A HIGH CAPACITY DIGITAL DATA HANDLING SYSTEM FOR USE WITH COUNTER HODOSCOPES AND DIGITIZED SPARK CHAMBERS IN ON-LINE COMPUTER AGS EXPERIMENTS*)

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

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

(presented by S.J. Lindenbaum)

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

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

**) See preceding paper and Foley, Lindenbaum, Love, Ozaki, Russell and Yuan, Phys.Rev.Letters 10, 376 (1963); 11, 425 (1963).

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

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

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

I. THE FAST GATES

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

II. THE DATA STACKER

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

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

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

III. THE MEMORY UNIT

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

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

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

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

IV. SYSTEM CONTROL LOGIC

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

The Up-Down Address Scaler is a 12 bit binary scaler which provides the information for the Address Register. The scaler is increased by one as each word is stored during the write cycle. When the memory readout is initiated by a readout command the scaler is not reset but addresses the last word written, then scales down one at a time until the entire memory is read out.

It should be noted that when a read-out command is given, before read-out is begun, two special words are written in the memory automatically. The last 12 bits of the second word contains the number of words that are stored in the memory. The remaining 84 bits may be used to record identifying information and other information such as the scaler numbers representing beam rate, etc.

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

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

V. THE MAGNETIC TAPE TRANSPORTS

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

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

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

VI. PARALLEL OPERATION

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

VII. EXPERIMENTS PLANNED WITH THIS SYSTEM

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

This is one of the first experiments planned to be done this year with the new data handling system. The experimental arrangement is given in

Fig. 6. The angular range measured will be ~ 1.5 mrad to ~25 mrad, corresponding to $|t|$ ranging from 0.001 to 0.5 $(GeV/c)^2$ spread over 20 t bins in each measurement.

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

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

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

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

3. Other Experiments with this Data System

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

Figure Captions

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

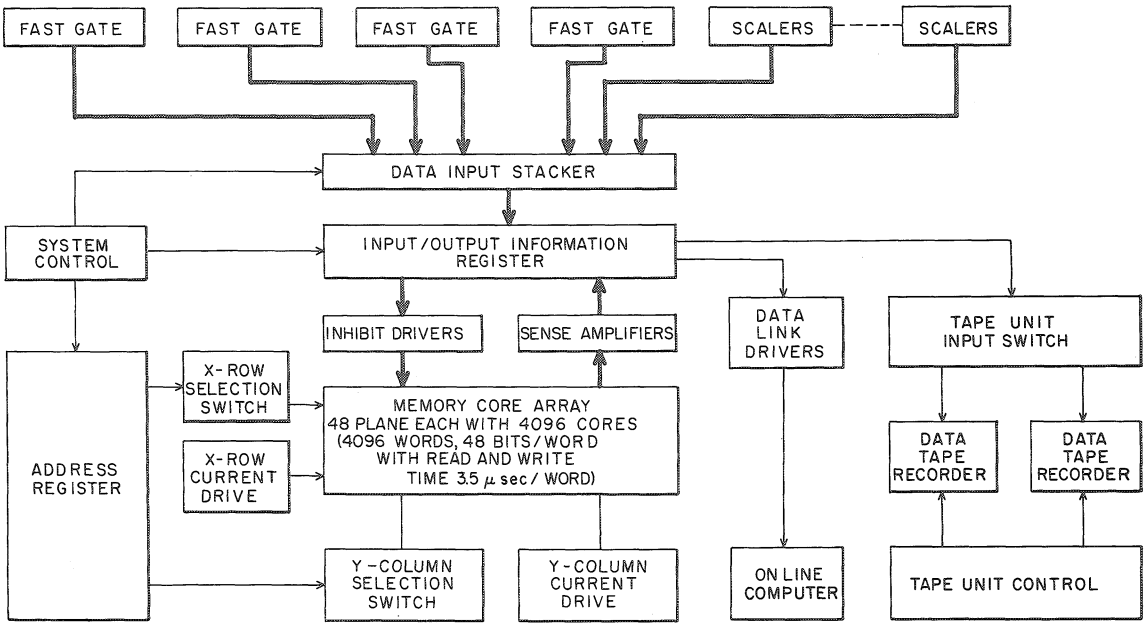

FAST GATE
FAST GATE
FAST GATE
FAST GATE
SCALERS
SCALERS
DATA INPUT STACKER
SYSTEM CONTROL
INPUT/OUTPUT INFORMATION REGISTER
INHIBIT DRIVERS
SENSE AMPLIFIERS
DATA LINK DRIVERS
TAPE UNIT INPUT SWITCH
ADDRESS REGISTER
X-ROW SELECTION SWITCH
X-ROW CURRENT DRIVE
MEMORY CORE ARRAY
48 PLANE EACH WITH 4096 CORES
(4096 WORDS, 48 BITS/WORD
WITH READ AND WRITE
TIME 3.5 μ sec / WORD)
DATA TAPE RECORDER
DATA TAPE RECORDER
Y-COLUMN SELECTION SWITCH
Y-COLUMN CURRENT DRIVE
ON LINE COMPUTER
TAPE UNIT CONTROL

