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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A scintillation detector of unique geometry

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Abstract

A scintillation detector meeting specific physics requirements and geometrical constraints is described. It operates with high efficiency inside a 1 T magnet in an intense charged particle beam of up to 3×10^6 particles/s. It uses a unique light collection system combining air space, wavelength shifter disc and conventional lucite light guides. The detector is used in a veto mode to identify interactions that produce an all-neutral final state. The details of the counter's design, construction and performance are described.

1. Introduction

We are reporting here on the construction of a scintillation counter of innovative design that is used as a charged particle veto detector (CPVA) in a fixed-target experiment at the Brookhaven Alternating Gradient Synchrotron (AGS). The detector is in a high magnetic field and in an intense charged particle beam. Strict geometrical constraints on the counter's design were imposed by its location in the narrow gap between an array of cylindrical detectors surrounding the target and an array of planar detectors downstream of the target region. The scintillator of CPVA is positioned transverse to the beam directly downstream of the vacuum jacket of a liquid hydrogen target that is recessed deep inside a cylindrical drift chamber surrounding it as shown in Fig. 1.

Experiment E852 at Brookhaven National Laboratory (BNL) for which the counter was designed is an experiment in meson spectroscopy using the Multi-Particle-Spectrometer (MPS) facility. An 18 GeV/c negative pion beam of up to several 10^6 particles/s is incident on a liquid hydrogen target located in the 1.0 T field of the MPS magnet. The 30-cm long cylindrical target is at the center of a system of coaxial detectors surrounding it that includes a cylindrical drift chamber (TCYL) and a cesium iodide (CsI) barrel detector. The scintillator of the CPVA counter is inside the central hole of TCYL, intercepting the beam after it traverses the target. The target region is followed by planar proportional and drift chambers, a lead-scintillator sandwich detector, and a lead glass calorimeter.

The CPVA counter's main task is to help identify, at the trigger level, interactions in which the final state is all

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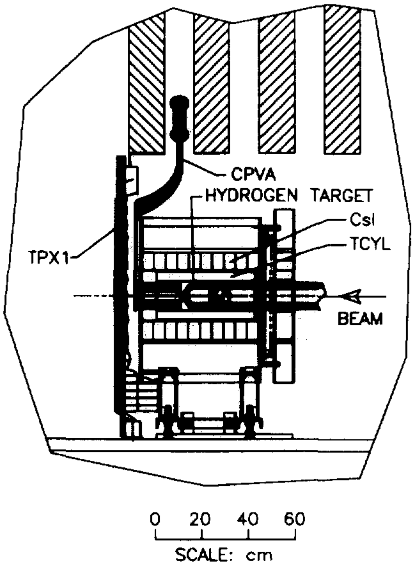

Fig. 1. Side view of the E852 target region detectors located inside a 1 T field of the MPS magnet. CPVA – charged particle veto; CsI – cesium iodide barrel veto; TCYL – cylindrical drift chamber; TPX1 – planar proportional wire chamber.

neutral. In addition, the counter is used as part of a trigger for events in which neutral particles, e.g. K_s^0, emerge from the target and then decay to charged particles after having traversed CPVA. Since the counter is used in veto mode, a very high rejection efficiency for charged particles is essential.

The high magnetic field, the limited space available for light guides and the requirement for high efficiency posed the main challenges in the design and construction of the counter.

2. Design considerations

The principle design criteria are as follows:

i) The counter has to be fast since it operates as an element of a trigger system in a high flux beam (up to 3×10^6/s).

ii) The counter has to detect both the non-interacting beam particles and the charged particles emerging forward from interactions in the hydrogen target. Its sensitive area of about 4.5 in. diameter includes the small cross sectional area of the beam.

iii) The counter's efficiency should be over 99% to allow for a high rejection of events with charged particles in the selection of reactions with an all-neutral final state. This high efficiency is particularly important in view of the intensity of the beam.

iv) The counter should be positioned as close as possible to the downstream end of the target and should fill the diameter of the hole in TCYL to maximize the acceptance for events with short-lived neutral particles in the final state, such as K_s^0 and Λ. These events are selected by requiring that there be no hit in the CPVA counter while the planar PWCs record hits of multiplicity corresponding to the number of charged particles produced in the decay of the neutral mesons.

