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A MULTIWIRE PROPORTIONAL CHAMBER TRIGGER SYSTEM FOR A RAPID-CYCLING BUBBLE CHAMBER†

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Abstract

A cylindrical multiwire proportional chamber operating within the vacuum tank of a rapid-cycling bubble chamber is described. The system is used in conjunction with the SLAC K^o-spectrometer to allow the selection of event topologies of several types of K^o_L p reactions having small cross sections (~ 0.1 to 1 mb) in comparison with the total cross section (~ 25 mb). Construction of the chamber, its electronics, data acquisition, and operational characteristics are presented.

Introduction

A multiwire proportional chamber system to provide a trigger for a rapid-cycling bubble chamber[1] has been constructed. This system is used in conjunction with the SLAC K^o-spectrometer to allow the selection of particular event topologies in K^o_Lp interactions. Details of the K^o-spectrometer have been previously published;[2] they will therefore be dealt with only briefly here. The proportional chambers have been placed within the vacuum tank of the SLAC 15" Rapid-Cycling Bubble Chamber (RCBC) which is located immediately upstream of the spectrometer, as shown in Figure 1. The inaccessible location of the MWPC's has imposed a unique set of mechanical and electrical requirements on the system, which we will discuss in this article.

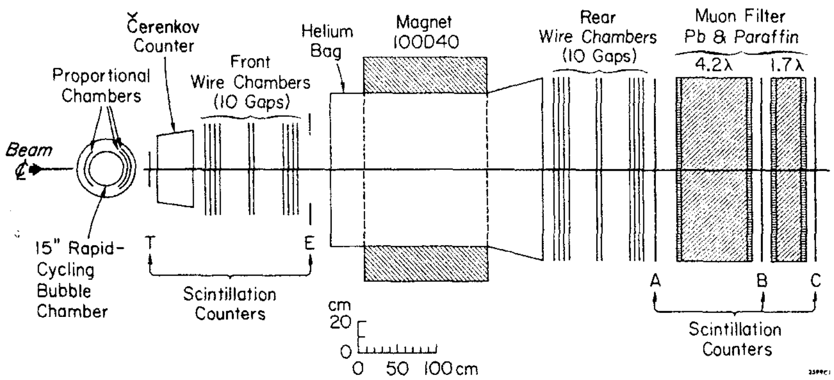

FIG. 1--Experimental setup.

The goal of the experiment for which this system has been devised is the study of exchange mechanisms in the interactions of K^o_L mesons with nucleons. In particular, it was desired to study with high statistics and good resolution in four-momentum transfer (t), the reactions

$$K^o_L p \rightarrow K^o_s p \qquad (1)$$

and

$$K^o_L p \rightarrow K^* (890) p \qquad (2)$$
$$\quad \hookrightarrow K^{\pm}\pi^{\mp}$$

These reactions proceed with a cross section of ~ .1 and 1 mb, respectively, in the K^o_L beam momentum range available at SLAC (2 - 12 GeV/c), whereas the total K^o_Lp cross section is approximately 25 mb. A previous K^o_L exposure of approximately one million pictures in the SLAC 40" bubble chamber had yielded 1929 examples of reaction (1) and about 6000 examples of reaction (2). In order to improve upon these yields, it was necessary to generate a selective trigger which would emphasize events of these topologies, i.e., one transverse prong and a neutral V, or three prongs with two fast forward particles. In principle, this could have been done by placing a conventional hydrogen target in front of the K^o-spectrometer, and detecting proton recoils through the side of the target in coincidence with two forward particles which traverse the wire spark chambers and scintillation counters of the spectrometer. This approach has two limitations, however: 1) The recoil proton must penetrate 5-10 cm of hydrogen and the walls of the target in order to be detected, thus limiting the observable four-momentum transfer to large values ($\gtrsim .1 (\text{GeV/c})^2$), and 2) if the outgoing K and π from reaction (2) are not identified, then ~ 10% of the K^* events will reconstruct with an invariant mass of the K^o_S, providing a 100% background for reaction (1). In order to overcome these limitations, it was decided to use the small rapid-cycling bubble chamber (38 cm diam × 14 cm deep) as a "visible target" in conjunction with the wire chamber spectrometer. This approach allows the observation of proton recoils as small as 1 mm ($t = .005 (\text{GeV/c})^2$) and minimizes the background of K^* events in the K^o_S sample by simply allowing the classification of the events as to topology on the scanning table.

