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Pion-Electron Separation by combined dE/dx and TR measurements in ATLAS Transition Radiation Tracker

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Abstract

The enhanced electron identification in the ATLAS experiment is one of the basic design consideration. In this paper the possibility to increase the identification power of ATLAS TRT in low momentum region through a combination of the detection of Transition Radiation from the electron and the differences in the energy losses (dE/dx) for an electron with momenta greater than 0.5 GeV/c and a less relativistic particle is examined. Results of MC simulation show that the combined TR and dE/dx electron-hadron separation is better than 100 for isolated electrons in momentum region down to 0.5 GeV/c without any change in the TRT construction and foreseen readout electronics.

1 Introduction

One of the major role of TRT in ATLAS experiment is the efficient detection of electrons with the rejection of hadrons [1]. The hadron rejection by TRT is achieved by counting the number of ionization clusters, i.e. hits with energy $E_{hit} > E_{thr}$ deposited inside some volume of the straw. For E_{thr} above a few KeV ionization clusters on the hadron track have origin mostly from energetic knock-on electrons, while on high momentum electron track a large part of clusters is produced by absorption of TR photons in Xe containing gas mixture.

Below a momentum of 2 Gev/c the effectiveness of e/h separation using TR photons starts to diminish because as the electron becomes less relativistic, the probability of a TR photon being emitted by the radiator decreases. For the separation of electrons in the momentum region 500 MeV/c to 2 GeV/c (with dE/dx already on the relativistic Fermi plateau) and relatively slow hadrons (with an energy of about 1 Gev, i.e. mip's), a significant contribution to the electron signal is given by the relativistic rise of dE/dx. Energy losses in Xe gas are large (6.76 keV/cm for mip's) and the relative relativistic rise for Xe is higher($\sim 80\%$ for a transferred energy > 500 eV) in comparison to gases usually used in gaseous tracking devices [2]. These properties of Xe permits to obtain a good e/h separation even for the relatively thin (~ 10 cm) total gas thickness used for dE/dx measurements.

The possiibility of using a detector made of packed straw-tubes for dE/dx measurements to separate pions and electrons in ATLAS experiment was studied in [3] by MC simulation showed that good electron-pion separation seems achievable at low ($< 7 GeV$) energies. In this paper the possibility to increase the identification power of ATLAS TRT in low momentum region through a combination of the detection of Transition Radiation and dE/dx measurements is examined. As was shown in [4], the simultaneous measurements of dE/dx by truncated mean energy technique and of TR by cluster counting method yield the combined rejection factor better then 1000 at 97 % electron efficiency in momentum region 0.5 to 5 GeV/c for 30 cm total thickness of Xe. Unfortunately, appliance of the truncated mean energy technique utilized in this work and proposed in [3] requires a spectrometric readout that significantly complicates readout electronic and raises its cost, which is crucial for ATLAS straw tracker consisting of more then 10^5 channels.

2 dE/dx e/π separation technique description and tests

We propose a simplified method of particle separation by relativistic rise of dE/dx, based on the cluster counting technique. It is known [5,6,7], that most of the relativistic rise of energy loss detected in a detector is due to the increase of the number of primary ionizing collisions and only little due to the increase of energy transfer in a single collision. The ionization cluster, as defined above, is composed of several primary ionizing collisions, therefore the number of ionization clusters above some energy threshold (in other terminology the number of hits) on a particle track in a gaseous detector depends on the particle ionization ability and can be used for particle separation by the dE/dx measurements.

The size of the cluster seen in a gaseous detector is determined by a combination of primary electron cluster sizes and locations; the electron diffusion, drift velocity and electric field over the drift distance, and the shaping time of the readout electronics; therefore the number of clusters depends not only on the threshold, but also on the time interval within which a cluster is registered. So counting the number of time intervals (time bins) with amplitude above some threshold yields a distribution depending on the particle ionization ability. The mean value and the widths of N of bins above threshold distributions for electrons and pions can be optimized for a better separation by adjusting the threshold value and width of the time bin. The proposed "time bin above threshold counting" method is much more easy in realization both in hardware and software then the truncated-mean energy method and according to the detailed MC simulation gives the same results for the separation power. In order to check the validity of the proposed method, on our request it was used in the analysis of the data, recorded in [3] using FADC clocked at 24.5 nsec. The results of this analysis showed, that N bin above threshold counting method yields the same separation power as the standard truncated-mean energy technique [8]. Optimized for the best electron-pion separation threshold value was found to be 0.6 KeV for the planar drift chambers used in this work.

In order to further check the validity of the proposed method for the straw tube charge collection geometry, the method was tested by ZEUS TRD straw tube prototype in a secondary electron beam at DESY and in cosmic runs [9]. The prototype consisted of four 10 cm modules, a total of 32 straw tubes were arranged in 8 rows, each containing four straw tubes, 12 mm in diameter and 120 mm in length. The space between straw rows (4*(41 and 27 mm)) was used to place radiator material. The electronic chain of each straw anode wire consisted of a preamplifier, a shaping amplifier (shaping time about 50 nsec) and a 6 bit flash ADC clocked at 10 nsec.

Large statistical samples of both electrons at a few momenta and cosmic particles were accumulated for the PP fibre radiator used in ZEUS TRD. In the analysis we accepted events that contained only single tracks crossing at least 6 straws and employed two threshold cuts for dE/dx and TR measurements. The examples of electron and muon events are shown in Fig 1. The e/mip separation has been determined by 2D histogramming the N bin above thresholds distributions for electrons and cosmic particles. In this measurements we have used cosmic particles instead of hadrons, so the results can be interpreted as a lower limit on the rejection power because of an unavoidable admixture of electrons and high momentum muons in the cosmic particle data sample. The results for separation of electrons and cosmic particles (mean energy 2 GeV) by TR measurements and combined dE/dx+TR measurements are shown in Fig. 2, where MC simulation results for electrons/cosmic muons and electrons/pions are also shown. It should be noted, that relatively high rejection factor for 40 cm overall length of the detector is due to high TR yield of ZEUS TRD polypropylene fiber radiator, which is close to the TR yield of regular foil-gas radiator.