v) The counter has to operate in a high magnetic field (1.0 T) and in an environment of relatively high electronic noise. Therefore, light guides that bring the scintillation light without too much attenuation to a location of lower magnetic field are essential. Even the Hamamatsu R2490-01 phototubes designed for operation in magnetic fields have severely reduced amplification in such a high field and thus the electronic noise could hinder their operation.

vi) The light guide shape has to conform to the space available downstream of the target along the beam, both for operating and for mounting the counter. The available space is bounded radially by the interior wall of the cylindrical drift chamber, TCYL, of 2.48 in. radius; and axially along the beam by the vacuum jacket of the recessed target upstream and by a planar proportional wire chamber (TPX1) downstream, a distance of 9 in. The gap between TPX1 and CsI is about 2 in. and is the only access from the target region to the space outside to which the light has to be piped. Thus, the detectors surrounding the target impose severe constraints on the counter geometry.

vii) The mass of the counter should be as low as possible to minimize the rate of beam interactions in the counter itself. This is obviously important in order not to introduce too many spurious events originating outside the target and in order to reduce the chances for secondary interactions.

3. The counter's novel concepts

We have studied several possibilities for the design of an appropriate detector. We considered using a proportional chamber but encountered difficulties due to the requirement of fast response, the presence of the very localized intense beam, the circular shape of the sensitive area, and the general geometry of the available space. In reviewing the choices for designing a scintillation counter we considered using fiber optics or solid lucite light guides for extracting the light signal from the scintillator and guiding it out of the tight space near the target to phototubes outside the intense magnetic field. These options presented several difficulties. First, the lucite light guides or fiber bundles could collect light only from the circular edge of the scintillator surface in order not to introduce excessive material in the beam path. Secondly, the sharp bends of the light guides imposed by the geometric constraints would cause considerable light losses and therefore reduce the counter's efficiency.

Eventually we found a simple concept for the counter that consisted of having the scintillator followed by an air light guide, then a wavelength shifter, and finally lucite light guides to pipe the light to the photomultipliers. The light generated in the scintillator disc travels through the air volume downstream of the target inside a reflective cylinder until it strikes a thin wavelength shifter disc that is parallel to the scintillator. The wavelength shifted light redirected to its periphery is collected there by two lucite light guides. These light guides transfer the light through the available narrow opening to two phototubes located in a region of low magnetic field.

The novel aspect of the counter is the use of an air light guide in combination with the redirection of the light by a wavelength shifter. This avoids the need for sharply bent lucite light guides and their unavoidable light attenuation and minimizes the material in the path of the beam. To ensure that such arrangement will provide superior light

