PARTICLE IDENTIFICATION BY ELECTRON CLUSTER DETECTION
OF TRANSITION RADIATION PHOTONS

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ABSTRACT

A transition radiation (TR) detector has been built which measures the distribution of charge along the particle track in the gas of a drift chamber. Charge clusters are observed arising from track ionization and the detection of TR photons. A cluster counting method based on these measurements is shown to have a considerable advantage with respect to the normal measurement of the total deposited charge.

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1. INTRODUCTION

The conventional method of registration of transition radiation (TR) quanta is to detect the sum of the ionization from the track and from the TR X-rays¹⁾. This is applicable when the number of X-ray photons from the transition radiator is large, so that their total ionization is greater than that due to the track. The big ionization fluctuations associated with the particle energy losses in thin gas layers²⁾ constitute an important background even in this case. The use of this technique is particularly difficult in the region of low γ ($\leq 10^3$)³⁾, of interest for K/ π separation with existing accelerators.

In a previous paper⁴⁾ we separated in space the TR photon signal from the track ionization background using the transverse drift method. To make this method practical, the distance between one transition radiator and the chamber must be ≥ 50 cm. In this case the length of the detector becomes large and design of a system with large aperture is difficult. Alternatively, the different characteristics of track ionization and photoelectrons of a few keV compared with TR quanta allow differentiation by a study of the charge distribution along the track, the method of cluster counting. The ionization due to a photoelectron in the gas of a proportional chamber is localized in a small space. For example, the range of a 10 keV photoelectron in xenon at normal pressure is ≤ 100 μm . The ionization cluster size from this photoelectron is mainly defined by the diffusion of the electrons in the gas, with a typical value at normal pressure being about 500 μm FWHM⁵⁾. The only background for TR registration is an occasional keV δ -ray from the ionizing particle. The number of δ -rays with energies ~ 1 keV is small; for example, $N_\delta(E_\delta > 3 \text{ keV}) \approx 0.1 \text{ cm}^{-1}$ in xenon. On the other hand, their energy is $> 10\%$ of the total energy loss of the relativistic particle.

Another advantage of cluster counting is that the distribution of the number of ionization clusters is better behaved than that of the total ionization energy. The latter has a long tail, while the former has a Poisson distribution. The number of TR photons is also less subject to fluctuation than their total energy, though this entails the disadvantage that the number of TR quanta changes more

slowly with $\gamma = E/mc^2$. However, there are at least two important cases where this disadvantage is insignificant and where it is difficult to use Čerenkov counters for particle identification:

- i) Hadron identification at energies of 100 to 200 GeV. In this region of low γ ($\sim 10^3$) the γ -dependence of the cluster number $N_{TR}(E/mc^2)$ is quite steep.
- ii) Electron-hadron separation at energies $\gtrsim 1$ GeV. In this case the large mass difference between electron and hadron makes the method effective.

2. EXPERIMENTAL SET-UP

The test TR detector (Fig. 1) consists of a radiator (1500 lithium foils of 30 μm thickness with 200 ± 50 μm gaps in a helium atmosphere) and a drift chamber for cluster detection. The drift chambers have a drift space of 10 mm, anode-cathode distances 3 mm, anode wires of diameter 20 μm spaced by 6 mm, and a cathode grid of 1 mm pitch. A purified gas mixture of 70% Xe + 30% CO₂ was continuously passed through the chamber. With drift field $E_d = 0.65$ kV/cm, the drift velocity was $v^{-1} = 116$ ns/mm. The window of the chamber consisted of 20 μm mylar + 5 μm aluminium. The chamber fed a current amplifier with 12 ns rise-time designed in such a way that the pulses produced by a ^{55}Fe source (5.9 keV) had a symmetrical shape. The pulse was transmitted to a 5-bit flash encoder (multiple time step analog-to-digital converter)⁶⁾ with a 20 ns period and total time span 64×20 ns. The anode pulse shape is shown in Fig. 1 and a typical display image in Fig. 2. The gas gain ($\approx 10^4$) of the chamber and electronics gain were checked by means of a ^{55}Fe source between beam pulses. The position of the beam was controlled within ± 3 mm with the aid of an additional drift chamber and a scintillation hodoscope.

The total energy deposition in the chamber was recorded, and for each cluster the energy and the depth at which the cluster appeared in the chamber (i.e. the drift-time) were recorded. This detector has been exposed in beam S3 of the CERN SPS. The 20 m long gas Čerenkov counter provided tagging of pions (which were about 98% of the beam from 40 to 140 GeV) and electrons (which were about 50% of the beam at 15 GeV).

3. EXPERIMENTAL RESULTS

Figure 3a shows the mean value of the detected charge versus drift-time for electrons and pions at 15 GeV/c with the transition radiator. The mean charge for electrons is considerably larger than for pions, owing to the presence of TR quanta. The rise of mean charge at short drift-times is a consequence of the greater drift velocity near the anode region. The shape of charge distribution at large drift-times is determined largely by variations in drift-time due to different transverse positions of the particles with respect to the anode wires. To avoid these two effects only the central part (≈ 7 mm) of the drift distance was used.