3 MC simulation of TR + dE/dx measurements in ATLAS TRT

The described above method of particle separation by dE/dx was applied in the TRT barrel MC simulation. We have used the GEANT package and dedicated routines for ionization losses (now included in GEANT version 3.16 and following) and transition radiation generation in radiator and straw walls developed by I.Gavrilenko. MC model of straw response also includes simulation of the gas gain fluctuation, charge space effect, ionization electrons drift in the straw, signal shaping and electronics noise. Electrons and pions at 4 momenta (0.5, 1.0, 3.0 and 5.0 GeV/c) were generated at spread (+/- 2mm) vertex perpendicular to detector. The simulated response of the straw readout chain on a 3 GeV/c electron passing through the straw is shown in figure 3. Two threshold cuts within a time bins were applied to the simulated signals of 36 straws: 4.8 KeV threshold was used for counting TR clusters and a low threshold (0.1 - 3 KeV) for counting dE/dx ionization clusters. The signal time binning was 1, 3, 25 (BX time) and 36 nsec. The electron-hadron separation has been determined by 2D histogramming the N bin above thresholds distributions for electrons and pions (Figure 4). The separation power dependence on the lower threshold value is shown in figure 5. The dependence of the combined dE/dx+TR separation power on the width of the time bins can be found in figure 6. Figure 7 shows the results for dE/dx and dE/dx+TR electron-pion separation as a function of particle momenta for thresholds 0.35 and 4.8 KeV and the bin width of 25 nsec, corresponding to the clocking BX time of the foreseen ATLAS TRT readout electronics.