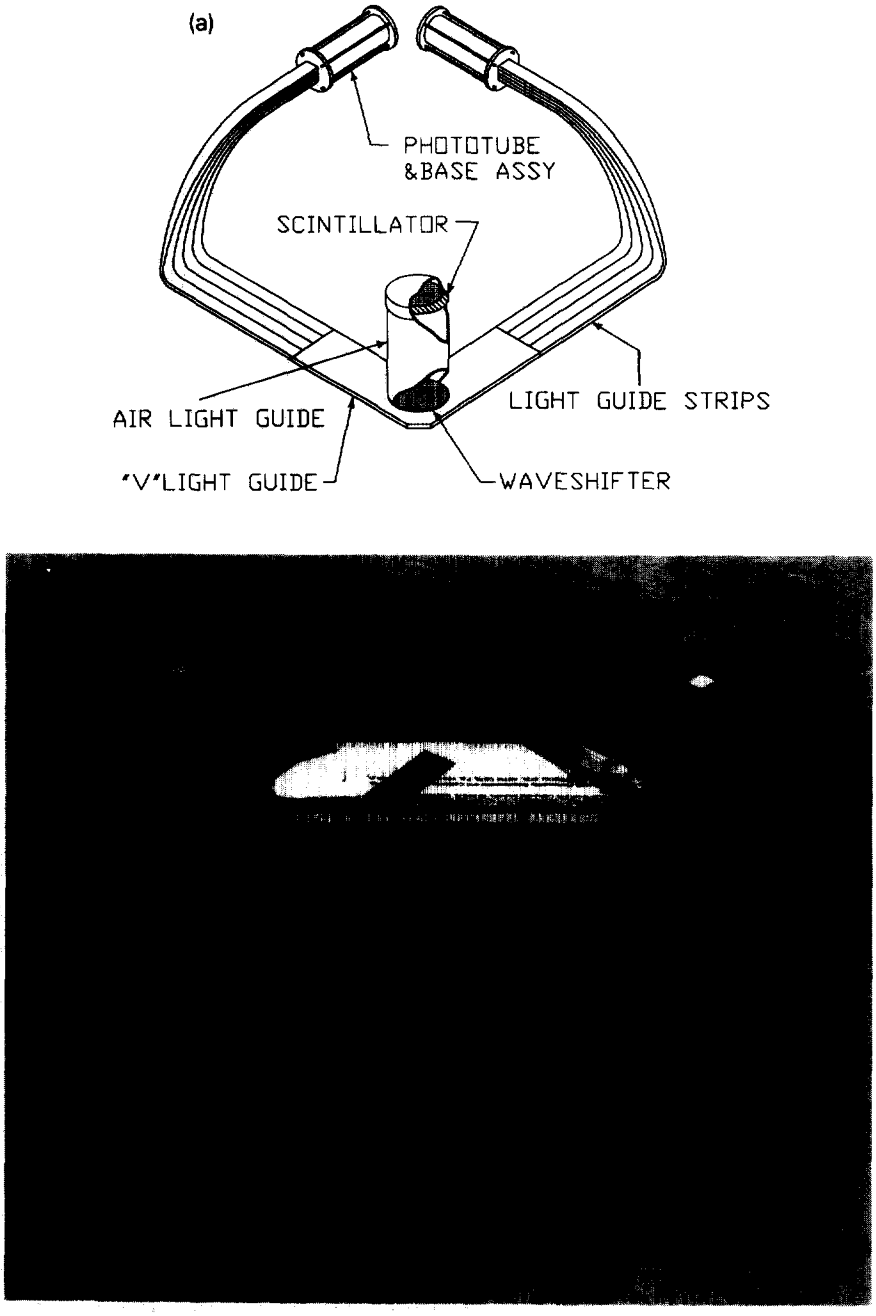

Fig. 2. The CPVA counter. (a) Schematic view. (b) Photograph of CPVA in its final light tight configuration with phototubes and bases.

collection and thus high efficiency, we tested the concept first using a prototype counter in a test beam. Based on the positive results of the test we adopted the concept and proceeded to optimize the design of the counter for its purpose in our experiment.

Another special aspect of the counter is the geometry of light collection and the placement of the phototubes. The light re-emitted by the wavelength shifter disc is collected by two lucite light guides transverse to the direction of the original light entering the disc. The light guides themselves are at 90° with respect to each other collecting the light from the rim of the wavelength shifter disc, as shown in Fig. 2. Much of the light from the opposite side of the rim is reflected back toward the light guides due to internal reflection and aluminized surface. Thus this arrangement provides better light collection than the traditional symmetric one with light guides opposite each other at 180°. The light is transferred by the gently bent light guides through the narrow gap left by the other detectors onto two photomultipliers located inside an air gap between the iron slabs that form the upper pole of the MPS magnet. In this location the field is not strong enough to affect the operation of these photomultipliers.

4. Description of the counter

The final CPVA counter is composed of a plastic scintillator, an air light guide, a wavelength shifter disc, lucite wave guides and two phototubes; their configuration and dimensions are given below. The entire counter assembly is light tight and is supported on the container of the CsI barrel detector, see Fig. 3. Additional supports were mounted inside the magnet's pole gap for positioning the phototubes and their bases with voltage dividers.

The scintillator (Bicron BC408) is of circular cross section 4.5 in. diameter and 0.375 in. thick. The cylindrical surface of the scintillator was machined at 45° and polished to produce a conical internally reflective surface for better collection of light generated in the scintillator. The scintillator is located inside a cylindrical air light guide enclosed by specular surfaces.

The air light guide walls were constructed from layers of 3-mil aluminized Mylar® (1-mil Al and 2-mil Mylar laminate), 2 mm thick Rohacell®, and 3-mil Kevlar®. These layers were laminated on a cylindrical mandrel using Epon® epoxy to produce a cylinder of precise dimensions 4.5 in. I.D., 4.75 in. O.D., and 7 in. length. The technique used for manufacturing the lightweight cylinder was developed previously by us [1].

