A SONIC SPARK CHAMBER SYSTEM

by

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ABSTRACT

This report contains a detailed description of a sonic spark chamber system used for measurements of proton scattering in the angular region of 2 to 20 mrad, at energies around 20 GeV at the CERN Proton Synchrotron. Up to 12 events per machine cycle could be recorded, the relevant parameters of each event being written on magnetic tape after having been checked by a small computer on-line. All subsequent calculations were done on a large computer off-line.
Acknowledgements

We wish to thank the staff of the CERN 7090 computer for their co-operation, Drs. H. Øverås and I. Pizer for their advice and help, R. Bell for programming assistance, and Professor P. Proiswerk for his constant encouragement.
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CHAPTER I

DESCRIPTION OF THE SYSTEM


1. INTRODUCTION

Spark chambers have become very popular in high-energy physics, because they combine good spatial resolution with reasonable time resolution. The resolution in space is usually better than a millimetre; the time resolution is in the microsecond region. The dead-time can be less than a millisecond, so that, in principle, it is possible to record many events per second with a spark chamber. This feature has been rarely utilized, however, because of the cumbersome method of intermediate data storage customarily used, namely, film. The spark pictures on the film have to be scanned and measured, which is time-consuming when it is done manually. Also the film transport in the camera is a speed-limiting factor.

The development of mechanical or electronic raster scans of the film has speeded up the scanning process appreciably. More speed can be gained by omitting the film completely, as is done in the vidicon system. With this method the spark images are temporarily stored on a vidicon, and via a raster scan their digitized co-ordinates are subsequently written on magnetic tape, which serves as a permanent record.

Other types of spark chambers have been developed, in which the sparks are actually not "seen", but "felt" or "heard". In the wire spark chamber one electrode is replaced by a mesh of closely spaced wires and the co-ordinate of the spark (in one dimension) is given by the wire through which the spark current passed. In the current distribution chamber one of the electrodes is connected to earth via more than one lead, and the distribution of the spark currents over the leads is a measure of the co-ordinate of the spark. In the sonic spark chamber the flight-times of the sound wave, produced by the spark, to a few sound detectors are used to
derive the spark position. In all of these systems, the digitized spark co-ordinates are usually written on magnetic tape, so that the data are immediately accessible for a computer. A description of these various methods, their advantages and disadvantages, can be found in other reports.\textsuperscript{1)}

The advantage of the general increase in speed of these systems is, of course, the increase in the data-taking rate and, even more important, the opportunity for feedback of results while the experiment is running. When a computer connected on-line to a system of digitized spark chambers is used, the time between the occurrence of an event and its complete analysis by the computer may be a small fraction of a second. Also, without a computer on-line, one may have a significant sample of the data analysed off-line within, say, an hour after the events were recorded. The experimenter is therefore continuously in full control of the development of the experiment.

This report describes a system of sonic spark chambers that has been used for measurements of proton scattering in the angular range of 2 to 20 mrad for energies around 20 GeV at the CERN Proton Synchrotron (CPS). The results of these measurements have already been published\textsuperscript{2)}. Some other experiments which made use of sonic spark chambers, are referred to in the references\textsuperscript{3)}. A description of earlier versions of the system under discussion can also be found in the references\textsuperscript{4)}.\textsuperscript{4)}

The remaining part of this chapter gives a short description of the complete system and its performance and the following chapters go deeper into some of the details.

2. EXPERIMENTAL ARRANGEMENT AND PERFORMANCE OF THE SYSTEM

Figure 1 shows the experimental arrangement. An effectively parallel, momentum analysed beam was made from protons diffraction scattered on an internal target in the CPS by means of bending magnets, quadrupole lenses, and collimators. The beam, defined by counters $C_1$, $C_2$, and $C_3$, had a momentum spread $\Delta p/p$ of about $\pm 0.3\%$, an angular divergence of about $\pm 0.15$ mrad and a diameter of 0.5 cm at the external target position.
Proton trajectories were measured by the scintillation counter C₁ and five sonic spark chambers, S₁ to S₅. Momentum analysis before and after the target was provided by two systems of bending magnets. For each event the co-ordinates of the scintillator of counter C₁ and the spark positions in chambers S₁ and S₂ were used to derive the momentum of the proton before the interaction, and similarly the spark positions in chambers S₃, S₄ and S₅ to derive the momentum after the interaction. The geometrical properties of the event, i.e. scattering angle and position of the interaction vertex along the beam, were derived from the measured spark positions in spark chambers S₁, S₂, S₃ and S₄. The coincidence 123456 was used as signature of a scattering event to trigger the spark chambers. The scintillator of counter C₄ defined the solid angle. It had a hole through which the beam passed and which limited the minimum accepted scattering angle (typically to about 2 mrad). Veto counter 6 aided in rejecting unscattered beam particles, and counter 5 gave a very rough momentum selection.

A spark gap switch, triggered by a solid-state trigger unit (see Chapter III), applied the high voltage to each chamber. The spark chambers were made of lucite, with thin foil aluminium plates. Each chamber had two 6 mm gaps filled with a neon-helium mixture. The various sizes of the rectangular sensitive areas are given in Fig. 1. Four piezo-electric transducers (lead-zirconate) were used in each gap, positioned opposite the centres of the sides of the gaps. The distance between transducer and sensitive area was at least 10 cm in order to get away from the shock-wave region around the spark. The spark chamber and transducer construction is described in Chapter II.

The transducers were wedge-shaped in order to obtain a uniform angular response within ± 45°. Under normal operating conditions (10 kV, with ~ 1 nF capacity per gap, and Ne He gas) the output pulses from the transducer had an amplitude greater than 10 mV and their rise-time was less than 1 μsec. After a few μsec the signal was damped out.

A schematic block diagram of the electronics of the system is shown in Fig. 2. A coincidence trigger pulse operated a commander circuit (see Chapter III) which performed the following operations:
i) pulses were generated to trigger the spark chambers;

ii) after a pre-set delay, normally 100 $\mu$sec, a set of gate
generators (one for each transducer) and a 2 kHz/sec clock
were switched on;

iii) any further coincidence trigger pulse was blocked by a
paralysis flip-flop until the event had been transferred
to the computer memory.

The 2 kHz/sec clock was driven from a free running 20 MHz/sec oscillator,
and the method of switching ensured that the timing error of the first clock-
pulse relative to the trigger was not greater than 0.05 $\mu$sec. A fast carry
scaler, counting the 2 MHz/sec clock, provided "half-write" signals for a
magnetic core memory, made up of two units each containing 32 words of 16
bits, 40 words being used in the present experiment. When a signal from a
transducer microphone arrived at the core memory unit, the content of the
fast carry scaler at that instant was written into the appropriate row of
cores. In this manner the flight-times for all 40 transducers were written
into the core memory within 3 msec of receiving the coincidence trigger.
A fuller account of the data acquisition system is given in Chapter IV.

The core memory, together with 12 scalers or parameter units containing
information about the trigger system (i.e. number of incoming particles) and
data needed for book-keeping purposes, were interrogated by a data transfer
unit 4 msec after the coincidence trigger. This transmitted a total of 52
words to the memory of an SDS 920 computer. The computer had a 8 $\mu$sec cycle
time and was equipped with a memory of 4096 words of 25 bits, a typewriter
and two tape units. Because of the interrupt and high speed interlace facili-
ties of the computer, only about 0.5 msec were needed to transfer the 52 words.
After this time the resetting procedure could be initiated to enable the
system to receive a new trigger. However, it was found that the spark chambers
took a longer time to recover their maximum operating efficiency, so that
usually a 20 msec dead-time was used. During a part of this dead-time the
clearing voltage of the chambers was pulsed to about 100 volt (Chapter III),
to speed up clearing the residual ions from the gaps. Because of the length
($\sim 50$ m) of the set-up, the high voltage could be applied to the spark chambers
only after about 0.5 μsec had elapsed following the passage of the particle. Therefore, the chambers had to be sensitive for this length of time, which allowed the use of only a 20 volt quiescent clearing field.

In the computer memory 12 events could be stored, sufficient to record all the events that were produced, in the present experiments, in one burst from the proton synchrotron, which usually lasted about 250 nsec. At the end of the burst the computer was instructed to execute a rough check of the events and subsequently to write them on magnetic tape.

The data-checking programme (see Chapter V) was limited somewhat by the capacity of the computer memory. The programme checked the 40 flight-times to lie within appropriate limits and the sum of the flight-times of opposite pairs of transducers were calculated. The reason for the latter calculation was that a sum smaller than an appropriate limit was a clear indication that more than one spark had occurred in that particular gap. The various types of failures were put into different classes and the occurrence of any particular type of failure a specified number of times was automatically printed out on a typewriter, while a summary of the current status of an experimental run (i.e. number of events and errors) could be obtained on request. In this manner the experimenter was continuously aware of the performance of the experiment and he could quickly make a diagnosis in case of a failure.

The events that passed the checking routines were transferred to magnetic tape in between proton synchrotron acceleration cycles.

The x and y co-ordinates of the sparks were calculated off-line on an IBM 7090 computer from the flight-times as recorded on magnetic tape. A full description of the analysis programme can be found in Chapter VI. Apart from x and y, two other unknowns are involved, namely, the sound velocity v and a parameter ΔT, characterizing the extent of the shock wave around the spark. Since each gap had four transducers, one could solve for these four unknowns. However, it was found that the values of v and ΔT did not change appreciably in a period of a day. Consequently, they were evaluated only occasionally, when analysing the events from a calibration run for which the system was triggered by unscattered particles using the coincidence signature 1235.
These runs were also used for calculating the average co-ordinates of the unscattered beam in each spark chamber. The mean values of $\Delta t$ and $v$ were used as fixed numbers for subsequent scattering runs, in which the equations were solved for only two quantities, $x$ and $y$. The redundant information served for checking, with greater accuracy, that only one spark had occurred in each gap.

Having calculated the spark co-ordinates in each gap, events were accepted or rejected according to pre-set criteria. It was demanded that the $x$ and $y$ values obtained from the two gaps of any chamber should agree within certain limits, and the proton trajectory had to satisfy linearity tests in the vertical plane, both before and after the scattering. From the sets of $x$ and $y$ co-ordinates of the accepted events, the mean position of the unscattered beam and the geometry of the experiment, the calculation of the scattering angles and momenta, and subsequently of the differential cross-sections, were performed.

Systematic errors in the calculated spark positions were quite small. For the small chambers, the error was not more than 0.1 mm, for the medium size chambers two or three times larger. Only for the biggest chamber did the error amount in extreme cases to 1 mm difference between calculated and real track co-ordinates.

The resolution of the system is illustrated by Figs. 3 to 5. Figure 3, which refers to a sample of events recorded at a trigger rate of five events per pulse (dead-time = 50 nsec), shows the distribution of the distance between the two sparks in adjacent gaps when a particle crosses the chamber. It was deduced that the sparks follow the beam track within $\pm 0.3$ mm. The resulting angular and momentum resolution of the system are shown in Figs. 4a and 4b; they amount to about $\pm 0.1$ mrad and $\pm 0.2\%$, respectively.

