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PRACTICAL PROTOTYPE OF A CLUSTER-COUNTING
TRANSITION RADIATION DETECTOR

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ABSTRACT

A transition radiation detector using a method of cluster-counting measurement has been tested. The performance is considerably better than with the usual method of total charge measurement, as well as offering advantages in simplicity of construction and operation.

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1. INTRODUCTION

In a previous paper¹⁾ it was shown that a very substantial improvement in the separation of particles by means of transition radiation (TR) can be obtained by counting ionization clusters from TR quanta, in comparison with the measurement of the total energy deposit as usually applied. This advantage is due to the relatively smaller background of δ -electrons from the charged particle track. These δ -electrons have a Poisson distribution in contrast to a very wide distribution of the total ionization energy released. However, the TR detector used in Ref. 1 served only for studying the possible advantages of the cluster-counting method and was not optimized as a practical TR detector as regards radiator thickness, gas layer thickness, total length, etc. In the present paper we describe the results obtained with a practical prototype of a TR radiator.

In constructing this prototype we used the results of Ref. 1 and the following ideas:

- i) The total thickness M of a TR radiator along the particle path should be small, i.e. in the case of π/e separation

$$M \lesssim 5-10\% \text{ of a radiation length}$$

or in the case of $\pi/K/p$ separation

$$M \lesssim 10\% \text{ of an interaction length .}$$

- ii) The requirement of a large TR detector aperture restricts its full length L :

$$L \lesssim 0.5-1 \text{ m .}$$

In particular, the detectors being considered in Ref. 1 had

$$M = 6 \text{ g/cm}^2 ; \quad L = 1.5 \text{ m for } \pi/e \text{ separation}$$

$$M = 30 \text{ g/cm}^2 ; \quad L = 7.5 \text{ m for } \pi/K \text{ separation .}$$

- iii) Simplicity and economy are very important requirements for TR detectors containing a large number of elements.
- iv) The possibility of use in a fast trigger is also very important.

2. EXPERIMENTAL EQUIPMENT

The TR detector (see Fig. 1) consisted of 12 sets of a radiator and a proportional wire chamber placed into a plexiglas box filled with helium. Each multi-wire proportional chamber (MWPC) (Fig. 1b) was $10 \times 10 \text{ cm}^2$, with cathode-anode distance equal to 4 mm, while the diameter of the anode wires was 20 μm . The chambers used the mixture 50% Xe + 50% CH₄; the gas gain was 5×10^3 to 10^4 .

At an anode tension of 2700 V the speed of electron drift $v^{-1} = 30 \text{ ns/mm}$. In this case the full time for electron collection from particle tracks in the chamber was about 160 ns. Entry and exit chamber windows, which simultaneously served as cathodes, were made of aluminized mylar of 10 μm thickness. Each chamber contained a γ source of ^{55}Fe (5.9 keV), with the help of which an energy calibration was made between accelerator cycles.

In this work TR radiators of three types were used. Their parameters are shown in Table 1. As radiator materials foils of 30-35 μm thickness metallic lithium and also fibres of 7 μm thickness pure carbon (density 1.9 g/cm³) were used.

The current pulses from the chambers were amplified and shaped by special filters, so that those from a pointlike ionization (γ quanta from ^{55}Fe) had a bell-like shape with a half-width of 15 ns (corresponding to the length $\sim 500 \mu\text{m}$). After being formed the current pulse was analyzed by two methods (see Fig. 2):

- i) With the help of four analog-to-digital converters (ADCs) operated by consecutive 40 ns width gates. Each ADC registered a part of the current pulse corresponding in space to 1 mm. In this way the amplitude of clusters and their number in the 12 chambers were measured.
- ii) A count of clusters whose energy exceeded a given threshold was made with the help of threshold discriminators with dead-time 10 ns.

On the left of Fig. 2 the average number distribution for clusters registered in four time intervals is shown; on the right, the shape of the current signal in the individual event is shown. The TR detector was exposed in the beam S3 of the

CERN SPS at energies of 10, 15, 40, and 140 GeV. At the lower energies, the beam was composed of comparable numbers of pions and electrons, while at the highest two energies it was $\geq 98\%$ pions. Pions of 40 GeV served for an imitation of K mesons with energy 140 GeV, as described in our previous paper¹⁾.

The beam was picked out by counters S_1 , S_2 , and S_3 , shown in Fig. 1. Its size was determined by the dimensions of the counter S_1 ($10 \times 10 \text{ mm}^2$). Two gas Čerenkov counters $\check{C}_1$ (length 21 m) and $\check{C}_2$ (length 11 m) distinguished electrons and pions in the beam. With an electron detection efficiency of 0.9 to 0.95 the counters $\check{C}_1$ and $\check{C}_2$ suppressed an electron admixture in the pion beam to a level $(0.5-1) \times 10^{-2}$. A lead-scintillator sandwich shower detector was used to suppress the electron admixture in the pion beam down to the level $\sim 3 \times 10^{-4}$.

Behind the TR detector there was the halo counter $\overline{S3}$ with an aperture of diameter 25 mm for the elimination of events with multiple particles. The counter S_4 served for pile-up rejection, forbidding double events in an interval of 200 ns.