The scintillator was fitted coaxially inside the cylinder at one of its ends. Three small brass pins spaced 120° apart around the circumference and protruding 1/8 in. through the cylinder wall about 0.25 in. from its end served as a stop for the scintillator to prevent it from falling in. A lid with a reflective inside surface was placed behind the scintillator to close this end of the cylinder. Thus the scintillator was held between the pins and the lid at the upstream (along the beam) end of the counter. The 45° bevelled edge of the scintillator was oriented to internally reflect the light down the air light guide formed by the cylinder.

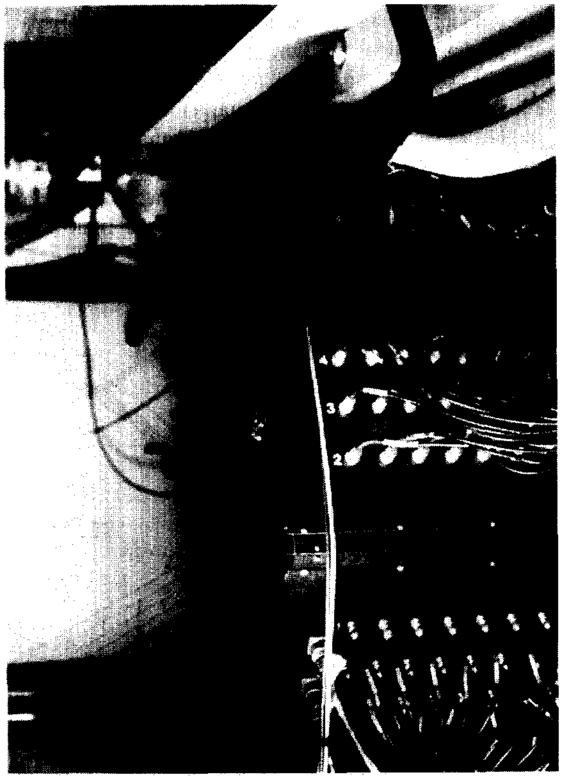

Fig. 3. The CPVA counter mounted on the CsI box inside the target region (in the absence of TPX1).

At the downstream end, the cylinder is closed by the disc-shaped wavelength shifter (Bicron BC482A). It is 1/8 in. thick with 4.75 in. O.D. and is inserted inside a specially configured lucite light guide that collects the light emitted by the wavelength shifter. Thus the light that originates in the scintillator is guided through the air inside the cylinder and enters the wave shifter disc through its planar surface. It is absorbed and re-emitted isotropically, and the lucite light guide collects this light through the narrow cylindrical surface of the wave shifter disc at 90° to the original light direction.

The lucite light guide system (see Fig. 2a) was made of several parts machined, polished and glued together with Bicron BC-600 optical cement. The lucite stock for the light guide parts was 1/4 in. thick. The wavelength shifter sits inside a circular opening machined at the vertex of a "V" shaped part of the light guide system. The arms of the "V" are at 90° with respect to each other and when in place (see Fig. 3) point symmetrically up at 45° with

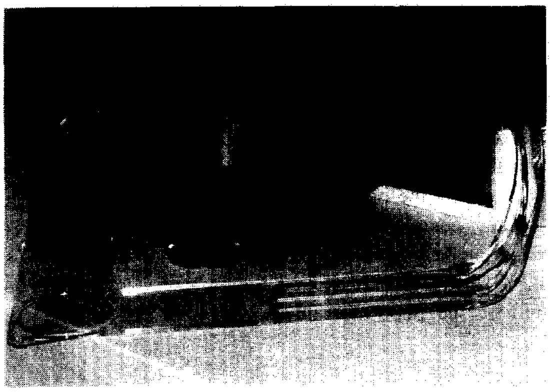

Fig. 4. Optics of the CPVA counter. Displayed are the components of the optical system of CPVA counter before their assembly. They are: 1) the "V" shaped Lucite light guide with the Lucite strips attached and the wave shifter disc inserted in the circular opening at the vertex of the "V"; 2) the beveled scintillator; and 3) the cylindrical container of the air light guide supported on its end cover.

respect to the vertical. Each arm is 5 in. wide and 10 in. long. The circular opening for the wavelength shifter disc was machined so that it would fit in to the depth of 3/8 in. and rest midway in the lucite against a lip of smaller I.D. (see Fig. 4).