The high accuracy in position determination allowed the longitudinal co-ordinate of the scattering vertex to be calculated to within about $\pm 10$ cm, as shown in Fig. 5. The events due to scattering in the spark-chamber walls and scintillators that surrounded the target could be clearly distinguished from those due to scattering in the target. The background produced by the target walls was always very small.
A disadvantage of the system described here is that when more than one spark occurs in a gap, no solution for the spark co-ordinates in that gap is possible. To minimize loss of events from this cause, a "rescue" procedure was adopted (see Chapter VI). Events for which only one gap from the first two chambers or from the last three chambers failed to give a solution were calculated on the basis of the co-ordinates in the remaining 10 or 11 gaps, provided that the criteria for the linearity tests were satisfied. Nevertheless, considerable care was necessary in choosing the experimental conditions to minimize loss of events from this cause. Typical running conditions for the present experiment were: a pulse length of 250 nsec, giving 1000 beam particles and 10,000 charged particles through the sensitive area of the spark chambers and five triggers. At 20 GeV/c the repetition rate of the proton synchrotron is $1/2$ sec$^{-1}$. Consequently, it was not difficult to collect 100,000 triggers in one day of running. The 7090 computer could handle 30,000 triggers per hour. Typically, 40% of these triggers were found to be good, 30% could be rescued, and 30% were not usable.

Figure 6 shows a final result in the form of a momentum spectrum of protons scattered on protons, in which the elastic peak and an inelastic continuum can be seen. Figure 7 shows the elastic differential cross-section for 19.3 GeV/c protons scattered from lead and copper in which it is possible to recognize the typical diffraction patterns.
REFERENCES


Purdue Conference on Instrumentation for High-Energy Physics (1965), to be published.


"Absolute measurements of proton-proton small-angle elastic scattering and total cross-sections at 10, 19 and 26 GeV/c".


"Evidence for a 1.40 GeV nucleon resonance from high-energy inelastic proton scattering in hydrogen and deuterium".


"The real part of the proton-neutron scattering amplitude at 19.3 GeV/c".


Figure captions

Fig. 1 : Experimental layout for a typical running condition.

Fig. 2 : A schematic block diagram of the sonic spark chamber electronics.

Fig. 3 : Distribution of the co-ordinate difference $x_1-x_2$ for the two sparks due to a particle passing through the gaps of spark chamber $S_2$.

Fig. 4a) : Angular resolution of the system defined as the distribution of the apparent scattering angle for unscattered particles.

4b) : Momentum resolution of the system, as defined by the difference between in- and outgoing momentum for unscattered protons.

Fig. 5 : Distribution of the longitudinal co-ordinates of the interaction vertices. Hydrogen events are clearly separated from events originating in the spark-chamber walls and the scintillators. All events scattered over an angle larger than about 1.7 mrad are included in this plot.

Fig. 6 : Example of the momentum spectrum of protons scattered in a particular angular interval. The scale for the events indicated by + signs has been divided by a factor 10.

Fig. 7 : Differential elastic cross-sections for protons scattered from lead and copper at 19.3 GeV/c.
EXPERIMENTAL LAY-OUT OF THE SMALL ANGLE PROTON-PROTON SCATTERING EXPERIMENT AT 19 GeV/c

<table>
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<th>Collimators</th>
<th>Counters</th>
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<td>$S_1: 2 \times 2$ cm$^2$</td>
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<td>$S_2: 2 \times 2$ cm$^2$</td>
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<td>$C_3: \phi = 0.5$ cm</td>
<td>$S_3: 5 \times 5$ cm$^2$</td>
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<tr>
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<td>$C_4: 10.5 \times 18$ cm$^2$</td>
<td>$S_4: 20 \times 30$ cm$^2$</td>
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<td></td>
<td>$C_5: 30 \times 50$ cm$^2$</td>
<td>$S_5: 30 \times 50$ cm$^2$</td>
</tr>
<tr>
<td></td>
<td>$C_6: \phi = 3$ cm</td>
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</tr>
</tbody>
</table>

Fig 1
OX-DISTRIBUTION IN GAPS 9, 10. EACH LINE REPRESENTS .010CM.

Fig 3
RESULTS FROM RUNS 61/94 OF TAPE 1231R48 1 OF 21/6/64. COMPUTED ON 9/7/64. RESULTS FROM RUNS 65/95 OF TAPE 1231R48 1 OF 21/6/64. COMPUTED ON 9/7/64.

SCATTER POSITION. TARGET CENTER MARKED *. EACH LINE = 10 CM.

```
1+
2+
3+
4+
6+
10+
11+
12+
13+
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99+
100+
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**H₂ IN** (targel length 65 cm)

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9+
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97+
98+
99+
100+
```

**H₂ OUT**

- Spark chamber
- Window

---

**Fig 5**
RESULTS FROM RUNS 120/155 OF TAPE -OPBIN -O
COMPUTED ON 23/1/64.

* R * L * C * R
ANGULAR RANGE FROM 4.00 TO 5.00 MRAD. MOMENTUM INTERVALS = 0.050 GEV/C

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1.00E-23 TIMES CROSS SECTIONS IN UNITS OF SQUARE CM PER STER PER GEV/C

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<td>0.250</td>
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</table>

Fig 6
Fig 7
CHAPTER II

THE SPARK CHAMBERS AND THE SOUND DETECTORS

C. Cocconi, A.N. Diddens, R. Donnet, L. Lillethun,
J.P. Scanlon, C.C. Ting, J. Walters, A.M. Wetherell.

1. THE SPARK CHAMBERS

All spark chambers were made of lucite with two gaps, 6 mm wide, each of them "seen" by four sound transducers.

The details of the construction are given in Fig. 1 and are the same for all chambers, although the useful sparking regions varied (2 x 2 cm², 5 x 5 cm², 10 x 10 cm² (Fig. 1), 15 x 30 cm² and 30 x 50 cm²). The minimum distance between the transducer and the sparking region was kept at ~ 10 cm; this distance was dictated by the fact that the velocity of the shock-wave produced by the sparks reached its asymptotic value only about 10 cm from the spark, under the present operating conditions.

The sparking region was covered by aluminium foils, 0.025 mm thick, stretched on the lucite frames. The foils were glued to the lucite with adhesive Eastman 910, which immediately sets under pressure. Before assembling, the lucite was cooled off to ~ 10°C while the aluminium foil was heated to ~ 50°C; the return to room temperature stretched the foils to very good flat surfaces.

The chambers were vacuum-tight; O-rings were used all around the two covers and at all connection leading to the inside of the chambers (high voltage to the plates; sockets of the sonic detectors; nipples of gas input and output). The joint made with the Eastman adhesive between the aluminium foil and the lucite frame was generally not vacuum-tight; however, araldite put along the external edge eliminated the leaks.

The main body of the chamber was machined out of one single piece of lucite, 8 cm thick, on which were located the sockets holding the sound detectors. Since the co-ordinates of each spark were deduced from the time-of-flight of the sound from the spark to the four detectors, the positions of
the detectors had to be known with an error smaller than that associated with the digitizing clock-unit, i.e. better than ~ 0.1 mm. After the chamber was completely assembled, the positions of the detector sockets were measured, with a large comparator, which gave the co-ordinates to within ~ 0.05 mm. As the position of the transducers with respect to the sockets was also known with comparable precision, the co-ordinates of the sound detectors were finally known to within the precision required.

Each chamber, once assembled, evacuated, and filled with a 75% helium 25% neon mixture, was enclosed in a box of dural plate, 5 mm thick, except in front of the sparking region where the thickness was reduced to that of a 0.035 mm aluminium foil. This metal box provided an efficient electric shielding that eliminated pick-ups from the sparks produced inside the chamber.

Although the chambers were reasonably leak-free (leaks of $\lesssim 1$ mm Hg per day), it was found that a continuous flow of gas mixture was necessary to achieve good efficiency. Both the degassing of the walls and gases produced by the sparking contributed to the contamination. The final arrangement consisted of one bottle of gas connected to each spark chamber through a pressure reducer, a needle valve, and a gas flow meter. A continuous flow of 20-50 cm$^3$/min was maintained and the surplus gas was eliminated, without recuperation, through silicon oil bubbles. Under these conditions a flask of 40 litres of gas at 150 atm lasted for about three months of continuous operation. If the gas outflow was drastically reduced the efficiency of the chambers suffered, while a much larger gas flow did not appreciably improve the chamber operation.

2. THE SOUND DETECTORS

The sound-sensitive detectors ("probes") used in the chambers, eight per chamber, are illustrated in Fig. 2. In this construction, commercial vacuum-tight 75 $\Omega$ coaxial connectors were used (Suhner UEF 75, with GE 071-75 socket), suitably modified to hold the piezoelectric disc that detected the spark sound. The connection of the socket to the spark chamber was made vacuum-tight by an O-ring, while a few drops of araldite ensured the tightness of the control wire, connected to the rear of the piezoelectric element. By keeping the dimensions of all probes the same within 0.1 mm, they could be freely interchanged.
The piezo-electric transducer was a disc, 5 mm diameter, 4 mm high, made of lead-zirconate and produced by Brush Company (Hythe, Southampton, England). In the smaller chambers, the discs were used as delivered, but in the larger chambers the end was tapered off on two opposite faces, under an angle of about 45°. The tapering produced a good sensitivity over an angle α of about ± 45° with respect to the axis of the element in the plane perpendicular to the edge of the dihedron. The amplitude of the signal produced by a transducer placed on a turn-table 20 cm away from a standard spark is plotted in Fig. 3 as a function of this angle. The same apparatus was also used for determining the effective centre of the transducer, i.e. the point in respect to which all sound travel times are independent of the angle α.

The effective centre of the present elements is located 0.8 mm inside the vertex of the lead zirconate.

The pulse shape produced in the transducer by a spark taking place in a gap of the spark chamber is illustrated in Fig. 4. The rise-time from 10% to 90% about 1 μsec. The amplitude of the pulse produced by the spark chamber operating at 10 kV and discharging a 500 μF capacitor was ~ 10 mV at ~ 30 cm distance. The amplitude is about inversely proportional to the distance spark-transducer. This weak dependence of amplitude on distance is a consequence of the containment of the sound within the gap.

A long ringing was always present after the sharp front of the sound wave. This was due to sound waves reflected by the walls of the chamber, to those propagating in the lucite frame, and to the reflections within the piezo-electric detector and its support. The ringing lasted several msec and prevented the detection of two or more simultaneous sparks. It limited the use of this kind of sonic chambers to the detection of events where only one ionized track is present in each gap when the high voltage is applied.
**Figure captions**

Fig. 1: The construction of a spark chamber.

Fig. 2: The mounting of a transducer.

Fig. 3: The response of the transducer as a function of the incidence angle of the sound wave.

Fig. 4: The signal of a transducer. Horizontal scale: 100 μsec/cm.
Average behaviour of eight probes

\[ \alpha = \text{Angle between probe axis and direction of sound} \]

Signal Amplitude (Arbitrary Units)

FIG. 3
CHAPTER III

THE ELECTRONICS FOR THE DATA PRODUCTION STAGE

H. Forret, J. Goodchild, A.C. Sherwood, C.A. Stählbrandt.

1. THE TRIGGER AND SPARK GAP SYSTEM

The trigger and spark-gap combination was designed to operate at a maximum frequency of 100/sec and to withstand at least 10⁶ discharges without need of supervision or repair.

