Particle ID with dE/dx at the TESLA-TPC

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Abstract. The dE/dx resolution of the TESLA-TPC has been studied using a toy Monte Carlo simulation based on measured cluster size distributions. Various parameters like sampling length, electronics noise, crosstalk etc. have been investigated. An optimum number of 240 samples has been found (5 mm sampling length) with a simulated dE/dx resolution of 4.1%. The particle separation power has been estimated.

Introduction

Studies have shown that only a few physics cases at Linear Colliders would gain from hadronic particle identification capabilities, e.g. background reduction at heavy flavour tags. Therefore, no dedicated particle ID detector has been foreseen. The dE/dx capabilities of a TPC, essentially coming "for free", have been considered as sufficient.

The situation is different with the "Giga Z" option, where a total of more than 10^9 Z^0 decays around 2×45 GeV would be produced. Z^0 physics does largely profit from good particle ID as experience at LEP and SLC has shown. Hawkings and Moenig [1] have studied CP violation in b decays where the reconstruction of $B^0 \rightarrow \pi^+\pi^-$ invariant masses can be improved from S/B = 10:1 to 40:1 by using dE/dx of reasonable resolution at the TESLA-TPC.

Estimated dE/dx Resolution

The estimated dE/dx resolution for a gaseous tracking detector mainly depends on the available total detector depth L = track length $\times$ gas pressure. Already in 1983, Lehraus [2] found a clear dependence of the dE/dx resolution on the total detector depth: $\sigma(\mathrm{dE/dx})/(\mathrm{dE/dx}) = 5.7\% \cdot \mathrm{L}^{-0.37}$. Using present detectors the parameters haven't changed much [3]: $\sigma(\mathrm{dE/dx})/(\mathrm{dE/dx}) = 5.5\% \cdot \mathrm{L}^{-0.36}$. Based on an interpolation between the measured dE/dx resolution of ALEPH (4.5% [4])

and DELPHI (5.7% [5]), a dE/dx resolution of about 4.8% can be expected for the TESLA-TPC.

A slightly better correlation is obtained using the total number of clusters generated along a track. This takes into account differences in gas mixtures that have been neglected by Lehraus. However, the general picture doesn't change much.

Toy Monte Carlo Studies

In order to verify the estimated dE/dx resolution of the TESLA-TPC, more detailed investigations need to be done. Various theoretical models and Monte Carlos are available to simulate the energy loss dE/dx in gaseous detectors, e.g. Allison, Cobb [6] or Sternheimer et al. [7]. However, some models are complicated to use and not always give consistent results.

A different attempt was made in a toy Monte Carlo study by M. Gruwe [8] where any use of theoretical models to describe the energy loss is avoided. Instead, cluster size distributions for Ar, He, CO_2 and CH_4, measured and parameterised by Fischle, Heintze and Schmidt [9] have been used as basis.

The simulation works in the following way: Poisson distributed cluster positions along a track are generated. Then, the cluster size of each cluster is generated according to the measured cluster size distributions. Diffusion and exponential gas gain fluctuations are added for each electron. The electrons are collected in samples where both electronics noise and crosstalk between samples is taken into account. The simulation of crosstalk is of particular importance as correlations between charge measurements of samples are introduced.

In order to verify the simulation, the Landau distribution of min. ion. pions measured in the OPAL jet chamber has been compared with the simulated Landau distribution. Measured and simulated Landau distributions are in reasonable agreement, in particular the Landau tail is well described.

dE/dx Resolution of the TESLA-TPC

The simulation has been applied for the TESLA-TPC assuming a track length of 120 cm and a gas mixture of Ar/CH_4 (90/10) at 1 bar. The truncated mean method was used to reconstruct the dE/dx per track. The dependence of the dE/dx resolution on the upper truncation has also been investigated. The Landau distributions and obtained dE/dx resolutions have been studied as function of the number of samples per track, and of electronics noise and crosstalk.

In summary, the following results have been obtained, see [8] for details:

- Too short sampling length leads to many empty samples which are difficult to handle in the later dE/dx reconstruction. The sampling length should be greater than 4 mm (about 300 samples maximum).

- At more than 300 samples, the mean reconstructed dE/dx becomes very sensitive to hit detection thresholds. Thresholds corresponding to only one or two primary electrons lead to variations of the reconstructed dE/dx by up to 50%.
- The dE/dx resolution depends on the upper truncation. For the range of 100 to 300 samples, an upper truncation of 75 to 80% was found to give best dE/dx resolutions gaining about 0.2 to 0.3% compared to, e.g. a 70% truncation.

