A SONIC SPARK CHAMBER SYSTEM WITH ON-LINE COMPUTATION FOR STUDYING THE REACTION $\pi^- + p \rightarrow f^0 + n$ AT 3 GEV/C

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1. INTRODUCTION

A data handling system for use with sonic spark chambers is being developed using a ferrite core store with a capacity of 128 sixteen bit words and with the facility for on-line connection to a Ferranti **ORION** computer. The experiment for which this equipment is being developed will be in the first case, a study of the reaction $\pi^- + p \rightarrow n + f^0$ [1] at 3 GeV/c. The reaction is to be identified by detecting the neutron at angles up to 30° in the laboratory system, its energy being determined by time-of-flight over two to three metres. The missing mass in the reaction will be determined from the input pion momentum, measured for each event by a system of sonic spark chambers and a bending magnet, and from the neutron energy and angle of emission. It is also intended to determine the spin of the f^0 by studying its subsequent decay into two charged pions. The latter measurement is made by measuring the direction of emission, the momentum and the sign of the charge of a single pion emerging in a forward direction in the laboratory corresponding to a centre-of-mass decay angle between 10° and 30°. The centre of mass decay angular interval of 60° to 120° is covered by separate sonic spark chambers which determine the angle of emission of both the decay pions. These chambers will also detect the $K^+ K^-$ decay mode of the f^0 which should occur in 1-2% of the decays. A beam intensity of 5.10^4 π^-/burst is expected to yield ~100 events/hour.

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2. THE EXPERIMENTAL LAYOUT

Figure 1 shows the layout of the experiment. The sonic spark chambers 1, 2, 3 and 4 together with bending magnet 2 serve to measure the pion input momentum. Chambers 5 and 6 define the pion trajectory into the 30 cm hydrogen target. The neutron counter consists of six 30 cm diameter, 30 cm long right cylinders of plastic scintillator each with a separate veto counter mounted immediately in front. Spark chambers 7, 8 and 9 together with bending magnet 3 determine the angle of production, the momentum and the sign of a forward decay pion. Chambers 10 and 11 detect both decay pions for decays between 60° and 120° in the centre of mass.

The high pressure gas Cerenkov counter $\hat{C}$ together with scintillation counters A, B and C define an incoming pion and counter D, run in anti-coincidence, marks the disappearance of the interacting pion from the beam and serves to reduce the coincident rate $\hat{C}$ ABC which is to be put in coincidence with the six neutron counters, a further counter E detects charged particles traversing BM 3.

3. THE SPARK CHAMBERS

Each chamber is a two gap module and the details are given in references 2,3). The plates consist of 0.001" hard aluminium foil and a layer of expanded polyurethene foam serves to further reduce the acoustic cross-talk between the two gaps. The method of mounting the cylindrical capacity type microphones is as previously [2,3]. These microphones however differ from those described earlier in the anodising technique used. 2% oxalic acid anodising solution has been used with 70 volts applied potential and a current density of 50 to 100 ma/cm^2. The other electrode used for the microphone is a layer of 1 μ aluminium foil laid over $\sim$180° of the cylinder and bonded in place at its extremities. Examination under X 500 magnification after sectioning and polishing show a smooth oxide layer 8–10 μ thick. The microphone bias potential is used in the same sense as the potential used for anodising and the breakdown voltage is 300 volts or higher. This is in contrast to the previous microphones where the microphone bias was in the opposite sense to that used for anodising and the breakdown potential was then only 50 to 100 volts. The average sensitivity of these microphones when used at 30 V bias is 8 to 10 times that of LZT flat piezoelectrics 5 mm x 3 mm x 1 mm thick and 16 to 20 times that for cylindrical piezoelectrics 3.17 mm in diameter and 5 mm wall thickness. 72 of these microphones have been tested and 90% of them have the same sensitivity $\pm$ 30%.