In the trigger circuit¹) (Figs. 1 and 2) an avalanche transistor was used for driving the silicon-controlled rectifier (SCR) switch. The avalanche transistors were of micro-alloy type with diffused base. From a trigger pulse of 1 V they gave an output pulse of 200 V across 1 kΩ with a rise-time \( t_r < 5 \) nsec. The recovery time was \( \approx 100 \) μsec. The SCR switches gave a 1.2 kV pulse with \( t_r < 30 \) nsec and a delay \( t_d = 50 \) nsec into the transformer that had a ratio of 1 : 6. The recovery-time for the SCR switches was chosen shorter than the recovery-time of the avalanche circuit. The trigger generated a 7 kV pulse on the trigger electrode in the spark gap.

Figures 3 and 4 show the spark gap and the high voltage (HV) distributor. The spark gap, laid out coaxially and pressurised with \( \text{N}_2 \) gas, was directly attached to the trigger and the distributor. A monitor and a clearing field access was provided at the distributor. Figure 5 shows the complete HV pulse set-up.

It was found that at a sparking rate of 250/sec and with a high voltage of 10 kV, the average delay until the firing of the spark was \( \approx 200 \) nsec with a time jitter of about ± 10%.

2. THE TRANSDUCER CHANNELS

The time-of-flight of the sound waves was measured by gating a 2 Hz/sec clock. The number of cycles that passed the gate was registered in the core memory. The gate (Fig. 6) was opened at the moment the spark occurred in the chamber and it was closed by the arrival of the shock-wave at the transducer²).
The transducer used (PZT 5) for the detection of the sonic sound-wave had a high impedance and generated an output signal of about 10 mV. In order to increase the signal-to-noise ratio and to achieve a power amplification, the impedance was transferred to a lower one by means of a two-stage emitter-follower (Fig. 7). The input impedance of this emitter-follower (≈ 3 MΩ) was essentially determined by R₂; the transistor input impedance is 15-20 MΩ, depending on the β of the transistor. The output impedance was ≈ 10Ω. The circuit had an a.c. feedback by means of C₃ and was temperature stabilized by R₂. The power gain was ≈ 50 dB.

The signal was then transferred over a distance of about 20 m to the data recording set-up. At the receiving end the signal was amplified and discriminated before it closed the gate. The two-stage amplifier (Fig. 3) was directly coupled and its gain was controlled by a variable feedback loop. The gain could be varied within 12-60 dB. The discriminator was set at a level of ~ 0.5 V and directly switched by a tunnel diode.

The gate circuit (see Fig. 9) consisted of a bistable. The bistable was opened by the command and closed by the discriminated sound pulse. If the chamber failed to spark, the bistable had a second reset input, fed from the command.

3. THE 10 HZ/SEC COMMANDER

The main function of the "Commander" circuit was to provide, when triggered, two pulses each having a pre-selected accurate delay in respect to the trigger pulse. The first of those two pulses opened a gate used in the measurement of the time-of-flight of the shock-wave of the spark. The second one closed this gate in case the microphone signal had not done it already. A 10 Hz/sec crystal-controlled oscillator was used as a time standard. The Commander also contained a paralysis circuit that determined the minimum time interval that had to elapse in between two triggers in order to allow the spark chambers to regain full efficiency.

The block diagram of the Commander is shown in Figs. 10 and 11. The other figures give detailed diagrams of the various parts.
i) In receiving an input trigger pulse (5 V, 50 nsec \( \Lambda \)) the paralysis bistable switches, and produces an output pulse (8 V, 100 nsec \( \backslash \)) that operates the "pre-sparker splitter"/"scope trigger unit" and switches the reset and gate bistables. On receipt of the above pulse (7 x 10 V, 20 nsec \( \checkmark \)), the pre-sparker splitter unit produces pulses for the "solid-state trigger" circuits, and one (12 V, 100 nsec \( \backslash \)) pulse for scope triggering purposes.

ii) The gate, opened by the gate bistable, feeds 10 Hz/sec clock pulses into the internal scaler. After 25.6, 51.2, 102.4, 204.8 \( \mu \)sec, a pulse is taken from the internal scaler via YAX 1 to switch the start scalers bistable. This bistable drives an output circuit, which provides a (12 V, 2 \( \mu \)sec \( \backslash \)) pulse to open all the clock scaler gates via the amplifier gate circuits.

iii) After 1.6384, 3.2768, 6.5536, 13.1072, 26.2144 msec a pulse is taken from the internal scaler via YAX 2 to switch the stop scalers bistable. The output pulse generated by this bistable (12 V, 2 \( \mu \)sec \( \backslash \)) closes all the clock scaler gates which have not received a sonic stop pulse via the amplifier/gate circuits. This pulse is also used after integration to start the recording cycle.

iv) The last pulse in the internal scaler (i.e. 26.2144 msec after the input) is also used to return the reset bistable. The pulse generated by this bistable returns the gate bistable, closing the gate, and resetting the interval scaler.

v) At the end of the recording cycle the busy pulse returns from -6 V to 0. The positive edge triggers the busy one shot which resets the paralysis, start, and stop bistables. The circuit is now ready to receive another input.

vi) The circuit can be triggered and reset manually. The busy reset switch changes the busy one shot into a multivibrator to reset the paralysis, start, and stop bistables.
vii) A visual display of the state of any one of the five bistables is incorporated.

Paralysis
Start scalers    these bistables remain switched until the end of the recording cycle when the busy pulse returns to zero.
Stop scalers

Reset
Gate    these bistables show only a small meter deflection as they are in the switched mode for 26.2 msec.

A 15 c/sec test pulse generator is provided (10 V, 100 nsec) for checking purposes.

viii) Start scalers dead-time monitor. This bistable is switched by the scope trigger pulse and reset by the start scalers pulse, giving a (7 V) waveform to gate an external scaler. This scaler records the delay between the occurrence of the negative presparker pulses and the start scalers pulse by counting the 10 kHz/sec clock pulse during this gating period. N.B. A connection must be made between the Commander and the sparker splitter for the above monitor to function.

ix) For minimum dead-time connection: remove the 150 pf from card 3 pin 9 and connect to card 4 pin 13 (i.e. wiper of YAX 2). The stop scaler time selected now determines the Commander dead-time. At present the dead-time is fixed at 26.2144 msec.

x) 10 kHz/sec oscillator. There is a fixed amplitude output providing the clock pulses for the Commander, and 12 separate clock scaler outputs, each capable of driving five scalers. The clock scalers pulse amplitude can be varied from 0 → + 3 V and the last of the five scalers driven by each output must be terminated with 75 Ω. This termination switches in the channel.
4. THE PULSED CLEARING FIELD

At event rates of one per proton synchrotron cycle, a steady clearing-field potential of 20 V had been found, in previous experiments, to be the best compromise between the conflicting requirements of a low clearing-field voltage for obtaining a sufficiently long chamber-sensitive time and a high clearing-field voltage for obtaining a sufficiently short recovery time between events.

When the core memory system in conjunction with the SDS 920 computer made it possible to operate at higher event rates (up to 12 events per proton synchrotron cycle), it was found that the ratio of good/bad events accepted and recorded by the system could be improved by pulsing the clearing voltages to a higher value between events.

The spark chamber clearing voltages were therefore pulsed from their quiescent value (20 V) to about 100 V for a period of 10 msec, starting 3 msec after the triggering of the chambers. They returned to their quiescent value some 5 msec before the next event could be accepted by the Commander.

The circuit used (see Fig. 17) is in effect an amplifier which is d.c. coupled between the INPUT socket and the six OUTPUT sockets. A voltmeter with selector switch gives indications of quiescent voltage, peak voltage, or output voltage, and the circuit may be checked in situ between input and output sockets by pressing the TEST switch, which injects a current corresponding to the correct signal input level into the emitter of T1 and observing the output voltage on the meter.

The transistors T1, T2, and T3 provide input matching, signal limiting, voltage-level shift and a low output impedance for driving the current switch transistors T4, T5, and T6. T5 is a silicon device with high collector voltage rating. Transistors T7 and T8 provide a low impedance supply to which the output sockets are clamped via diodes D1 and D2.

* *

REFERENCES


Figure captions

Fig. 1 : Block diagram of the high-voltage set-up. Average delay is 200 nsec at 10 kV and a pulse separation < 10 nsec.

Fig. 2 : Solid-state trigger. V_{out} = 7 kV at V_{in} = 4 V. Delay τ_d < 100 nsec.

Fig. 3 : Block diagram of spark gap and distributor.

Fig. 4 : Spark gap.

Fig. 5 : Spark chamber with solid-state trigger, spark gap, and distributor unit.

Fig. 6 : Block diagram of transducer channel.

Fig. 7 : Emitter follower for transducer. The power gain is ≈ 50 dB.

Fig. 8 : Sonic amplifier with discriminator. The voltage gain is variable in the range 12 to 60 dB. The discriminator level is ≈ 0.5 V.

Fig. 9 : Scaler gate. The output time constant is ≈ 0.2 sec. Input OFF, is for the amplifier, OFFs for the Commander.

Fig. 10 : Principle of Commander.

Fig. 11 : Main diagram of Commander.

Fig. 12 : Diagram of scale-of-two, 10 Hz/sec oscillator, amplifier/emitter follower (A/EM) and gate.

Fig. 13 : Diagram of test pulse generator, busy one shot, bistable indicator, and gate.

Fig. 14 : Diagram of sparkor splitter.

Fig. 15 : Diagram of output circuit, basic bistable and -5 V line power line.

Fig. 16 : Connections to the various cards.

Fig. 17 : Pulsed clearing field supply.
$\tau < 200 \text{nS}$

Pulse separation $< 10 \text{mS}$

**-FIG. 1-**

**BLOCK DIAGRAM OF H.V. SET UP**
-FIG 6-

BLOCK DIAGRAM FOR TRANSUDER CHANNEL
FIG. 7

EMITTER FOLLOWER FOR TRANSDUCER
FIG. 8
SONIC AMPLIFIER WITH DISCRIMINATOR
FIG 11
**FIG 13**

**15 c/s TEST & GATE CARD.**
- VAX. 3
- PARALYSIS
- RESET
- GATE
- START
- STOP
- 8-2K
- 1ma
- FSD
- ESD
- 14: 15 c/s
- 15: RESTART
- 16: GATE OUT
- 17: SCOPE TRIGG. IN
- 18: START SCALERS IN

**D1820 2N769 2N708**

**~15 c/s TEST PULSE GENERATOR**

**BIStABLE INDICATOR**

**SCOPE TRIGGER**
- 17: IN.
- 15: 1M
- 14: 2M
- 13: MAKE BUSY

**OPEN SCALERS**
- 18: IN.
- 10: 10µ

**GATE (SCALER DEAD TIME)**
- 16: OUT
- 7v
- 150 1K
- 150
- 2N708

**BUSY ONE SHOT**

**D1820 OC44**

10v, 1µs, 10µ, 1K

- 2K
- 100
- 1K
- 6-8K
- b1
- 1-8n

+12 V. 10µ 10µ 40p 2µ 1K 47K 10µ 2µ 40p 10µ 1K 10µ 1K 330 5-6K 300

-12 V. 10µ 10µ 40p 2µ 1K 47K 10µ 2µ 40p 10µ 1K 10µ 1K 330 5-6K 300
CHASSIS
PLUG
1 • START SCALERS PULSE.
2 • SCOPE TRIGGER PULSE.
3  5
7
10  30
21 +12
22 -12

SPARKER  SPLITTER

FIG 14
CHAPTER IV

THE DATA ACQUISITION SYSTEM

F. Iselin, A. Lång, A. Maurer, F. Ponting, E. Schüller

The data acquisition system in a counter experiment using sonic spark chambers can be split into two major parts:

1. The measurement of the sonic times-of-flight (and of other relevant parameters).
2. The transfer of the measured values to a buffer or computer.