An attempt was made to examine the possibility of pion-kaon rejection by dE/dx measurements with the same technique. The results are shown in figure 8.

4 Conclusions

The examination of the possibility to increase the electron-hadron separation power of TRT in low momentum region by combined dE/dx + TR measurements shows, that pion-electron separation of the order of 100 at 90 % electron efficiency in momentum region down to 0.5 GeV/c can be achieved for isolated particles. The implementation of the proposed method doesn't require any change in the present TRT design and readout electronics, excluding the adjustment of the low threshold value foreseen for drift time measurements. It should be noted, that utilizing of the "time bin counting" method for high threshold impruves also particle separation power by TR measurements compare to hit counting method (25 and 36 nsec curve in figure 6).

The influence of the low threshold adjustment on the tracking performance of the TRT in ATLAS experiment demands more detailed and complicated studies by DICE, as well as pile-up effects and the separation power of proposed method for non-isolated particles.

5 Acknowledgments

We are very grateful to I.Gavrilenko for his software products which we are extensively using and for the valuable discussions and exchanges of ideas on the dE/dx and TR particle separation methods.

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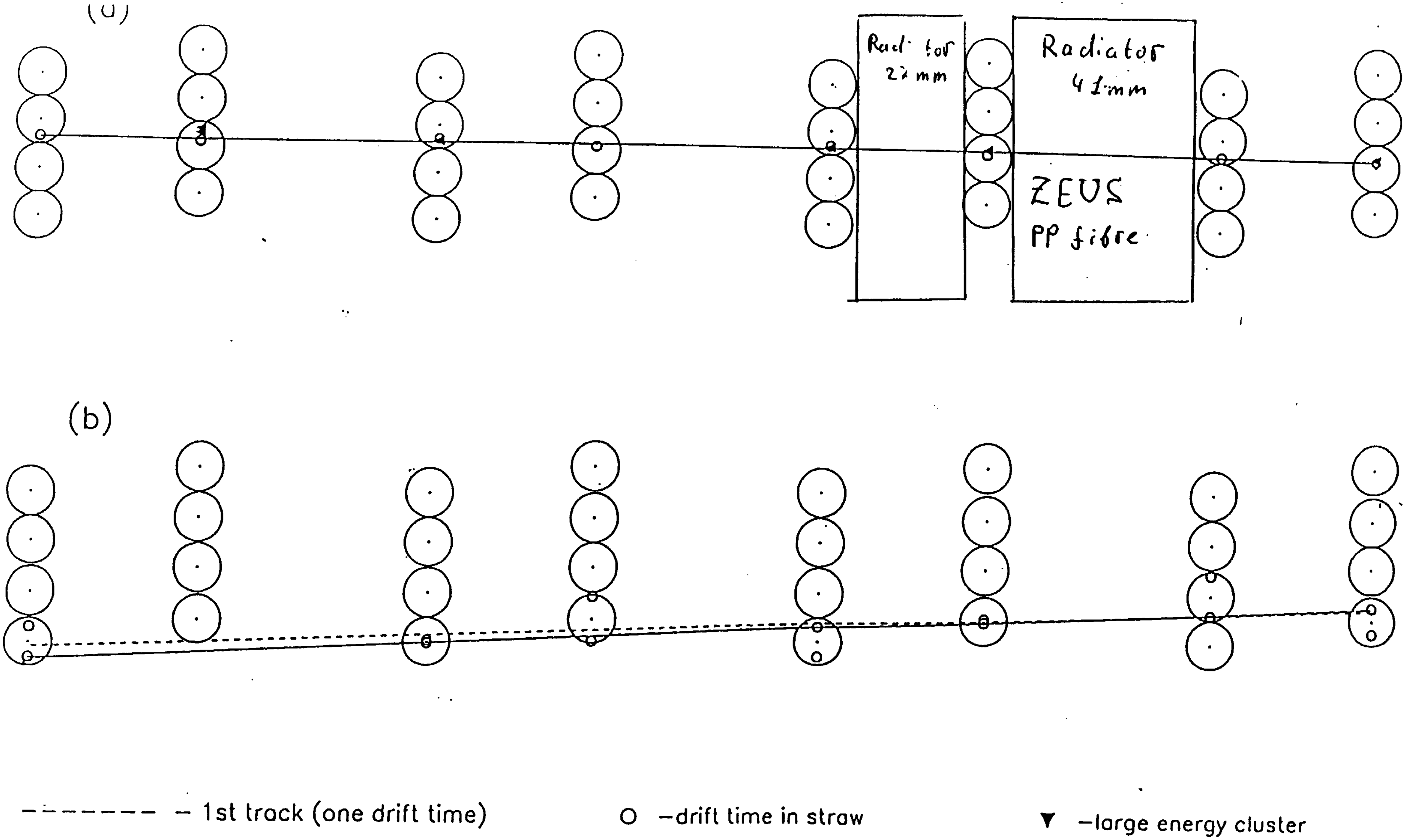
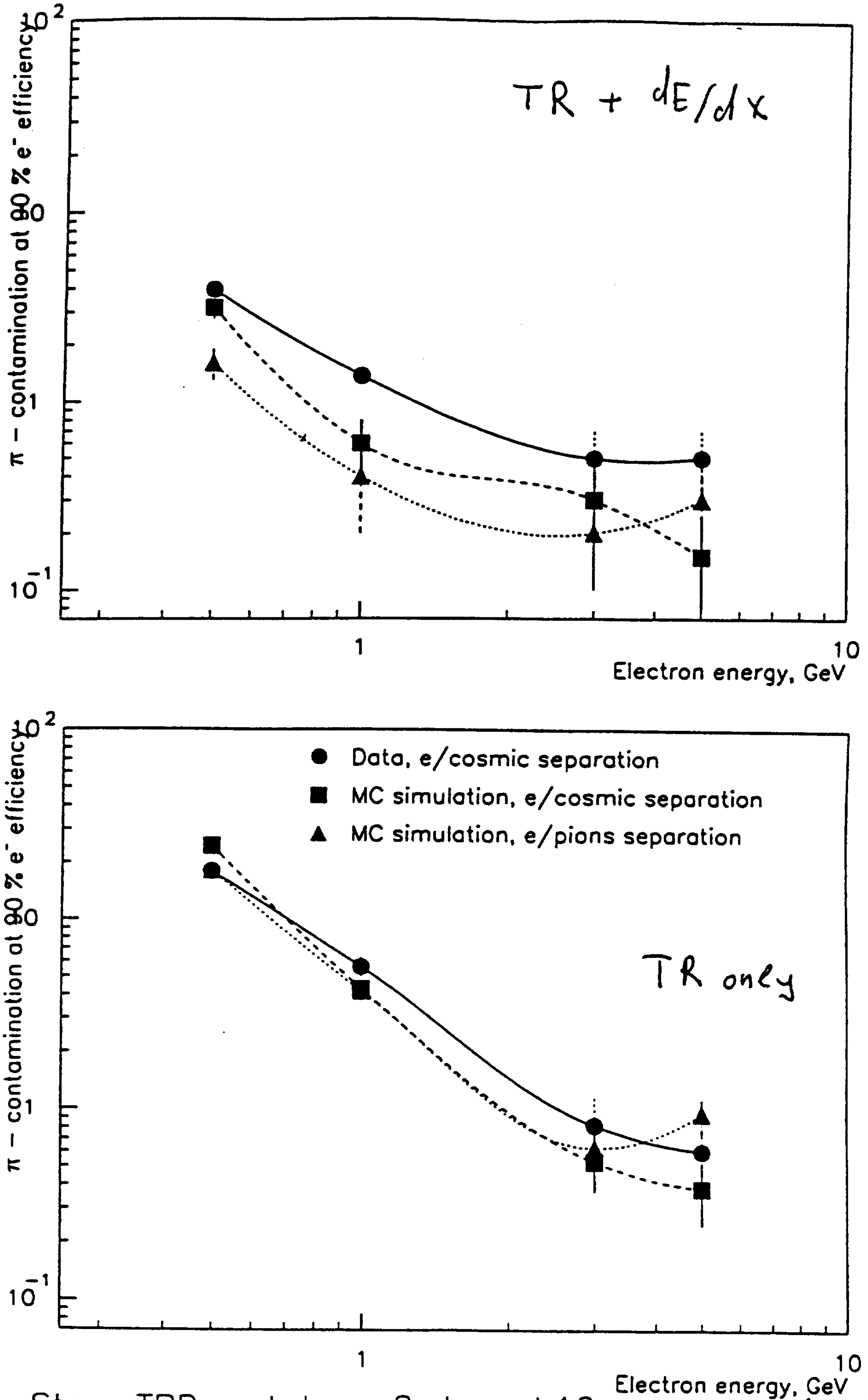


