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RELATIVISTIC RISE MEASUREMENT BY
CLUSTER COUNTING METHOD IN TIME EXPANSION CHAMBER*

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ABSTRACT

A new approach to the measurement of the ionization energy loss for the charged particle identification in the region of the relativistic rise was tested experimentally. The method consists of determining in a special drift chamber (TEC) the number of clusters of the primary ionization. The method gives almost the full relativistic rise and narrower "Landau" distribution. The consequences for a practical detector are discussed.

1. Introduction

Growing interest has been shown in recent years in the use of the relativistic rise of the ionization energy loss to particle identification in high energy physics experiments.¹⁻⁴ If the momentum of a particle is known (or measured at the same time), the η (= momentum/mass of particle) dependence of the energy loss is used to separate different particles (pions, electrons, protons, and k ions) up to a momenta corresponding to η -value of several hundred. The method is intrinsically suitable for high multiplicity events, being able to distinguish and to analyze particles at very small distances from each other.

The most serious drawback of the method is the relatively small difference of the energy loss for different particles compared with the typical FWHM of the energy loss within a thin detector. The width is determined by the statistical fluctuations which is known as the Landau distribution, and for a gas gap of a few mg/cm², it is about 70%. Due to the peculiarity of the high energy tail of the Landau distribution (the distribution cannot be narrower than $\approx 40\%$), useful results can be obtained by repeated measurements of the energy loss in many relatively thin samples. Repetitive measurement enhances the statistical quality of the information and the calculation of an appropriate "mean value" reduces the fluctuations so the particle identification becomes possible.

Devices designed for particle identification in the "100 GeV region" EPI¹ and ISIS² have a large number of individual layers in a total length of about 6 m. A design of a similar device for an experimental facility covering a large fraction of the solid angle around an intersection zone of the accelerator storage rings will be optimized differently, but to achieve the same performance the detector diameter has to be about 4 m and pressurized to several atmospheres. To surround such a device with a hadron calorimeter can present a serious problem.

In this paper, we present a new and different approach to reduce the statistical fluctuations of the energy loss. This method should allow the "EPI or ISIS quality" of identification for a total length of the device of less than 1.5 m.

The new approach is based on counting the number of primary ionization collisions (clusters) rather than

on conventional total ionization loss measurement.

It has been realized previously that cluster counting might greatly improve the particle identification.^{5,6} It is believed that most of the relativistic rise of energy loss is due to the increase of the number of primary collisions. The energy content of the cluster is almost independent of particle velocity, and its fluctuations are responsible for the large fluctuations in conventional total charge measurement.

The theoretical calculation of the number of primary collisions in the region of the relativistic rise was published recently by J. H. Cobb *et al.* (Ref. 3). Figure 5 in Ref. 3 shows that the rise of the number of primary collisions follows the rise of ionization loss up to η -value ≈ 300 . Briefly, the cluster counting technique should preserve the full relativistic rise up to this value and greatly decrease the fluctuation of the individual ionization samples. (Primary collisions should obey the Poisson statistics.)

2. Experimental Confirmation of the Relativistic Rise for the Number of Primary Collisions

Until now, the only attempt to measure the primary collisions was made in the streamer chamber.⁶ This measurement was done using the helium at low pressure due to the problem of close streamer counting, resulting in mean number of clusters as low as 2 per cm, and it had to be extrapolated to zero diffusion time, which introduces unknown errors to their measurement. In addition, these data are not useful for us, since for practical particle identification one is interested in the relativistic rise of gases with higher density and higher Z.

To test the relativistic rise of the number of primary collisions, we first used a method which cannot be implemented in a practical detector, but which does not suffer from some unknown detection effects connected with a real time cluster counting.

If a beam particle crosses the anode wire of a proportional counter, the time delay between the passage of the particle and the signal from the anode measures the distance between the wire and the nearest cluster. The distribution of the time delay obeys a simple exponential law. The slope of the distribution (in a semi-logarithmic scale) is related to the mean cluster density independently of the time resolution of the system. (Convolution of an exponential function with a Gaussian one is the same exponential function.)

Figure 1 shows the measured delay time distributions for 4 GeV/c pions ($\eta = 28.6$) and protons ($\eta = 4.3$). The corresponding cluster density for protons (which are very close to the energy loss minimum) is 12.3 clusters per cm, and the relativistic rise between protons and pions is $(23 \pm 2)\%$. The measured relativistic rise for the number of primary collisions agrees very well with the rise of the ionization loss measured for the same gas previously.⁷

We have repeated the measurement for various discriminator threshold settings and various shaping time constants. The measured cluster densities are

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reduced, but the relativistic rise stays constant indicating that the energy content of a cluster does not depend on the η of the particle.