Some basic information on these items has already been given elsewhere¹).

The complete system has now been working with the new measuring and transfer system on-line with an SDS 920 computer. Figure 2 shows a view of the electronics of the system, the block diagram of the whole system is given in Fig. 1.

1. THE MEASUREMENT OF THE SONIC TIMES-OF-FLIGHT

1.1 General

Four time intervals have to be measured for each gap. These four values allow the determination of the spark position²). Each value represents the time interval between the triggering of the chamber and the arrival of the sound on one of the four microphones placed around the gap between the plates.

The simplest and most evident solution for measuring these times is to count clock pulses in a scaler during this interval. This system has been used successfully for many months¹), the recording medium being a magnetic tape.

Recently the so-called "Sonic event recorder" has been built which uses a different arrangement. This new system, as well as the original scaler system, can work with the basic read-out system developed some years ago for printing, punching, and also magnetic-tape recording.
1.2 **Sonic event recorder** (Fig. 3)

This consists mainly of two parts:
- a single central clock driving a fast carry scaler, and
- a fast core memory.

The idea is to start the clock at the chamber trigger time (slightly delayed to avoid spurious interferences), and then to let it run for a time longer than the one corresponding to the biggest chamber (longest travel time).

The value given by this clock, a binary number, is applied to the columns of a matrix (here 16 bits) as a partial current not yet able to write into the cores.

The memory is used as a buffer and also as a "multiple AND gate". To each row (here $2 \times 16$ rows) there corresponds a microphone, and when a sound signal is received it is "quantized", or synchronized, and fed to its row through adequate drivers. The coincidence of clock value and probe signal switches the cores of the corresponding row into the clock value.

The "quantizer circuit" de-randomizes the input probe signal and places it in the nearest clock count position. As indicated in Fig. 3, a 20 Mc/sec oscillator is used, and then a division by 10 to reduce the starting error to practically zero.

To avoid writing into the columns for each count of the fast carry scaler, a gate is provided which allows partial column writing only if one or more of the 32 probe inputs is present. This procedure avoids shifting in the core characteristics by limiting the clock partial writings to a maximum of 32.

The fast carry scaler is a master-clock scaler. It has to remain static between counts for a time sufficiently long to allow writing into the cores. This means that the longest carry time (111...1 to 000...0) has to be negligible compared to 0.5 μsec (count period). This was obtained using a logic gating system in combination with a flip-flop already used in the CERN scalers.
The principle is shown in Fig. 4a. The count can only go through the gate if the preceding flip-flops are on one. Each binary value, or flip-flop configuration, is preparing the gates during the 0.5 μsec clock period, and when the next count comes it triggers the required flip-flop(s) without delay. In theory a minimum delay d is necessary, but in practice, due to the transistors delays and by making the count pulse quite short (10 nsec), this delay d is made zero.

Figure 4b shows the scheme of the circuit.

The memory unit uses two commercial 16 x 16 planes of fast cores (Siemens R495); some faster cores are now available, but this type satisfied our speed requirements and offered low driving currents (70 mA/120 mA). The general principle of the sonde event recorder could, of course, be used with thin film memories, tunnel diodes, etc. to obtain very good resolutions if other uses are foreseen.

Since the basic driving circuits are classical, although faster than usual, they are not given here.

Figure 5a shows the principle of the quantizer circuit, and Fig. 5b the detailed circuit. As indicated before, such a circuit demodulates the input pulse and defines the next nearest arrival time coincident with the master-clock (fast carry scaler).

This guarantees a full synchronism of columns and rows writings for the complete writing period between counts. The maximum error is therefore one count (0.5 μsec).

One should note the major difference between this memory and a classical computer memory. In a computer, only one address is (in general) selected at any one time. In the sonic event recorder all 32 inputs may want to write at the same time. The circuitry must be able to do it even if this case is highly hypothetical. In fact, during tests it can be a common case, namely, when a single value is given to all inputs.

One should also remark that the reading cycle in the memory is immediately followed by a rewriting cycle. If it is necessary to retransmit the information, it stays available until a final O.K. signal resets the memory. This
has been useful when working with a magnetic-tape system where any
parity error (lateral or longitudinal) backspaces the tape and rewrites
the information\(^1\).

2. **THE TRANSFER**

2.1 **General**

The transfer to the CERN SDS 920 has been made using the very
similar principles, selection, output interconnections, etc. as for
the systems already existing at CERN\(^3\).

Now units have been designed to cope with the selection speed
increase (8 \(\mu\)sec/word), to produce a 25th parity bit, and to converse
by means of "interrupts" with the computer on-line.

The proton synchrotron beam spill-out being some 250 milliseconds
long, there is now the possibility of transferring a high number of
events/burst. For example, the content of 50 scalers are transferred
in less than 0.5 milliseconds.

Each transfer operation is started by a warning, or demand, to
the computer to execute this transfer. This demand has priority over
the normal operation of the data acquisition programme. (See Chapter
V: Transfer Interrupt).

One of the main features of these "small" computers is to be
able to execute a prescribed work on call. Since many calls or
interrupts may occur, a degree of priority is generally available and
the user has full freedom to define which one should have priority over
the others.

In the system described, three interrupts are used:
- transfer interrupt
- synchronism with the proton synchrotron
- warning that an error has occurred during transfer.

2.2 **The transfer system** (see also Fig. 1)

Once the measurement itself has been made, a transfer interrupt
is sent to the SDS. The main programme is interrupted; that is, a
sub-routine is selected which produces (in the high-speed interlace
case that is available in the CERN SDS) a train of N pulses called PIN pulses. N is set by an instruction. These N pulses are used in the selector of the transfer unit to select the N scalers (or N words) in sequence, each word 24 bits long.

A parity generator unit generates a 25th parity bit necessary for the computer internal check. The parity of each word extracted from the memory is checked and any error stops the computer. A recent modification to the computer avoids the stopping in this case, and instead generates a high priority interrupt.

Just before the train of N pulses is generated, an identification address and a warning signal (called "Sys") are sent by the computer to the transfer equipment. The delay between transfer demand (interrupt) and "Sys" is about 50 μsec.

The transfer rate is 8 μsec for one word of 24 bits, all transferred in parallel by the high-speed interface.

In the present experiment the identification address is not used since there is only one user.

The data acquisition subroutine of the programme fixes the addresses where the incoming numbers have to be placed in the computer memory by giving the first address and the number of words N to be transmitted. The fast interface system then automatically sets the incoming numbers in successive order.

The second interrupt synchronizes the SDS 920 with the PS accelerator which has a repetition rate of about 0.5/sec. This interrupt is called the "End-of-burst" interrupt since it is sent just at the end of the accelerator burst.

The third interrupt, called "Failure interrupt" is produced by the transfer electronics when a discrepancy exists between the final electronic selector position at the end of the transfer, which should be the number of words, compared to a manually pre-selected switch position.
Once the transfer (the so-called PIN phase) has taken place, the sub-routine goes automatically back to the main programme.

The transfer logic is reset and also produces a reset pulse for the measuring equipment at the end of the PIN phase.

The interface box indicated in Fig. 1 is, in fact, only a part of the total interface. It consists mainly of level adapters and buffers.

A new interface will soon replace this one to allow connection to three experiments (for input) and also permit conversation between the SDS 920 and CDC 6600 installed at CERN.
Fig. 2 - DATA ACQUISITION SYSTEM

PARAMETER UNIT
TYPE 3011

FAST BINARY SCALER
TYPE 3016
(24 BITS)

FAST SCALER (DECIMAL)
TYPE 3009 B
(6X4 BITS)

SPARE FAST SCALER
TYPE 3009 B

FAST CARRY SCALER
TYPE 3015

DATA TRANSFER SYSTEM
TYPE 7053

POWER SUPPLY
TYPE 1015 B
PARITY GENERATOR UNIT
TYPE 7047 (25th BIT)
DATA TRANSFER UNIT
TYPE 7046

MEMORY UNIT
TYPE 7040
WITH POWER SUPPLY
TYPE 1028

"SONIC EVENT RECORDER" =
FAST CARRY SCALER +
MEMORY UNIT

INPUT SIGNALS
(FROM OUTPUT OF
MICROPHONE
AMPLIFIERS)

POWER SUPPLY
TYPE 1015 B
Fig. 3 - BLOCK DIAGRAM OF THE SONIC EVENT RECORDER
Fig. 4 - FAST CARRY SCALER
a) Principle

b) Circuit

Fig. 5 – QUANTIZER
REFERENCES


CHAPTER V

THE DATA ACQUISITION AND CHECKING PROGRAMME
FOR THE ON-LINE COMPUTER

G. Bellettini and P. Zanella

1. INTRODUCTION

An SDS 920 digital computer was used on-line to the detector system to act as a fast buffer store and to perform real-time checks on the digitised information provided by the transfer electronics.

An essential feature of this computer was meant to be its ability to store up to \( \approx 10 \) events per burst, such a limitation to the repetition rate being set by the requirement of an efficient operation of the spark chambers. The computer memory could accommodate up to 12 events per burst, together with the programme; therefore the storing ability requirement was fully accomplished.

In addition, the computer was required to perform on-line enough computations to be able to: a) control the operation of the spark chambers; b) control the operation of the trigger electronics and the beam status; and c) reduce the off-line analysis work to be done on the magnetic tape information, by rejecting bad events and storing the good events in compact form on the tape.

Because of the limited size of the computer memory (4 K, 24-bit words) only a few simple checks on the recorded events could be programmed. These proved extremely effective, however, in discovering failures in the operation of the equipment.

Concerning point a), elementary checks were programmed to detect electromagnetic pick-ups of the microphones, failures of the microphones in detecting the sound shock-waves, and no spark or more than one spark in any gap of the spark chambers. These checks fully accomplished the control of the operation of the chambers.

The control of the beam and of the electronics, point b), was also satisfactorily achieved by checking the beam intensity and the level of the background radiation in the experimental area, and by making some consistency
checks on the readings of the scalars giving the number of triggers and the number of incoming particles leading to each event.

Finally, the requirement c) was also satisfied to a large extent by grouping five events in binary form (Fortran IBM compatible) in each magnetic tape record. This speeded up the off-line computations by a factor of \( \approx 2 \), with respect to the previously used system without intermediate buffer, which provided only a single event in binary coded decimal form for each record. On the other hand, to avoid possible biases on the collected samples, events were rejected by the programme only in extreme cases, corresponding to a few per cent of the total number of triggers. Therefore, most of the bad events were still rejected by the off-line analysis. However, since in the normal running conditions about 70% of the events were acceptable, this limitation was not essential.