3. RESULTS

The number of clusters registered in the TR detector should obey the Poisson distributions, except in the case of a large average number of clusters, when cluster superposition occurs. In the case of a small average cluster number (e.g. when registering particles without transition radiation) the cluster distribution is very close to the Poisson form (see Fig. 3). In Fig. 4 the π/e separation (Li I radiator) at particle energies of 15 GeV by means of the total energy deposit (Q) and cluster-counting (N) methods is shown. The second method gives an advantage in π/e separation by a factor ~ 25 for an electron efficiency of 90%. Figures 5 and 6 also demonstrate a large gain in the π/e separation using the cluster method with either the Li II radiator or carbon fibres. The cluster-counting method, with the use of simpler discriminator electronics turns out to be most effective, as seen in Fig. 6. The level of pion detection, $\leq 5 \times 10^{-4}$, may be due to a beam impurity, which sets the limit under these experimental conditions.

A dependence of the particle separation on cluster threshold energy is an important characteristic of the cluster-counting method. In Fig. 7 the π/e separation, as a function of threshold energy, is shown. It is seen that in a wide region (2.5-4 keV) the particle separation changed only slightly. This property defines a requirement on the stability of the whole system and, in particular, appears to allow the use of simple and cheap electronics for cluster counting. (The present experiment, with particles taken in separate runs is not as free from stability requirements. This leads to systematic errors on the rejection of unwanted particles of the order of 50%.)

Figure 8 shows a dependence of π/e separation on the total length of a TR detector. The results presented in Fig. 8 for detectors containing various numbers of elements are obtained from the experimental data for a TR detector of 12 elements. For more than 12 elements the data for two different particles passing through the TR detector were used. It follows from Fig. 8 that for a TR detector of length 40 to 70 cm it is possible to get a π/e separation of 100 to 3000. The small length needed allows the possibility of the construction of large-aperture detectors.

The hadron separation for π/K at 140 GeV is shown in Fig. 9. A substantial advantage of the cluster-counting method is also seen in this case. A separation factor of about 100 is achieved with the use of the carbon fibre radiator, which was the most effective one for this case. The TR detector consisted of 24 elements with full length 132 cm. The application of more effective radiators for the region $\gamma \lesssim 10^3$ (e.g. 10 μm thick lithium foil) should allow a higher rejection of hadrons in the energy region ~ 100 GeV, where the use of large-aperture Čerenkov counters is very difficult.

4. CONCLUSIONS

The results obtained with a practical prototype of a TR detector have shown the effectiveness of the cluster-counting method for particle separation in the γ range between 10^3 and 3×10^4 . The method allows construction of a TR detector having the following characteristics:

- i) a particle separation factor $\sim 10^2$ - 10^3 ;
- ii) compactness ($L \approx 0.5$ - 1 m), that is, the possibility to construct a larger-aperture detector;
- iii) the use of simple and comparatively cheap electronics;
- iv) the possibility to obtain an identified particle trigger within a time of ~ 150 - 200 ns;
- v) the ability to work at high intensities.

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REFERENCE

- 1) T. Ludlam et al., Particle identification by electron cluster detection of transition radiation photons, submitted to Nuclear Instrum. Methods.

Table 1
Parameters of TR radiators

Type of radiator	Foil thickness (μm)	Foil separation (μm)	Approximate length of one radiator		Total length of twelve-radiator assembly		
			(cm)	(g/cm ²)	(cm)	(g/cm ²)	(interact. length)
Li I (foils)	30	160 ± 80	2.0	0.19	36	2.28	2×10^{-2}
Li II (foils)	35	240 ± 80	4.5	0.30	66	3.6	3.5×10^{-2}
C-fibres	7	-	4.5	0.30	66	3.6	3.5×10^{-2}

Figure captions

Fig. 1 : Schematic picture of experimental equipment:

a) The system of selection and identification of particles

S_0-S_4 : scintillator counters

$\check{C}_1, \check{C}_2$: gas threshold Čerenkov counters

Shower detector: lead-plastic sandwich.

b) Scheme of one radiator-detector element.

Fig. 2 : a) The distribution of cluster number in four shifted time gates.

The gate width is 40 ns. Each gate is shifted in respect to the previous one by 40 ns.

b) The current shape from the proportional chamber for an individual event.

Fig. 3 : The points are the probability distributions for detecting a given cluster number in the case of non-radiating particles. The curve is a Poisson distribution for the same value of the average number of clusters.

Fig. 4 : The π/e separation for 15 GeV particles, using a radiator made of lithium foil, Li I.

Fig. 5 : The π/E separation at particle energies of 10 and 15 GeV using a radiator made of lithium foil, Li II. In the upper part of the figure, as an example, the distributions in cluster number N and in deposited charge Q are shown for electrons and pions.

Fig. 6 : The π/e separation for 15 GeV particles using a radiator made of carbon fibres.

Fig. 7 : The π/e separation as a function of cluster threshold energy when the electron registration efficiency is 90%.

Fig. 8 : The dependence of π/e separation on total TR detector length for various radiators. The numbers near total curves indicate the number of elements for a given length transition radiator.

Fig. 9 : The π/K separation for a given efficiency of K meson registration. In the upper part of the figure the distributions for a cluster number N and in a deposited charge Q are shown for π and K mesons.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9