Group)</td>
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<td>Installation</td>
<td>Machine(s)</td>
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<td>Current State</td>
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<tr>
<td>Brookhaven National Laboratory (Bubble Chamber Group)</td>
<td>Super mangiagapo</td>
<td>SDS 920</td>
<td>D. G. Hill</td>
<td>6/65</td>
<td>Production</td>
<td>12 image-plane digitizers on line. 1/2 rough digitizing for FSD, 1/2 measuring. 100,000 events/year.</td>
</tr>
<tr>
<td>Brown University*</td>
<td>HERMES Sr.</td>
<td>PDP 9 – 360/50</td>
<td>A. M. Shapiro</td>
<td>5/67</td>
<td>Production on four.</td>
<td>The six machines are being put on-line to PDP 9, with fast interface to 360/50. System completed and working.</td>
</tr>
<tr>
<td>Franckenstein</td>
<td>4 IPD's</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>California, University of, at Los Angeles</td>
<td>SMP (5)</td>
<td>IBM 360/40G on line to SMP's shortly will be replaced by 360/44G. TVGP-SQUAW runs on IBM 360/91.</td>
<td>P. E. Schlein, W. E. Slater, D. R. Stork, H. K. Ticho</td>
<td>1965</td>
<td>Production</td>
<td>In a project where no 2-prong events are measured, 4000-5000 events/wk are scanned and measured. 14 full-time equivalent scanners employed.</td>
</tr>
<tr>
<td>California, University of Lawrence Radiation Lab</td>
<td>Spiral reader</td>
<td>PDP 4 – CDC 6600</td>
<td>F. Solmitz</td>
<td>1958</td>
<td>Production</td>
<td>Minimum guidance measurement at 100 events/hr.</td>
</tr>
<tr>
<td>Berkeley</td>
<td>HPD</td>
<td>IBM 7094 II (2 core, MP)</td>
<td>H. White</td>
<td>1961</td>
<td>HAZE production</td>
<td>1,800,000 events measured in six years. 500 K this year, in HAZE (full guidance) production. DAPR (auto. mode) in production 1/70. 50 K events measured through 4/70 at 150 triads per hour.</td>
</tr>
<tr>
<td>Cobweb</td>
<td>COBWEB (6 Franckensteins + 10 scan table teletyper)</td>
<td>IBM 7044</td>
<td>R. W. Birge</td>
<td>3/66</td>
<td>Production</td>
<td>High speed computer controlled and checked track following machines.</td>
</tr>
<tr>
<td>Carnegie-Mellon University</td>
<td>SMP (3)</td>
<td>Univac 1108</td>
<td>A. Engler</td>
<td>1967</td>
<td>Production</td>
<td>3 SMP's operating one 8-hr shift. Rate of production 5 x 10^4 events/yr. Expected 2-shift operation July 1, 1970 which would double production to 10^5 events/yr. Machines on line to PDP 8 have approximately 60% capacity of SMP's.</td>
</tr>
<tr>
<td>Vanguard IPD's (2)</td>
<td>PDP 8</td>
<td></td>
<td></td>
<td>1968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HERMES</td>
<td>PDP 8</td>
<td></td>
<td></td>
<td>1968</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case Western Reserve University</td>
<td>Image plane (3)</td>
<td>PDP 8 – on line, IBM 1800 minor data processing.</td>
<td>D. K. Robinson</td>
<td>7/66</td>
<td>Production</td>
<td>Conventional on-line system. Computer controlled lights and film motions, smoothness checks, etc. 2 shifts/day, 5-day week.</td>
</tr>
<tr>
<td>University</td>
<td>Film plane (2) (manual)</td>
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<td>Installation</td>
<td>Machine(s)</td>
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<tr>
<td>Cavendish Laboratory Cambridge, U.K. (Contd.)</td>
<td>Conventional film-plane digitizers (CLARA's) 1 μ least count</td>
<td>PDP 8/S (on line)</td>
<td></td>
<td>1964</td>
<td>Operational</td>
<td>Circle fits and format checks.</td>
</tr>
<tr>
<td></td>
<td>Manual measuring (9) and predigitizing machines (connected)</td>
<td>CII 510</td>
<td>B. Deler</td>
<td>1963</td>
<td>Operational</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manual measuring and predigitizing tables.</td>
<td>PDP 15/20</td>
<td>C. Kochowski</td>
<td>6/69</td>
<td></td>
<td>Spiral reader built by SAAB.</td>
</tr>
<tr>
<td></td>
<td>HPD I</td>
<td>160 A on line. Filtering done on CDC 6600.</td>
<td>C. Frank</td>
<td>1964</td>
<td>Production</td>
<td></td>
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<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
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<tr>
<td>CERN</td>
<td>ADAM + EVA</td>
<td>PDP 8/L's + 3200</td>
<td>C. Verkerk</td>
<td>1968</td>
<td>Development</td>
<td>Highly automated, manual machine for combined scanning and measuring of film from the large bubble chambers. A number of ADAM + EVA's connected to a CDC 3200 via the PDP 8/L's. PDP 8/L's control hardware; 3200 provides aid in scanning and measuring. Pictures will come from Gargamelle, Mirabelle and possibly BEBC (e.g. up to 8 views on up to 4 films).</td>
</tr>
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<td></td>
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<td></td>
<td>(a) HPD Ω is HPD 1 rebuilt to HPD 2 accuracy, for 70 mm film, with a 1500 rpm disc. Rebuild January-July 1970.</td>
</tr>
<tr>
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<td>(b) Minimum guidance is now in production on HPD 2.</td>
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</tr>
<tr>
<td></td>
<td>HPD 1 (HPD Ω)</td>
<td>CDC 6600/CDC 6500</td>
<td>W. Blair (bubbles)</td>
<td>1960</td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(sparks/bubbles)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>HPD 2 (bubbles)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Six Miladies are on line; 8 later.</td>
</tr>
<tr>
<td></td>
<td>Luciole (sparks)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Predigitising</td>
<td>IBM 1130. Subsequent</td>
<td></td>
<td>1966</td>
<td>Production</td>
<td>Copy of Berkeley SR adapted to CERN chamber 20,000 events measured in 1969 average 60 ev/hr. Peak 87 ev/hr.</td>
</tr>
<tr>
<td></td>
<td>tables - Milady(10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 IPD's for HLBC measurements. 5 IPD's for Gargamelle scanning and measurement. Full geometry on line.</td>
</tr>
<tr>
<td></td>
<td>LSD spiral reader</td>
<td>PDP 7 + CDC 6000/6500</td>
<td>J. Trembley</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Computer does 3-dimensional geometric reconstruction to check on accuracy of the measuring. The system can handle up to three sets of optical constants simultaneously.</td>
</tr>
<tr>
<td></td>
<td>7 + 5 IPD's</td>
<td>CDC 3100 on line</td>
<td>D. C. Cundy</td>
<td>1966</td>
<td>Production (7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Construction (5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPD (5) FPD (1)</td>
<td>EMR 6050</td>
<td>N. Gelfand</td>
<td>1965</td>
<td>Working</td>
<td></td>
</tr>
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</tr>
<tr>
<td>CNAF</td>
<td>Sogenique</td>
<td>IBM 360/44 + IBM</td>
<td>M. Masetti</td>
<td>1967</td>
<td>Production</td>
<td>The HPD-360/44 on-line program decodes the picture number, finds the fiducials, centers and gates the digitizations. The new global filter program works off line. The Luciole-360/44 on-line program decodes the picture number and finds the fiducials and sparks Centers.</td>
</tr>
<tr>
<td>Bologna, Italy</td>
<td>HPD 2</td>
<td>THRESH, GRIND</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Luciole</td>
<td>IBM 360/44</td>
<td></td>
<td></td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>test</td>