2. **THE COMPUTER**

The SDS 920 is a digital computer with the following characteristics:

- 24-bit word plus parity bit
- binary arithmetic
- single address instructions
- indirect addressing
- one index register
- 8 \( \mu \)sec basic machine cycle
- typical execution times: single precision fixed point addition 16 \( \mu \)sec
  
  single precision fixed point multiplication 32 \( \mu \)sec

The configuration of the system available in the experiment being described, included the following peripheral equipment:

- 300 characters/sec Paper Tape Reader
- 60 characters/sec Paper Tape Punch
- on-line automatic typewriter
- 2 Magnetic Tape Units (200 bits/inch, 15 kilocharacters/sec).
All the above peripheral equipment was connected to the computer via a 6-bit parallel Input/Output channel. Furthermore, a 24-bit parallel I/O channel was available to connect non-standard external equipment. A feature called INTERLACE, to be associated with either of the two channels, was available to carry out the I/O of blocks of words in a fully automatic way. When attached to the 24-bit channel and operating in the HIGH SPEED mode, it permitted the achievement of the maximum I/O rate, i.e. one word/cycle.

Finally, a PRIORITY INTERRUPT SYSTEM was included. It consisted of the two standard interrupt channels (channel No. 31 = end of word interrupt, channel No. 33 = end of record interrupt) used in connection with I/O operations from/to standard peripheral equipment, and 16 additional interrupt channels (channel Nos. 200 to 217 octal) available for a variety of control functions.

Each interrupt channel had its own unique priority and its status in the priority hierarchy depended with increase in the interrupt channel number. An interrupt occurring on a given interrupt channel caused the computer to jump to a memory location which was unique to the given channel, at the completion of the current instruction. If other interrupts of higher priority were being serviced, then this interrupt would be inhibited until termination of all higher level interrupts.

Interrupt channels could be used in a NORMAL and in SPECIAL mode: NORMAL INTERRUPT CHANNELS remained in active state at their priority level under programme control, while SPECIAL INTERRUPT CHANNELS became inactive immediately after execution of the instruction located in the forced location. [For further details see SDS 920 Computer reference manual].

3. ALLOCATION OF FUNCTIONS AND PRIORITIES

The following functions were allocated to the various pieces of peripheral equipment.

The programme was loaded through the punched paper tape reader.

The on-line typewriter was allocated to the man-machine communications, i.e.:
a) - INPUT of new constants
b) - OUTPUT of short messages
c) - OUTPUT of requested summaries.

The magnetic tape units were devoted to the recording of the experimental data. Programme sensing of the end-of-tape indicator ensured automatic switching to the spare unit to avoid loss of data.

Raw data from the experimental equipment reached the computer memory via the 24-bit parallel I/O channel used in connection with the HIGH-SPEED INTERFACE register. A portion of the memory containing up to 12 events was allocated to the acquisition of these data.

The standard channels 31 and 33 were used only to allow output of requested summaries [point c) above]. In addition, three non-standard priority interrupt channels were used as follows:

1) - channel No. 200 - "End of Burst" interrupt (NORMAL mode)
2) - channel No. 201 - "Data Transfer Failure" interrupt (SPECIAL mode)
3) - channel No. 202 - "Data ready to be INPUT" interrupt (NORMAL mode).

The End of Burst interrupt (interrupt 200) was a signal allowing operation of the computer in phase with the accelerator cycle.

The variation with time of the magnetic field of the CERN PS when operated for counter experiments (long burst) can be schematized as follows:

![Diagram]

T₁ is the acceleration time (of the order of 1 sec), T₂ roughly coincides with the spill-out time (T₂ ≈ 300 msec), and T₃ is the recovery time of the accelerator (T₃ ≈ 1 sec).
The End of Burst signal was provided by the accelerator control system a few milliseconds after the end of T₂. This signal caused the programme to start checking the events collected during the burst. An Output Buffer containing up to 5 good events was allocated in the computer memory and was emptied onto magnetic tapes whenever full.

The data transfer failure interrupt (interrupt 201) was a signal provided by the data transfer electronics in case of failure during the transmission of the 52 words to the parallel input channel. This signal caused the programme to disregard the event during which the failure occurred. Signal 3), the data input interrupt (interrupt 202) was provided by the data transfer electronics as soon as the 52 data words were ready to be read in by the computer. This signal caused the programme to give control to the Data Acquisition Routine.

Figure 1 summarizes the priorities given to the various computer activities, and gives a possible time sequence (out of scale) of the computer status in the various priority levels.

In the normal status, the computer executes the main loop (lowest priority level). Interrupt 202 brings the computer into the first priority level, where the data acquisition operations are performed. The actual transfer of the 52 words corresponding to each event is made releasing control to the high-speed interlace, whose operation is completely automatic, and which has the highest priority level. If a failure in the transfer operations occurs, interrupt 201 operated in the SPECIAL mode brings the computer for a single instruction into the second priority level.

While the programme is in the main loop, a sense switch request by the operator to allow input of new constants via the typewriter will disable the interrupts, thus raising the programme to the 5th level of the diagram. Although the operations performed at levels 5 and 6 do not overlap, higher level has been assigned to the high-speed interlace operation, to emphasize that this operation cannot be interrupted by any other computer activity.

The computer is raised into the third level by the end-of-burst signal (interrupt 200), and at this level the checking operations are performed. During these operations short failure messages can be printed out and accepted
events are recorded on magnetic tape. These output activities were allowed by disabling the interrupts under programme control, as in the operation to input new constants.

Under sense switch request summaries can be printed out via the on line typewriter. The programme carries out this operation making use of priority interrupt channel 31. The computer status can be raised to the corresponding level at any time, except during the operation of the high-speed interface or during the printing of failure messages or the recording on tape. This fact was indicated in the diagram in Fig. 1 with a dot-dash horizontal line at the typewriter output level.

A schematic diagram of the data flow is given in Fig. 2. The experimental data are input from the transfer electronics to the 24-bit parallel I/O channel and fed by the high-speed interface into the allocated 12-event buffer in the computer memory. The checked events are stored in the 5-events output buffer, and through the 6-bit parallel I/O channel are recorded on magnetic tape. Input of constants from the typewriter to the computer memory, and output of summaries from the computer memory, are also performed making use of the 6-bit I/O channel.

4. THE LOGIC OF THE PROGRAMME

The SDS 920 programme was written in the Symbol 4B assembly language, because the Fortran compiler available did not allow the use of interrupts.

Storage taken by programme instructions was about 1500 memory locations. The remaining 2500 locations were used for I/O buffers, constants, working space, and library subroutines.

The Main Programme is schematised in Fig. 3. After some initial operations, where the bookkeeping of the run was initiated and the proper status of the magnetic tape units was controlled, the interrupts were enabled and the programme entered the main loop. During this loop, the various programme flags were checked, which were set when messages had to be printed out. In addition, the sense switches setting was checked. Four selections were available to the operators.
Selection (1) made the computer print out a short summary of the operation of the system from the beginning of the run to that particular moment (see next section). This selection was very often used, because, while giving relevant information on the operation of the system, it neither stopped the data-collecting ability of the computer, nor changed the book-keeping of the run which was continued normally.

Selection (2) forced the computer into a waiting status, in which events were not accepted and information could be provided to the computer in a suitable format via the typewriter. Messages could be typed in this way to change all the fixed parameters which were used by the programme when checking the events (see next section).

The next selection (3) caused the computer to change run. The main end-of-run summary was also printed (see next section), and the memory of the computer was made ready for the next run.

Finally, selection (4) flipped the magnetic tapes. As previously mentioned, this was also done automatically by the programme at the end of each tape.

In normal operation with all the sense switches reset, the main loop was continued indefinitely until priority interrupts caused the programme to give control to either of the two following routines:

1) DATA ACQUISITION ROUTINE (INTERRUPT 202)
2) DATA CHECKING ROUTINE (INTERRUPT 200)

The first was concerned with the storage of the data in the memory input buffer. Events exceeding the maximum of 12 per burst were disregarded. The second performed the checking operations which are described in the following section.

5. THE CHECKING OPERATIONS

Fifty-two words were transferred to the computer for each event, words 1 to 12 containing information needed for book-keeping and information on the trigger electronics and on the beam status, words 13 to 52 containing the digitized sound times-of-flight.
Figure 4 gives a schematic array of the 52 words, with an indication of their meaning. No check was made on the content of word 1 (event number). The content of word 2 (run number) was compared with what was found in the previous event. When the two numbers were found to be different, a special end-of-run mark was written on the output magnetic tape, a summary of the results of all the checks made during the run was printed via the on-line typewriter, and a new run was started. Because of this check, the facility was provided for the experimentalists of changing run simply by changing the run number on the appropriate parameter unit. As previously mentioned, the change of run could also be achieved by making use of the sense switches.

No automatic check was made on the content of word 3 (date). However, each operator was bound to check that it never exceeded June 1965. Scaler 4 counted the singles rate of a large-area scintillation counter used in the triggering system. To keep the level of the background radiation in the experimental area under control, at each end of burst interrupt the computer checked that the sum of the content of word 4 over the events recorded in the burst did not exceed a preset value. A message was printed via the on-line typewriter when this check failed a preset number of times.

Scaler 5 counted the number of beam particles. This number was added up for all events in a burst, and was checked to be contained within two given limits. When these checks failed a preset number of times, messages were typed to warn against too low or too high beam intensity.

Scalers 6 and 7, which were run in parallel from the same splitter also counted the number of beam particles, but these scalers were gated off immediately after a spark chamber trigger, and remained off during the busy time of the electronics. The number of incident particles leading to each event, which was provided by these scalers, was needed in the calculation of the absolute cross-sections. At each event words 6 and 7 were checked to contain the same number. If this condition failed, an immediate message was printed via the on-line typewriter. Events showing this major fault were rejected by the programme.
Scaler 8 was gated in the same way as scalers 6 and 7 and was counting the number of scattered protons, i.e., the number of particles which satisfied the triggering criteria. Under proper operation of the gating system, this scaler counted 1 at each trigger. At each event this was checked by the computer; when an event failed this check, it was rejected and an immediate message was typed out.

Scalers 9 to 12 were not used; they were spare scalers, available for any possible modification or additional feature of the experiment, which could provide information to be stored on tape.

Checks performed on the time-of-flight information, contained in words 15 to 52, aimed at detecting the following failures in the spark chambers:

a) A single microphone showing an electromagnetic pick-up from the spark. Such a failure was characterized by an extremely short apparent sound time-of-flight, and it was detected by checking whether each time-of-flight was greater than a certain minimum.

b) A single microphone failing to detect the sound shock wave. When such a failure occurred, the microphones indicated a preset known time-of-flight much longer than those actually possible.

c) No spark in a gap. When this failure occurred, all the four microphones of that particular gap signalled, simultaneously, extremely long apparent times-of-flight of preset value, as in b). To detect failures of type b) or c), the times-of-flight were checked to be smaller than a certain maximum. The failure was of type b) or c), depending on whether a single microphone or more than one microphone in a gap failed this check.

d) More than one spark in a gap. To detect this failure, the condition was required

\[ T_i + T_{i+2} > \pi_i \]

for the times-of-flight, \( T_i \) and \( T_{i+2} \), signalled by each pair of opposite microphones, \( \pi_i \) being a preset number proportional to the distance between the two opposite microphones. Under normal conditions, single
sparks occurring along the straight line joining microphones $i$ and $i+2$
give rise to a fixed value for the quantity $T_i + T_{i+2}$, which is the minimum
possible for single sparks. Only multiple sparks can cause the quantity
$T_i + T_{i+2}$ to be smaller than this minimum. On the other hand, multiple
sparks can occur, the times-of-flight still satisfying condition 1) (namely,
when they occur in a corner of a spark chamber); in other words, a simple
check on 1) could not detect all cases of multiple sparks. However, the
check was completely effective in signalling the rate of multiple sparks.
Since this rate in normal conditions was known by experience, the check
allowed the immediate discovery of any deterioration of working conditions
of the chambers due to multiple sparks.

