A wedge-shaped scintillation counter with high spatial resolution

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A new instrument for the measurement of the spatial position of a particle is described. The pulse height analyses of the output of a simple wedge-shaped plastic scintillation counter has been used to provide information on the spatial position of particles passing through the counter. A resolution of $0.2 \pm 0.02$ mm was obtained. Various applications of this counter are also discussed.

* This work was performed while the author was on leave at CERN, Geneva, Switzerland.
Introduction

In investigations of the properties of beams of high energy particles it is often desirable to know the spatial distribution of the particles. (e.g. to measure the image size at the foci of a beam). It is of advantage if this information can be collected with speed and with precision.

The beam profile may be examined by use of a thin scanning counter or by a hodoscope, or even by a bubble or spark chamber. Normally, the former has sufficient resolution but requires time to scan through the image, while the hodoscope technique suffers from poor spatial resolution. The two visual techniques have the disadvantage that the information is not normally readily available in the most useful form, although recently there have been several attempts to extract rapidly information from spark chambers using electronic methods rather than photography.\textsuperscript{1,2,3} This report concerns the development of a simple scintillation counter which combines a high spatial resolution with the facility of measuring simultaneously over the required range. The information from this counter is available in both analogue and digital form.

Description of Counter

The counter consists of a wedge of plastic scintillator which is viewed by a photomultiplier. The information on the spatial position of the particle is obtained by pulse height analyses on the output from the photomultiplier. At high energies (i.e. relativistic energies), the particles being counted lose the same amount of energy per unit length in the scintillator independent of their mass, to a first approximation. Therefore, given good energy resolution for the counter, the pulse height from the photomultiplier is a direct measure of the position of the particle along the wedge.
The application of the counter was to examine the image sizes and separation of π, and K mesons in the high energy K-meson beam at the CERN proton-synchrotron. These were expected to be of order 1 mm and 2-3 mm respectively. The spatial resolution of such a counter is proportional to the tangent of the opening angle of the wedge. The counter used in these investigations was a plastic scintillator (N.E. 102A) 100 mm long, 20 mm deep and 20 mm to the apex of the wedge. (See Fig. 1). The scintillator was mounted in a thin black paper housing which was lined with aluminised mylar to give good light collection together with a minimum of distortion of the image due to scattering of, and secondary production by, the beam particles in the walls of the mounting. This whole assembly was coupled to a 58 AVP photomultiplier by an air light guide. This tube was chosen to give good pulse height resolution, and the air light guide was used to avoid Čerenkov affects from passage of beam particles through material. The inter-dynode voltages of the photomultiplier were adjusted for maximum gain compatible with good linearity in the region of pulse height under examination in these investigations.

Measurements

The pulse height resolution of the counter was found by examining the Compton Edge formed by the 1 MeV γ-rays from a Na\(^{22}\) source. The resolution was found to be ≤ 11%, full width at half height.

The spatial resolution of the wedge counter was found by mounting it in the well focussed 3.0 GeV/c beam of π\(^{-}\) mesons at the CERN P.S. The image size at the final focus of this beam was 0.08 mm full width at half height, as measured with a \(\frac{1}{2}\) mm thick scanning scintillation counter. The wedge counter was moved across the beam focus in \(\frac{1}{2}\) mm steps, and the pulse height spectra from the counter measured using a 256 channel T.M.C. pulse height analyser.

* The optimum pulse height resolution which could be obtained with this scintillation-photomultiplier combination would be 8 o/o. The above result represents a satisfactory resolution with the geometry used.
The results of these investigations are shown in Fig. 2 and together with the Na\textsuperscript{22} measurements may be used to show that a resolution of $(0.22 \pm 0.02)$ mm/channel had been obtained.\footnote{In addition, the beam profile obtained with the wedge counter agreed with that obtained with the thin scanning counter, when allowance was made for the known pulse height resolution.}

The electronics was arranged as in Fig. 3. A scintillation counter, C, was put in coincidence with the wedge counter to reduce random background events, and the coincidence output was used to trigger a fast gate unit.\footnote{This unit accepts, when triggered, the fast photomultiplier pulses from the wedge counter and lengthens and amplifies them to a suitable shape for input to the pulse height analyser. The input stage of the gate is paralysed until the pulse height analyser is ready to receive another count.} This unit accepts, when triggered, the fast photomultiplier pulses from the wedge counter and lengthens and amplifies them to a suitable shape for input to the pulse height analyser. The input stage of the gate is paralysed until the pulse height analyser is ready to receive another count.