Only 12 have been tested yet for azimuthal response but all 12 show a uniform response over more than 120°; the limits of the response being the bonding at one extremity of the foil and the electrical connection at the other. Microphones have been made with response uniform over 270°.

It has been observed that the variation of signal with distance using these microphones in a spark chamber is of the form $V = \frac{V_0}{d} e^{-0.027d}$ and to compensate for this variation the voltage bias applied to the microphones is no longer d.c. but has the inverse form $E = E_0\, d\, e^{+0.027d}$. Using this technique with a chamber 70 cm x 50 cm the signal from the microphone is constant to ± 20% for sparks anywhere in the chamber. For such a chamber and with these microphones the voltage ramp rises to 5 to 10 volts in 3 msec.

Figure 2 shows a view of the front of the chamber; four microphones are mounted at the positions 1, 2, 3, 4 and a fifth microphone mounted in the second gap of the module at a position opposite microphone 1. Thus as a minimum, five microphones are used in each module. The spark chamber gap containing the four microphones is termed the measuring gap and the other the check gap. The time of arrival of the signals are to be recorded for all five microphones and in the subsequent analysis it is required that flight times 1 and 5 should agree to an extent depending on the angle of incidence of the particle. Such agreement renders it highly probable that the two sparks were in fact associated with a single traversing particle and were not spurious.

A calibration point-to-plane spark gap is mounted at position S, midway between microphones 1 and 4, in each gap of the module. These calibration gaps are discharged by a completely separate system from that for the spark chambers. These gaps are included for the following reasons:

a) As an aid to setting up the microphones and data handling system.

b) As a running check during the course of an experiment that the system is functioning correctly.

c) As a method of determining the velocity of propagation of sound in the chamber during the experiment.

4. DATA

At least 65 microphones will be used in the experiment and the flight times determined from these microphones will be recorded as 65 sixteen bit words in the ferrite store using a clock frequency of 4 Mc/s.

The neutron flight times are taken as from counter C to the neutron counters and will range from 20 nsec to 50 nsec and will also be recorded in the ferrite store. A time expander is being developed for us by Electronics Division, Harwell, for this purpose which expands a 50 nsec time interval to 250 μsec. The timing resolution sought is 1 nsec and will be determined chiefly by photomultiplier characteristics (a single 58 AVP is used on each scintillator cylinder) and the 30 cm length of the neutron detectors.

A single word is reserved for this neutron time-of-flight information and six bits are reserved elsewhere to indicate which of the six neutron counters was triggered.

The number of beam particles incident on the hydrogen target during the time when the equipment was active will also be recorded as previously and a similar provision is also being made to record other monitoring type information event by event.

A 14 bit word is reserved to specify information such as target full or empty, bending magnets on or off etc. and as a run number. As these changes occur relatively infrequently this 14 bit word will be set by hand switches and will be recorded together with all the timing information etc. for each event.

The magnetic fields of BM 2 and BM 3 will also be recorded, in the first instance, by hand switches as the magnet stability should be adequate (better than 1 part per 1000) but the possibility of recording the magnetic field directly via a nuclear magnetic resonance method is being investigated.

5. THE DATA HANDLING SYSTEM

Figure 3 shows a simplified block diagram of the data handling system. The coincidence $\hat{C}$ABCDPN is used to trigger the spark chambers and this same pulse opens the gate allowing a 4 Mc/s clock train to enter a 16 bit fast carry binary scaler, as stated previously[2,3] the method is now to enter the content of this scaler at time t_i (the time of arrival of the signal from the i^{th} microphone) into the i^{th} row of the store. With a 4 Mc/s clock only ~ 100 nsec would be available to transfer the scaler content unambiguously to the store. This situation is eased by the master binary scaler feeding a Gray or Reflected Binary Register. This register is essentially 16 flip-flops, one to each of the binaries in the master scaler, and these flip-flops only change their state when their associated binary changes from "0" to "1" and not from "1" to "0". This has the effect of reducing the frequency of change of each of the 16 bits of the word by a factor of 2 and increases the time available for the transfer of the Gray Code Register to ~ 200 nsec. Plessey ferrite cores are used in the store and half write pulses of 0.22 amps and 100 nsec duration are applied, after staticising, to the i^{th} row and down the columns for which the Gray Code Registers are in the "1" state thus transferring the content of the master binary scaler transposed into Gray Code into the i^{th} row. In this way the times are recorded to ± 250 nsec with essentially random access to the store and it is believed that 16 or more rows can have the same number transferred into those locations without error should such a remote possibility occur.