The results of the simulation have also been compared with measured dE/dx resolutions of other tracking detectors (table 1). The detectors are of different type with different sizes, gas mixtures and pressures. Good agreement has been found in general. However, the simulation tends to result in 0.2–0.5% better dE/dx resolutions compared to the measurements. This can be attributed to remaining calibration systematics, e.g. time dependent gas gain variations, that were not simulated.

TABLE 1. Comparison of simulated and measured dE/dx resolutions.

detector	type	pressure	no. of samples × sampling length	dE/dx resolution simulated	dE/dx resolution measured
ALEPH	TPC	1 bar	338 × 4 mm	4.2%	4.5% [4]
DELPHI	TPC	1 bar	192 × 4 mm	5.2%	5.7% [5]
TOPAZ	TPC	3.5 bar	175 × 4 mm	3.5%	4.4% [10]
TPC/2γ	TPC	8.5 bar	183 × 4 mm	2.5%	3.0% [11]
OPAL	Jet Ch.	4 bar	159 × 10 mm	2.6%	2.8% [3]
TESLA-CDR	TPC	1 bar	120 × 10 mm	4.6%	
TESLA opt. truncation	TPC	1 bar	240 × 5 mm	4.1%	

Particle Separation Power

More important for physics analysis is the particle separation power between two particles A,B $= [(\mathrm{dE/dx})_\mathrm{A} - (\mathrm{dE/dx})_\mathrm{B}]/\sigma(\mathrm{dE/dx})_\mathrm{A,B}$. So far, both simulation and measured dE/dx resolutions are obtained for the ideal case of isolated, "test-beam like" tracks with the full number of samples available. In contrast, particle ID in physics analysis is mainly applied to tracks in dense track environments (multihadronic jets). Therefore, the number of samples is reduced due to the limited double track resolution and the quality of the charge measurement is affected by additional corrections. The three large LEP tracking detectors ALEPH, DELPHI and OPAL [3] typically only make use of 60–70% of the full number of samples in jets. Thus, the average dE/dx resolution in jets is about $\sqrt{2}$ worse compared to the best possible resolution.

Figure 1 shows the expected particle separation power for the TESLA-TPC both for isolated tracks with 120 samples, with 240 samples and optimised truncation and for tracks within jets. Calibration systematics of 0.2–0.3% w.r.t. to the best simulation results (table 1) have been included. A $2\,\sigma$ particle separation power in

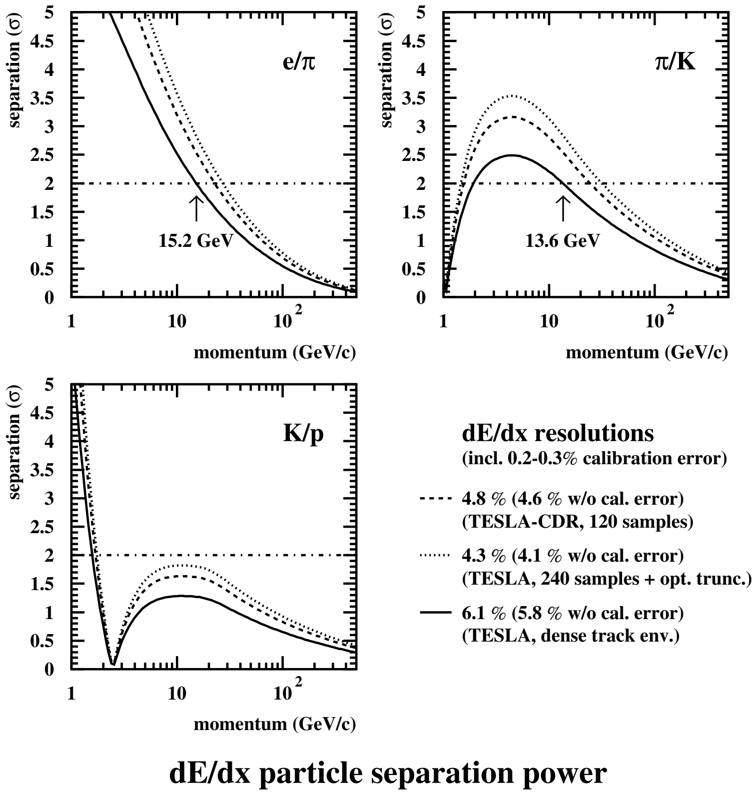

FIGURE 1. Expected dE/dx particle separation power for the TESLA-TPC.

the relativistic rise is obtained for e/π up to 15.2 GeV and for π/K up to 13.6 GeV. The maximum separation obtained for K/p is 1.2 σ around 10 GeV.

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