Letter to the Editor

Double Track Resolution of Cathode Strip Chambers

V. Gratchev [a,1], M. Mohammadi-Baarmand [b], V. Polychronakos [a], J. Shank [c], V. Tcherniatine [a], A. Vaniachine [*,d]

[a] *Brookhaven National Laboratory, Upton NY 11973, USA*

[b] *State University of New York at Stony Brook, Physics Department, Stony Brook NY 11794, USA*

[c] *Boston University, Physics Department, Boston MA 02215, USA*

[d] *Royal Institute of Technology, Physics Department, Frescativägen 24, 10405 Stockholm, Sweden*

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Abstract

Details are presented of a method to resolve close tracks in cathode strip chambers based on the fit to the induced charge distribution. The analysis of muon beam test data demonstrated a double track resolution of about 2 mm for a readout pitch of 5 mm. The degradation of the position resolution in presence of a close track is limited to 10% of the readout pitch.

1 Introduction

We have tested a four layer Cathode Strip Chamber (CSC) with geometry suitable for large area muon detectors at the LHC. Interpolation of the cathode induced charge provided single particle position resolution of 1% of the readout pitch [1]. To determine the track location in case when more than one particle passes close to the same strip, charge interpolation needs to be replaced by a method that is more accurate in the presence of another track. We have used a fitting algorithm that measures the track position from a fit of the cathode induced charge distribution and also can reliably detect the presence of another track. Although the induced charge spans over several readout strips, because of the stability of the charge distribution shape, the fitting algorithm provides double track resolution better than the CSC readout pitch.

To evaluate the double track resolution, we applied our fitting algorithm to overlaid single track events from chamber tests with a 300 GeV/c muon beam in the RD5 experiment at CERN [2]. Preliminary results of this study were reported in [3]. The performance of the fitting algorithm was also measured by analyzing multi-track events of muons accompanied by electromagnetic secondaries produced as a muon beam passed through a copper block upstream of the chamber.

2 Cathode Strip Chamber

The details of the CSC construction are described in [1]. The CSC is a multi-wire proportional chamber with a symmetric cell in which the anode-cathode spacing is equal to the anode wire pitch (Fig. 1). To improve position resolution and linearity we used a new strip pattern with intermediate strips between readout nodes, which

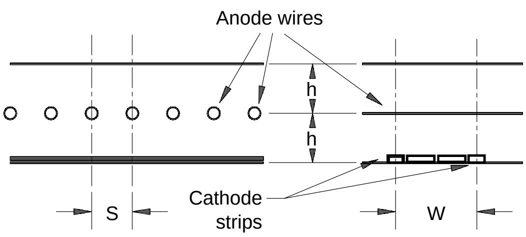

Fig. 1. Schematic diagram of the Cathode Strip Chamber. In our chamber the anode-cathode spacing, h = 2.54 mm, the wire pitch, S = 2.54 mm, and the readout pitch, W = 5.08 mm.

* Corresponding author.

[1] Visitor from St.Petersburg Nuclear Physics Institute, Gatchina, Russian Federation.

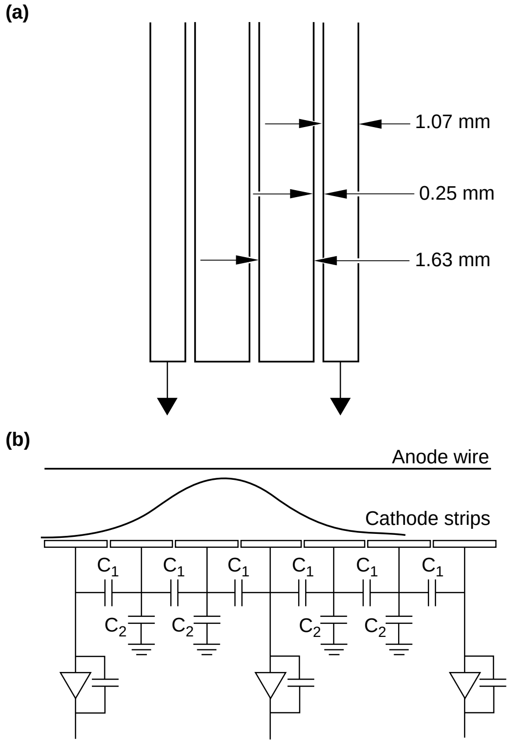

Fig. 2. (a) The geometry of the readout and intermediate strips. (b) The equivalent circuit showing the principle of capacitive interpolation using the two intermediate strips. In our chamber $C_1/C_2 \approx 10$.

is shown in Fig. 2a, along with the equivalent electrical circuit in Fig. 2b.