After failures a) to d) having occurred a preset number of times,
messages were printed via the on-line typewriter which indicated the type
of failure and the microphone or the gap involved.

At the end of all checks, acceptable events were recorded on magnetic
tape. Events were accepted which did not show any major fault, as discussed
above, or more than one failure in the spark chambers either upstream or
downstream from the target. This was because events with only one failure
could possibly be rescued by the main programme which performed the full
analysis (see next chapter).

Making use of a particular sense switch selection, it was also possible
to drop all the checks making the computer act only as a fast buffer store.
In this case, of course, all the events were recorded on tape.

In addition to the prompt and the delayed failure messages described
above, the computer was instructed to print via the on-line typewriter, after
a preset number of events, a short summary on the operation of the detector
system from the beginning of the run. This summary comprised the total number
of events, the number of events without any failure (= clean events), the
number of accepted events which, however, showed some failures (possible
rescued events), and the number of rejected events. The number of rejected
events due to major electronics failures and to failures of the spark chambers
in the first or in the second section of the experimental set-up, were also
specified. The same summary could also be obtained by making use of a sense-
switch selection, as discussed in Section 3.

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As mentioned earlier in this section, a more complete summary (main end-of-run summary), comprising the number of failures of any type for each microphone and each gap, was provided automatically at the end of each run. Some additional information was also contained in this summary; in particular, the fraction of good events was given, for events which were first, second, etc., in the bursts. This fraction was found to be a decreasing function of the event order along the burst, thus indicating that the spark chamber efficiency was a decreasing function of the number of previous sparks in the same burst. When the efficiency was reduced too much, no effective gain was obtained by increasing the triggering rate. In the actual conditions of our experiments, this efficiency reduction limited the rate of data-taking to \( \sim 7 \) events per burst.

In the main end-of-run summary, the ratios of the number of clean, possible rescued, and rejected events to the corresponding number of protons were also given. Any systematic difference among these ratios could be due to the checking and rejecting criteria acting in a selective manner on different types of physical processes; therefore, this information could be used to understand if the on-line checks were selecting an unbiased sample of events.

6. **CONCLUSIONS**

The programme previously described was used over about 12 weeks of running time, showing several attractive features. Among these, the ability to provide real-time messages concerning any possible failure of the detector system proved to be the most useful one. Extensive use was also made of the possibility of changing, via the typewriter, the values of the parameters in the checking routine. The short summaries proved very useful for checking the stable operation of the system. The main end-of-run summaries provided, in nice form, part of the information needed for book-keeping.

The most delicate task of the programme was, of course, dealing with interrupts. Indeed, during the setting-up period, some effort was needed to cure programme weaknesses which showed up under particular combinations of priorities.
REFERENCES


2) SDS 920 Computer reference manual.
Figure captions

Fig. 1 : Diagram illustrating the priority levels attributed to the various operations, and a possible time sequence of the computer status. The order of magnitude of the time needed for the various operations is also indicated, and a scheme of the accelerator cycle is given for comparison.

Fig. 2 : Schematic data flow diagram. The 24-bit parallel channel is used in connection with the high-speed interlace to input raw data. The 5-bit parallel output is used to output the checked data on the magnetic tape, and to communicate with the typewriter.

Fig. 3 : Main data flow diagram. At any time (according to the priority scheme illustrated in Fig. 1) interrupts can cause the programme to leave the loop and switch to the data taking or checking routines, as discussed in the text.

Fig. 4 : Schematic diagram illustrating the content of the 52 words transferred to the computer for each event.
Fig. 1 PROGRAM LEVEL DIAGRAM
Fig. 2 DATA FLOW DIAGRAM
Fig. 3 MAIN PROGRAM FLOW DIAGRAM
<table>
<thead>
<tr>
<th></th>
<th>EVENT NUMBER</th>
<th>2</th>
<th>RUN NUMBER</th>
<th>3</th>
<th>DATE</th>
<th>4</th>
<th>COUNTER 5 SINGLES RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>NOT INHIBITED BEAMSUM</td>
<td>6</td>
<td>1st INHIBITED BEAMSUM</td>
<td>7</td>
<td>2nd INHIBITED BEAMSUM</td>
<td>8</td>
<td>NUMBER OF EVENTS PER TRIGGER</td>
</tr>
<tr>
<td>9</td>
<td>SPARE</td>
<td>10</td>
<td>SPARE</td>
<td>11</td>
<td>SPARE</td>
<td>12</td>
<td>SPARE</td>
</tr>
</tbody>
</table>

DIGITIZED SOUND TIMES OF FLIGHT

Fig. 4 EVENT CONTENT OF INFORMATION
CHAPTER VI

THE MAIN COMPUTER PROGRAMME FOR THE ANALYSIS OF THE SCATTERING DATA

E. Lillevolun and P. Zanolla

The programme described here was specifically made for the analysis of events recorded with the system described in Chapter I of this report. The description will not be complete, but rather it will show the flow of the analysis in the computer and discuss in detail only some parts that can be of more general use.

The programme was written in Fortran II for the IBM 7090 computer.

A brief summary of the experiment is necessary in order to define some variables:

A particle of interest is a proton that has been scattered elastically, or nearly elastically, in an angular range of about 1.5-20 mrad. A candidate for such an event is defined by a coincidence of counters $C_1C_2C_3C_4C_5$ with $C_6$ in anti-coincidence (see Fig. 1). The passage of the particle through the system is described by the position of counter $C_1$ and the spark positions in the spark chamber $S_k (k = 1,2,3,5)^*.$

The spark co-ordinates are computed from the sound flight-times, $T_i (i = 1,40)^* \text{, from the sparks to the microphones.}$

Together with the spark co-ordinates $X_j,Y_j (j = 1,2,3,10)^* \text{, the programme also computes } v_j$ and $\Delta T_j,$ where $v_j$ is the velocity of sound and $\Delta T_j$ is a variable defined in Section 2.2. For the reconstruction of the event the average co-ordinate position $X_k,Y_k (k = 1,2,3,5)^* \text{ for the two gaps of a chamber is used. This is because the distance between chambers } (\sim 7 \text{ cm}) \text{ is very large compared to the distance between adjacent gaps } (\sim 5 \text{ cm}).$ The position of a chamber along the particle trajectory is given by $Z_k,$ but more useful quantities are the lengths $L_n (n = 1,2,3,8)$ as shown in Fig. 1.

* The index i runs from 1 to 40, the index j from 1 to 10 and the index k from 1 to 5, since there are 5 two-gap spark chambers with four microphones per gap, thus 5 (k) spark chambers, 10 (j) gaps, and 40 (i) microphones.
The momentum of the incoming proton $p_0$ is given by the bending angle $\Phi$ in Magnet $M_4$, defined by the position of $C_1$, the horizontal spark coordinates $X_1$ and $X_2$, and the distances $L_1$, $L_2$ and $L_3$. Similarly the momentum of the outgoing fast proton, $p_1$, is defined by $X_3$, $X_4$ and $X_5$, and $L_6$, $L_7$ and $L_8$.

The scattering angle $\Theta$ is defined by $X_k, Y_k$ (k = 1, 2, 3, 4), $L_3$ and $L_6$. Since both the scattering angle and the deviations from the mean bending angles are very small (<20 mrad) the approximation $a = \sin a = \tan a$ is used.

The positions of the microphones were measured with respect to the bottom side of the chambers, so that all x and y axis were parallel when these sides had been adjusted in horizontal positions. The mean beam positions in the spark chamber gaps, as found from short runs with countors $C_2$ and $C_5$ taken out of the system and the target replaced by vacuum, defined mean bending angles in the magnets and zero scattering angle. The programme was run in a special mode, ALIGN *, to find these average positions.

The other main mode of the programme, PPSC.MT, made use of the mean values from a corresponding ALIGN run in the reconstruction of the scattering events.

In the description of the programme the following definitions are used:

- Read = read from cards, magnetic tape or bring out from fast memory;
- Print = write on magnetic tape for subsequent printing;
- Store data = store the data in the computer memory in suitable arrays;

The programme breaks up naturally into the following main parts:

1. START. Read parameters, compute more complex parameters, set book-keeping parameters, etc.
2. FINDXY. Computation of spark positions.
   2.1 Read experimental data
   2.2 Compute $x_j, y_j, v_j, \Delta T_j$.

* Words written in capitals refer to subroutine names
3. **ALIGN.**

For each event

3.1 Store \(x_j, y_j, v_j, \Delta T_j, T_j\).

3.2 If wanted, print \(x_j, y_j, v_j, \Delta T_j, T_j\).

At end of run

3.3 Form average of \(x_j, y_j, v_j, \Delta T_j, T_j\) and print.

3.4 If wanted, print histograms of \(x_j, y_j, v_j, \Delta T_j\).

4. **PPSCAT.**

4.1 Compute solid angles.

For each event

4.2 Reconstruct event.

4.3 Store \(x_k, y_k, p_o, p_1, \Theta\).

4.4 If wanted, print \(x_k, y_k, p_o, p_1, \Theta\).

At the end of run

4.5 Compute differential cross-sections and print.

4.6 If wanted, print histograms of \(d^2\sigma/d\Omega dp\).

5. **SPECIAL ROUTINGS**

5.1 **ERROR**

5.2 **RESUME**

5.3 **SPECIAL HISTOGRAMS**

6. **AFTER-COMPUTATION CORRECTION**

In the above, all checking has been left out, since checking occurs throughout the programme in order to stop handling an event as soon as it is found defective. The more important checks will be described within the parts where they occur.

1. **START**

The programme reads from cards the co-ordinates of the microphones, the distances \(L_i\), the tolerances for rejection of events, etc. Some of these parameters, in particular the microphone co-ordinates, are used at this point in computation of more complex parameters, such as distances between opposite microphones, angle between a line through these microphones and the horizontal, etc. To this category also belongs the computation of solid angle, which is described under Section 4.
2. FINDXY

2.1 Read experimental data

During the experimental runs the data were stored by the on-line computer on magnetic tape with five events per record. Consequently the data are read for five events at the time and stored in the computer memory.