The electronics therefore has a dead time, which is the natural dead time of the pulse height analyser ($\approx 30 \mu\text{sec}$). This limitation on the rate of collection of data was no problem during investigations on the properties of the beam as the beam burst length was operated at $\approx 100 \mu\text{sec}$ and a useful spectrum obtained at each pulse. However, during a bubble chamber experiment it is necessary to use burst lengths of $\approx 1 \mu\text{sec}$, and under these conditions it was necessary to count for $\approx 50$ pulses to obtain a significant spectrum.

The wedge counter was also used to examine the separation of the $\pi$ and K mesons in the high energy K-meson beam at the CERN P.S.\footnote{Figs. 4a, 4b and 4c show typical separation curves obtained during the experiments with 3.0 GeV/c and 3.5 GeV/c K$^-$ and 3.0 GeV/c K$^+$ mesons in the 81 cm H.B.C. Also Fig. 5 is a photograph of the cathode ray tube display from the T.M.C. pulse height analyser. These spectra were obtained by counting for $\approx 100$ machine pulses during the experiment. The image sizes shown from these measurements are larger than the real image size, as the focus was placed within a mass slit, to effect separation of the $\pi$ and K mesons, and the distance between the focus and the wedge counter was, of necessity, some 50 cm. The separation may be clearly seen, and by use of the C.R.T. display, easily monitored.} Figs. 4a, 4b and 4c show typical separation curves obtained during the experiments with 3.0 GeV/c and 3.5 GeV/c K$^-$ and 3.0 GeV/c K$^+$ mesons in the 81 cm H.B.C. Also Fig. 5 is a photograph of the cathode ray tube display from the T.M.C. pulse height analyser. These spectra were obtained by counting for $\approx 100$ machine pulses during the experiment. The image sizes shown from these measurements are larger than the real image size, as the focus was placed within a mass slit, to effect separation of the $\pi$ and K mesons, and the distance between the focus and the wedge counter was, of necessity, some 50 cm. The separation may be clearly seen, and by use of the C.R.T. display, easily monitored.
Conclusion

The high spatial resolution and rapid recording of data of the wedge counter have proved to be useful in beam-handling studies. Further, the availability of the analogue display on the C.R.T. has proved a great advantage in allowing easy and immediate assessment of the experimental conditions. A permanent record of the spectra is also available from the automatic print-out of the pulse height analyser. This may be set to print-out the beam-profile at regular intervals throughout the experiment. Several other applications of the use of such a counter are discussed in the appendices (I) and (II).
Appendix I

Further Uses in Beam Handling Studies

a) It may be of interest to examine the spectrum of pulses from the wedge counter as in Figs. 4a, b and c and also in coincidence with a counter in the beam after separation. That is, one displays two spectra on the pulse height analyser, one with the normal conditions as described above, and a second spectrum, which is gated by a counter situated behind the "separating collimator". A fixed voltage, E, is added to this second spectrum, displacing it from the normal spectrum. (See Fig. 6). Such a display allows ready estimation of the fraction of wanted particles in the total flux reaching the final separating collimator, and of the contamination of unwanted particles in the separated beam.

b) It is often imperative in a separated beam, especially when working near to the limit of separation between wanted and unwanted particles, to maintain to a very high accuracy, the vertical position of the beam. A further use of the wedge counter may be as a monitor on the vertical spatial stability of a beam.

The wedge counter may be placed near to the focus of the beam, and the output analysed in the usual manner. Any change in the position of the peaks observed on the cathode-ray tube display of the pulse height analyser indicates that either the high tension of the separator tanks, or the magnetic field of the vertical bending magnets has changed. However, as it takes several hundred pulses to obtain a statistically significant spectrum, the wedge counter output may be split, one channel being analysed normally, while the other may be taken to a discriminator, the output of which drives a scaler. If the discrimination level is set on the fast-falling edge of one of the peaks, any change in beam position may be seen immediately from the scaler counts per machine pulse.