Fig. 1 Event display of electron (a) and muon (b) crossing the ZEUS TRD prototype



Straw TRD prototype, 8 straw d 12mm, separation by TR

Fig. 2

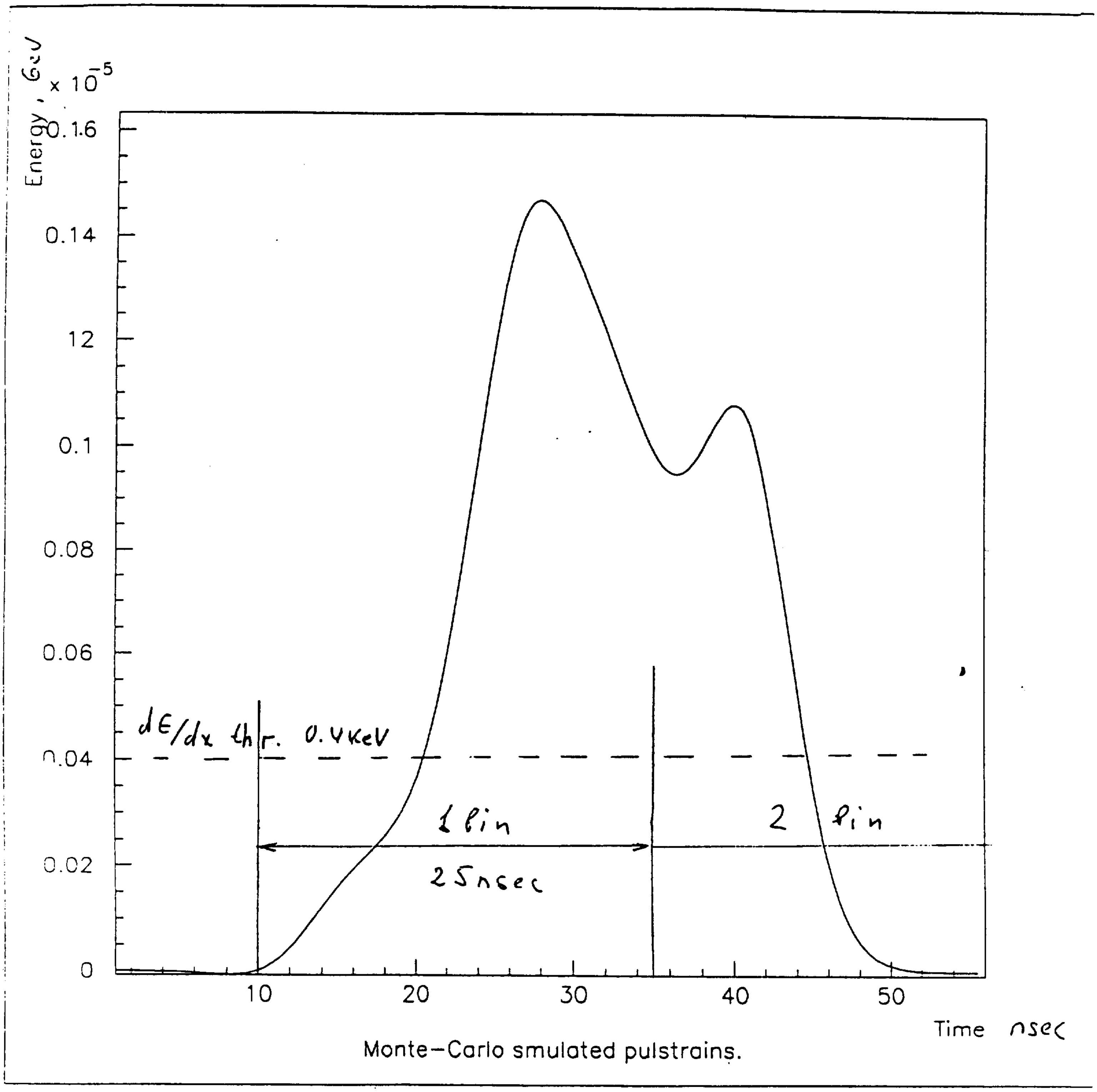

Energy , GeV x 10^-5
0.16
0.14
12
0.1
0.08
0.06
0.04
0.02
0
dE/dx thr. 0.4keV
1 bin
25nsec
2 bin
10
20
30
40
50
Time nsec
Monte-Carlo smulated pulstrains.

Fig. 3

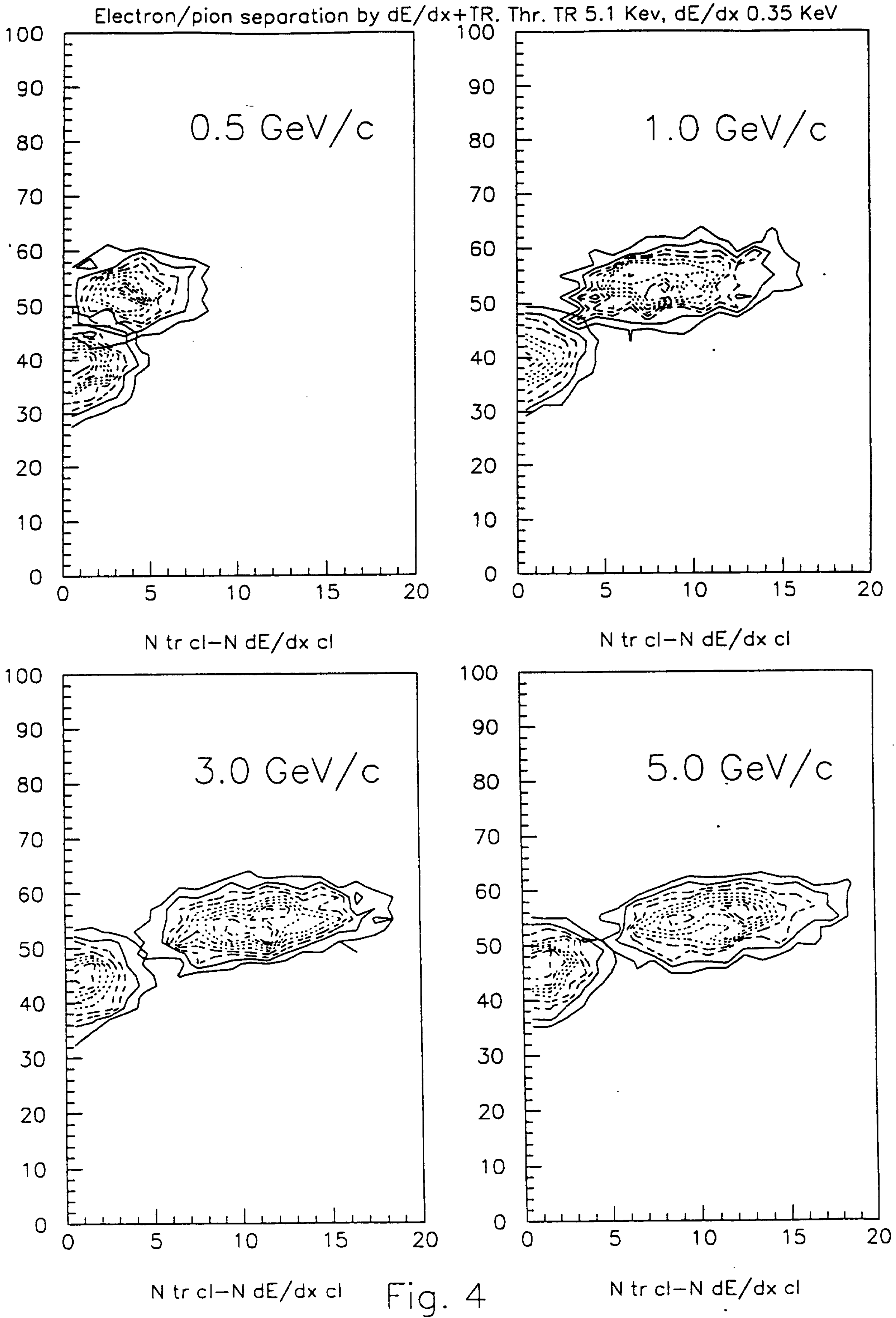

Electron/pion separation by dE/dx+TR. Thr. TR 5.1 Kev, dE/dx 0.35 KeV
0.5 GeV/c
1.0 GeV/c
3.0 GeV/c
5.0 GeV/c
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
N tr cl−N dE/dx cl