Let us briefly estimate the potential of the cluster counting method. In a device 1.5 m long, we can count about 2200 primary collisions giving a distribution with 5% FWHM. The identification power of such a detector is roughly the same as the one for conventional 6 m long devices (at NTP).

3. Cluster Counting in the Time Expansion Chamber

The time expansion chamber⁸ was used for the direct cluster counting.

The principle of the chamber is shown in Fig. 2. Inside the chamber, the drift region is separated from the amplification (detection) region by a grid. Applying the proper potentials to all electrodes within the chamber, a low field can be maintained in the drift region, while a normally high field is obtained in the amplification region. In this way, the clusters of a track crossing the chamber parallel to the drift field (Fig. 2) arrive at the grid in time intervals larger than time intervals corresponding to a drift velocity in a chamber without the grid. Since the field in the amplification region is high, the anode signal is not slowed down and arriving clusters are resolved (origin of the name "time expansion"). The gas used was P-10 with 4% methylal $\text{CH}_2(\text{OCH}_3)_2$. (We have also tried other quenching gases without improving the results.)

The current from the anode was amplified in a fast current amplifier⁹ mounted directly on the chamber and transmitted via a short coaxial cable for further processing.

At the receiving end, the anode signal was shaped into a short bipolar pulse of the total duration of about 15 ns. This signal was an input into a fast Schmidt trigger with a hysteresis equal to the threshold level. The cluster counting was done by integration of the standardized pulses from the Schmidt trigger arriving during the presence of an external gate. (Gate was usually applied about 80 ns after the particle passage so that the ionization from the amplification region was not analyzed.) At the same time, the signal from the preamplifier was picked up by a charge integrator for the conventional ionization loss analysis.

The low noise features of the preamplifier are crucial since it is obvious that a fully efficient cluster counting has to include the fully efficient detection of single electrons from the primary ionization. An increase of the gas amplification factor, however, finds it limits at the frequent occurrence of afterpulses or even breakdown. On the other hand, the noise of the preamplifier is mostly determined by the shaping time which has to be short for good double pulse (cluster) resolution. In our measurements, an optimum has not yet been investigated. The preliminary measurements described below favor a very short shaping time in order to avoid limitation by the dead time.

The measurements of the number of primary collisions were performed at the test beam of the Alternating Gradient Synchrotron (AGS) at the Brookhaven National Laboratory. For particle selection, two gas Cerenkov counters (at suitable pressures) and/or time of flight measurements were used. Four scintillation counters defined the beam.

4. Results and Discussion

A typical distribution of the number of clusters in the drift volume of the time expansion chamber is shown in Fig. 3. We can see (i) the mean number of clusters is lower than the number deduced from the time delay measurement, which indicates that we are not counting all clusters; (ii) the width of the measured distribution is slightly narrower than the width of the fitted Poisson distribution. The discrepancy is statistically significant and is present in all measured distributions. Figure 4 shows the mean number of clusters as a function of η . We see the well known shape of the energy loss curve; however, the relativistic rise is less than one half of the rise measured by the ionization loss method or by the delay time method. The discrepancy between the amount of the relativistic rise measured by direct counting and the amount measured at the same conditions by the delay time method suggests that a fraction of the clusters directly counted were not the clusters created by primary collisions.

To understand the problem, we have studied cluster counting methods by varying operating conditions of the chamber. Figure 5 shows the amount of relativistic rise between 4 GeV pions and protons as a function of the avalanche size. We see a constant relativistic rise of about 10% (instead of about 25%) independent of the measured number of clusters. The independence of the relativistic rise from the number of clusters indicates that the cluster size carries very little information about the particle velocity. If we accept this statement, we cannot explain the deficit in the amount of the relativistic rise by attributing it to the higher energy content of a cluster.

Figure 6 shows the number of clusters counted in a given time interval as a function of its time position (relative to the particle passage). The short time values correspond to the ionization being created close to the grid; the high values close to the end of the drift space. We can see that from the more distant region, we are counting more clusters than from the region closer to the anode. During the drift of the primary clusters, the longitudinal diffusion can transform a primary cluster into an "electron cloud" which is recognized by our electronics as several clusters. The effect is stronger than Fig. 6 indicates, because due to the very same diffusion process a small cluster can be lost if its diffused parts are below the threshold.