In this manner, warning may be given quickly that the beam composition behind the separating slit, has changed and the appropriate action taken.

*The first focus after the beam element under examination.
Appendix II

Particle Marking for Bubble Chambers

In certain circumstances it may be desirable to know the position of the unwanted (wanted) particles in a bubble chamber. For example, in a high energy K-meson experiment, the contamination of π's in the beam could be as great as 30-40%. In such a case it may be of considerable help in analysis if it were possible to know which of the particles, in each photograph, were pions. A device like the wedge counter could be used for this purpose.

The output pulse height from the wedge counter would be analysed by the standard method of charging a condenser by the input pulse and then discharging it by an oscillator. In this case, the oscillator would drive a scaler, and not be fed into the memory matrix of a pulse height analyser. A switching circuit would ensure that the oscillator drives only one scaler per particle, and a different scaler for each particle. A photograph of the bank of scalers would provide the information of the position of each particle in the respective bubble chamber photograph. A fast pulse height analyser is already under development at CERN, and could very well be used in place of the bank. The calibration between scaler number and the actual spatial position of the particle with respect to the bubble chamber window could be accurately effected with a well collimated source.

The wedge counter output would be placed in coincidence with that of a Čerenkov counter, and therefore only display on the scaler bank the position of a particular kind of particle (e.g. only counting the background pions in a kaon beam).
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Figure Captions

Fig. 1 (a) A schematic diagram of the wedge scintillator, showing two beams of particles traversing the counter. For fast particles, the light output of the scintillator is proportional to the path length traversed, thus a pulse height analysis of the light output would provide information on the spatial separation of the two beams. The spectrum from such an analysis is shown in (b).

The actual dimensions of the scintillator used were

\[
\begin{align*}
a &= 100 \text{ mm} \\
b &= 20 \text{ mm} \\
c &= 20 \text{ mm}
\end{align*}
\]

The scintillator was Ne 102A plastic phosphor, and the triangular face of the wedge was viewed by a 58 AVP photomultiplier.

Fig. 2 (a) Plot of the output pulse height of the wedge counter against the position of the counter in the high energy \(n\)-beam. The resolution found in this way was \(0.22 \pm 0.02 \text{ mm per channel}\).

(b) The pulse height spectra from the wedge counter when placed near the focus of the high energy pion beam. The wedge counter was displaced 5 mm across the beam between spectra, thus presenting a different path length in the scintillator to the incident pions.

Fig. 3 A schematic diagram of the electronics used in the experiments.

Fig. 4 Separation curves for \(\pi, K\) mesons as obtained with the wedge counter

(a) \(\pi^+, K^+\) mesons at 3.0 GeV/c; (b) \(\pi^-, K^-\) mesons at 3.0 GeV/c and (c) \(\pi^-, K^-\) mesons at 3.5 GeV/c.

Fig. 5 Typical photograph of the pulse height analyser display, showing the separation between \(\pi, K\) mesons in the 3.0 GeV/c beam, as measured with the wedge counter.
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Fig. 6 A typical separation curve before the separating collimator is shown in a), together with that part of the particle flux passing through the mass separation slit in b). The latter curve would be obtained by the wedge counter in coincidence with another scintillation counter behind the separating slit. Also shown are the position of the mass separating slit and in a), a possible discrimination bias level, if this device were used to monitor the spatial stability of the beam (Appendix Ib). In the case shown here, if the counting rate from the discriminator increases, the beam purity is not drastically affected, but the wanted particle flux falls. However, if the counting rate decreases, the purity of the beam will deteriorate very rapidly.
Figure 1

(a) BEAM 1

(b) BEAM 2

PATH LENGTH 1

PATH LENGTH 2

CHANNEL NUMBER (PULSE HEIGHT)

COUNTS PER CHANNEL

Figure 1
Figure 2a

WEDGE COUNTER DISPLACEMENT.
Figure 2b

SHIFT EQUIVALENT TO 5 mm. MOVEMENT.
Figure 3
Figure 4b
Figure 4c
Figure 6a
Figure 6b

COUNTS PER CHANNEL

MASS SLIT

CHANNEL NUMBER.

Figure 6b