<td></td>
</tr>
<tr>
<td>College de France</td>
<td>Coccinelle</td>
<td>ClI 9010 (like SDS 910)</td>
<td>B. Eguer, G. Reboul</td>
<td>1968</td>
<td></td>
<td>Assisted scanning and automatic measuring (CRT) of Mirabelle pictures. Control electronics built (half of it tested). Film transport being designed.</td>
</tr>
<tr>
<td>Paris, France</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
</tr>
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<td>---------------------------------------</td>
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<td>-----------------------------------------------</td>
</tr>
<tr>
<td>College de France</td>
<td>HPD</td>
<td>CDC 160 A (control)</td>
<td>G. Reboul</td>
<td>1963</td>
<td>Operational</td>
<td></td>
</tr>
<tr>
<td>Paris, France (Contd.)</td>
<td></td>
<td>CDC 6600 (processing)</td>
<td>B. Equer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spiral reader</td>
<td></td>
<td>PDP 9 (control)</td>
<td>C. Ghesquiere</td>
<td>1967</td>
<td>Being tested</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CDC 6600 (processing)</td>
<td>M. Moynot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbia University</td>
<td>Sogenique</td>
<td>IBM 360/91 – HPD control + track following.</td>
<td>D. Burd</td>
<td>1963</td>
<td>Production</td>
<td>Full production on two experiments (automatic mode).</td>
</tr>
<tr>
<td></td>
<td>HPD</td>
<td>IBM 360/44 – event recognition, reconstruction and kinematic fitting.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daresbury</td>
<td>SEE: DNFL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Democritos</td>
<td>HPD</td>
<td>CDC 3300</td>
<td>E. Simopoulou</td>
<td>1966</td>
<td>Analysis of experiments started.</td>
<td></td>
</tr>
<tr>
<td>Athens, Greece</td>
<td>IEP</td>
<td>CDC 1700</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mangiastpago (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DESY</td>
<td>Scanning tables (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamburg, Germany</td>
<td>MÜHLE</td>
<td>CII C90-10 (control)</td>
<td>K. Höhne</td>
<td>1964</td>
<td>Production</td>
<td>FSD for spark chamber pictures. TV scan, 512 lines, accuracy ± 10 μm, measuring time 5 sec/frame. IBM 360/75: on line - consistency checks, bookkeeping; off line - pattern recognition, physics.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IBM 360/75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FPD (5)</td>
<td>PDP 8 and 360/75</td>
<td>E. Raubold</td>
<td>1965</td>
<td>Production</td>
<td>Premeasuring.</td>
</tr>
<tr>
<td></td>
<td>IPD</td>
<td>PDP 8</td>
<td>E. Raubold</td>
<td>1967</td>
<td>Production</td>
<td>In connection with Bonn University, Physikalisches Institut.</td>
</tr>
<tr>
<td></td>
<td>HPD</td>
<td>PDP 9 and 360/75</td>
<td>E. Raubold</td>
<td>1966</td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DNPL*</td>
<td>Daresbury</td>
<td>B. Zacharov</td>
<td>1968</td>
<td>Hardware incomplete (1968).</td>
<td>Lower section digitized mechanical stage; upper section CRT light generator with 3 modes - normal or orthogonal line scan, or addressable spot.</td>
</tr>
<tr>
<td>Daresbury, U.K.</td>
<td>FSD</td>
<td>IBM 360/65 + 1800</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
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</tr>
<tr>
<td>Dubna, SEE: Joint Institute for Nuclear Research</td>
<td>OMAR</td>
<td>DDP-24</td>
<td>L. Fortney</td>
<td>6/64</td>
<td>Operational</td>
<td>Manual. Two Hermes Juniors ~ 40,000 events/yr.</td>
</tr>
<tr>
<td>Duke University</td>
<td>RIPPLE</td>
<td>Sigma 5</td>
<td></td>
<td>6/68</td>
<td>Nearly operational</td>
<td>Semi-automatic. CRT concentric circle scan, provisions for operator intervention.</td>
</tr>
<tr>
<td>Glasgow University, Glasgow, U.K.</td>
<td>FPD (2)</td>
<td>IBM 7040</td>
<td>I. S. Hughes</td>
<td>1961</td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SMP (3)</td>
<td>IBM 7040</td>
<td></td>
<td>1965</td>
<td>Production</td>
<td>385,000 events measured. SMP's are SOM-Glasgow-Heidelberg systems.</td>
</tr>
</tbody>
</table>
| | POLLY | IBM 360/44 | | 1969 | Testing | (a) Controller: complete and tested.  
(b) Analogue circuitry: copy of Argonne circuitry, complete and under test.  
(c) Optical bench and film transport: under construction. |
<p>| Harvard University | SPASM | PDF 1 Sigma 7 | A. E. Brenner (at NAL) K. Sisterson | 1966 | Production | The two sets of optical-mechanical systems for the one-view spark chamber SPASM and the three-view bubble chamber SPASM are both driven by the same power supplies and central electronics. PDF 1 does all scanning filtering and measuring. Broad band connection to Sigma 7 for geometric reconstruction, etc. |
| | SPASM (bubble chamber) | | | 1968 | Final test stage | |
| Hawaii, University of | SMP (4) | IBM 7040 (on line) IBM 360/65 | V. J. Stenger | 9/63 | Operational | Three machines at a time – about 12 hours/day. |
| Heidelberg University, Heidelberg, Germany | IEP (2) | IBM 7040 | H. Filthuth H. Ströbele (hardware) | 1965 | Production | Subsequent processing on IBM 360/65. |
| | SMP (4) | | F. Klein (software) | | | |
| | IPD (10) | PDP 7 | | 1966 | Production | Program development and beginning of production. |
| | PEPR | PDP 10 | | 1968 | Production | |
| Illinois, University of Urbana, Illinois | DOLLY | CSX-1 (home design, controlling) | R. M. Brown | 8/68 | Testing | Digital version of POLLY. |
| | SMP (5) | CSX-1 | | 1963 | Production | |</p>
<table>
<thead>
<tr>
<th>Installation</th>
<th>Machine(s)</th>
<th>Computer(s)</th>
<th>Contact</th>
<th>Started</th>
<th>Current State</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois Institute of Technology</td>
<td>On-line meas. tables</td>
<td>PDP 8/1</td>
<td>R. A. Burnstein</td>
<td>6/68</td>
<td>Production</td>
<td>Manual machines being coupled to PDP 8/1 for data collection and checking. Output of systems is on magnetic tape. System controlled by PDP 8/1. Data processed by Univac 1108.</td>
</tr>
<tr>
<td>Imperial College</td>
<td></td>
<td>Univac 1108</td>
<td>H. A. Rubin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Predigitizers (6)</td>
<td>DDP 576</td>
<td>B. K. Penney</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual meas. machines</td>
<td>DDP 576</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiana, University of</td>
<td>CRUDI</td>
<td>CDC 3400</td>
<td>R. Crittenden</td>
<td>1/66</td>
<td>Production</td>
<td>Computer-controlled film scanning and measuring machine.</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institut de Physique Nucleaire</td>
<td>PEPR</td>
<td>Sigma 5</td>
<td>H. J. Martin</td>
<td>10/68</td>
<td>Limited Production</td>
<td>CDC 3300 controls the 11 measurement machines. The CDC 6600, beside its batch processing use, performs THRESH in real time (priority roll-in, roll-out feature in the CDC 6600 monitor). 2500 ev/wk with THRESH on line. The SMP are used for scanning and measurement.</td>
</tr>
<tr>
<td>Paris, France</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Institut fur Hochenergiephysik</td>
<td>SMP (5)</td>
<td>CDC 3300 linked to CDC 6600</td>
<td>C. Ouannes</td>
<td>1964</td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td>Berlin, Germany</td>