The two arms of the "V" constitute the beginning of the two light guides used for transmitting the light through the geometric constrictions to the phototubes. To the end of each arm four strips of lucite were glued each 1.25 in. wide, 0.25 in. thick and about 30 in. long. The strips were preformed by heating and bending so that they conformed on one end to the cross section of the rectangular end of the "V" and on the other to the dimensions of the photocathode surface of the multiplier. In the design of the strips, major attention had to be given not only to the geometrical constraints of the space available, but also to the installation procedure. After constructing a mock-up of the target region where the counter had to fit and after selecting the low magnetic field location for the phototubes, a jig was made for bending the lucite strips. They were heated to 180°C and bent on top of the jig to the proper shape and then cooled to room temperature at which they retain the acquired shape. Two sets of four strips, individually formed, were assembled. Each set had its ends machined and polished and then one end was aligned and glued to the arm of the "V" using optical cement. The other end was glued to a transition lucite disk to aid in the later attachment of the phototube.

The photomultiplier tubes chosen for the counter are Hamamatsu R2490-01 that operate well in a magnetic field up to 1 T. At the location of our phototubes the field is about 0.2 T and has no significant effect on the tube's operation. The high voltage divider bases used for the phototubes were designed for operation at high current in view of the intense beam and the ensuing high event rate.

During the assembly of the counter, major efforts were made to optimize the light collection efficiency. The contact area between the wavelength shifter and the lucite light guides were greased using Dow Corning optical grease except for the corner region of the "V" which was covered with reflective aluminum. The different parts of the lucite light guide were carefully glued together using optical glue and the phototubes were attached using a transparent silicone layer. The whole counter was wrapped using aluminum foil, black/reflective plastic (that is opaque on one side and specular on the other) and black electrical tape.

The insertion of the CPVA counter into its position inside the MPS magnet required preparation and care. The arms of the "V" shaped light guides were supported using specially designed clamps. The counter was brought into the magnet through its open side with the "V" rotated horizontally. The cylindrical part of the counter was inserted into the TCYL and then the counter was rotated back so that the light guides with the photomultiplier tubes and their bases would enter the slot between the iron slabs of the magnet's upper pole. The counter was freed of the clamps and attached to the container of the CsI barrel for support. The light guides inside the magnet's pole received additional support.

5. Performance

The CPVA counter was tested extensively. First we used cosmic rays defined by a scintillation counter tele-

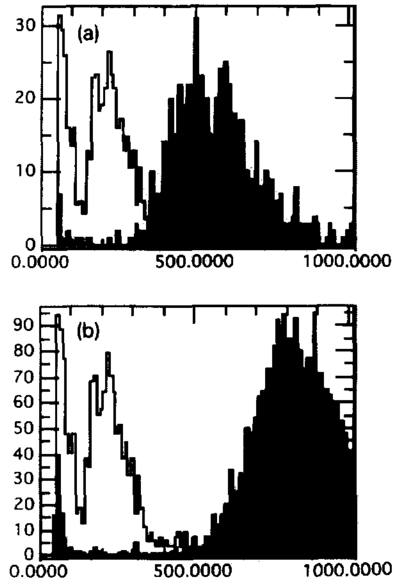

Fig. 5. The CPVA pulse height spectra with (dark) and without (light) scintillator, (a) using 1/4 in. scintillator, (b) using 3/8 in. Scintillator. The spectrum without scintillator is due to the Cherenkov light produced in the wave length shifter.

scope. Then the counter was mounted in a mockup system simulating the actual geometry of the target region and tested in an 18 GeV pion beam. The mockup system was used for developing and then practising the method for handling the fragile counter during transfer and insertion into the actual experimental setup. Finely the counter was inserted into its position in the spectrometer and its overall performance in the full 1 T magnetic field was studied using an 18 GeV π^- beam.

The reasons for the extensive testing were to:

1) optimize the light collection;
2) balance the contribution of the two photomultiplier tubes;
3) evaluate counter performance as a function of high voltage and discriminator settings;
4) assess the pulse height of the Cherenkov light produced in the wavelength shifter;
5) determine the optimal thickness of the scintillator.