We have also tested different gas mixtures. One mixture (adding $\approx 25\% \text{ CH}_4\text{H}_{10}$) gave a larger diffusion and also an additional drop in the relativistic rise from 10% to 6% (between the protons and pions at 4 GeV/c). The measured drop in relativistic rise gives a very strong indication that also in the case of the standard gas the diffusion contributes to the reduction in the amount of the measured relativistic rise.

Since we have at the same time the cluster number information and the ionization loss information (total charge), we can determine the correlation between these two. The correlation coefficient, defined by

$$CF = \frac{(Q_i - \bar{Q})(n_i - \bar{n})}{\sigma_Q \cdot \sigma_n}$$

where σ_Q and σ_n are the corresponding rms values. This correlation coefficient is easily determined by using a two-dimensional pulse height analyzer. The measured

correlation coefficient was 0.13, which means almost no correlation. A simplified Monte Carlo simulation showed a correlation coefficient of 0.31.

In order to gain more insight from the response of the TEC, a "weighted" cluster counting method has been investigated. The weight was the duration of the leading lobe of our shaped signal. The measured correlation coefficient then was 0.36. It is interesting that this method showed in our test the greatest discrimination power. Figure 7 shows the measured distribution for 4 GeV/c protons and pions. The distributions are practically Gaussian with FWHM 63% and 55%, respectively. The amount of relativistic rise is 17%. A slight deficit in the observed relativistic rise, compared with the ionization loss method, is more than compensated for by the narrower width and Gaussian shape of the distribution. If a detector based on the same readout were constructed, less than 3 m of the length would be enough to achieve EPI-ISIS identification power.

Although the underlying physics of the "weighted" method has not been investigated in detail, its higher correlation with the ionization loss measurement, rather than with the Monte Carlo simulation for cluster counting, indicates that the method measured the total charge to some extent. Its better identification power, when compared with direct counting, can be understood by its smaller sensitivity to instrumental effects. The longitudinal diffusion has a less dramatic effect, and also afterpulses which are typically short, are counted with less weight than larger pulses due to the clusters. Clearly, the "weighted" cluster counting method does not give more weight to the bigger clusters, as can be seen from Fig. 7 by the absence of a long Landau tail. (For a somewhat similar approach, see Ref. 10.)

5. Conclusion

- (i) We have measured the relativistic rise of the number of the primary collisions. It was experimentally confirmed that the relativistic rise is mainly due to the increased number of the primary clusters, rather than due to the energy of clusters.
- (ii) The direct cluster counting in the time expansion chamber shows a reduction of the relativistic rise due to the instrumental effects, most likely due to the longitudinal diffusion and afterpulses.
- (iii) We have found empirically the "weighted" cluster counting method which gives almost the full relativistic rise and narrower, Gaussian type distribution. The application of the "weighted" cluster counting method to the 3 m long detector gives the same identification power as a 6 m long detector based on the conventional ionization loss method.
- (iv) The clean cluster counting method (as was verified in [1]) should decrease the length of the detector down to 1.5 m. We believe that this potential improvement is big enough to stimulate the further study of the method.

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Fig. 1. Delay time distribution for 4 GeV/c pions (lower curve) and protons (upper curve). The ratio of the indicated slopes (note the semi-logarithmic scale) is a measure of the relativistic rise in primary ionization.

Fig. 2. Electrode arrangement and principle of the time expansion chamber.

Fig. 3. Typical measured distribution of the cluster number from the drift volume of the chamber. The smooth line is the best fitted Poisson distribution.

Fig. 4. The mean number of clusters as a function of η (=momentum/mass of the particle). The five lowest points are obtained using protons, the five middle points using pions, and the highest point by using electrons. All measurements are in the momentum range of 1 to 4 GeV/c.

Fig. 5. Number of clusters and relativistic rise as a function of the avalanche size (pions). The plotted relativistic rise is between 4 GeV protons and pions.

Fig. 6. Mean number of clusters within a 200 ns long time gate versus the position of the gate relative to the particle passage. Small t -values correspond to the ionization drifting from the region close to the wire.

Fig. 7. Time weighted cluster distribution for protons and pions at 4 GeV/c. Both distributions are practically Gaussian with FWHM of 53% and 55%, respectively. The amount of the relativistic rise is 17%.