3 Algorithm

Figure 3 shows the induced charge vs. the distance between the strip center and the avalanche position for selected (see Section 4) single muon events. The measured distribution exhibits small fluctuations of the shape at normal (or nearly normal) particle incidence.

To parametrize the induced charge distribution we used the semi-empirical expression by Gatti et al. [4]. For our case of two adjacent interpolating strips for each readout strip, the collected charge is described by the formula:

$$Q(x) = \sum_{i=1}^{6} f_i \frac{K_1}{K_2\sqrt{K_3}} \arctan[\sqrt{K_3}\tanh(K_2((x-b_i)/h))].$$

Here, x is the distance from the avalanche position to the readout strip center; h is the anode-cathode gap; f_i are parameters determined by the strip capacitive coupling

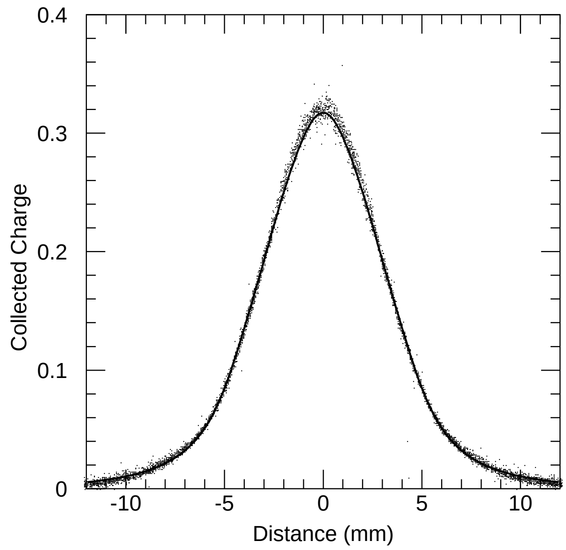

Fig. 3. The scatter plot of the measured charge (normalized) vs. the distance between the strip center and avalanche position for single muon events. The line shows calculated charge distribution parametrized from X-ray data.

(in our CSCs they are measured to be $f_6 = -f_1 = 0.304$, $f_5 = -f_2 = 0.326$, $f_4 = -f_3 = 0.371$); b_i are coordinates of the strip boundaries, for our strip geometry (Fig. 2a) $b_6 = -b_1 = 4.40$ mm, $b_5 = -b_2 = 2.54$ mm, $b_4 = -b_3 = 0.68$ mm. The values of chamber parameters K_i are determined from the best fit to the induced charge distribution measured with an ^{55}Fe source [1] (since the X-ray data are free of distortions caused by multi-track contamination). The solid line in Fig. 3 shows the resulting charge distribution.

To resolve two-particle events, for every charge cluster in each chamber layer we compare results of the fit to the normalized charge distribution with two separate hypotheses: "single-hit" and "double-hit". The single-hit fit has one fit parameter: the avalanche position. The double-hit fit has three parameters: position and amplitude for the first hit and position of the second hit. (The amplitude of the second hit is fixed by normalization.) Fig. 4 shows a typical comparison of both hypotheses. A charge cluster is considered as two particles if its shape is better fitted by a double-hit hypothesis.

The CSC response to muons was simulated using GEANT [5], taking into account the geometry of the chamber, electronic noise, etc. The primary ionization deposited in the gas by charged particles was calculated, then the total charge was distributed across the readout nodes according to the collected charge formula mentioned above.