2.2 Compute \( x_j, y_j, v_j, \Delta T_j \)

The distance from the spark to a microphone is given by

\[
R_i = \int_0^{T_i} v(t) \, dt. \tag{1}
\]

The spark sends out a shock-wave whose velocity decreases with time, asymptotically reaching the sound velocity \( v_j \) (the index \( j \) is used since the velocity, which varies with temperature, may be different from gap to gap). The microphones are assumed to be so far from the sensitive areas of the spark chambers that the waves reach the microphones with the velocity \( v_j \). The excess velocity \( v(t) - v_j \) closer to the spark is taken into account as an addition \( \Delta T_j \) to the flight times. Thus \( v_j \) and \( \Delta T_j \) are assumed equal for all four microphones in a gap. Then

\[
R_i = v_j \left( T_i + \Delta T_j \right). \tag{2}
\]

Based on these assumptions, two co-ordinate-finding subroutines have been used in the final version of the programme, namely SIMPLE and REFINE.

In SIMPLE, \( v_j \) and \( \Delta T_j \) are fixed, given values and the spark co-ordinates are found as follows (see Fig. 2):

Beginning with two microphones placed opposite each other in a gap \( \text{e.g., Nos. 2 and 4} \), circular arcs are drawn with these microphones as centres and with radii \( R_2 \) and \( R_4 \), respectively. The spark is taken to lie on the common secant to those arcs. With a similar construction for the other two probes,
another common secant is found and the spark position is taken to be the intersection of the two secants. [A more complete description of the computation is given by Lillethun et al., page 326.]

If no satisfactory solution is found, the event is called "bad" in that particular gap.

REFINE makes use of the co-ordinates found by SIMPLE as a first attempt in an iterative method for finding the best solution for x and y. The following equations are used

\[ K = \frac{R_1 - R_2}{R_4} = \frac{T_1 - T_2}{T_3 - T_4} \]  \hspace{1cm} (3)

\[ I = \frac{R_1 - R_4}{R_2 - R_3} = \frac{T_1 - T_4}{T_2 - T_3} \]  \hspace{1cm} (4)

The right-hand sides of Eqs. (3) and (4) are independent of \( v_j \) and \( \Delta T_j \) and can, in principle, be solved for x and y. However, the equation is of 4th order and one uses an iterative method which is described by Lillethun and Zanella, pp. 175-178.

It became apparent that REFINE was, in certain regions of the chambers, more sensitive to errors in the recorded flight times \( T_i \) than SIMPLE. In PPSCAT the latter was therefore used to compute the co-ordinates, while REFINE was used to compute \( v_j \) and \( \Delta T_j \) when SIMPLE showed that the spark had occurred within a safe region of the chamber. The found values of \( v_j \) and \( \Delta T_j \) were averaged with the initial values to take into account the slow variations of these quantities with temperature. The new values were accepted only if they differed from the previous values by less than a variable fraction, usually kept to 1 or 0.5%, and they were then averaged with the old values with a weight 0.1.

In the ALIGN mode of operation REFINE was used.

A measure of the accuracy obtained in this way is shown in Fig. 3. The histogram shows the distribution of \( \Delta x_k = x_j - x_{j-1} \) in chamber \( S_4 \) when all sparks occurred in a limited area of the chamber (diameter ~ 2 cm). With a

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* Gaps 9 and 10 in the heading of Fig. 3 are gaps 7 and 8 according to the definitions of this paper. The reasons for this difference are of interest only to historians.
base width of 1 mm it shows that the sparks in one gap followed the particle within 0.5 mm. The systematic error in position determination across the chambers amounted to 1 mm in the worst places of S5. In all other chambers, and for the regions mostly used in S5 this error was less than 0.5 mm.

3. ALIGN

3.1 Store \( x_j, y_j, v_j, \Delta T_j, T_i \).

The main purpose of this programme was to find the average positions of an unscattered beam in the spark chambers. If FINDXY gave a bad solution in one gap, the whole event would be rejected in order to use only "perfect" events. Another important check was that \( \Delta x_k \) and \( \Delta y_k \), defined as in the previous paragraph, should be smaller than 1 or 2 mm. Usually about 50% of the events from an ALIGN run would be rejected.

After a successful passing of all checks an event would be stored. There was place for only 200 events at a time in the memory, so the averaging had to be done in steps, as usually 500-1000 events were used to get a good mean value.

3.2 If wanted, print \( x_j, y_j, v_j, \Delta T_j, T_i \).

In particular, for the initial testing of the equipment it was important to study each chamber. Therefore an option was made so that all \( x_j, y_j, v_j, \Delta T_j \) and \( T_i \) could be printed out for each event.

3.3 Form averages of \( x_j, y_j, v_j, \Delta T_j, T_i \) and print.

At the end of a run the final averages were formed, printed and also stored in the fast memory for subsequent use in the following FPSCAT run.

3.4 If wanted, print histograms of \( x_j, y_j, v_j, \Delta T_j \).

If asked for, the programme would print simple histograms of the distributions of all the computed values \( x_j, y_j, v_j, \Delta T_j, \Delta x_k \), and \( \Delta y_k \). Figure 3 shows the histogram distribution for \( \Delta x_5 \) for chamber S5, and Fig. 4 shows the distributions of \( v_j \) and \( \Delta T_5 \).

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4. **PPSCAT**

4.1 **Solid-angle calculation**

As the beginning of the analysis in the PPSCAT mode the programme had to work out the useful solid angles for the angular regions specified on the input cards. Figure 5 is a sketch showing the section of the set-up of interest for the solid-angle computations.

The geometry of counter C₄, which defines the accepted scattering angles, was in general chosen so as to use the full azimuthal angle up to about 7 mrad. Figure 6 shows the projection of C₄ on spark chamber S₄. The following variables were used:

- \( Y_{\text{min}} \) : minimum value of \( y \) as measured from the beam centre to the top or bottom edge of the counter;
- \( X_{\text{min}} \) : distance from beam centre to left side of counter;
- \( X_{\text{max}} \) : distance from beam centre to right side of counter;
- \( \Delta \) : a small variable to reduce the dimension of the counter by, for example, 1 mm to account for small variations in beam position;
- \( \text{worst} \) : radius of the beam at target plus the product of maximum angle of divergence of the beam and distance from target to S₄;
- \( \theta_i \) : scattering angle;
- \( \theta_{\text{min}} \) : smallest scattering angle possible, a parameter read from cards;
- \( R_i \) : \( \theta_i \cdot (L_5 + L_6) \);
- \( \eta_i \) : maximum azimuthal angle accepted for \( \theta_i \);
- \( \Delta \Omega_i \) : solid-angle for the interval \( \theta_{i-1} \) to \( \theta_i \).

Full solid angles, i.e.,

\[
\Delta \Omega_i = \pi (\theta_i^2 - \theta_{i-1}^2)
\]  

were used when the conditions

\[
R_i \leq Y_{\text{min}} - \text{worst}
\]

and

\[
R_i \leq X_{\text{min}} - \text{worst}
\]

were fulfilled.
The solid angles for larger $\theta_i$ were computed as

$$\Delta \Omega_i = (\theta_i^2 - \theta_{i-1}^2) \cdot \eta_i$$ \hfill (8)

[for each side of the beam if condition (7) was fulfilled] where $\eta_i$ was defined by

$$\tan \eta_i = \frac{y_{\text{min}} - \text{worst}}{[R_i^2 - (y_{\text{min}} - \text{worst})^2]^{1/2}}.$$ \hfill (9)

As Fig. 6 shows, such a definition of the solid angles excluded all areas where distributions would have to be folded in with the date, thus avoiding uncertainties due to such folding operations.

If required, the programme could be run so that left and right scattering remained separated or a fixed azimuthal angle $\eta$ could be specified to check for asymmetries in the detection. The asymmetries found were never outside the limits due to statistical uncertainties.

4.2 Reconstruction of the event

Before a reconstruction was attempted, the data went through checks similar to those described in Section 3. A linearity check was also included, based on the linearity of the projection of the particle trajectory in the vertical plane before and after the scattering. The test was performed by producing the lines defined by the sparks in chambers $S_1$, $S_2$ (or $S_3$, $S_4$) to counter $C_1$ (or chamber $C_5$) and demanding that the positions found agreed with the position of $C_1$ (or of the spark in $S_5$) within given limits, usually 5 (and 4) mm.

The same linearity check was used to rescue events where one gap on either or both sides of the target was found bad by a check routine in FINDXY.

There were two typical cases:

1) FINDXY found no solution for $x$ and $y$ in one gap. If the co-ordinates in the other gap of the chamber passed the linearity check, the same co-ordinates would be substituted in the first gap.
ii) FINDXY found good solutions in both gaps but $\Delta x_k$ or $\Delta y_k$ were too large. The linearity test then pointed out the gap co-ordinate (if any) that fitted the trajectory.

As a result the events were classified into three categories:

i) **Clean**. These events had given an $x,y$ solution in all 10 gaps and the co-ordinates satisfied all checks.

ii) **Rescued**. One gap on either or both sides of the target was found bad in FINDXY, but the event could be rescued by the linearity check.

iii) **Bad**. Two or more gaps were found bad on at least one side of the target or the event could not be rescued. All events in this category were discarded.

"Clean" and "Rescued" events together were called "Good" events.

4.2.1 Determination of scattering angle $\theta$

Referring to the mean positions in the chambers, computed by ALIGN, as $X_{ok}$, $Y_{ok}$ the following equations were used for the computation of $\theta$:

$$\theta = \sqrt{\theta_x^2 + \theta_y^2}$$  \hspace{1cm} (10)

where $\theta_x$ and $\theta_y$ are the projections of $\theta$ in the horizontal and vertical plane, respectively:

$$\theta_x = \theta_x - \theta_{x1} \quad \text{and} \quad \theta_y = \theta_y - \theta_{y1}$$

where

$$\theta_{x1} = \frac{1}{L_3} (x_2 - x_1 - x_{o2} + x_{o1})$$ \hspace{1cm} (11)

$$\theta_{x2} = \frac{1}{L_6} (x_4 - x_3 - x_{o4} + x_{o3})$$ \hspace{1cm} (12)

$$\theta_{y1} = \frac{1}{L_3} (y_2 - y_1 - y_{o2} + y_{o1})$$ \hspace{1cm} (13)

$$\theta_{y2} = \frac{1}{L_6} (y_4 - y_3 - y_{o4} + y_{o3})$$ \hspace{1cm} (14)
4.2.2 Determination of momentum

The mean bending angles in the magnets are defined by the position of $C_1$, $x_{0c}$, and the co-ordinates $x_{ok}$, and are taken to represent the momentum $P_{\text{mean}}$ read in as a parameter in START. Deviations from this momentum were computed on the assumption that the bending occurs at the centre of the magnet system. Then the line defined by the sparks in the two chambers on one side of the magnet $S_1$ and $S_2$ or $S_3$ and $S_4$ is produced till it cuts the central plane in the magnet. This point, together with the $x$ co-ordinate of $C_1$ ($x_c$) or $x_5$, defines the direction of the trajectory on the other side of the magnet. (During these runs $x_c = x_{0c}$, but they were still left in the programme in case $C_1$ should be substituted by a spark chamber).