The success of this approach depends critically on our ability to detect the presence of two and only two fast forward particles associated with the interaction of a neutral particle in the sensitive region of the bubble chamber. Both K^o_L decays, and interactions in the bubble chamber walls, could result in events of the desired topology, so it was necessary to place our detection apparatus as close as possible to the sensitive region. It was also important to have reasonably good spatial and time resolution. To meet these criteria, we decided to place multiwire proportional

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chambers within the vacuum tank of the RCBC.

Because of the shape of the bubble chamber and the acceptance of the K^0-spectrometer it was only necessary to determine the horizontal coordinate of each track as it left the RCBC; the probability of two tracks hitting the same vertical MWPC wire and the event being accepted by the spectrometer was negligibly small. This allowed us to construct a chamber solely with vertical sense wires and solid HV electrodes. The curved HV electrodes were made from copper-clad G-10 which was strong enough to provide mechanical rigidity. Two planes were mounted upbeam of the hydrogen. One was a spare, the other had groups of 3 and 4 wires ganged together and was operated as a veto. Two planes were mounted downbeam. Both of these were used: the trigger requirement was that there be two and only two non-adjacent wires struck in one of the two planes. The electronics was of necessity remote from the chamber itself. The signal was sent on 2.4 meters of subminiature coaxial cable to preamplifiers, which then drove 33 meters of twisted pair to the discriminators and latches. Mechanical and electronic details will be discussed in the ensuing sections, as will system performance.

Mechanical Construction

The technique of curved chamber construction described here is easily generalizable to a complete cylinder, any portion of an arc, or highly specialized shapes. Our application calls for 120^0 of a circle. One proportional chamber consists of one inner and one outer radius frame. The inner frame has a solid HV plane on its innermost radius and a readout plane on its outer radius. The outer frame has a solid HV plane on its outer radius and this is bolted to the inner frame. Wires strung on the readout plane are sandwiched equidistantly between the two HV planes. A two-plane module is shown in Figure 2.

were cut and interlaced in a flat rectangular shape. Each strip was then spread with a thin layer of epoxy and bent onto the curved form. In order to apply uniform pressure, a 6.4 mm steel strap, bent to the required radius, was clamped over the laminated frame; the radius of the inner electrode is 30.79 mm ± 80 μm. An occasional high spot is hand-sanded to specifications. Following a similar procedure, successive spacers were built on top of the first one. The high voltage planes are made of single-sided copper-clad G-10 sheets of 0.79 mm ± 50 μm thickness. The additional multiple scattering contribution of these thick electrodes is small compared to the total contribution of the bubble chamber windows. A prototype chamber was constructed with guard strips, but these were found to be unnecessary, and were not included in the final design.

Uniform wire spacing is achieved by scribing lines on the readout frames using a titanium roller with 13 cutting edges. 20 μm diameter gold plated tungsten wire is placed in these inscribed grooves and soldered to the PC frame under a tension of 50 ± 2.5 gm. The wires were soldered using 63-37 tin-lead solder and ordinary liquid flux. Great care in soldering was necessary to ensure a good bond to the wire. As an additional precaution, the joints were coated with epoxy. The wires are spaced 2.032 mm ± 50 μm.

For cleaning, the chambers are first lowered into fumes of a vapor degreaser filled with trichloroethylene, then cleaned in an ultrasonic cleaner with alconox, i.e., soap and water; finally they are washed thoroughly with distilled water, dried with warm dry air and then bolted together. This method results in very low dark counts.