Using cosmic rays, we found that the use of optical grease in the joint between the light guide and the wavelength shifter disc improved the light collection as measured by the phototube pulse height by about 20%. The

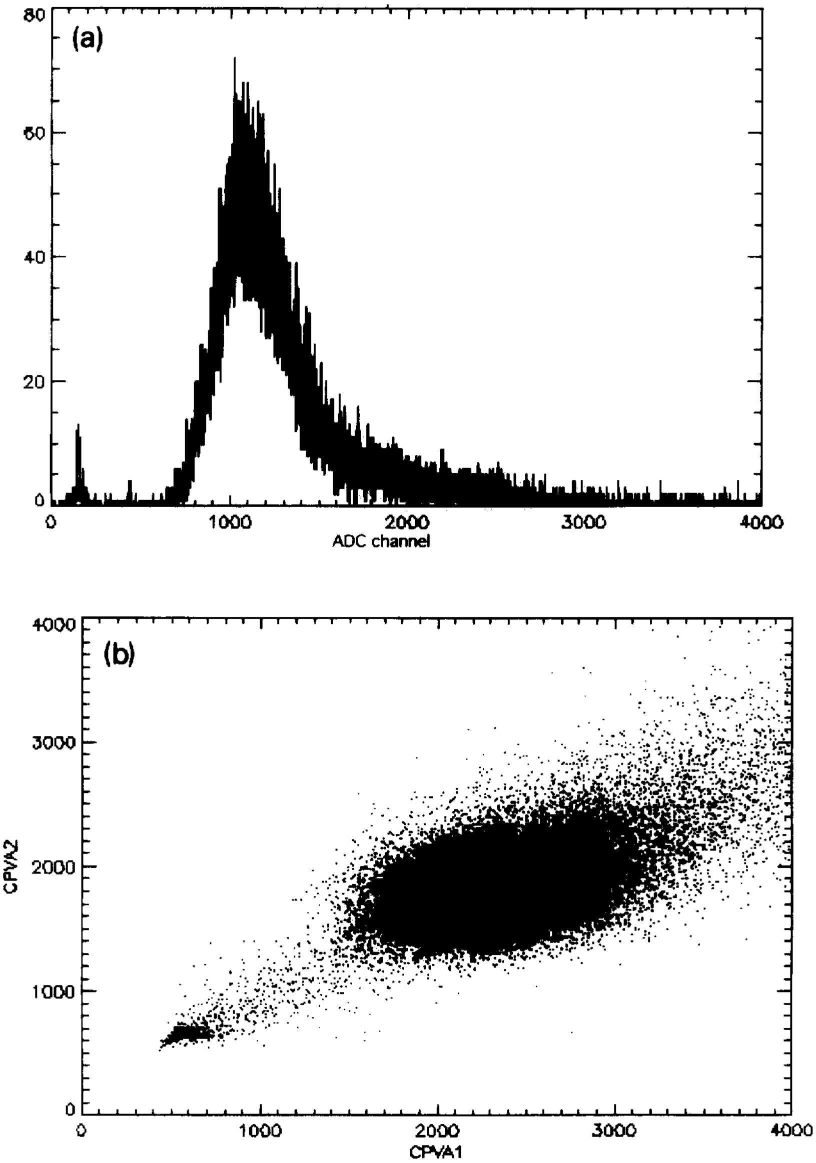

Fig. 6. (a) CPVA ADC spectrum for 18 GeV/c non-interacting beam particles. (b) CPVA1 ADC vs CPVA2 ADC.

Table 1
Efficiency measured using tracked profile events

Data runs	Hits	Misses	Efficiency
1	27305	8	99.97(1)
2	22577	7	99.97(1)
3	18801	4	99.98(1)
4	16954	5	99.97(1)
5	15026	4	99.97(1)
6	15854	6	99.96(2)
Total combined efficiency	116517	34	99.971(5)

two Hamamatsu tubes used were preselected for their high gain and photocathode efficiency, but since one of them had particularly high gain the nominal voltages assigned to the two phototubes differed substantially. They were 1.95 and 2.5 kV, respectively.

In the above test the counter telescope selected particles traversing both the scintillator and the wavelength shifter disc. We needed to understand the extent to which the Cherenkov light produced in the wavelength shifter contributed to the resulting pulse height. This was relevant since the detection of the K^0s traversing the CPVA scintillator required that there will be no signal from the CPVA counter. We were concerned that the Cherenkov light produced in the wave shifter by the pions from the decay of the K^0_s would veto the event. To assess the effect of the Cherenkov light we ran a test of the CPVA counter without its scintillator, i.e. with just its wave shifter. The resulting pulse height spectra for 1/4 and 3/8 in. scintillators with the overlay of the Cherenkov light spectrum are shown in Fig. 5. To obtain very good separation of the pulses from charged particles traversing the scintillator and those traversing just the wavelength shifter, we used a 3/8 in. scintillator in our test run.