Fig. 4

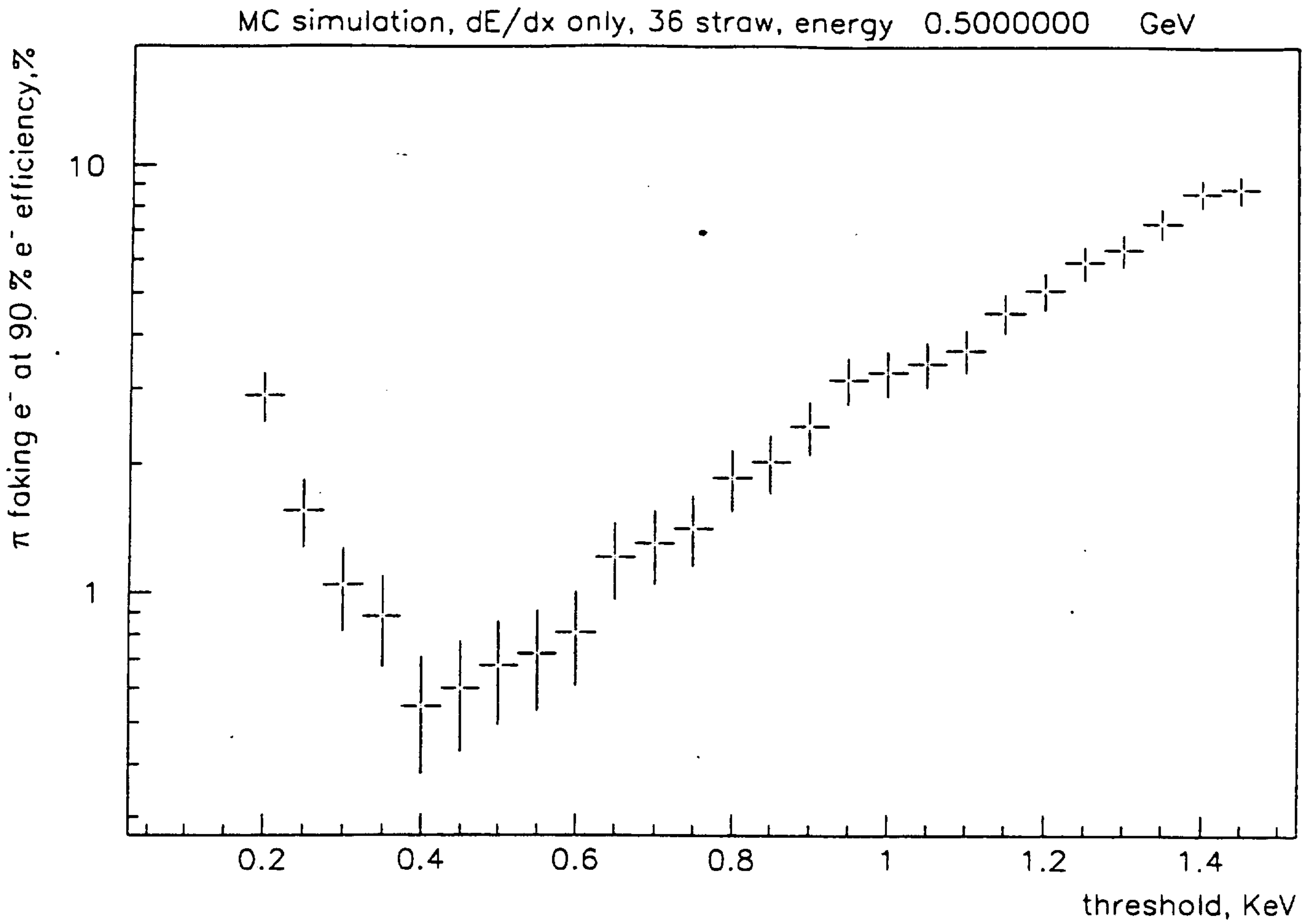

MC simulation, dE/dx only, 36 straw, energy 0.5000000 GeV

Fig.5a Straw TRD rejection by N bin(1 nsec) above thr meth.

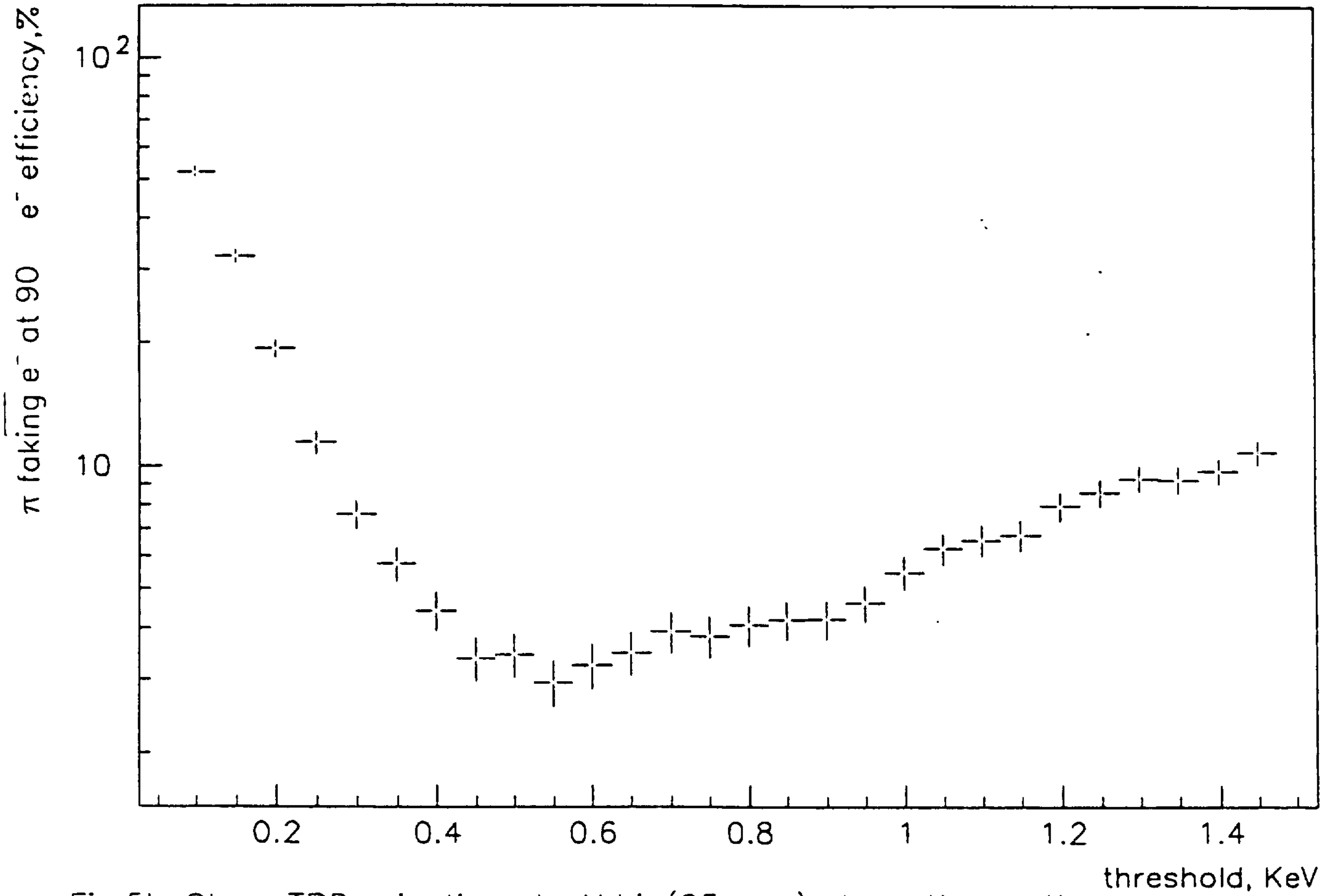


Fig.5b Straw TRD rejection by N bin(25nsec) above thr. meth.