The chambers are installed inside welded stainless steel cans which are mounted in the bubble chamber vacuum jacket, as close as possible to the sensitive volume. There are two gas systems, one circulating magic gas inside the

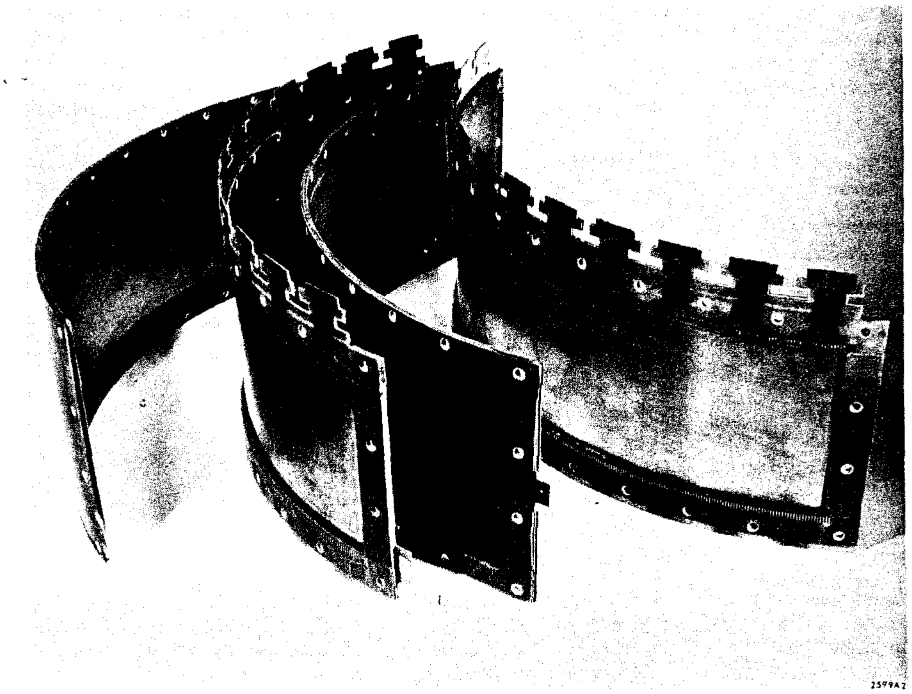

FIG. 2--Exploded view of a 2-plane multiwire proportional chamber.

The spacing of the HV plane to the readout wires is 5.08 mm with a tolerance of ±75μm to ensure uniformity of the chamber plateau. The first step in construction was to make 4 concentric spacers by laminating G-10 strips together with epoxy on an aluminum jig consisting of 2 semicircles 3.2 cm thick held together by three 13.3 cm aluminum cross blocks. These blocks define the active area of the wires. Two of the blocks were placed 120^0 apart to define the end of the arc. 25.4 mm wide strips of 0.79 mm G-10

chambers, and the other circulating argon through the rest of the can. A regulator system is provided to maintain a differential pressure between the two volumes of less than 50 mm of water. As the mounting can is in close proximity to both LH_2 and LN_2, it is wrapped in twenty layers of superinsulation, and can be heated using a feedback control system. It is necessary to provide an average of 10 watts to maintain the chambers at 20^0C.

Circuit Considerations

The MWPC signal is transmitted via 50Ω subminiature coaxial cables to a set of preamplifiers, μA733 (see Figure 3). After a nominal amplification of 280, the signals are sent via a 33m twisted pair transmission cable (AWG 22) to discriminators and to the subsequent electronics. Several problems had to be solved to ensure a good signal-to-noise ratio: the distance from the MWPC to the preamplifiers is 2.4m and the available dimensions in the RCBC allow the use of subminiature coaxial cables only. Good design practice demands an amplifier at the receiving end of the coaxial cable having a characteristic input impedance matching that of the cable. Practical and economic considerations, however, dictated the utilization of readily available circuit components such as integrated circuits. By using μA733 preamplifiers, a mismatch is created and the coaxial cable looks like a capacitance of some 240 pF.

