AN EXPERIMENT ON THE ELASTIC SCATTERING OF DEUTERONS ON CARBON

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(presented by C. Whitehead)

1. INTRODUCTION

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

2. EQUIPMENT

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

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

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size at the carbon target. Two spark chamber modules were used to determine the trajectory of the scattered particle. The flight time of the particle between counters 1 and 5 was determined and the pulse height in counter 5 was also measured. The latter two measurements serve to identify the deuterons and also the protons produced in competing reactions. To establish an absolute cross-section the beam particles registered by $12\bar{3}$ were counted but only during the time that the equipment and data handling system was ready and able to detect and deal with the information associated with a scattering event. This beam monitoring system was used to obviate the necessity of knowing the dead time correction of the whole system including the data handling equipment and also it rendered the problem of recording the number of beam particles used more amenable.

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

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

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

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

A further system was built into each measuring gap to measure the velocity of sound in the chamber itself. This consisted of a point-to-plane spark gap and two further microphones arranged along the edge of the chamber. The microphones were separated by $\sim$15 cm and 27 cm in the two chambers.

The calibration gaps were pulsed from a thyratron at 15 kV and the time taken for the sound to pass from one microphone to the other was determined from a gated scaler and a 5 Mc/s clock frequency. Data taking runs lasted 15 minutes and in the intervening period five measurements were made of the sound transit time for both chambers. Over a period of 10 hours the average change in the velocity of sound during the 15 minute runs was 0.05% and the maximum change observed was 0.3%.

2. THE MAGNETIC MEMORY STORE

Figure 3 shows a simplified block diagram of the buffer store, it consists essentially of a 16 × 16 ferrite matrix of Mullard FX 1899 cores driven from a 16 bit binary scaler fed by a 1 Mc/s clock. The scaler is started when the spark chambers are fired and when the signal from the i^{th} microphone arrives the scaler content at that time is transferred non-destructively and essentially instantaneously to the i^{th} row of the matrix. This transfer is made unambiguously to an accuracy of ± 1 clock pulse by using the fact that between clock pulses, for a period of 400 ns, all the binaries are in a steady state and using the technique of staticising[2)] the transfer is arranged to take place at this time using half write currents from the binaries in the "1" state and a synchronised half write current along the i^{th} row of cores. The half write currents used are ~ 100 ma with a duration of 200 ns.

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

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

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

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

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

4. ANALYSIS

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

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

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

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

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

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

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

Chamber efficiencies defined as the number of 1-5 coincidences per number of chamber discharges, were monitored throughout the experiment. In clean test conditions with the deuteron beam passing through both chambers efficiencies in excess of 99% were obtained for both chambers. In the scattering position the maximum efficiencies observed were 98% and it is believed that this decrease is probably due to neutrons emitted by the target being converted in counter 5 which was 7 cm thick. Such an event would trigger the spark chambers but no charged particles would have traversed them. As an example, in one run on aluminium, the chambers were discharged 2380 times, 1-5 coincidences were observed on 2300 events for chamber 1 and on 2320 events for chamber 2 and acceptable solutions of events were obtained in 2120 cases and of these 80 corresponded to events not originating from the target. In this case the efficiency of analysis was 89%.

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

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

5. RESULTS

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

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

References

1. B. Rose, L. Bird, D. West, E. Wood, C. Whitehead, G.W. Hutchinson, D.G. Crabb, J.G. McEwen, R. Orr, D.R. Jennings, D. Aitkin, J. Hague and A.J. Parsons, "A sonic spark chamber system with on-line computation for studying the reaction $\pi^- + p \rightarrow f^0 + n$ at 3 GeV/c", present proceedings, Session V.

2. C. Whitehead, Proceedings of the International Symposium on Nuclear Electronics, Paris, 379 (1963).

3. B. Buck, R.N. Maddison and P.E. Hodgson, Phil. Mag. 5, 1181 (1960).

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

Figure captions

Fig. 1 Layout of the experiment.

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

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

Fig. 4 Angular distribution of deuterons scattered from carbon.

Fig. 5 Angular distribution of deuterons scattered from aluminium.

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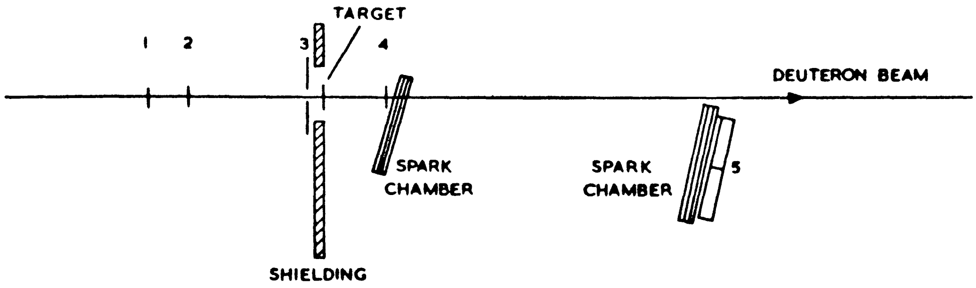

