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

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

At the recent CERN Conference on Filmless Spark Chambers, we described this system⁽¹⁾ which had just been tested and made operational.

Since then we have used the system at the AGS in some experimental runs on the small angle elastic scattering experiment.

Description of the Digital Data Handling System

The original⁽²⁾ digital data handling system had 96 input bits per event and a 32 event core memory, and even though it allowed orders of magnitude improvement in these classes of elastic scattering experiments, it was designed as a first trial system and not necessarily to match the possible data rate and complexity of events limits of a wide class of experiments.

For example, the 96 input bits were fewer than the number of counters and we had to resort to coding to reduce the number of bits required to describe an event. Furthermore, although we could handle and record 50,000 events per hour, it was clear that for example in small angle elastic scattering we could usefully in high beam rate cases handle over a million trigger events per hour. We had foreseen these limitations, even before the first series of experiments with the old system in 1962, and had already planned a digital data handler expanded by about two orders of magnitude in memory bit capacity, expanded both in depth and number of bits per event. Figure 1 is a block diagram of the system.

Figure 2 is a description of the 10-30 BeV/c small angle elastic scattering experiment set-up at the AGS.

We will now briefly describe the characteristics of the system. Each scintillation counter hodoscope signal passes through a fast gate, all of which are opened by the trigger gate generator, whenever the event satisfies all the trigger logic requirements set for it. Although the minimum gate width is 6.5 nanoseconds, we generally use a 30 nanosecond gate width to avoid a very critical counter timing requirement. A tunnel diode store in each gate stores the pulse information received until transferred to the buffer memory.

(1) 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. A. Higinbotham, S. J. Lindenbaum, W. A. Love, S. Ozaki, D. Potter & L. C. L. Yuan, Proceedings of the CERN Conference on Filmless Spark Chambers. See also Brookhaven National Laboratory Report #7921 (March 1, 1964).

(2) 7-to 20-BeV/c π^+p AND $p+p$ ELASTIC SCATTERING AND REGGE POLE PREDICTIONS, K. J. Foley, S. J. Lindenbaum, W. A. Love, S. Ozaki, J. J. Russell & L. C. L. Yuan, Phys. Rev. Letters, 10, 8, 376 (1963) and Nuclear Instruments & Methods (in press).

The Data Stacker is controlled by a front panel switch - (the words per event decoder) - and provides for selectable 1-15 word (48 bits each) per event storage in memory automatically and successively. Inputs for six words are provided by the input word mixer; the sixth input can be repeatedly loaded automatically to stack up to ten words into memory per event. Hence we can handle up to 720 bit events. The basic memory unit is ^a4096 word 48 bit random access coincident current unit which takes 3.5 μ sec for the split cycle used. 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. The pulse information output of the input word mixer is transferred to the I/O information register, and then sequentially stored in memory, this latter operation being controlled by the up-down address scaler, the count in which is increased by one as each word is stored. The memory readout is initiated when the memory is full or by a trigger signal readout current supplied for example by an AGS signal that the pulse has ended. An adjustable minimum address flag allows selection of a minimum number of words before a readout can occur. Before readout two special words which contain the number of words in memory (12 bits) and 84 bits of identifying information such as beam counts scaler numbers, magnetic current settings, etc. are stored in memory.

During readout, the memory is read out backwards from the last word sequentially, the output from the sense amplifiers delivering the information in parallel into the I/O 48 bit register which is also wired as six eight bit shift registers, which are shifted eight times to provide eight 6 bit characters for recording on tape and transmission to the on-line computer.

There are two Potter Model MT120 tape transports which operate at a speed of 112.5 inches per second at packing densities of 200, 555.5 and 800 characters per inch. IBM binary format output is used - each character consisting of 6 data bits and a parity check bit. The contents of the memory is written in a single IBM "record" and is followed by a longitudinal parity check character. A Dual Transport Control Circuit allows the two transports to be used alternately to avoid data loss. After sensing a low tape situation the first transport stops recording and automatically rewinds while the second transport commences recording. The first is then reloaded by a technician.

One should finally note that each of the two individual 48 bit wide units can be connected by a tie-line cable to operate as one 96 bit-4096 word unit; one unit is "master" and the other a "slave."

Operational Experience with the System.