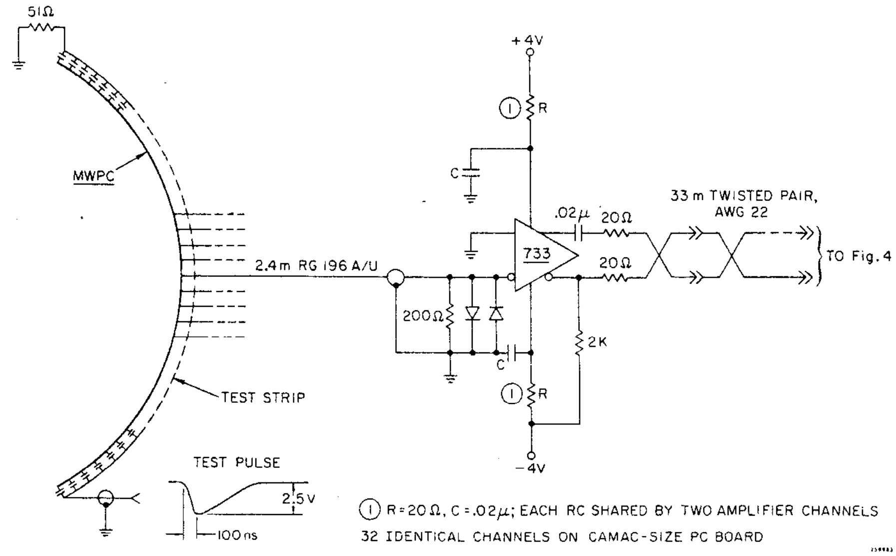

FIG. 3--Preamplifier.

The gain and the bandwidth of the amplifier are dependent on the supply voltages which are chosen to be ±4V, mainly to reduce the bandwidth and thus achieve good stability when the amplifiers are excited by transients. The outputs of the μA733's are back-terminated and applied to the 90Ω (nominal) twisted pair transmission line. A resistor of 2K is added as a current sink at the output of the μA733 to achieve a higher output swing of negative polarity. With the minor addition of components described above the μA733's operate well as differential line drivers and under test conditions are required to deliver signals of 300 mV, minimum, into the transmission line. Signals of twice that amplitude are readily observed and the onset of saturation varies between the units. One CAMAC double width module incorporates 32 preamplifiers.

At the receiving end (see Figure 4), quad 1:2 transformers[3] are used to remove common-mode noise and obtain single-ended signals from a balanced transmission line. The quad comparator[4] MC 3450 has an offset voltage of ±10 mV, is operated with a threshold voltage of 200 mV, and delivers a standard TTL pulse. The 9602 single-shot is chosen because of its favorable time delay vs temperature characteristics. The latches 74S74 employ feedback from $\overline{Q}$ to S_D to lock out any signals that might arrive after the event when the coincidence pulse has already been removed. The latches act as temporary storage and the information is transferred in parallel to shift registers type SN74165 and then serially to a PDP-9 interface. A "FAST OR" of 32 wires is available for initial triggering decisions which have fairly liberal triggering criteria. (Triggering decisions are further discussed under Timing and Triggering Criteria.) One CAMAC size module contains 32 identical channels described above, as well as buffering of the control signals: CLEAR, COINC., SHIFT-REGISTER LOAD, CLOCK.

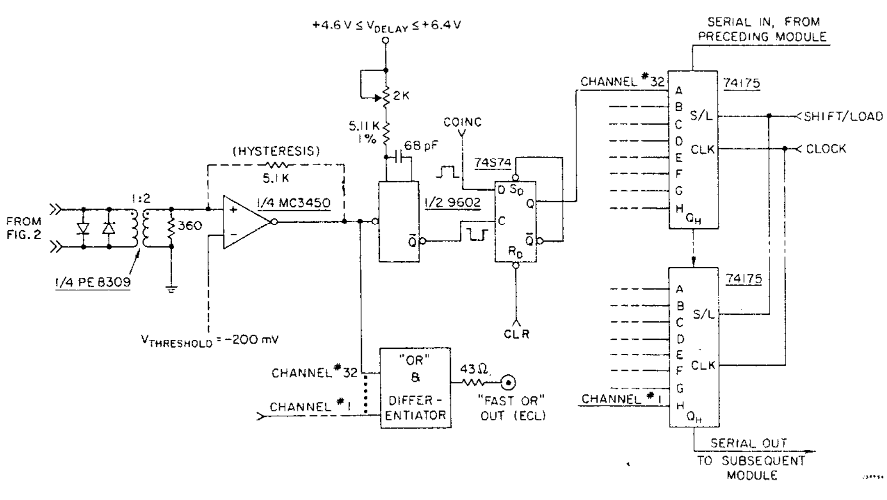

FIG. 4--Discriminator and logic circuits.