<td>IEP (6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Installing (ZMP 2, ZMP 3)</td>
<td></td>
</tr>
<tr>
<td>Johns Hopkins University</td>
<td>PEPR</td>
<td>Sigma 7</td>
<td>A. Pevsner</td>
<td>8/68</td>
<td>Quasi-production</td>
<td>PEPR as per Astodata (MIT).</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Dubna, USSR</td>
<td>HPD</td>
<td>CDC 1604 A</td>
<td>V. Shigaev</td>
<td>1967</td>
<td>Development</td>
<td>Bubble chamber film, HPD-1604 A connection made 10/68.</td>
</tr>
<tr>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
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<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Joint Institute for Nuclear Research* Dubna, USSR (Contd.)</td>
<td>PUOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Three PUOS hand-measuring projectors in production with MINSK 22. First of a group of PUOS is connected to BESM 4.</td>
</tr>
<tr>
<td>Liverpool, University of Liverpool, U.K.</td>
<td>Sogenique FSD MK2</td>
<td>IBM 360/65</td>
<td>W. H. Evans</td>
<td>1/68</td>
<td>Production</td>
<td>Full road guidance system used with FSD.</td>
</tr>
<tr>
<td>Maryland, University of</td>
<td>PEPR PDP 10</td>
<td></td>
<td>T. B. Day R. G. Glasser</td>
<td>Mid-68</td>
<td>Hardware works. Software not yet.</td>
<td></td>
</tr>
<tr>
<td>Massachusetts Institute of Technology*</td>
<td>PEPR PDP 6</td>
<td></td>
<td>I. A. Pless</td>
<td>1961</td>
<td>Production</td>
<td>Two PEPR's; one is a prototype, one is Astrodata production model. Three-view PEPR under development.</td>
</tr>
<tr>
<td>Max-Planck Institut Munich, Germany</td>
<td>ENETRA Vanguard (2)</td>
<td>IBM 7090</td>
<td>K. Gottstein J. Seyerlein</td>
<td>1966</td>
<td>Production</td>
<td>PDP 8, 8K 12-bit memory with IBM compatible magnetic tape format control; fiducial mark distance check; sequencing program; circle fit in film plane; sagitta check; and simple space check.</td>
</tr>
<tr>
<td>Melbourne, University of Victoria, Australia</td>
<td>SLEEPNIK PDP 15</td>
<td>IBM 7044</td>
<td>A. G. Klein</td>
<td>3/69</td>
<td>Nearing completion</td>
<td>Semi-automatic, SLEEPNIK-type. This development is based on the Cavendish Laboratory SLEEPNIK MK1 and incorporates improvements in the electronics and film handling.</td>
</tr>
<tr>
<td>Michigan State University</td>
<td>IPD's</td>
<td>CDC 3600 CDC 6500</td>
<td>G. A. Smith</td>
<td>9/67</td>
<td>Production</td>
<td>Off-line batch processing at central computing lab. Four machines in production. 175 K events/year.</td>
</tr>
<tr>
<td>National Accelerator Laboratory Batavia, Illinois</td>
<td>IPD (2) FPD (1)</td>
<td>PDP 9-L</td>
<td>R. Hanft</td>
<td>1970</td>
<td>Measuring</td>
<td>4-view device.</td>
</tr>
<tr>
<td></td>
<td>POLLY PDP-10</td>
<td></td>
<td></td>
<td></td>
<td>Construction</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
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<td>-----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>New York, State University of, at Stony Brook</td>
<td>PEPR</td>
<td>PDP 7/9 + IBM 360/50</td>
<td>R. T. Van de Walle</td>
<td>Mid-67</td>
<td>Operational (hardware and software)</td>
<td>First ~ 500 tracks measured and reconstructed (5&quot; CRT).</td>
</tr>
<tr>
<td>Nijmegen, University of the Netherlands</td>
<td>Hermes Jr. (2)</td>
<td>DDP-124</td>
<td>V. P. Kenney</td>
<td>1967</td>
<td>Production</td>
<td>All film plane machines operating on line. Interface and software ready for 6 machines.</td>
</tr>
<tr>
<td>Notre Dame, University of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fiducial and vertex reconstruction, sequencing, etc. Job table for each machine.</td>
</tr>
<tr>
<td>IPD</td>
<td>PEPR II (5)</td>
<td>PDP 6 (part)</td>
<td>P. G. Davey</td>
<td>1966</td>
<td>Production (all except PEPR II: 1969)</td>
<td>1969 throughput ~ 150 K events.</td>
</tr>
<tr>
<td>Oxford, University of U.K.</td>
<td>PEPR I (5)</td>
<td>DDP-516 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-ps (5) IPD</td>
<td>PDP 6 (part)</td>
<td>PDP 8 (2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(all control)</td>
<td>(processing)</td>
<td>(all control)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SEE: Institut de Physique</td>
<td>IBM 360/65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nucleaire</td>
<td>PATR</td>
<td>PDP 7</td>
<td>M. E. Sekely</td>
<td>1/66</td>
<td>Operational (PATR)</td>
<td>PDP 7 is for control and pattern recognition; PDP 1 for analysis biology scanner and tapes.</td>
</tr>
<tr>
<td>Princeton University</td>
<td>PDP 1</td>
<td>PDP 7</td>
<td></td>
<td>3/70</td>
<td>Testing (PATR)</td>
<td>CRT bar or point scan, undistorting optical system, 3-view and variable stroke film drive.</td>
</tr>
<tr>
<td>Palmer Laboratory</td>
<td></td>
<td>(PATR)</td>
<td></td>
<td></td>
<td>Operational (PATR)</td>
<td>1500 frames/hour. SC throughput achieved. Bioscan for on-line processing of x-ray diffraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(bioscan)</td>
<td></td>
<td></td>
<td>Testing (bioscan)</td>
<td>patterns.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(bioscan)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
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</tr>
<tr>
<td>Purdue University</td>
<td>SMP (5)</td>
<td>IBM 360/40</td>
<td>F. J. Loeffler</td>
<td>1968</td>
<td>Production</td>
<td>Control of measuring and data input through/40. Filter and on-line TVGP on/44. 183 K events through TVGP in calendar 1969.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IBM 360/44 (coupled)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>NRI microscopes (2)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(film plane digitizers)</td>
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<tr>
<td>Rochester, University of</td>
<td>FPD (2)</td>
<td>PDP 1</td>
<td>T. Ferbel</td>
<td></td>
<td>Production</td>
<td>PDP 1/PDP 8 on line to two FPD's, two IPD's going on line soon. When fully manned, on average, system has ~ 50 events/shift/machine output.</td>
</tr>
<tr>
<td></td>
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<td>PDP 8</td>
<td>F. Slattery</td>
<td></td>
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<tr>
<td>Rutgers University</td>
<td>PEPR</td>
<td>PDP 6</td>
<td>R. Plano</td>
<td>11/68</td>
<td>Development (software)</td>
<td>Hardware and software installed.</td>
</tr>
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<tr>
<td></td>
<td>IPD (2)</td>
<td>PDP 6</td>
<td></td>
<td>6/65</td>
<td>Full operation</td>
<td>Complete logical checking.</td>
</tr>
<tr>
<td></td>
<td>(data tech.) and</td>
<td></td>
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<tr>
<td></td>
<td>Vanguard (2)</td>
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<tr>
<td>Rutherford Laboratory</td>
<td>HPD I</td>
<td>DDP 224 and IBM 360/75</td>
<td>A. J. Oxley</td>
<td>1960</td>
<td>Production</td>
<td>3000-5000 events/week.</td>
</tr>
<tr>
<td>Chilton, U.K.</td>
<td></td>
<td>IBM 360/75</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>HPD II</td>
<td>DDP 516 and IBM 360/75</td>
<td>J. W. Burren</td>
<td></td>
<td>Development</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>IBM 360/75</td>
<td></td>