The progressive decrease of charge in the central part is due to the attachment of electrons during the drift-time. A correction for attachment was made according to the curve of mean charge for pions, where there are no TR quanta and the mean charge distribution should be uniform. Figure 3b shows the corrected charge distribution. Figures 4a and b show the cluster number distribution along the drift coordinate for cluster energy $E_{cl} > 2$ keV. Our definition of a cluster is an amount of charge in any time interval of 100 ns (5 of the 20 ns bins, equivalent to a space interval of 850 μ m), corresponding to a calibrated energy E_{cl} . The "kaons" in Fig. 4b are simulated by pions with an energy of 40 GeV which have the appropriate value of γ . In Figs. 3b and 4a and b one can see the absorption of the TR quanta as a function of the path length in the chamber gas for 15 GeV electrons and 140 GeV pions. Figures 5a and b show the energy distribution of the cluster number and Figs. 6a and b show the distribution of the number of clusters with $E_{cl} > 2$ keV. In the case of a low mean number of clusters ($\bar{N}_{cl}$) as for π at 15 GeV and K at 140 GeV, the shape of distribution is nearly Poissonian. In the other cases the right part of the distribution is strongly distorted as a consequence of overlapping of clusters in space. In these cases the mean number of clusters can be taken from expression

$$\bar{N}_{cl} = - \ln W(0) ,$$

where $W(0)$ is the Poisson probability of detecting no cluster.

4. PARTICLE IDENTIFICATION

The performance of the transition radiator detector described is not optimized for e/π or π/K separation; however, it may serve to compare the different methods of particle identification by means of TR.

One can compare three methods:

- i) The conventional method of total energy measurement (Q).
- ii) The cluster-counting method $N = N(E_{cl} > E_{THR})$.
- iii) The maximum likelihood method using the identification function

$$F = \prod \frac{W^{\pi(\text{or } e)} [E_{cl}, z]}{W^{K(\text{or } \pi)} [E_{cl}, z]},$$

where $W^{\pi} [E_{cl}, z]$ is the probability of cluster creation with energy E_{cl} at the gas depth z by a pion, and similarly for kaon and electron.

Figures 7 and 8 show the comparison of the Q, N and W methods for cases of π/e (15 GeV) and π/K (140 GeV) separation. For the case π/e three successive radiator-detector sets were assumed, while for the case π/K 15 sets were taken. A group of three (or 15) particles traversing one detector were taken from experimental data, which should approximate one particle traversing three (or 15) detectors.

Looking at Figs. 7 and 8 one can see:

- i) Method N has a considerable advantage compared with method Q.
- ii) Method W, which used the information about the energy and spatial distribution of clusters, does not improve the particle identification appreciably.

Figure 9 shows the particle separation by means of cluster-counting with "fixed time bins". The total depth of the chamber was divided into intervals of 100 ns with fixed position. Then one counts the intervals with total charge $Q > Q_{THR}$ ($E > E_{THR}$). One can see that this very simple method does not give a poorer result than the "free time bin" method of cluster search.

Figure 10 summarizes the experimental data for cluster counting (with energy > 2 keV) for the particle track length 6.8 mm (in 70% Xe + 30% CO₂) without transition radiator (dE/dx) and with radiator ($dE/dx + TR$).

5. CONCLUSIONS

We have shown experimentally, for the examples of π/e ($\gamma_e = 3 \times 10^4$) and π/K ($\gamma_\pi = 10^3$) separation, that the detection of TR quanta by means of ionization cluster counting considerably improves the particle identification in comparison with conventional total energy measurement. The use of discrete information (N_{cl}) should simplify the stability required of detectors and electronics. The possibility of using the fixed bin method with layers of gas in the chamber ~ 1 mm thick will allow the use of simple electronics for practical TR detectors.

REFERENCES

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- 5) See, for example, F. Sauli, CERN 77-09 (1977).
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Figure captions

- Fig. 1 : Diagram of the experimental set-up. Also shown is a picture of the signal current waveform for illustration of the method.
- Fig. 2 : Computer display of a typical event for a 15 GeV electron.
- Fig. 3 : Mean charge distribution along the drift path, uncorrected (a) and corrected (b) for the attachment of electrons.
- Fig. 4 : The distribution of cluster number with energy $E_{cl} \geq 2$ keV along the track, for 1000 incident particles. One bin in the histogram represents 170 μ m.
- Fig. 5 : The cluster energy distribution for 1000 particles $E_{THR} = 2$ keV.
- Fig. 6 : The cluster number distribution for 1000 particles $E_{cl} > 2$ keV.
- Fig. 7 : Pion-kaon separation by different methods, with the "free bin" method of cluster definition:
- a) Identification function method, W.
 - b) Total energy measurement, Q.
 - c) Cluster counting, N.
- Fig. 8 : Pion-electron separation by means of three methods (Q, N, W), using the "free bin" method of cluster definition.
- Fig. 9 : Particle separation by means of cluster counting, using the "fixed bin" method of cluster definition.
- Fig. 10 : The cluster number in 6.8 mm of 70% Xe + 30% CO₂ mixture versus $\gamma = E/mc^2$ for ionization δ -rays without radiator and for TR quanta + ionization with radiator.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10