Fig. 1

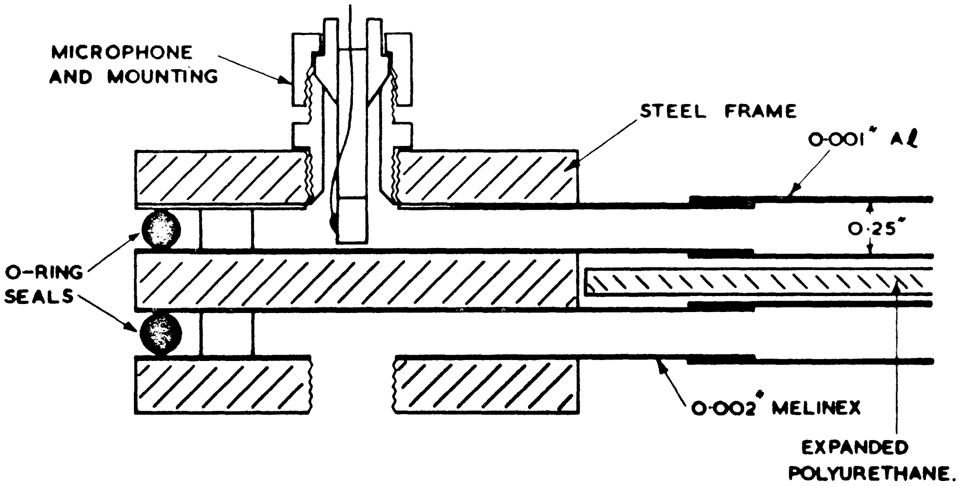

Fig. 2

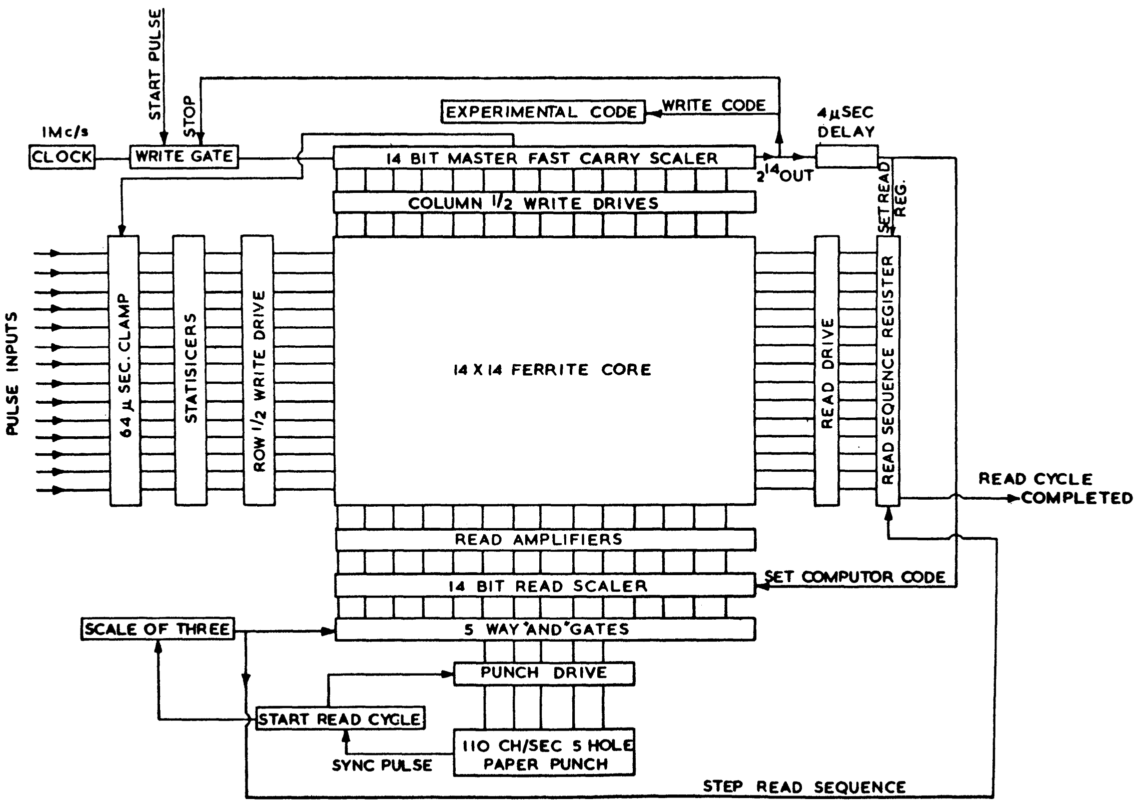

Fig. 3

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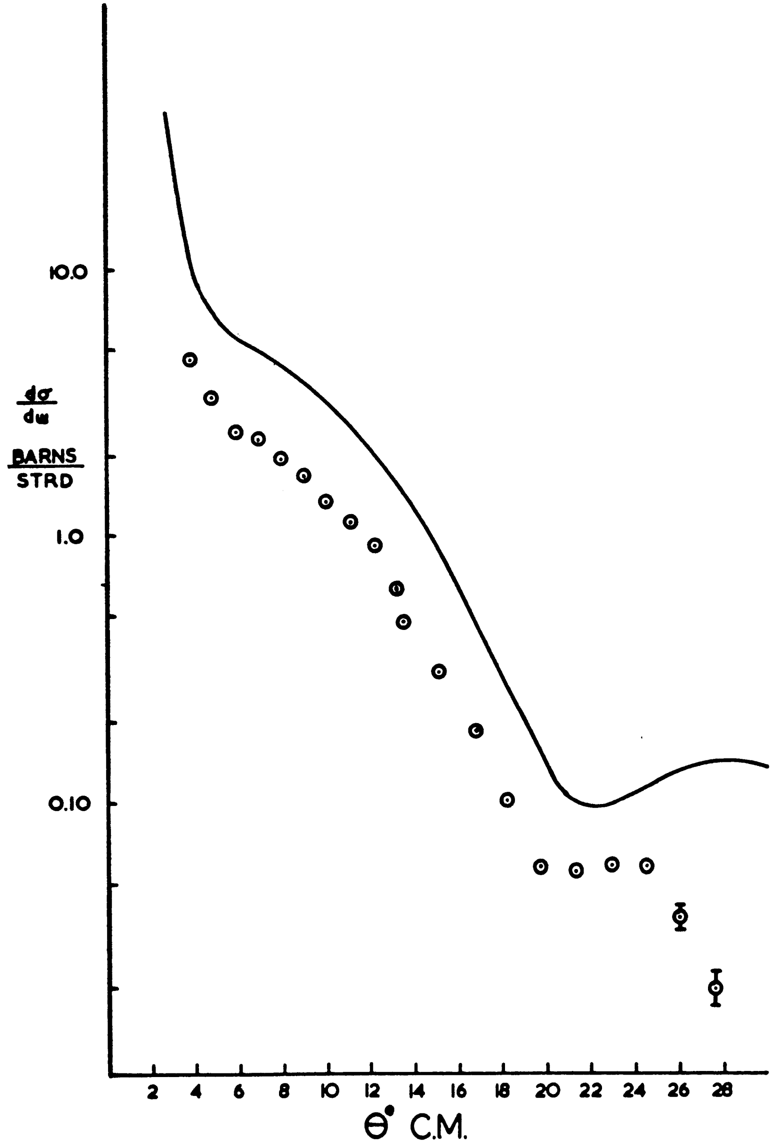

Fig. 4

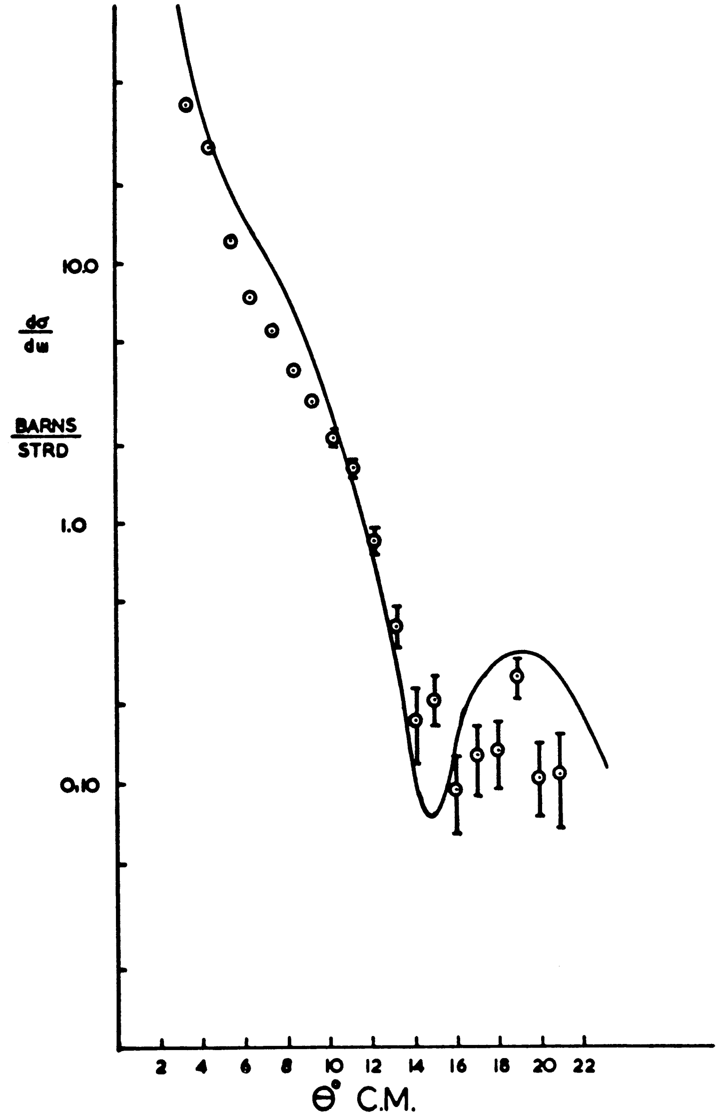

Fig. 5

DISCUSSION

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

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

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

WHITEHEAD: 180 nsec.

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

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

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

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

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

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

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

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