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<tr>
<td></td>
<td>CYCLOPS</td>
<td>DDP 224 and IBM 360/75</td>
<td>J. Sparrow</td>
<td>1964</td>
<td>Production</td>
<td>20000-35000 events/week.</td>
</tr>
<tr>
<td></td>
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<td>IBM 360/75</td>
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<tr>
<td></td>
<td>IPD (10)</td>
<td>IBM 1130</td>
<td>J. F. McEwan</td>
<td>1969</td>
<td>Production</td>
<td>Figures not yet available.</td>
</tr>
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<tr>
<td></td>
<td>Tektronix 611</td>
<td>DDP 516</td>
<td>R. Rosner</td>
<td>1/70</td>
<td>Construction</td>
<td>Scopes with keyboards and trackerballs. Will be connected to 360/75. HPD spark-chamber data from magnetic tape. 40 ev/hr for events with 2 V0's.</td>
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<tr>
<td>Saclay, France</td>
<td>HPD (3)</td>
<td>BESM-6</td>
<td>A. Ivanov</td>
<td>1970</td>
<td>Installation</td>
<td>3 HPD's planned, one at Radio-technical Institute, Moscow. Spiral Reader from SAAB.</td>
</tr>
<tr>
<td>SEE: CEN</td>
<td>Spiral Reader</td>
<td>BESM-4</td>
<td>M. Popov</td>
<td></td>
<td></td>
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<tr>
<td>Serpukhov, USSR</td>
<td></td>
<td>ICL-1903A</td>
<td>Hardware</td>
<td></td>
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<tr>
<td>Inst. of H. E. Physics</td>
<td></td>
<td>ICL-1906A</td>
<td>P. Gorishhev</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>(Software)</td>
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<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
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<tr>
<td>SLAC (Stanford Linear Accelerator Center)</td>
<td>Hummingbird</td>
<td>IBM 360/91</td>
<td>J. L. Brown</td>
<td>9/65</td>
<td>Production for SC. Development for BC.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spiral reader</td>
<td>PDP 9</td>
<td></td>
<td>11/67</td>
<td>Production</td>
<td>Since Jan. 1970 the SLAC spiral reader had processed 45,000 events. Mechanical hardware constructed at LRL, Berkeley electronics and software developed at SLAC.</td>
</tr>
<tr>
<td></td>
<td>NRI</td>
<td>ASI 6020</td>
<td></td>
<td>1966</td>
<td>Production</td>
<td>Conventional on-line system for six NRI measuring machines. Controls stage motion, etc. and performs data checks.</td>
</tr>
<tr>
<td>Stockholm, University of Danish-Swedish Project Stockholm, Sweden</td>
<td>SAAB spiral reader</td>
<td>PDP 9 + CDC 3600</td>
<td>J. E. Hooper</td>
<td>1/68</td>
<td>Hardware ordered for 9/69.*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENETRA</td>
<td>CDC 8090 (control)</td>
<td>G. Blomquist</td>
<td></td>
<td>Development</td>
<td>Modification of CERN modification of Berkeley spiral reader.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>U. Svedin</td>
<td>Mid-68</td>
<td></td>
<td>For manual measurements.</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>P. O. Vlieth</td>
<td></td>
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</tr>
<tr>
<td>SUNY at Stony Brook* (State University of N.Y.)</td>
<td>SMP (2)</td>
<td>PDP 8</td>
<td>J. A. Cole</td>
<td></td>
<td>Testing (1968)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technische Hochschule Aachen, Germany</td>
<td>FPD (6)</td>
<td>PDP 6</td>
<td>M. Deutschmann</td>
<td>1965</td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td>SOM ENETRA</td>
<td>IBM 1130 (control)</td>
<td>A. Werbrouck</td>
<td>1/68</td>
<td>Production</td>
<td>Working to connect another IPD and another FPD.</td>
</tr>
<tr>
<td>Torino University</td>
<td>IPD</td>
<td>IBM 360/44 (processing)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Torino, Italy</td>
<td>Coordinatograph</td>
<td>FPD</td>
<td></td>
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</tr>
<tr>
<td>Toronto, University of Toronto, Canada</td>
<td>Manual meas. machines (3)</td>
<td>CDC 1700</td>
<td>E. C. West</td>
<td>12/66</td>
<td>Production</td>
<td>Produces 60000-65000 events/year.</td>
</tr>
<tr>
<td>Toronto, University of Toronto, Canada</td>
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<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
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<tr>
<td>Toronto, University of Toronto, Canada (Contd.)</td>
<td>POLLY</td>
<td>360/65 + 7094</td>
<td></td>
<td>11/68</td>
<td>Development</td>
<td>POLLY project moving slowly; needs financial support.</td>
</tr>
<tr>
<td>Vienna (Inst. for HEP) Vienna, Austria</td>
<td>Spiral reader (SAAB) IEPS (2)</td>
<td>PDP 9 (on line) CDC 3300 (filtering)</td>
<td>H. Wahl I. Wacek</td>
<td>12/70</td>
<td>Waiting to start</td>
<td>Work done in connection with Danish-Swedish Spiral Reader Project. Possible combination of SR with SWEEPNIK facilities.</td>
</tr>
<tr>
<td>Weizmann Institute Rehovoth, Israel</td>
<td>Spiral reader IEP Vanguard TMP (TV meas. projector)</td>
<td>PDP 9 GOLEM (2) CDC 1604 A CDC 6600 – to be installed</td>
<td>Y. Eisenberg G. Yekutieli</td>
<td>10/67</td>
<td>Production</td>
<td>Throughput: Hand-measuring devices — ~ 50,000 events/year. Spiral reader – 200,000 during the next 12 months. By 1972 we should reach 400,000/year. Current measuring rate: 60 events/hour. Hardware by Berkeley. The GOLEM is a general purpose home-made computer, roughly equal to the CDC 3400. The CDC 6600 should be installed by end 1970.</td>
</tr>
<tr>
<td>Wisconsin, University of</td>
<td>HPD (SATR) Manual meas. machines (15) (on line)</td>
<td>SCC 4700 CDC 924</td>
<td>M. A. Thompson D. Brown</td>
<td>1966 1963</td>
<td>Development Operating</td>
<td>HPD has 4 film gates plus a fifth gate for test strips. Recognition is done in 3 dimensions by special hardware. Have digitized film, constructing recognition hardware. Scientific Control Corp. 4700 is 24 K. 16 bits; will also use an 1108. 924 does circle fits and handles film from 15 different experiments and chambers. 16 k and 24 bits.</td>
</tr>
<tr>
<td>Installation</td>
<td>Machine(s)</td>
<td>Computer(s)</td>
<td>Contact</td>
<td>Started</td>
<td>Current State</td>
<td>Comments</td>
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</tr>
<tr>
<td>Wisconsin, University of (Contd.)</td>
<td>Manual meas. (3) (on line)</td>
<td>PDP 8</td>
<td>L. Pondron</td>
<td>1969</td>
<td>Operating</td>
<td>Intended mostly for spark chamber film.</td>
</tr>
<tr>
<td>Yale University</td>
<td>PEPR</td>
<td>PDP 6</td>
<td>D. Bogert</td>
<td>6/64</td>
<td>Operational</td>
<td>PDP 6 is 48 K, 36-bit words.</td>
</tr>
<tr>
<td></td>
<td>Predigitizing tables (6)</td>
<td>PDP 1</td>
<td>T. Ludlam</td>
<td>8/69</td>
<td>Operational</td>
<td>Magnetostrictive tables on-line to a PDP 1 computer (16 K, 18-bit words). Least count 100 $\mu$ on table.</td>
</tr>
<tr>
<td>Zeeman Laboratory</td>
<td>ENETRA FPD (3) (on line)</td>
<td>CDC 3200</td>
<td>A. G. C. Tenner</td>
<td>9/64</td>
<td>Production</td>
<td></td>
</tr>
<tr>
<td>Amsterdam, The Netherlands</td>
<td>HPD II A</td>
<td></td>
<td>D. Harting</td>
<td>6/66</td>
<td>Production</td>
<td>HPD is in production but minimum guidance chain has still to be optimized.</td>
</tr>
</tbody>
</table>
LIST OF PARTICIPANTS
ANDERS, Mr. H., DD Division, CERN, 1211 GENEVE 23, Switzerland.