System Architecture

The MWPC is part of a large spectrometer system including four scintillation hodoscopes, a 1m × 1m × 2.5m magnet, and 20 planes of spark chambers with capacitor-diode readout.[1] Data acquisition is done by a PDP-9, while communication and data formatting is effected via the interface. For ease of interfacing with existing circuitry, the three planes of the MWPC are treated as "PLANE 21" of this system. The data format consists of 9 bits identifying the wire number that was hit in an event, 2 bits identifying the plane (1, 2 or 3) of the MWPC, and one bit that is set to logic 1 whenever an RCBC exposure is taken.

The sequence of operations is shown in the flow diagram, Figure 5. This diagram is modified and simplified for clarity and does not show the interfacing connections with other data acquisition components of the spectrometer; nor is the signal-flow in the TEST mode shown, as this will be discussed in the next section. Also omitted was the track counter and its associated logic to be discussed later.

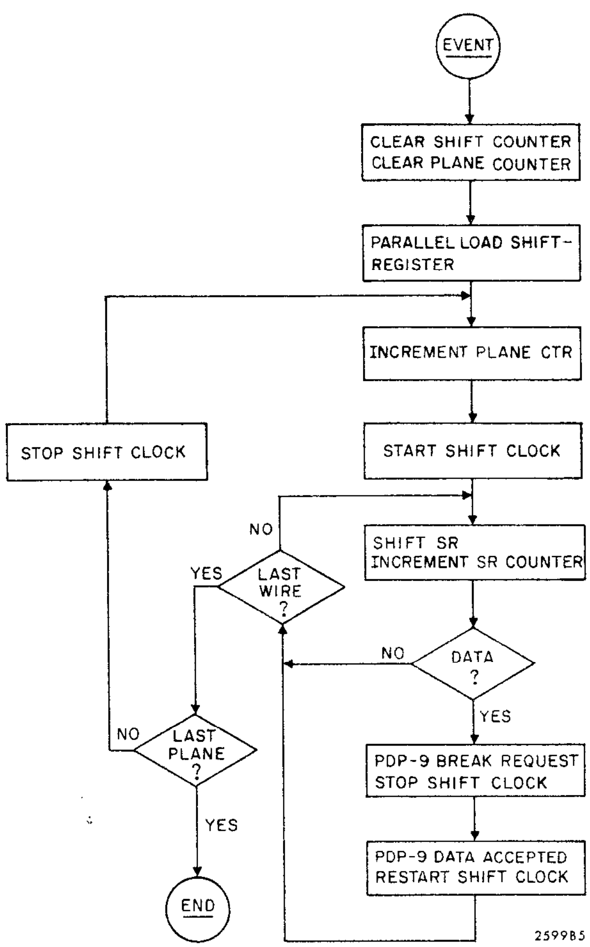

FIG. 5--MWPC simplified flow diagram of data acquisition

The input to the computer specifies the wire number hit and the plane number at which the hit was recorded. In a cluster of adjacent hits, such as in the case of delta rays or heavy particles at large laboratory angles, each wire is recorded separately and the software program finds the exact position by reconstructing the ionization path seen in the (upstream) RCBC and the (downstream) spark chambers.

Computer Controlled Self-Test

It has been our design philosophy to include computer controlled test features in any system of sizable magnitude.[2] The purpose of such a feature is to locate fault conditions as closely as possible to the failure source to enable rapid repair during an experiment. Ideally, such a feature should utilize digital logic already existing in the interface circuitry. This philosophy demonstrated its effectiveness in the past and is incorporated in the MWPC electronics described here.