The equations for the deviations from mean bending angles in the two magnets were

for $M_1$: \[ \Delta \phi_1 = \frac{1}{L_1} \left( x_c - x_1 - x_{0c} + x_{01} + (I_1 + I_2) \theta_{x1} \right) \] \[ (15) \]

for $M_2$: \[ \Delta \phi_2 = \frac{1}{L_2} \left( x_5 - x_4 - x_{05} + x_{04} - (I_7 + I_8) \theta_{x2} \right) \] \[ (16) \]

The momenta were then determined by the relationship

\[ \frac{\Delta P}{P_{\text{mean}}} = - \frac{\Delta \phi}{\phi_{\text{mean}}} \] \[ (17) \]

or

\[ P = P_{\text{mean}} + \Delta P = P_{\text{mean}} \left( 1 - \frac{\Delta \phi}{\phi_{\text{mean}}} \right) \] \[ (18) \]

$\phi_{\text{mean}}$ is known from the geometry of the experiment.

4.2.3 Determination of the point of interaction

The longitudinal position of interaction $Z_{\text{int}}$ was found by first computing the projections of this point in the horizontal and vertical plane, $Z_{\text{int}}(x)$ and $Z_{\text{int}}(y)$. If the projected scattering angle in one
plane was less than a given value (typically 1.7 mrad) only the other projection would be used. If both projections were found, a weighted mean value would be used, namely,

\[ Z_{\text{int}} = \frac{|\Theta_x| Z_{\text{int}(x)} + |\Theta_y| Z_{\text{int}(y)}}{|\Theta_x| + |\Theta_y|} \]  \hspace{1cm} (19)

where

\[ Z_{\text{int}(x)} = \frac{1}{\Theta_x} (x_2 - x_3 - x_0 - x_0 + y_1 L_4 + y_2 L_5) \]  \hspace{1cm} (20)

and

\[ Z_{\text{int}(y)} = \frac{1}{\Theta_y} (y_2 - y_3 - y_0 - y_0 + x_1 L_4 + x_2 L_5) \]  \hspace{1cm} (21)

\[ Z_{\text{int}} = 0 \] corresponds to the middle of the target.

Figure 7 shows two histograms of the quantity \( Z_{\text{int}} \). a) with a 60-cm long H\(_2\) target in position, and b) with the target replaced by the vacuum.

The events plotted with + signs were rejected as not coming from the target.

4.3 Store data

An event which had passed all checks up to this point would be stored in an array, labelled according to scattering angle and momentum difference \( p_0 - p_1 \) between the momentum measurements with magnet M\(_1\) and magnet M\(_2\).

"Rescued" and "clean" events were stored separately, and so were left- and right-scattered ones.

The number of incoming particles recorded from one event to the next was stored at this point for later use in computing the cross-sections.

4.4 Print information

If required, the programme would print the following line of information: Event number, asterisk if event was rescued, \( p_0, p_0 - p_1, \Theta_x, \Theta_y, \Theta, x_k, y_k \) (\( k = 1,5 \)). These print-outs were of particular interest during the initial testing of programme and apparatus.

In order to allow the data to be regrouped for different output modes, the programme could store on magnetic tape the following information: Event No., run number, number of incoming particles leading to this event, \( p_{\text{mean}} \).
$P_0$, $P_1$, $\Theta_x$, $\Theta_y$, $\Theta$, "rescued" or "clean", $Z_{\text{int}}$. This information was written 10 events per record. A special programme, PPSORT, essentially consisting of the present, but excluding FINDXY, several check routines, etc., was used to reanalyse this information.

4.5 Compute cross-sections

At the end of a computing run (several actual experimental runs could be analysed together) the differential cross-sections were computed from the formula

$$\frac{d^2\sigma}{d\Omega dp}(p,\Theta) = \frac{\Delta^2N(p,\Theta)}{N_1N_2\Delta\Omega \Delta p}$$

(22)

where $\Delta^2N(p,\Theta)$ is the number of events found in the momentum interval $\Delta p$ around $p$, and in the solid angle $\Delta\Omega$ around $\Theta$. Here $N_1$ is the number of scattering centres per cm$^2$ in the target and $N_2$ is the sum of incident particles recorded during the run for the accepted ("clean" and "rescued") events. Both cross-sections and number of events were printed out in arrays labelled by $p$ and $\Theta$.

The momentum spectra would generally have a high elastic peak, followed by a small tail of inelastic scattering (see Fig. 8). The elastic cross-section ($d\sigma/d\Omega)(\Theta)$ was found in the following way:

i) A subroutine, BOXMAX, would find the momentum for which the cross-section was highest.

ii) The cross-section in the found momentum interval was added to those in the neighbouring intervals, including up to $\pm 200$ MeV/c from the central momentum.

The elastic cross-sections were printed out together with the statistical error, number of events, $\Delta\Omega$, and the maximum azimuthal angle accepted, $\eta$. The cross-sections obtained in this way were always checked and, if necessary, corrected for possible inclusion of inelastic scattering, but this correction was never greater than $\sim 1\%$.

The cross-sections were always computed for "clean" and for "clean + rescued" events separately, and in the case of the programme PPSORT also "rescued" events were treated separately.

4.6 Histograms of the cross-sections

If wanted, the programme would make simple plots of the momentum spectra as shown in Fig. 8. The cross-section in intervals where $+$ signs have been used had been multiplied by 10 before plotting. The plots also included the
number of events, cross-section, and error printed for each interval, and
would list at the bottom of the page the elastic cross-section found by
summing (as described in Section 4.5) $d^2\sigma/d\Omega dp$ over $\pm 150$, $\pm 200$, and
$\pm 250$ MeV/c intervals around the centre of the elastic peak. This print-
out made it easy to estimate whether corrections to the elastic cross-
sections were needed or not.

5. SPECILL Routines

5.1 ERROR

Whenever an error was detected during the analysis, the type of error,
gap number, etc., was stored by means of the subroutine ERROR. If required,
the routines would print the event and gap number and a comment on the type
of error, e.g., DT or V if REFINE found velocity or $\Delta T$ too different from the
original, or "Non Lin" if the event did not pass the linearity check. This
information would be followed by a list of the four $T_i$ for the gap and, if
computed, the values $x_j$, $y_j$, $v_j$, $\Delta T_j$, $\Delta x_k$ and $\Delta y_k$. A "Non Lin" error would
cause all this information to be printed for all gaps. The printing could
be omitted or kept up for a chosen number of events. This error-log proved
very important in the search for more subtle faults in the system.

5.2 RESUME

A subroutine called RESUME printed a summary of the results from a
run both on-line, for a quick check, and as a page together with the complete
listing of results.

RESUME listed the numbers of the runs, events (first and last) and
magnetic tape, and the date of data recording and of computation. It gave
the total number of events, the total sum of incoming particles, and the
ratio of these two numbers, together with the same specification for "good",
"bad", "clean", and "rescued" events. A list of the rejects according to
type, and finally the ratio of bad (of certain categories) to good in each
gap, gave at a glance information about particularly bad (or good) spark
gaps.

5.3 Special histograms

It was found useful to include a histogram showing the divergence of
the incoming beam in vertical and horizontal projection and a diagram showing
the distribution of sparks in chamber $S_4$. The latter (see Fig. 9) would
give an indication of the alignment of the beam in the hole of counter $C_4$,
and would warn against bad asymmetries in the recording of events in $S_4$.

A last histogram plotted the logarithm of the number of events as
function of incoming particles leading to the event. The logarithmic plot
(see Fig. 10) should be linear. If, for example, it dipped down for small
values of the number of incoming protons, it would indiceto that such events
were badly recorded, probably because a second event had followed the former
so closely that the spark chambers had not recovered.

6. AFTER-COMPUTATION CORRECTIONS

Before the analysed data were ready for publication they had to be
checked and adjusted for small effects which the programme could not handle.

One of the corrections applied to the computed elastic cross-sections
is described in Section 4.5.

The selection of events as "bad", "clean", and "rescued" could possibly
favour one type of events for one of these three groups (e.g. very small angle
events frequently "bad"). The ratio of number of events in one group to the
sum of incoming beam leading to these events was therefore compared to the ratio
for the other groups. A difference of the order of 1-2% was usually found and
the effect on the cross-sections was also of the order of 1%. When the cross-
sections were adjusted by a factor given by the above-mentioned ratio divided
by the ratio for the total number of events, the cross-sections for the
different groups became equal (within statistical errors) and these values
were adopted as correct.

Thanks to the rejection of background events from counters and spark
chambers by the help of the computed interaction position $z_{int}$ (see Section
4.2), the corrections for background were small. For the smallest angular
interval it could be $\sim 4\%$, but for all other angles $\lesssim 1\%$. 

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REFERENCES


Figure captions

Fig. 1 : The beam layout.

Fig. 2 : Construction of the co-ordinates.

Fig. 3 : Distribution of $\Delta x_k$ for $S_4$.

Fig. 4 : Distribution of $v_s$ and $\Delta z$. 

Fig. 5 : Sketch illustrating how the finite beam size and divergence diffuse the scattering events at fixed scattering angle over a two-dimensional area of circular shape. The width of this area is the diameter of the beam; its borders are diffused as a consequence of the beam divergence. The definition of some parameters used in the calculation of the solid angles is also illustrated. Counter 4 is the counter defining the solid angle. The interaction region can be considered as two-dimensional (interaction area) for the very small scattering angles involved in the present experiment.

Fig. 6 : Illustration of the useful area, namely the area covered by the projection of the counter defining the solid angle, on spark chamber 4. Safety borders of thickness "worst" were subtracted around both the full ($\Delta \Omega_1$) and the partial ($\Delta \Omega_1'$) solid angles, to make sure that protons anywhere in the beam, and from any direction inside the beam, scattered at an angle $\Theta$ such that $\Theta_{1-'1} < \Theta \Theta_1$ or $0_{1'-1} < \Theta \Theta_1'$, respectively, were detected by the system. The distances $R$ correspond to the angles $\Theta$, as explained in the text.

Fig. 7 : Histograms of $Z_{int}$, the scattering vertex position along the beam direction for target in and out.

Fig. 8 : Momentum spectrum.

Fig. 9 : Distribution of sparks in $S_4$.

Fig. 10 : Logarithmic plot of the number of beam particles leading to an event.
MOMENTUM ANALYZED "PARALLEL" BEAM FROM PS

ANALYZING MAGNETS (106 mrad bending)

SHIELDING WALL
55 m FROM INTERNAL TARGET

Fig 1
**DX-DISTRIBUTION IN GAPS 9, 10. EACH LINE REPRESENTS .010CM.**

**MEAN VALLE CORRESPONDS TO LINE +**

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**Fig 3**
Fig 4
RESULTS FROM RUNS 128/155 OF TAPE -O-R-0 IN -O- COMPUTED ON 23/1/64

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1.00E 23 TIMES CROSS SECTIONS IN UNITS OF SQUARE CM PER STER PER GEV/C

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Fig 8
RESULTS FROM RUNS 90/96 OF TAPE 125ORBIN 10 OF 21/6/64. COMPUTED ON 25/6/64.

DISTRIBUTION OF SPARKS IN MEDIUM

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Fig 9
RESULTS FROM RUNS 61/ 94 OF TAPE 1231RBIN 1 OF 21/ 6/64. COMPUTED ON 9/ 7/64.
NUMBER OF BEAM PARTICLES LEADING TO EVENTS. EACH LINE = 25 PARTICLES. INTERVAL STARTING AT O IS MARKED
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