The other advantage of Gray Code is that the addition of one to any Gray Coded number changes the state of only one bit so that should the staticising be slightly misphased only an error of one unit is introduced in contrast to the binary case where the same misphasing could give rise to errors up to 2^{14}. In this way the times of arrival of the sound wave at the 65 microphones are transferred to the store. The expanded neutron times-of-flight are entered in an exactly similar way and monitor scaler contents are entered into other locations by stopping their accumulations of beam particles at the time of the event, clocking up the scaler with the 4 Mc/s clock train and entering into the store the, say, 10,000 out signal from the scaler overflow. In this case the number entered into the store is 10000 - N, where N is the scaler content at the time of the event.

Sonic flight times in the chambers to be used will not exceed 4 msec and at this time the clock gate is closed and also gates on the 128 rows are closed. These latter gates are only opened 100 μsec after an event to remove the possibility of pick up from the discharge of the spark chamber entering spurious numbers into the store.

At the end of this 4 msec period, information from hand switches or bistables can be entered by parallel access. In this mode the Gray Register is set by a bank of hand switches or bistables and this word transferred to its appropriate location in the store. Four such parallel access words will be provided in the store.

Thus after 4.5 msec the store contains, say, 65 flight times and 5 scaler contents in Gray Code and 4 labels in binary. In general this information is now transferred to magnetic tape. A Potter Tape Deck MT 120 has been chosen with a tape speed of 120"/sec, 200 bits per inch and a start-stop time of 5 msec total. The content of the store is transferred serially to tape, the 65 sonic channels and the 5 scaler channels being converted to binary for transfer and the parallel access channels being transferred in the binary form they have in the store. This transfer is made non-destructively and the store content is in fact transferred twice to the magnetic tape in successive blocks. It is also possible to have a decimal print out of the content of the store using a binary to decimal converter and a Solatron High Speed Printer with 15 lines/sec and, for entirely off-line checks, the information can be transferred to 5 hole paper tape at 110 characters/sec.

The time for transfer to magnetic tape is 42 μsec/word and thus the total time per event using all 128 words would be 4.5 msec + 2 msec + 128 x 42 x 2 μsec + 3 msec = 20 msec.

On line use with the ORION computer can be split into four categories.

a) One in n events passed immediately to the computer for checks and a small amount of analysis.

b) Short periods, relatively frequently, during which time the events of the previous hour, say, are passed to the computer for analysis sufficient to be a guide to the conduct of the experiment.

c) Complete or near complete analysis of many events and transfer of the events to a computer magnetic tape in computer format for subsequent analysis in further detail or analysis on a faster computer, for example the Ferranti ATLAS.

d) Complete on-line running with every event passed to the computer for, probably, checks and partial analysis and transfer to a computer tape in computer format for subsequent detailed analysis.

e) The sampling of one in n is achieved by this system in the following way. The n^{th} event is transferred to tape as described in two identical blocks and then immediately the tape is reversed and the 2nd block is transferred back to the buffer store word by word using parallel access. The first block is then written into the store over the second block. This technique is used to eliminate errors due to drop-outs. Any drop-outs occurring in this transfer can be counted. The store should then contain the same information as originally and this is then transferred word by word by command of the computer.