Two tests are performed: (a) Readout test for components "stuck at logic 1". This test checks out some failure modes in the bi-stables and the shift-registers of Figure 4, and some failures in the transmission lines. The test is invoked when the software simulates the data acquisition instruction set that is associated with an event of interest. Under normal functioning, i.e., when no failures are present, the serial data stream that is processed by the interface should not write any data into the computer memory. (b) The readout test for components "stuck at logic 0" checks a broader range of component failures. To effect this test a signal is simultaneously applied to all channels of the MWPC. Thus every one of the channels, if operating properly, would generate a computer interrupt with a request to write data into the DMA. Much saving of time and memory is achieved by logically inverting the serial data entering the interface during this test phase. Hence, only those channels which have not responded to the test signal (presumably because of component failures) demand a break request and are entered into the computer memory via a DMA port. The test signal is applied at the MWPC, as shown in Figure 3, via a G-10 strip with a copper-clad ground plane on one side. Since the coupling to the preamplifiers is capacitive, the shape of the signal should ideally be a ramp to obtain a rectangular pulse at the inputs of the μA733's. The test pulse waveform shown in Figure 3 produces, after differentiation, a negative rectangular pulse of 100 ns duration followed by a small positive overshoot, and provides a very adequate test method.

Timing and Triggering Criteria

The MWPC is an effective tool in reducing the number of undesired bubble-chamber exposures. Ample time is available to make limited decisions as to whether the track multiplicities obtained are of interest in a given experiment, since about 1 ms is required for full development of the bubbles in the bubble chamber. Two options were considered for implementation of the hardware decision. In one option a row of multiplexers used as logic decision elements, followed by cascading and fanning-in digital adders, yielded a decision in < 140 ns. This is sufficiently short to inhibit the triggering of spark chambers. However, a large number of IC's is required in this parallel mode adding unless MWPC wires are grouped. Such grouping, however, degrades the spatial resolution and hence the accuracy with which track multiplicities can be identified.

An alternative method, and the one adopted for this system, interrogates at every event the complete MWPC at a rate of 2.5 MHz. An event itself is defined by the logical AND:

$$\mathrm{EVENT} = 2A \cdot 2T \cdot Q \cdot \overline{V}$$

where 2A (2T) means that two or more hodoscope counters in group A (T) show hits while $\overline{V}$ signifies that no charged particle traversed the veto region of the MWPC. Once a possible event has been thus recognized it is followed by interrogation of the MWPC, wire by wire, to establish the exact number of hits. Each cluster is considered as one hit (unlike in the "normal" data acquisition of the previous section, in which each hit wire is counted separately). A logic decision circuit determines whether the number of hits, n, is of interest in a given experiment, where $1 \leq n \leq 4$. Additionally, provisions are available to base the decision on the results from one plane or both, or a logical combination (AND, OR) of both planes. MWPC efficiencies and the multiplicities of interest dictate the selection of the triggering logic. In this method that we refer to as "second tier decision" (the first tier decision being effected by the fast OR in coincidence with scintillation hodoscopes) some 240 μs are required to yield a decision to activate the RCBC camera mechanism. Therefore, the spark chambers are fired each time $2A \cdot 2T \cdot \bar{V}$ is satisfied. However, the number of bubble chamber exposures is reduced by a considerable factor utilizing the results obtained from a detailed examination of track counts (see Summary).

System Performance

Stable and efficient operation of the system is achieved with threshold voltages of the MC3450 corresponding to 0.5 mV signals at the MWPC, although, for greater noise immunity, the system is typically run with a 1.0 mV threshold.

As the MWPC signals are carried on closely packed coaxial cables to the 733 preamplifiers for a distance of 2.4 meters and then through cables consisting of 32 twisted pairs, low crosstalk was an important design criterion. This is especially true in view of the "n and only n" aspect of the "second tier decision". Crosstalk among groups of 32 adjacent channels was measured to be $\leq$ -32 dB.