Fig. 1

Fig. 2

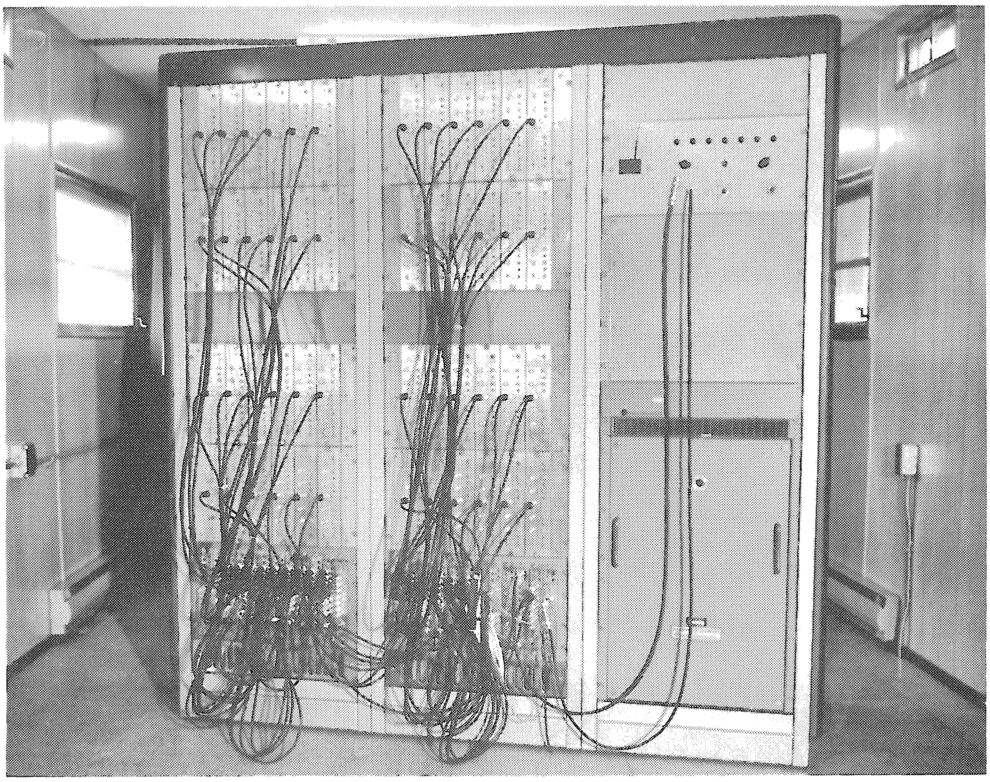
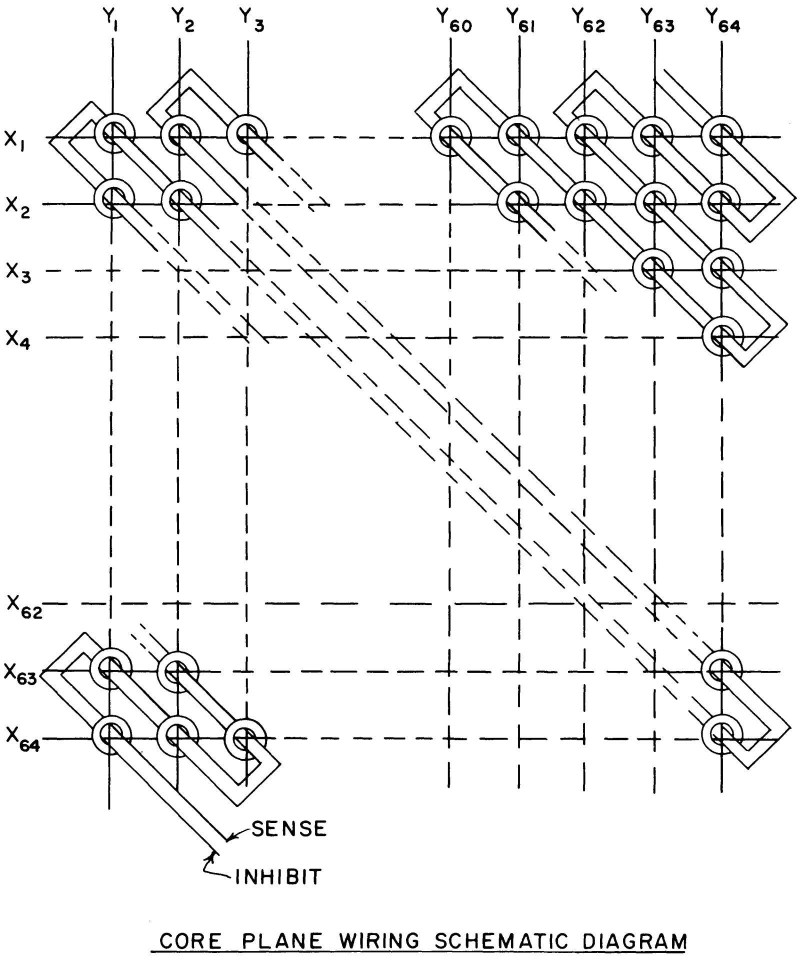