ANTOINE, Mr. P., Institut de Physique Nucléaire, Tour 32, 9 quai St. Bernard, 75 - PARIS V, France.

ATHERTON, Dr. A.R., Cavendish Laboratory, CAMBRIDGE, UK.

BACON, Dr. T.C., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

BAIRSTOW, Mr. R., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

BALTAY, Prof. C., Department of Physics, Columbia University, NEW YORK, N.Y. 10027, USA.

BEALE, Dr. J.S., NP Division, CERN, 1211 GENEVE 23, Switzerland.

BERGE, Dr. J.P., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK.

BILLING, Prof. Dr. H., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Föhringer Ring 6, Germany.

BINST, Mr. P. van, Service de Physique Nucléaire A, Université Libre de Bruxelles, avenue F.D. Roosevelt 50, B - 1050 BRUXELLES, Belgium.

BIZEAU, Mr. C., Laboratoire de Physique, Ecole Polytechnique, 17 rue Descartes, 75 - PARIS V, France.

BLAIR, Dr. W.M.R., TC Division, CERN, 1211 GENEVE 23, Switzerland.

BLOBEL, Dr. V., II. Institut für Experimentalphysik, 2000 HAMBURG 50, Luruper Chaussee 149, Germany.

BLOCH, Dr. M., Institut de Physique Nucléaire, 9 Quai St. Bernard, 75 - PARIS V, France.

BLOMQVIST, Mr. G., Institute of Physics, University of Stockholm, Vanadisvägen 9, STOCKHOLM VA, Sweden.

BÖCK, Dr. R.K., TC Division, CERN, 1211 GENEVE 23, Switzerland.

BROOKES, Dr. G.R., Department of Physics, The Hicks Building, University of Sheffield, SHEFFIELD, S3 7RH, UK.

BROOKS, Mr. C.B., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3 RH, UK.
BROWN, Prof. R.M., Department of Physics, University of Illinois, URBANA, Illinois 61801, USA.

BROWNING, Dr. G.K.S., Department of Natural Philosophy, University of Glasgow, GLASGOW, W.2., UK.