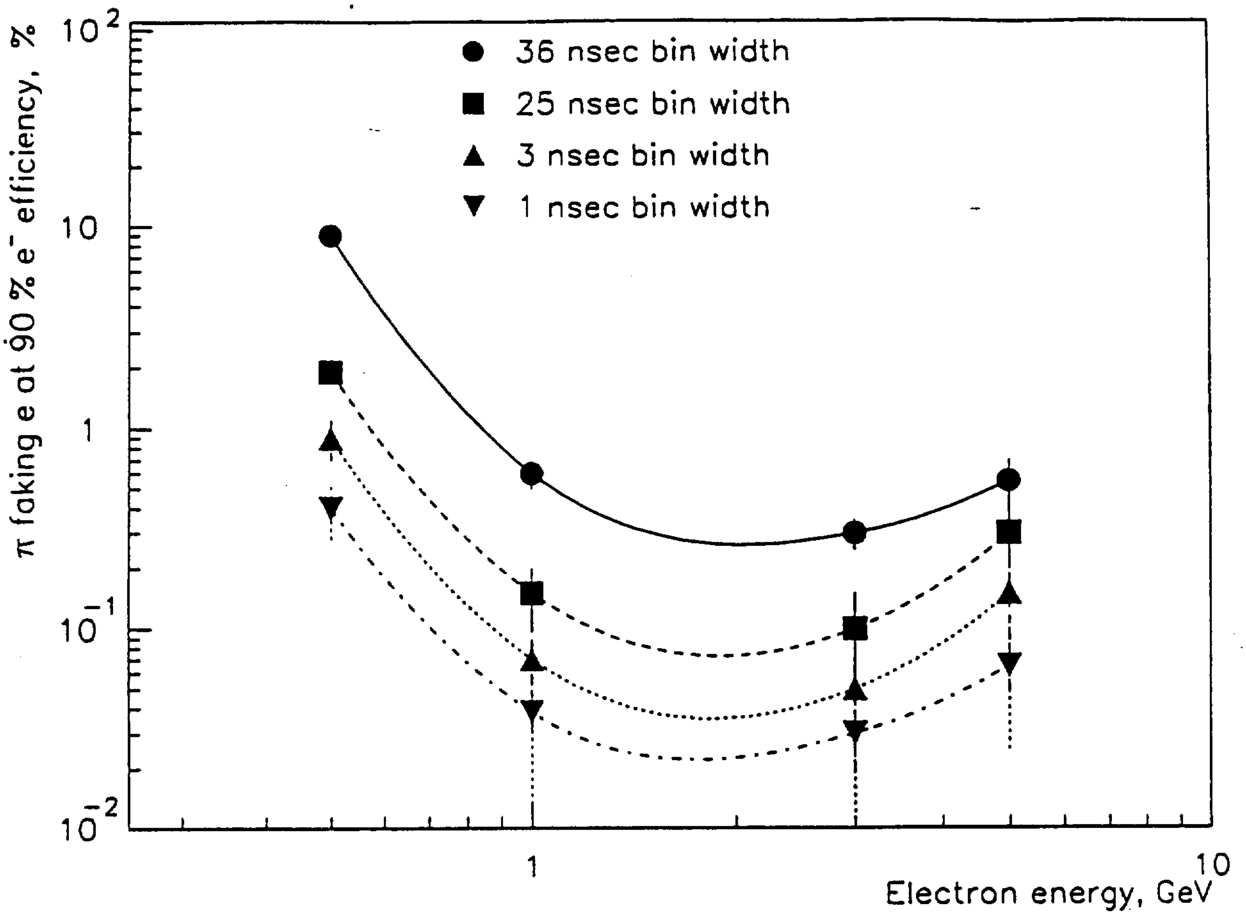


Fig.6 MC simulation, 36 straw, dE/dx+TR separation vs t

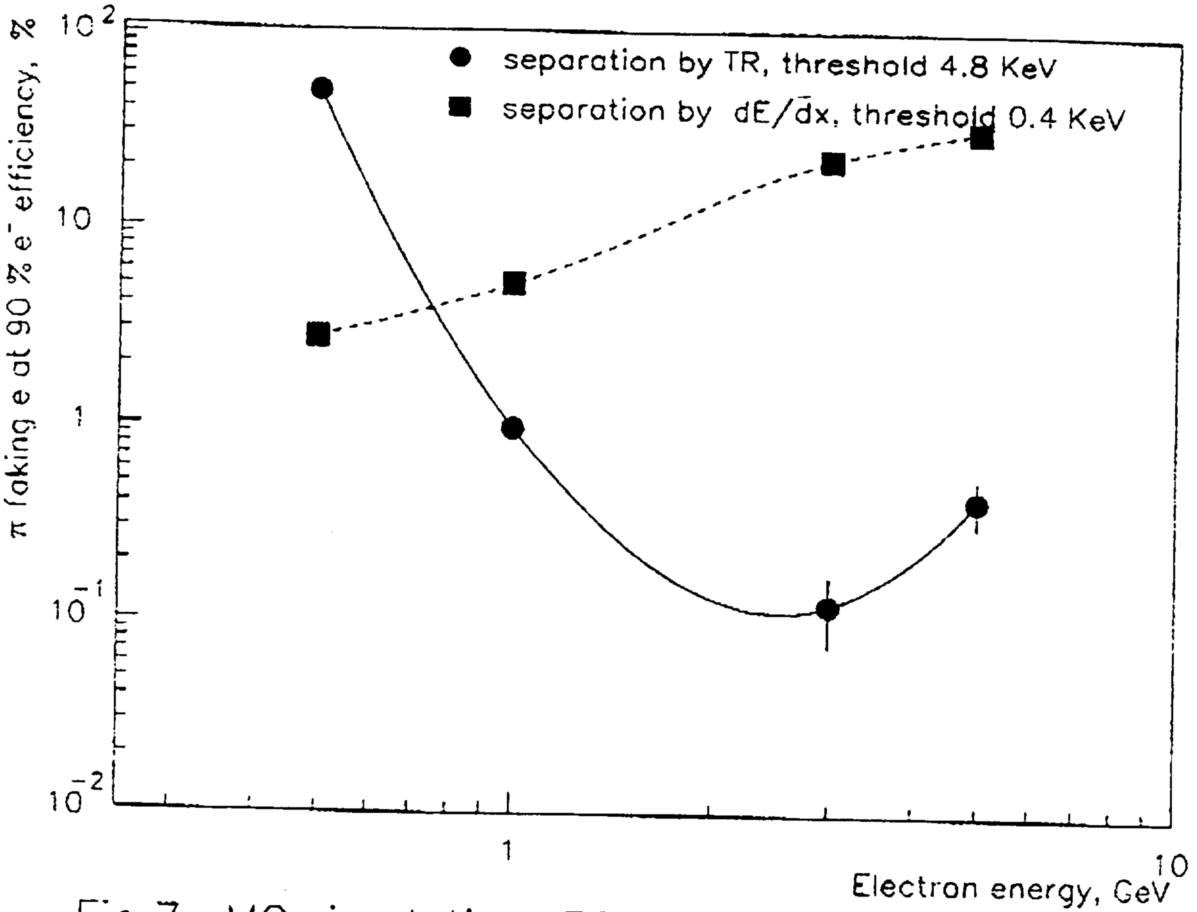