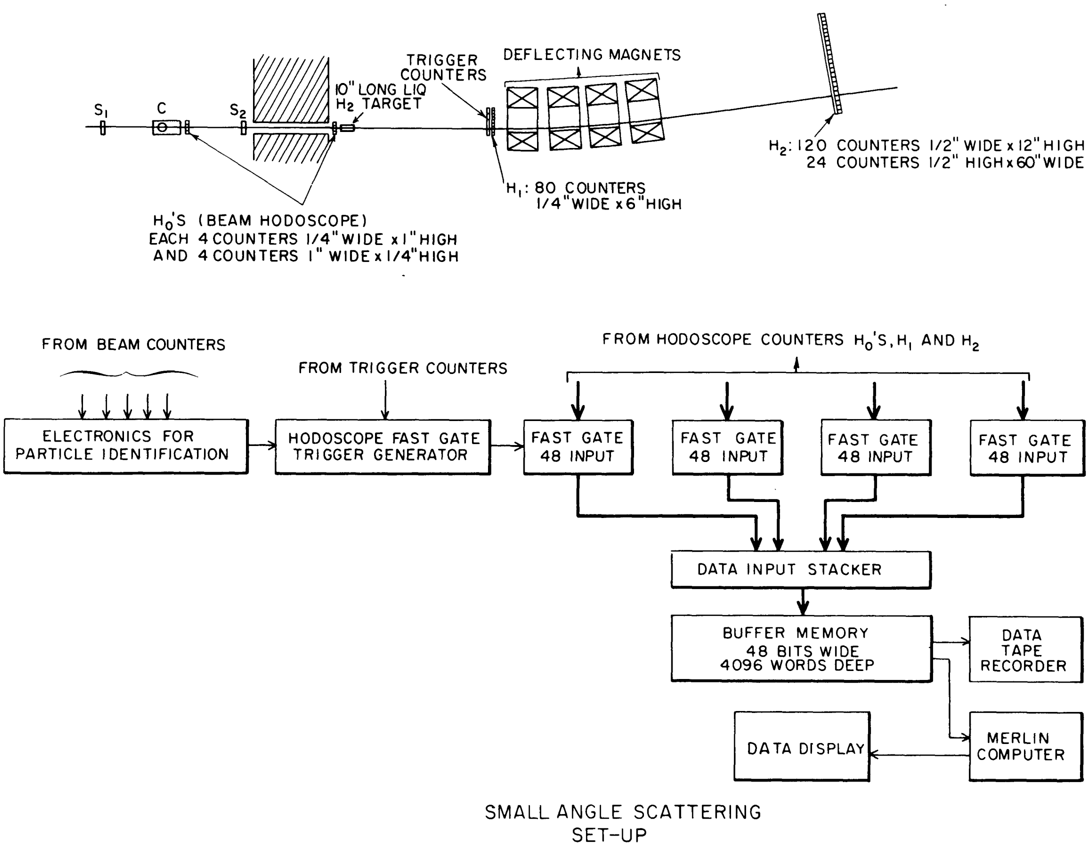
Fig.3

Fig.4



CORE PLANE WIRING SCHEMATIC DIAGRAM

Fig. 5



SMALL ANGLE SCATTERING SET-UP

Fig. 6

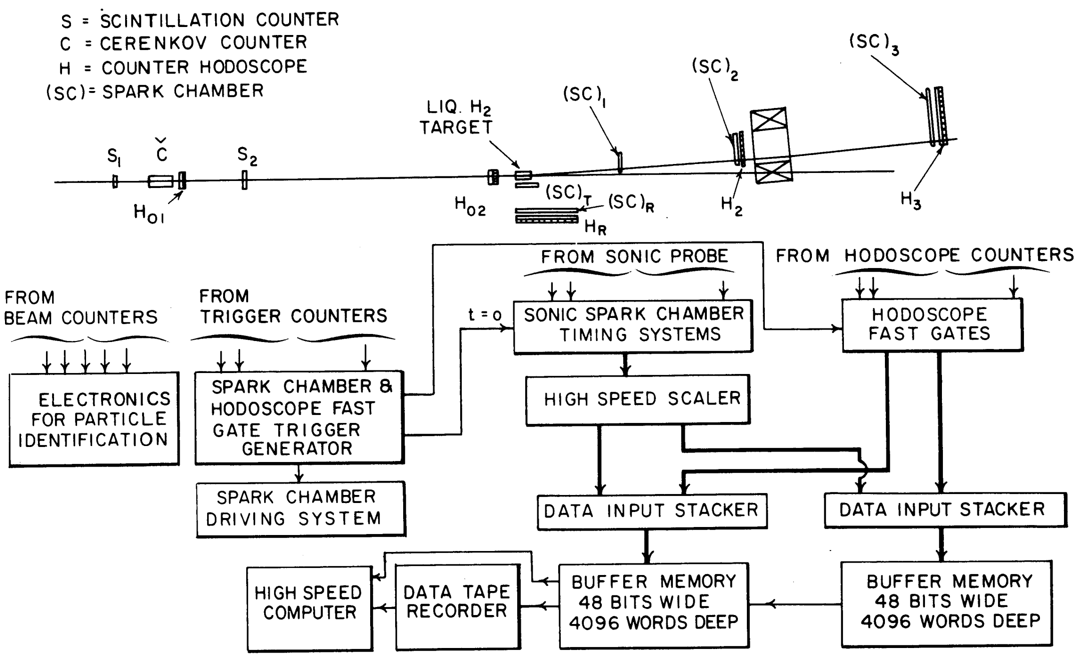

S = SCINTILLATION COUNTER
C = CERENKOV COUNTER
H = COUNTER HODOSCOPE
(SC) = SPARK CHAMBER
S1
C
S2
H01
LIQ. H2 TARGET
H02
(SC)T
(SC)R
HR
(SC)1
(SC)2
H2
(SC)3
H3
FROM BEAM COUNTERS
ELECTRONICS FOR PARTICLE IDENTIFICATION
FROM TRIGGER COUNTERS
SPARK CHAMBER & HODOSCOPE FAST GATE TRIGGER GENERATOR
SPARK CHAMBER DRIVING SYSTEM
t = o
FROM SONIC PROBE
SONIC SPARK CHAMBER TIMING SYSTEMS
HIGH SPEED SCALER
DATA INPUT STACKER
FROM HODOSCOPE COUNTERS
HODOSCOPE FAST GATES
DATA INPUT STACKER
BUFFER MEMORY 48 BITS WIDE 4096 WORDS DEEP
BUFFER MEMORY 48 BITS WIDE 4096 WORDS DEEP
DATA TAPE RECORDER
HIGH SPEED COMPUTER

Fig. 7

DISCUSSION

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

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

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

LINDENBAUM: The total cost of the first 4096 word data handling system unit (including indirect costs, salary overhead etc.) was several hundred thousand dollars, but I think you could do a double unit for under $ 200,000 and a single unit for $ 100,000 or less. This is not the major cost by the way. We spent more money on magnetic tapes and computing cost. The bulk of the programming was done by Bill Love, a member of our experimental group. As a check the problem was programmed for the IBM 7094 by Calkin's

Data Handling Group. We ran a tape through both programmes and the results agreed, event by event, except where the tape starts and stops. Bill Love took about 3 months to write the basic on-line programme with a further month debugging it on-line. That is a total of 4 man-months, a good deal of which involve 16 hour days.

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

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

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

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

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STARK: Do you have troubles with the data transmission via the telephone lines, and do ycu provide any data for error correcting or detecting codes and if so to what extent?

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