BRYDEN, Dr. A.D., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

BULLOCK, Dr. F.W., Department of Physics, University College London, Gower Street, LONDON, W.C.1., UK.

BURD, Mr. D., Department of Physics, Columbia University, Box 98, Pupin Hall, NEW YORK, N.Y. 10027, USA.

BURMEISTER, Dr. H., TC Division, CERN, 1211 GENEVE 23, Switzerland.

BURREN, Mr. J., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

CARTER, Dr. A.A., Cavendish Laboratory, CAMBRIDGE, UK.

CENTRO, Dr. A., Istituto di Fisica Galileo Galilei, Via F. Marzolo 8, 35100 PADOVA, Italy.

CHARLTON, Dr. G.R., High Energy Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, ARGONNE, Illinois 60439, USA.

CIAPETTI, Dr. G., Istituto Nazionale di Fisica Nucleare, Piazzale delle Scienze 5, 00185 ROMA, Italy.

CLAYTON, Dr. J.A., Oliver Lodge Laboratory, University of Liverpool, Oxford Street, LIVERPOOL, L69 3BX, UK.

COLE, Dr. J.A., Department of Physics, State University of New York at Stony Brook, STONY BROOK, N.Y. 11790, USA.

COLLINS, Mr. M.W., Daresbury Nuclear Physics Laboratory, Daresbury, WARRINGTON, Lancs., UK.

CRESTI, Dr. M., Istituto di Fisica Galileo Galilei, Via F. Marzolo 8, 35100 PADOVA, Italy.

DAVEY, Mr. P.G., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK.

DAVIDIAN, Mr. M., Laboratoire de Physique Nucléaire, Collège de France, 11 Place Marcelin Berthelot, PARIS V, France.

DEERY, Dr. B.J., Fysisch Laboratorium, Katholieke Universiteit, Driehuizerweg 200, NIJMEGEN, Netherlands.

DEGRANGE, Dr. B., Laboratoire de Physique, Ecole Polytechnique, 17 rue Descartes, 75 - PARIS V, France.
DEL GUERRA, Dr. A., Istituto Nazionale di Fisica Nucleare, Piazza Torricelli 2, 56100 PISA, Italy.

DELER, Dr. B., Département de Physique des Particules Elémentaires, CEN-Saclay, B.P. No. 2, 91 - GIF-sur-YVETTE, France.

DEUTSCHMANN, Prof. Dr. M., III. Physikalisches Institut, Rhein.-Westf. Technischen Hochschule, 51 AACHEN, Charlottenstr. 14, Germany.

DORNAN, Dr. P.J., Department of Physics, Imperial College of Science and Technology, Prince Consort Road, LONDON, S.W.7., UK.

EDWARDS, Dr. M., Daresbury Nuclear Physics Laboratory, Daresbury, WARRINGTON, Lancs., UK.

EQUER, Mr. B., Laboratoire de Physique Nucléaire, Collège de France, 11 Place Marcelin Berthelot, PARIS V, France.

ERBE, Mr. R., IBM Deutschland, Wissenschaftliches Zentrum Heidelberg, 6900 HEIDELBERG, Tiergartenstrasse 15, Germany.

FAISSNER, Prof. H., Rheinisch-Westfälischen Technischen Hochschule, Templergraben 55, 51 AACHEN, Germany.

FERRAN, Mr. P.M., DD Division, CERN, 1211 GENEVE 23, Switzerland.

FORTNEY, Dr. L., Department of Physics, Duke University, DURHAM, North Carolina 27706, USA.

FRANK, Mr. C., Département de Physique des Particules Elémentaires, CEN-Saclay, B.P. No. 2, 91 - GIF-sur-YVETTE, France.

FRESE, Mr. H., Deutsches Elektronen-Synchrotron, 2 HAMBURG 52, Notkestieg 1, Germany.

FREUND, Mr. P., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Föhringer Ring 6, Germany.

FRISCH, Prof. O.R., Cavendish Laboratory, CAMBRIDGE, UK.

GAMBA, Dr. D., Istituto di Fisica, Università di Torino, Via P. Giuria 1, TORINO, Italy.

GARIC, Mme B., Institut de Physique Nucléaire, 9 Quai St. Bernard, 75 - PARIS V, France.

GEISSLER, Dr. K.K., TC Division, CERN, 1211 GENEVE 23, Switzerland.

GOLDWASSER, Mr. M., Département de Physique des Particules Elémentaires, CEN-Saclay, B.P. No. 2, 91 - GIF-sur-YVETTE, France.

GOUACHE, Dr. J.C., TC Division, CERN, 1211 GENEVE 23, Switzerland.
GRANSTRÖM, Mr. L., Danish-Swedish Spiral Reader Project, Fysiska Institutionen, Vanadisvägen 9, STOCKHOLM 23, Sweden.

GRARD, Dr. F., Institut Interuniversitaire des Sciences Nucléaires, 4 rue Hobbema, 1040 BRUXELLES, Belgium.

GRIMM, Mr. H.J., Institut für Hochenergiephysik, Albert-Überlestrasse 2, 69 HEIDELBERG, Germany.

GROTE, Dr. H., DD Division, CERN, 1211 GENEVE 23, Switzerland.

GUIGNARD, Dr. C., T.I.T.N., 28 rue Maurice-Tenine, 94 - FRESNES, France.

HANERFELD, Dr. H., Département de Physique des Particules Elémentaires, CEN-Saclay, B.P. No. 2, 91 - GIF-sur-YVETTE, France.

HARRIS, Mr. J.F., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK.

HEUGHEBAERT, Dr. J., Laboratoire Interuniversitaire Belge des Hautes Energies, 4 rue Hobbema, 1040 BRUXELLES 4, Belgium.

HOCHWELLER, Mr. G., Deutsches Elektronen-Synchrotron, 2000 HAMBURG 52, Notkestieg 1, Germany.

HODGES, Mr. D., Applied Mathematics Division, Argonne National Laboratory, 9700 South Cass Avenue, ARGONNE, Illinois 60439, USA.

HÖHNE, Dr. K., Deutsches Elektronen-Synchrotron, 2 HAMBURG 52, Notkestieg 1, Germany.

HOLTHUIZEN, Dr. D.J., Zeeman-Laboratorium, Plantage Muidergracht 4, AMSTERDAM-C, Netherlands.

HOOPER, Dr. J.E., Danish-Swedish Spiral Reader Project, Fysiska Institutionen, Vanadisvägen 9, STOCKHOLM 23, Sweden.

HULTH, Mr. P.O., Fysiska Institutionen, Kungl. Universitetet, Vanadisvägen 9, STOCKHOLM VA, Sweden.

HUYBRECHTS, Dr. M., Institut Interuniversitaire des Sciences Nucléaires, rue d'Egmont 11, 1050 BRUXELLES, Belgium.