Fig.7a MC simulation, 36 straw on track, 25 ns bin.

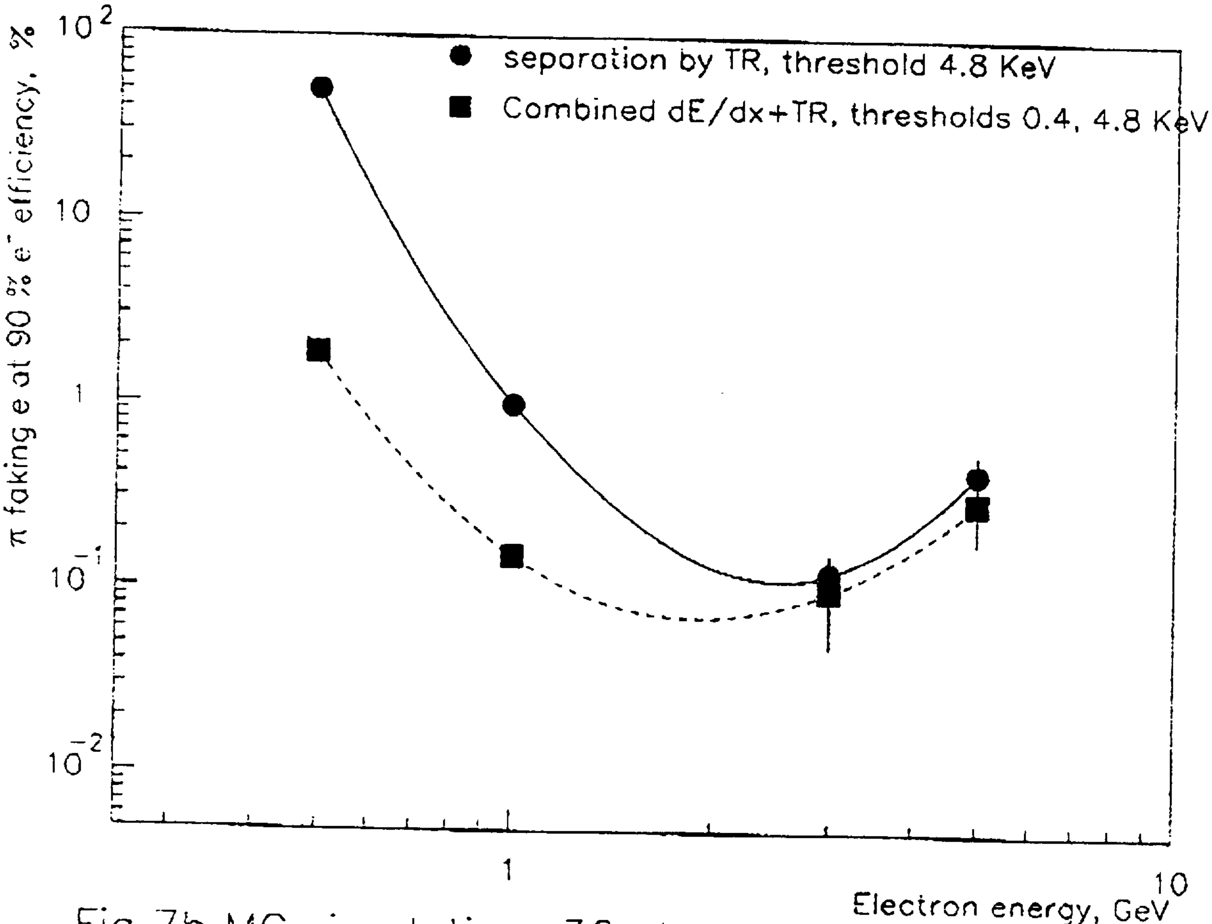
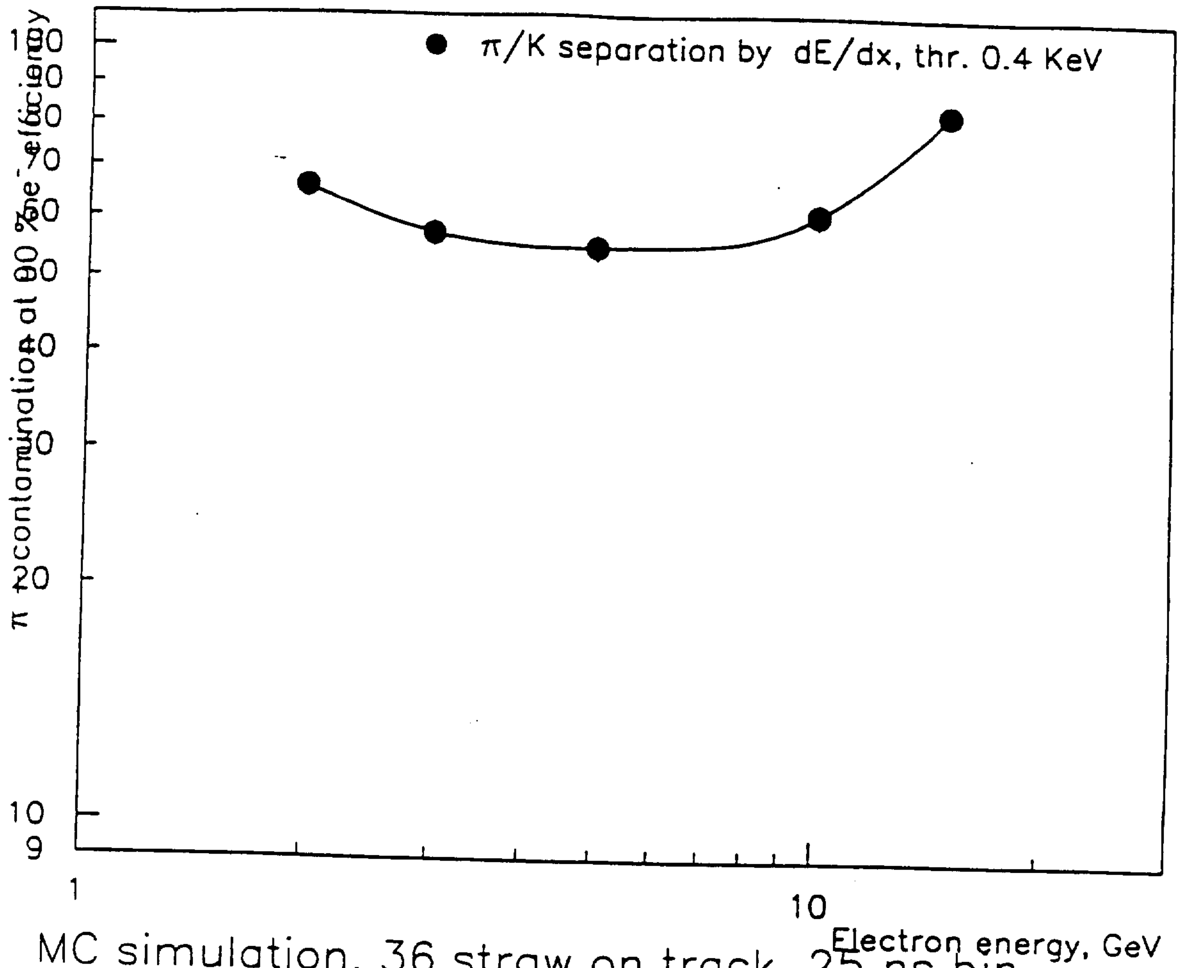