The system has been used recently in the experimental set-up shown in Figure 2. After some minimum de-bugging time for a short period, it has operated just about as expected and highly reliably (generally at least several hundred hours between electronic failures). The major preventive maintenance requirement is in keeping the tape transports

adjusted and the heads clean. So far we have been mainly investigating 8-15 BeV/c $p + p$ and $\pi + p$ small angle elastic scattering and we quite often at high beam rate ($\sim 10^5$ /pulse) condition handle and record ≈ 1.5 million trigger events per hour containing 192 bits of information (4-48 bit words) per event. At this rate a 2500' reel of magnetic tape is filled with bits in less than ten minutes.

An on-line program for the Merlin computer calculates the measured elastic cross section $d\sigma/dt$ vs. t^* and includes the various necessary corrections automatically. At the high beam rates the Merlin computer can only process the results at a rate about one-seventh that of the rate they are obtained at and hence can only be used to sample the data on-line. In fact, the site IBM 7094 computer takes about an hour of processing time to handle the data obtained in an hour's run at high rates. Therefore, the lack of available computer time is a most serious limit on this experiment and has considerably hampered it.

Even this on-line data sampling by the Merlin computer is only done periodically since this small angle experiment is actually set-up as a parasite run on the larger angle experimental set-up which is the prime experiment and this experiment is run on-line to the Merlin most of the time. The Merlin computer can keep up with the processing of the data for this larger angle scattering experiment. The IBM 7094 computer is then used off-line as its availability permits, generally at a considerably later time, to process the complete run for the small angle experiment.

Figure 3 shows a photograph of the digital data handling system in the 40' long by 10' wide trailer. The two tape transports are at the far end. The first memory unit and 192 gates are in the left side of the background.

Figures 4 - 5 are photographs of the counter hodoscope set-up.

Figure 6 is a photograph of the scope display of the momentum spectrum in one of the 20 t bins.

Typical experimental results on small angle elastic scattering extending from well into the Coulomb scattering region (through the interference region) to well into the nuclear scattering region will be presented for $p + p$ and $\pi - p$, in Figures 7-8. Of course, inelastic scattering is also studied as byproduct in our magnetic spectrometer.

Digitized Spark Chamber Experiments.

Figure 9 is a diagram of the proposed set-up for study of elastic scattering of 11-21 BeV/c $\pi^\pm$, $\bar{p}$, p and $K^\pm$ by protons in $|t|$ range 0.7 to 3 (BeV/c)² using a combination of digitizable spark chambers and scintillation counter hodoscopes.

Two digitizable spark chambers SC1 and SC2 after the hydrogen target will accurately measure the direction of the forward scattered particle. The space resolution will be $\leq \frac{1}{2}$ mm for either wire or sonic spark chambers, either of which could be used in such a set-up. Then a magnet followed by a third spark chamber will determine its momentum to $\sim 0.6\%$. Other spark chambers will simultaneously measure the recoil θ angle to ≈ 0.7 mrad

* the invariant four momentum transfer squared.

which is a gain in θ resolution of an order of magnitude compared to our previous results and the recoil angle will be determined to 12 mrad (an increase in resolution by a factor of 3). This combined with the high magnetic resolution for the forward scattered particle is expected to provide a negligible background error out to the highest $|t|$ measured.

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

If the velocity of the recoil particle is measured also by time of flight or other means we have a missing mass spectrometer for three particle states.

Other Experiments with these Techniques.

It is clear that polarization in elastic scattering experiments can be done with set-ups of this type employing a polarized target.

It is obvious that multi-particle inelastic interactions can be investigated with techniques like this. Our future plans involve a series of multi-particle inelastic experiments detecting at least four final state particles.

A simple possible set-up of an experiment of this type is sketched in Figure 10, where three crossed plane wire chambers are used to uniquely identify two simultaneous tracks and almost uniquely identify up to several simultaneous tracks.

For example, $\pi^- + p \rightarrow Y + K + (\text{other particles}) \rightarrow (p + \pi^-) + (\pi^+ + \pi^-) + (\text{other particles})$

The simplest case is with no other particles, which is illustrated in a qualitative sketch.

The Digital Data Handling System is used to record spark information in each chamber⁽³⁾ and pulse information from the counter elements and a program calculates the desired characteristics of the events.