The direct data link into the ORION computer accepts 48 bit words of which 32 bits will be available for our use and two 16 bit words from the buffer store will be combined to form a 32 bit word for entry to the computer. The time taken to enter the word is 32 μsec thus requiring $\sim$ 2.2 msec to transfer the entire content of the buffer store to the computer. The maximum possible delay in initiating the transfer of the store content to the computer will be 10 msec but the average delay is likely to be only 100 μsec. Interruptions in the transfer can occur as we will share the direct data link with the HPD but these interrupts should not exceed 3 msec and should be infrequent. The amount of computer store for programme will be limited to a few hundred instructions for this mode of operation.

Under condition b) all the events accumulated on tape for the past one or two hours are transferred to ORION via the buffer store as above. For this mode of operation a more comprehensive programme can be stored in ORION and for a period of a few minutes events can be analysed with sufficient detail to guide the experiment. The limitation under this condition will be the number of events to be analysed and the time for analysis compared to the computer time available.

Under condition c) data collected over many hours will be passed to the computer during a break in the experiment and at the end of the experiment. Permanent storage of the data in computer format on a computer tape takes place at this time and detailed analysis is performed or, depending on the loading on the computer, the analysis is deferred until later.

Condition d) is critically dependent on the loading on the computer. It can be accommodated as for condition a) with n = 1 when each event will be stored on the Potter Tape deck and passed to the computer or the event can be passed solely to the computer.

6. FORMAT OF DATA AND CHECKS

It is intended that after an event has occurred and has been transferred to magnetic tape, all the calibration spark gaps will be fired and this pseudo-event will then be recorded and stored on magnetic tape. Coincidence type equipment is also being constructed that will give a visual indication that for each module the signals from microphones 1, 4 and 5 were in coincidence with a resolving time of say 5 μsec and further that the signals from microphones 2, 4, and 3 were in coincidence. This visual check indicates that all the microphone channels are functioning correctly. Events passed to the computer will consist of the block of data from the real event plus the block from the pseudo-event. From the pseudo-event the velocity of propagation of sound in each chamber can be rapidly computed by the computer and these values will be used to analyse, in the first instance, the event proper.

At the beginning and end of every run an identifying label is transferred to the Potter tape and by recognising these run labels any run can be located on the tape for transfer to the computer via the buffer store. A further experimental label is written in the first few characters of each event block and this will be used to indicate any relatively minor change of condition in the experiment during a run.

Under conditions a) and b) the following checks of the reliability of the data will be made:

A. - for the pseudo-event

i) The times recorded from microphones 1, 4 and 5 should agree with each other to 5 μsec and this time should agree to within 1% of that expected from the separation of calibration spark and microphone.

ii) Similarly for microphones 2 and 3.

iii) Two values of the velocity of sound can be calculated from microphones 1 to 4 and these should agree to 0.5%.

Under regime c) a complete solution of the four times from the measuring gap will be sought, its validity being determined by the velocity of sound and the shock parameter given by the solution. In parts of the chamber (i.e. symmetry axis) where the coordinate solutions are somewhat independent of the values of velocity and shock parameter confirmation of the solution will be sought using the velocity as determined from the calibration sparks.

8. CONCLUSION

This experiment is scheduled for Phase II on Nimrod which is a six months period commencing in July and 100 hours have been allocated to this experiment. A further period has been requested to further the study and to extend this technique to other resonant reactions.

References

1. Resonances in the reaction $\pi^- + p \rightarrow p + X$ will also be sought during this experiment.

2. "The use of sonic spark chambers and data handling technique in a scattering experiment", presented by C. Whitehead at the International Symposium on Nuclear Electronics, Paris, November 1963;

3. L. Bird, B. Rose, C. Whitehead, E. Wood, E.G. Auld, D.G. Crabb, G.W. Hutchinson and J.G. McEwen, "An Experiment on the elastic scattering of deuterons on carbon", present proceedings, Session III.

Figure captions

Fig. 1 Layout of beam line for the experiment.

Fig. 2 Plan view of spark chambers showing positions of microphones 1 to 5 and calibration spark gap S.