The performance of the counter in the magnetic field was examined using non-interacting beam particle events reconstructed using the PWCs and the drift chambers downstream of the target. The ADC spectra of the two phototubes, CPVA1 and CPVA2, showed distinct separation between pedestals and signals, see Fig. 6. The plot of CPVA1 ADC versus CPVA2 ADC indicate balanced light collection between the tubes and independent high efficiency of each of them.

To study the CPVA counter efficiency using the beam particle events, we projected the tracks of the analyzed events to the location of the CPVA counter and recorded both ADC pulse height values. The following three conditions were imposed on the events:

1) only one outgoing track emerged from the target;
2) the projection of the tracks intercepted the CPVA scintillator;
3) an ADC pulse from either CPVA1 or CPVA2 was required to be above a cutoff value of channel 700.

Events that satisfied all three conditions we defined as "hits". The events that satisfied only the first two condition but not the third were defined as "misses". The efficiency was calculated as: hits/(hits + misses). The results are presented in Table 1. The combined efficiency with high statistics is 99.971(5)% as indicated.

When we removed the second condition, the single tracks with ADC pulses below channel 700 accounted for about 1% of the single track events. These events are displayed in Fig. 7. In this figure the x–y scatterplot of the projected track position is displayed at the location of the CPVA scintillator. The events seen in the scatter diagram

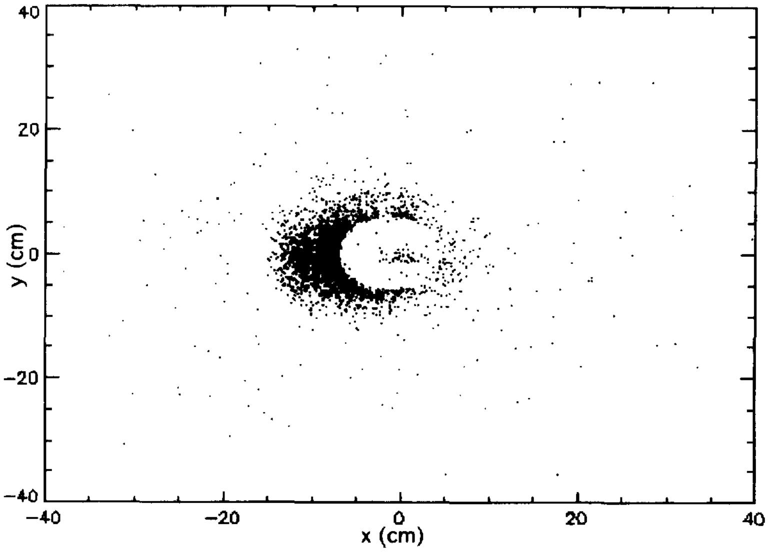

Fig. 7. CPVA distribution. The x–y scatter plot of the tracks projected to the z position of CPVA that do not fire the CPVA counter. (The non circular shape is due to different x- and y-scales.).

inside the radius of the CPVA scintillator are the "misses" that are responsible for the 0.03% measured inefficiency of CPVA. It is obvious that the vast majority of the missed events are due to beam tracks that narrowly missed CPVA, and not due to any inefficiency of CPVA. Although the scattering of some particles downstream of CPVA could result in an inaccurate projection of the track to the CPVA scintillator, the quality of the track reconstruction is evident in the sharpness of the CPVA profile.

6. Summary

We have built a novel scintillation counter adopting techniques that met specific physics and geometrical requirements. Its features are:

1) use of a wavelength shifter instead of sharply bent lucite light guides to redirect light in a tight geometry;
2) use of an air light guide separating the scintillator and wavelength shifter to minimize the material in the path of the beam;
3) use of two lucite light guides (at 90°) to maximize the light collection and for placing the phototubes in a reduced magnetic field;
4) use of Hamamatsu phototubes for operation in a magnetic field.

The resulting counter is distinguished by its high efficiency 99.97% while operating in a 1 T magnetic field.

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