The experiment can be done on-line to a computer or sampled on-line periodically and the remainder processed off-line.

Many more complicated experiments can and obviously will be invented quite easily in the future application of these general techniques.

- (3) Higinbotham, Fischer and Pate of the BNL Instrumentation Division have been developing general wire chamber equipment including standardized core readers and standardized wire chambers. Figure 11 shows a schematic of the wire chamber spark location readout system.

Figure Captions

1. A block diagram of the Digital Data Handling System.
2. 10-30 BeV/c small angle scattering set-up, which measures angles from beam center to ≈ 25 mrad. At present, $p+p$ and π^+p are being investigated primarily. $\bar{p}+p$ and K^+p investigations will occur later.
3. The Digital Data Handling System in its 40' long by 10' wide trailer (view is along the length). The left foreground shows the data monitoring scalers followed by fast electronics, fast input gates and the memory and remainder of one of the two 48 bit, 4096 word cores of the data handler. One of the two tape transports is shown at right background. To the left of it is the tape transport control, to the left of which is the second tape transport (hidden).
4. The left background contains the hodoscope H2 which measures the horizontal position of the forward scattered particle and is followed by the momentum analyzing magnets. Logic trigger counters cover this hodoscope. In the center foreground is a hodoscope HS which locates by crossed vertical and horizontal planes the forward scattered particle in the wider angle scattering experimental set-up which is shown in parallel with the small angle scattering experiment. HS is moveable on its track, which is also shown.
5. The momentum measuring hodoscope H4 consists of 128 $\frac{1}{2}$ " wide vertical slab counters and crossed $\frac{1}{2}$ " horizontal slabs to cover the same area. On the right side are the three counters which monitor the beam momentum. One should note that H4 is just outside of the primary beam.
6. A photograph of the scope display of the magnetic spectrum in one of the 20 t bins.
7. A plot of $d\sigma/dt$ vs. t for small angle $p+p$ scattering.
8. Small angle π^-p scattering - $d\sigma/dt$ vs. t .
9. 11-21 BeV/c elastic scattering AGS experimental set-up which utilizes digitized spark chambers and counter hodoscopes.
10. The investigation of the process $\pi^+p \rightarrow Y + K$ using a combination of triple crossed wire plane hodoscopes and counter hodoscopes (including logic scintillators). The incident beam direction is determined by counter hodoscopes H10 and H02. SC (TW) 1 and SC (TW) 2 determine the direction of Y decay products. Of the two possible solutions, only one should match event origin and other consistency requirements. However, the third spark chamber would remove these dual solutions. SC (TW) 3 and SC (TW) 4 again determine the directions after magnetic bending and hence the momentum and sign of each particle is determined. SC (TW) 5 and SC (TW) 6 determine the direction of the decay products and then they pass through a magnet and SC (TW) 7 and SC (TW) 8 again determine their direction. Hence their momentum and sign is also determined. Triple crossed counter hodoscopes can be substituted for wire chamber hodoscopes wherever the resolution and mass in the beam requirements allow this substitution which could be especially valuable where high particle rates hit the detector. The dotted line logic scintillators would generally be counter hodoscopes.
11. A simplified diagram of the wire chamber spark location readout system, which interrogates wires in groups of 32 and only scans individual wires if there is one or more flipped cores in a group.

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

ELASTIC p-p SCATTERING

FIGURE 7

FIGURE 8

FIGURE 9

ILLUSTRATIVE SKETCH (NOT TO SCALE)

LEGEND: SC (TW) = TRIPLE CROSSED WIRE PLANE SPARK CHAMBER
 TRIPLE CROSSED SCINTILLATION COUNTER HODOSCOPES
 CAN BE USED ALTERNATELY IN HIGH RATE CASES WHEN
 SPACE RESOLUTION AND MASS IN BEAM REQUIREMENTS
 ARE NOT TOO SEVERE

S = SCINTILLATION COUNTER
 C = CERENKOV COUNTER
 H = COUNTER HODOSCOPE
 (SC) = SPARK CHAMBER

DATA HANDLING SYSTEM

FIGURE 10

SIMPLIFIED DIAGRAM OF
SPARK CHAMBER READOUT
SYSTEM.

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FIGURE 11