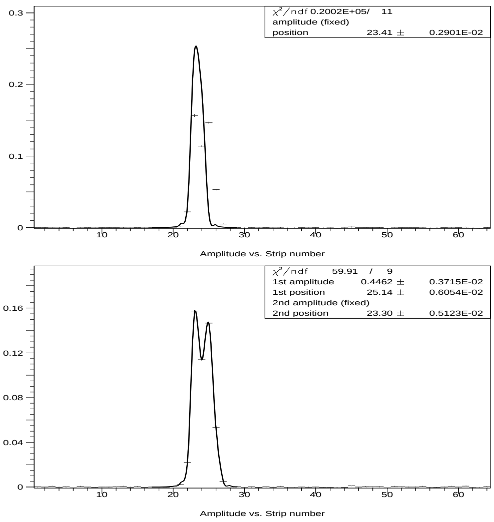

Fig. 4. Fit to a normalized charge distribution in a simulated two-particle event with a single-hit (top) and double-hit (bottom) hypothesis.

4 Data analysis

To produce a data sample of two-particle clusters, we overlaid two single muon clusters selected from data taken at RD5. The single particle position was determined by the center-of-gravity method, which gave a position resolution of $\sigma = 50\ \mu$m [1]. In any CSC layer, it is probable that the shape of the single muon cluster is distorted by δ-ray emission. The position measurements of those clusters are expected to be corrupted. To reduce the fraction of such events, in addition to the simple single particle selection criteria used in [1] we required that the residuals for selected single clusters were within the 3σ range (150 μm).

Fig. 5 shows the efficiency of two-particle reconstruction vs. distance between them, measured from our overlaid two-particle sample. We believe that the difference between the results from simulation and overlaid data is caused by the remaining contamination of the "single-track" data sample with clusters corrupted by multiple hits. Simulation studies showed that the efficiency is not significantly affected by a $\sqrt{2}$ noise increase due to overlaying of events. Fig. 5 shows that CSC's are efficient in reconstructing both particles for tracks separated by more than 2 mm. A CSC double track resolution better than the readout pitch was also demonstrated in NA44 experiment using a similar fitting algorithm [6].

Fig. 6 shows the position resolution in presence of a second particle. The degradation of the position resolution for close tracks is limited to about 10% of the readout strip pitch. Although inadequate for precision tracking, such a measurement may still be used for muon pattern recognition. A limited degradation of CSC position resolution for close tracks was also demonstrated in [7].

We believe that our results on CSC performance for close tracks are better than the estimates reported in [8] due to the more accurate treatment of the induced charge distribution in our fitting algorithm.

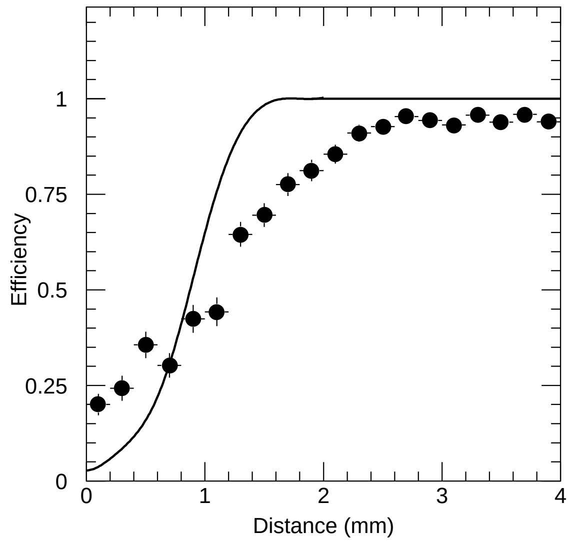

Fig. 5. Efficiency of reconstructing both particles vs. distance between them. Points are from overlaid events, line is from simulation.