Fig. 3 Simplified block diagram of 4 Mc/s ferrite core store and associated electronics.

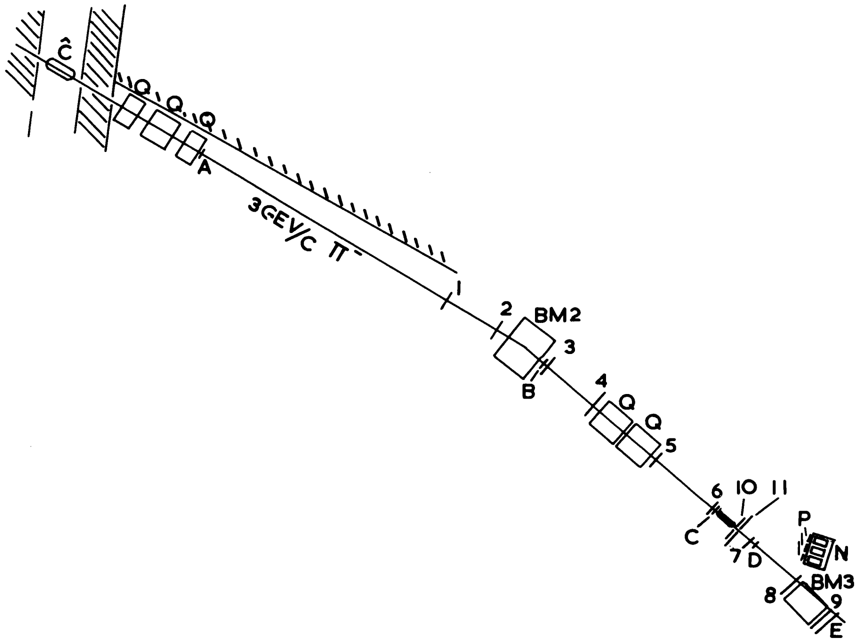

Fig. 1

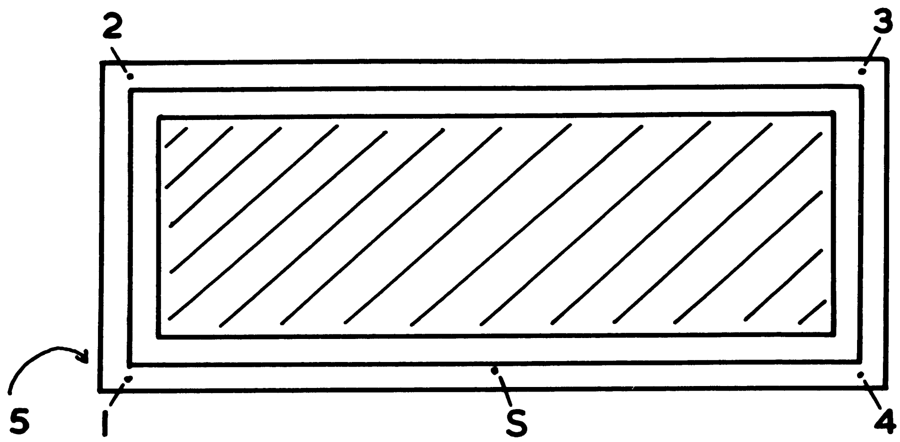

Fig. 2

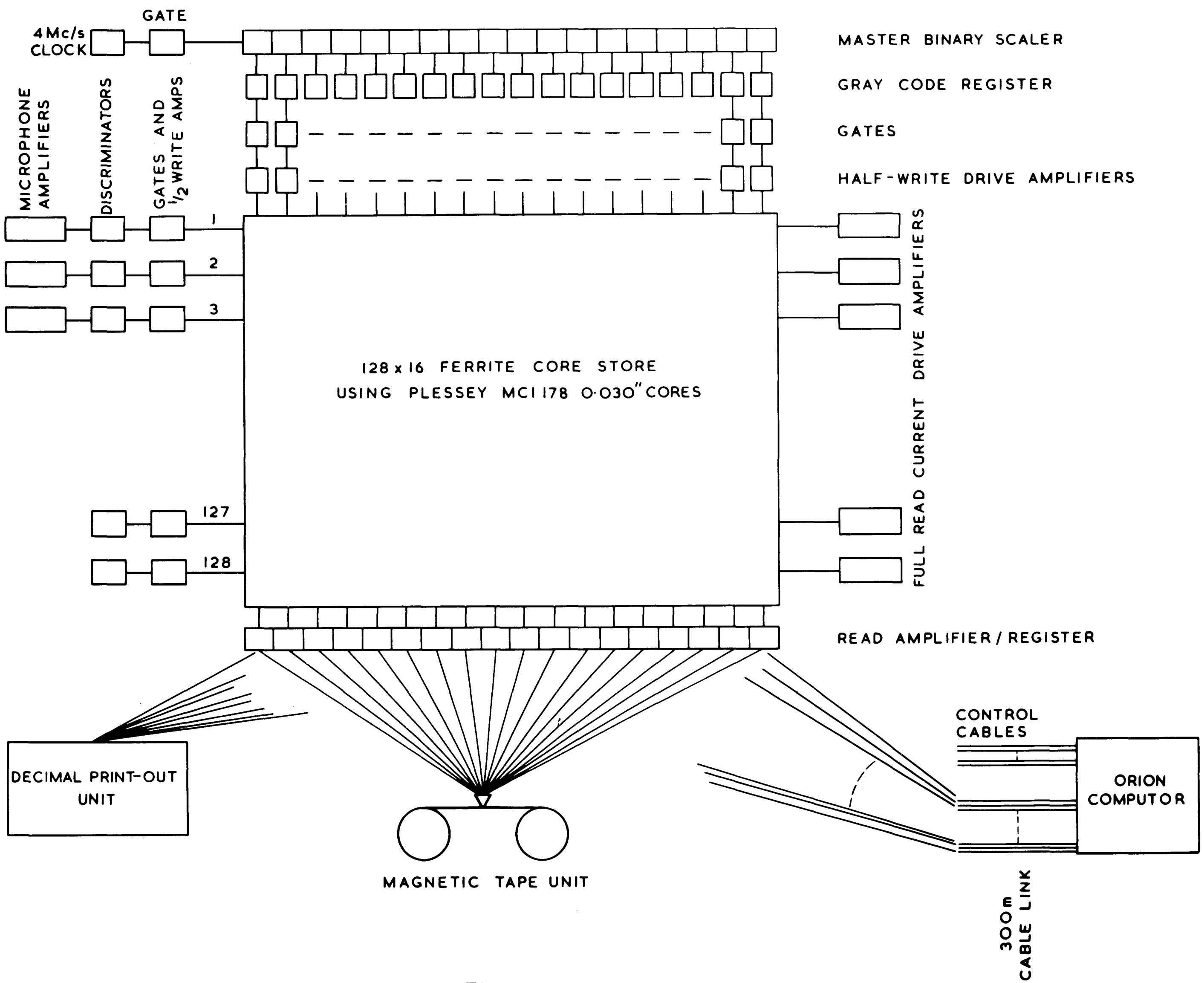
4Mc/s CLOCK
GATE
MICROPHONE AMPLIFIERS
DISCRIMINATORS
GATES AND ½ WRITE AMPS
MASTER BINARY SCALER
GRAY CODE REGISTER
GATES
HALF-WRITE DRIVE AMPLIFIERS
1
2
3
127
128
128 x 16 FERRITE CORE STORE
USING PLESSEY MC1178 0·030" CORES
FULL READ CURRENT DRIVE AMPLIFIERS
READ AMPLIFIER / REGISTER
DECIMAL PRINT-OUT UNIT
MAGNETIC TAPE UNIT
CONTROL CABLES
ORION COMPUTOR
300m CABLE LINK

Fig. 3