JARLSKOG, Dr. G., Lunds Universitet, Fysiska Institutionen, Synkrotronavdelningen, Solvegatan 14, LUND, Sweden.

JOHNSTAD, Mr. H., Niels Bohr Institutet, Blegdamsvej 17, 2100 KØBENHAVN Ø, Denmark.

KALOGEROPoulos, Dr. T.E., Physics Division, Greek Atomic Energy Commission, Nuclear Research Center "Democritos", Aghia Paraskevi-Attikis, ATHENS, Greece.
KATZ, Mr. A., Département de Physique des Particules Elémentaires, CEN-Saclay, B.P. No. 2, 91 - GIF-sur-YVETTE, France.

KATVARS, Mr. S.G., Cavendish Laboratory, CAMBRIDGE, UK.

KEPPEL, Mr. E., IBM Deutschland, Wissenschaftliches Zentrum Heidelberg, 6900 HEIDELBERG, Tiergartenstrasse 15, Germany.

KLEIN, Mr. A.G., School of Physics, University of Melbourne, Parkville, VICTORIA 3052, Australia.

KOWARSKI, Dr. L., Applied Physics Division, CERN, 1211 GENEVE 23, Switzerland.

KROPP, Mr. D., IBM Deutschland, Wissenschaftliches Zentrum Heidelberg, 6900 HEIDELBERG, Tiergartenstrasse 15, Germany.

KUHLMANN, Mr. P.E., Deutsches Elektronen-Synchrotron, 2000 HAMBURG 52, Notkestieg 1, Germany.

LAMBERT, Mr. P.G., Daresbury Nuclear Physics Laboratory, Daresbury, WARRINGTON, Lancs., UK.

LARICCIA, Dr. P., Istituto Nazionale di Fisica Nucleare, Piazza Torricelli 2, 56100 PISA, Italy.

LASSALLE, Mr. J.C., DD Division, CERN, 1211 GENEVE 23, Switzerland.

LEEUWEN, Dr. W.M. van, Zeeman-Laboratorium, Plantage Muidergracht 4, AMSTERDAM-C, Netherlands.

LOKEN, Dr. J.G., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK. (On leave from Argonne National Laboratory.)

LORD, Mr. D.H., DD Division, CERN, 1211 GENEVE 23, Switzerland.

LÜERS, Dr. D., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Föhringer Ring 6, Germany.

LUVISETTO, Dr. Maria L., Centro Nazionale Analisi Fotogrammi, Via Mazzini 2, 40138 BOLOGNA, Italy.

MCKENZIE, Dr. J., Department of Physics, University College London, Gower Street, LONDON, W.C.1., UK.

MACLEOD, Dr. G.R., DD Division, CERN, 1211 GENEVE 23, Switzerland.

MARBOT, Mr. R., Laboratoire de Physique, Ecole Polytechnique, 17 rue Descartes, 75 - PARIS V, France.

MASSONNET, Mr. L., Institut de Physique Nucléaire, B.P. No. 1, 91-ORSAY, France.
MOORHEAD, Mr. W.G., DD Division, CERN, 1211 GENEVE 23, Switzerland.

MULVEY, Dr. J.H., Nuclear Physics Department, Oxford University, Keble Road, OXFORD OX1 3 RH, UK.

NAGEL, Dr. H.H., Physikalisches Institut, 53 BONN 1, Mulfassallee 12, Germany.

NEALE, Dr. W.W., Cavendish Laboratory, CAMBRIDGE, UK.

OSMON, Dr. P.E., Department of Physics, Westfield College, LONDON N.W.3., UK.

OUannes, Dr. C., Institut de Physique Nucléaire, 9 Quai St. Bernard, 75 - PARIS V, France.

OXLEY, Dr. A., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

PALANDRI, Dr. E., DD Division, CERN, 1211 GENEVE 23, Switzerland.

Palfrey, Prof. T.R., Department of Physics, Purdue University, LAFAYETTE, Indiana 47907, USA.

PasSeneau, Mr. J., Institut de Physique Nucléaire, Tour 32, 9 Quai St. Bernard, 75 - PARIS V, France.

Penney, Mr. B.K., Department of Physics, Imperial College of Science and Technology, Prince Consort Road, LONDON, S.W.7., UK.

Perl, Prof. M.L., Stanford Linear Accelerator Center, P.O. Box 4349, STANFORD, California 94305, USA. (At present at Westfield College, London, N.W.3., UK.)

Peruzzo, Dr. L., Istituto di Fisica Galileo Galilei, Via F. Marzolo 8, 35100 PADOVA, Italy.

PetmezAs, Mr. G., Daresbury Nuclear Physics Laboratory, Daresbury, WARRINGTON, Lancs., UK.

Phelan, Dr. J., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

Pierazzini, Dr. G., Istituto Nazionale di Fisica Nucleare, Piazza Torricelli 2, PISA, Italy.

Pose, Dr. R., Joint Institute for Nuclear Research, Head Post Office, P.O. Box 79, MOSCOW, USSR. (On leave from Institut für Hochenergiephysik, Zeuthen, East Germany.)

Powell, Dr. B.W., DD Division, CERN, 1211 GENEVE 23, Switzerland.

PrinzE, Mr. M., Control Data France S.A., Tour Nobel, 3 Avenue du Général de Gaulle, 92 - PUTEAUX, France.
QUERCIGH, Dr. E., TC Division, CERN, 1211 GENEVE 23, Switzerland.

RAAYMAKERS, Dr. M., Fysich Laboratorium, Katholieke Universiteit, Driehuizerweg 200, NIJMEGEN, Netherlands.

RAMBALDI, Dr. Annette, Istituto Nazionale di Fisica Nucleare, Piazzale delle Scienze 5, 00185 ROMA, Italy.

RAUBOLD, Dr. E., Deutsches Elektronen-Synchrotron, 2000 HAMBURG 52, Notkestieg 1, Germany.

READ, Dr. E.J.C., Department of Physics, University of Liverpool, Oxford Street, LIVERPOOL, L69 3BX, UK.

REBOUL, Mr. G., Laboratoire de Physique Nucléaire, Collège de France, 11 Place Marcelin Berthelot, PARIS V, France.

RILEY, Dr. K.F., Cavendish Laboratory, CAMBRIDGE, UK.

RIIPINEN, Mr. E., Department of Nuclear Physics, University of Helsinki, Siltavourenpenger 20, HELSINKI, Finland. (At present at TC Division, CERN.)

ROBINSON, Dr. C.J., Department of Natural Philosophy, University of Glasgow, GLASGOW, W.2., UK.

ROMANO, Dr. F., Istituto di Fisica, University of Bari, Via Amendola 173, 70126 BARI, Italy.

ROSNER, Dr. R.A., Rutherford High Energy Laboratory, Chilton, DIDCOT, Berks., UK.