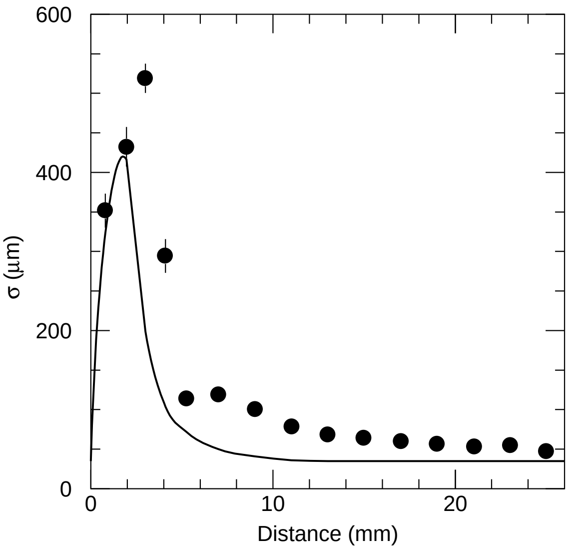

Fig. 6. Position resolution vs. distance to a close track. Points are from overlaid events, line is from simulation.

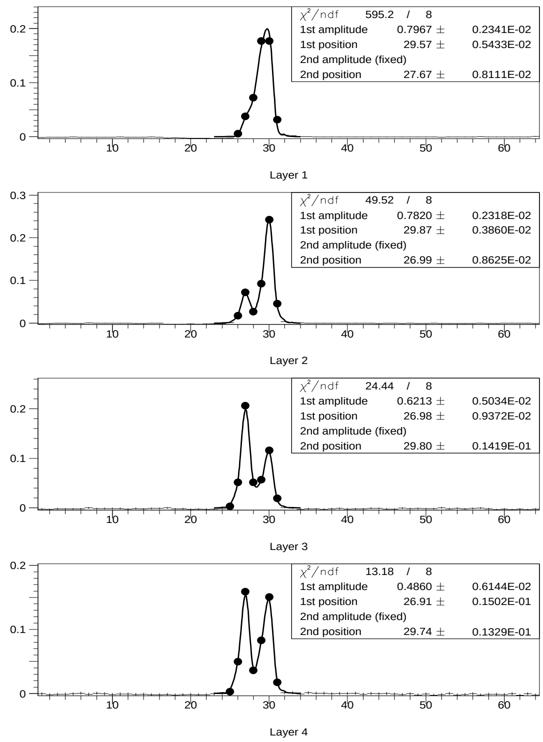

Fig. 7. A typical double track event display (normalized charge distribution vs. strip number) for a muon accompanied by a secondary particle.

As a further test of the fitting algorithm, it was applied to multi-track events produced by muon-induced electromagnetic secondaries. These secondaries were generated by passing a high energy muon beam through a dense material in the RD5 experiment [9]. The dense material was a 40 cm block of copper placed 30 cm upstream of the CSC's. In each of the four chamber layers, a charge cluster was considered as "double hit" if its shape was better fitted by a two-particle hypothesis. A "track" was then defined as a set of four hits, one per layer, and "double track" events were selected by requiring at least two hits in each of the four chamber layers. Fig. 7 presents a typical double track event display. The distribution of the average separation between the first and the second hits found in the four layers (a measure of the distance between the muon and the secondary track) is shown in Fig. 8. The solid line shows the prediction of our simulation, which agrees well with data, demonstrating the stability of the fitting algorithm.

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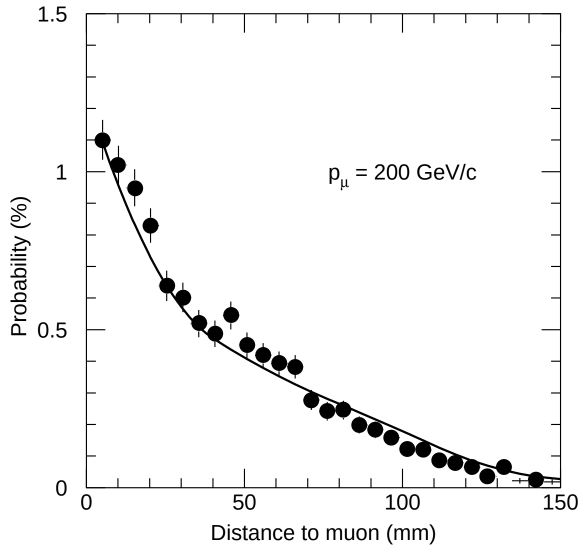

Fig. 8. Comparison of measured (points) and simulated (line) probability of secondary tracks vs. distance to muon for 200 GeV/c incident muons.

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