In order to allow measurement of the incident K_L^o momentum by time of flight, the already poor SLAC duty cycle is worsened by chopping the 1.6 μs beam spill into narrow bunches separated by 12.5 or 25 ns. As good a time resolution for the MWPC's as possible is therefore important to avoid accidentals. Aside from time variations in the formation of the pulse in the chamber itself, this system has contributions to the time resolution from transit time and gain variations of the 733's (± 4 ns), dispersion in the twisted pairs (± 3.5 ns), propagation delay time in the MC3450's (± 6 ns), and propagation delay time of the monostables (± 14 ns). In order to obtain the best possible time resolution, the electronics variation for individual wires is tuned out to a level of ±5 ns by adjustment of the pulse width of each 9602 monostable. In this way it is possible to achieve > 99% efficiency for a group of 320 wires with a coincidence pulse width of 35 ns. (See Figures 6 and 7.)

The chambers reach full efficiency over the range of 3.4 - 4.0 KV (see Fig. 8) with a 1 mV threshold using a gas mixture consisting of 71% argon, 24.5% isobutane, 0.5% freon, and 4% methylal. With such a plateau length, it is easily possible to find a common operating point for all chambers. Figure 8 also shows the distribution of single, double, and triple wire hits as a function of the high voltage.

Summary

A multiwire proportional chamber trigger system has been operated inside the vacuum jacket of a rapid-cycling bubble chamber. The number of RCBC exposures taken by this method is reduced by a factor of 15 for K* production and a factor of 3 for K_S production. Moreover, another factor of ten reduction in the amount of scanning, measuring, and processing time results from the use of the K^o-spectrometer information, which allows one to reconstruct the mass and position of the recoiling system. Placing the MWPC inside the RCBC vacuum jacket results in a reduction of the sensitive volume, which appreciably decreases background triggers. The MWPC lends itself to this application as its performance is not impaired by the high magnetic field of the RCBC.

Acknowledgments

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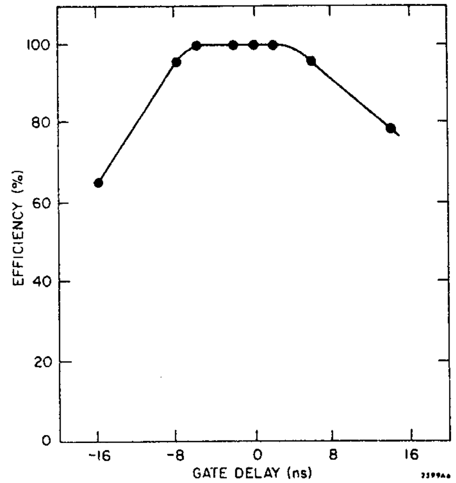

FIG. 6--MWPC efficiency versus coincidence delay for a coincidence width of 35 ns.

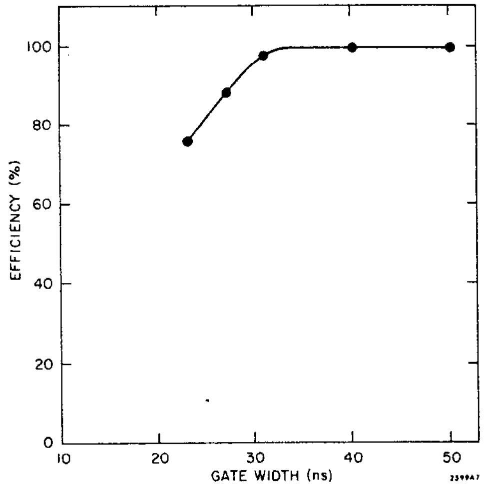

FIG. 7--MWPC efficiency versus coincidence gate width at HV = 3.9 kV.

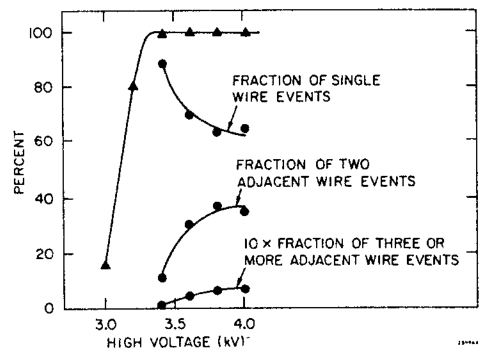

FIG. 8--(a) MWPC efficiency versus applied high voltage (▲). (b) Distribution of number of wire hits versus high voltage (●).

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