ROSSO, Dr. E., TC Division, CERN, 1211 GENEVE 23, Switzerland.

ROYSTON, Mr. R.J., Scientific Control Systems Ltd., 49-57 Berners Street, LONDON W.1., UK.

ROZOV, Dr. R., Moscow Institute for Engineering in Physics, Kashirskoe shosse 1, MOSCOW, M-709, USSR.

RÜDIGER, Mr. A., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Föhringer Ring 6, Germany.

RUMPF, Mme M., Institut de Physique Nucléaire, 9 Quai St. Bernard, 75 - PARIS V, France.

RUSHBROOKE, Dr. J.G., Cavendish Laboratory, CAMBRIDGE, UK.

RUST, Dr. D., High Energy Physics Division, Argonne National Laboratory, 9700 South Cass Avenue, ARGONNE, Illinois 60439, USA.

SCHILLING, Mr. R., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Föhringer Ring 6, Germany.
SCHMITZ, Mr. P., III. Physikalisches Institut, Rhein.-Westf. Technischen Hochschule, 51 AACHEN, Charlottenstrasse 14, Germany.

SCHNEIDER, Dr. H., Institut für Hochenergiephysik, Albert-Uberle-Str. 2, 69 HEIDELBERG, Germany.

SHKUNDEKOV, Dr. V.N., DD Division, CERN, 1211 GENEVE 23, Switzerland. (On leave from JINR, Moscow.)

SEKELY, Mr. M.E., Princeton-Pennsylvania Accelerator, 116 Chemical Sciences Bldg., P.O. Box 682, PRINCETON, N.J. 08540, USA.

SEYERLEIN, Dr. J., Max-Planck-Institut für Physik und Astrophysik, 8 MÜNCHEN 23, Führinger Ring 6, Germany.

SHAYLOR, Mr. H.R., Department of Physics, University of Birmingham, P.O. Box 363, BIRMINGHAM 15, UK.

SIMMONS, Dr. J., Department of Physics, University of Birmingham, P.O. Box 363, BIRMINGHAM 15, UK.

SLATER, Dr. W.E., Department of Physics, University of California, LOS ANGELES, California 90024, USA.

SLETTEN, Mr. H.I., TC Division, CERN, 1211 GENEVE 23, Switzerland.

SMALL, Mr. P.W., Cavendish Laboratory, CAMBRIDGE, UK.

SMITH, Prof. A.J.S., Department of Physics, P.O. Box 708, Princeton University, PRINCETON, New Jersey 08540, USA.

SMITH, Dr. I.L., Daresbury Nuclear Physics Laboratory, Daresbury, WARRINGTON, Lancs., UK.

SMITH, Dr. K.M., Department of Natural Philosophy, University of Glasgow, GLASGOW, W.2., UK.

SPINETTI, Dr. M., Istituto Nazionale di Fisica, FRASCATI, Italy.

STEIN, Dr. J., III. Physikalisches Institut, Jägerstrasse, 51 AACHEN, Germany.

STENGGER, Dr. V.J., Department of Physics and Astronomy, 2565 The Mall, University of Hawaii, HONOULULU, Hawaii 96822, USA. (At present at the Institut für Hochenergiephysik, 69 Heidelberg, Germany.)

STREET, Dr. G.S.B., Cavendish Laboratory, CAMBRIDGE, UK.

SVEDIN, Mr. U., Fysiska Institutionen, Kungl. Universitetet, Vanadisvägen 9, STOCKHOLM, Sweden.

SWETMAN, Dr. T.P., Cavendish Laboratory, CAMBRIDGE, UK.
THOMPSON, Dr. M.A., Department of Physics, University of Wisconsin, 475 North Charter Street, MADISON, Wisconsin 53706, USA.

TOWNSEND, Mr. D.W., Department of Physics, Westfield College, 29 Kidderpore Avenue, LONDON, N.W.3., UK.

TREMBLEY, Mr. J., TC Division, CERN, 1211 GENEVE 23, Switzerland.

VAISSIERE, Mr. Ch. de La, Institut de Physique Nucléaire, 9 Quai St. Bernard, 75 - PARIS V, France.

VENTURI, Mr. D., Centro Nazionale Analisi Fotogrammi, Via Mazzini 2, 40158 BOLOGNA, Italy.

VERKERK, Mr. C., DD Division, CERN, 1211 GENEVE 23, Switzerland.

VILLEMOS, Mr. P., DD Division, CERN, 1211 GENEVE 23, Switzerland.

VOVENKO, Dr. A., NP Division, CERN, 1211 GENEVE 23, Switzerland. (On leave from JINR, Moscow.)

WAHL, Dr. H., Institut für Hochenergiephysik, A-1050 WIEN, Nikolsdorfergasse 18, Austria.

WALLE, Prof. Dr., R.T. van de, Fysisch Laboratorium, Katholieke Universiteit, Driehuizerweg 200, NIJMEGEN, Netherlands.

WATTS, Dr. T.L., Laboratory for Nuclear Science, Massachusetts Institute of Technology, CAMBRIDGE, Mass. 02139, USA.

WEBSDALE, Dr. D., NP Division, CERN, 1211 GENEVE 23, Switzerland.

WENNINGER, Mr. H., TC Division, CERN, 1211 GENEVE 23, Switzerland.

WERBROUCK, Dr. A., Istituto di Fisica, Università di Torino, Via P. Giuria 1, TORINO 10125, Italy.

WEST, Dr. E.C., Department of Physics, University of Toronto, TORONTO 5, Ontario, Canada.

WESTWOOD, Dr. B., Cavendish Laboratory, CAMBRIDGE, UK.

WHITE, Mr. H.S., Lawrence Radiation Laboratory, University of California, BERKELEY, California 94707, USA.

WILKINSON, Dr. C.A., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK.

WILDER, Mr. S.S., Nuclear Physics Department, Oxford University, Keble Road, OXFORD, OX1 3RH, UK.

WILLIAMS, Dr. Janet, Cavendish Laboratory, CAMBRIDGE, UK.
WINSTON, Dr. R., The Enrico Fermi Institute for Nuclear Studies, University of Chicago, 5630 South Ellis Avenue, CHICAGO, Illinois 60637, USA.

WISKOTT, Dr. D., DD Division, CERN, 1211 GENEVE 23, Switzerland.

WOHLMUT, Mr. P.G., Department of Physics and Astronomy, 2565 The Mall, University of Hawaii, HONOLULU, Hawaii 96822, USA.

WORTHINGTON, Mr. R.G., Department of Physics, University College, Gower Street, LONDON, W.C.1., UK.

ZANELLA, Dr. P., DD Division, CERN, 1211 GENEVE 23, Switzerland.

ZOLL, Dr. J., TC Division, CERN, 1211 GENEVE 23, Switzerland.