Fig.7b MC simulation, 36 straw on track, 25 ns bin.



MC simulation, 36 straw on track, 25 ns bin.

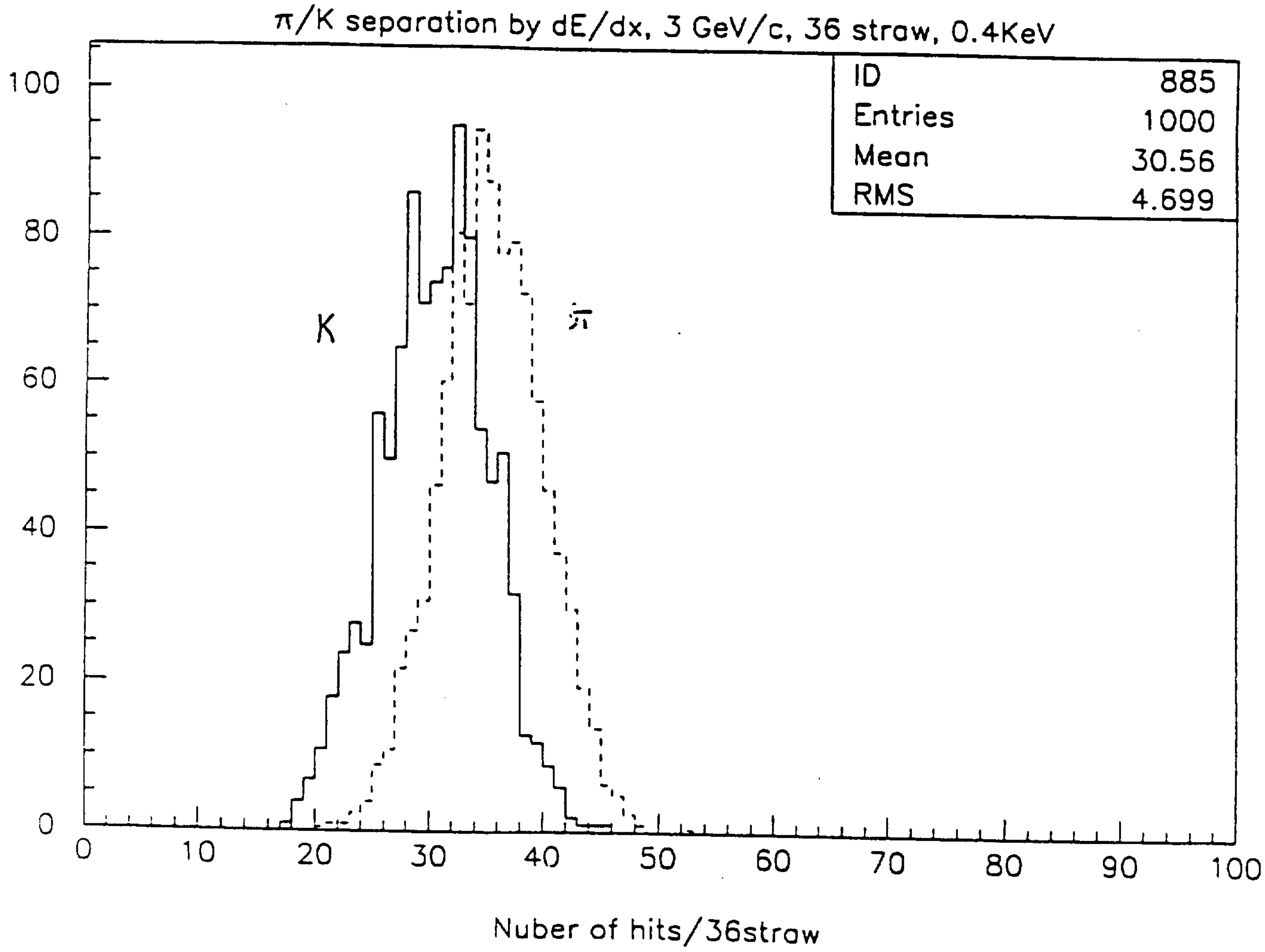


Fig. 8