Systematic Dependences of the dE/dx Measurement at H1 in HERA-2 Data

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1 Motivation

A narrow resonance decaying to $D^{*-}p$, and its charge conjugate decaying to $D^{*+}\bar{p}$, has been observed in inelastic electron-proton collisions at center-of-mass energies of 300 GeV and 320 GeV at HERA [1]. To select proton candidates requirements are made upon the particles ionization loss (dE/dx) measurement. The likelihoods that a particle is a pion, kaon or proton are obtained from the proximity of the measured dE/dx to the most probable values for each particle type with the reconstructed momentum. The most probable dE/dx values are derived from phenomenological parametrisations [2], which are based on the Bethe-Bloch formula. Data taken between 1996-2000 has been calibrated, with a resulting average dE/dx resolution of 8 %. The purpose of this paper is to look into the collected data in 2004, after detector and accelerator upgrades, and analyze the systematic dependences of the dE/dx measurement on track parameters, particle charge and detector geometry.

2 Particle Identification by Measurement of dE/dx

On their passage through matter charged particles essentially lose energy trough ionization [1]. The measurement of the energy loss together with the measurement of the particles momentum allows the identification of the particle, at least for low values of the particles momentum. This is particularly important for the reconstruction of exclusive decay channels, since combinatoric underground can be strongly reduced if the particle is identified.

[1] This is only has a limited validity for electrons. For electron energies of a few hundred MeV a major part of the electrons energy is lost through 'Bremsstrahlung'

2.1 Energy Loss of Heavy Charged Particles by Atomic Collisions

In general, two principal features characterize the passage of charged particles through matter: (1) a loss of energy by the particle and (2) a deflection of the particle from its incident direction. Two processes are primarily responsible for these effects:

1) elastic scattering from the nuclei.

2) inelastic collisions with the atomic electrons of the material

These reactions take place many times per unit path length in matter. Their combined result accounts for the two principal observed effects. Other processes that can occur, like for example Cherenkov radiation, nuclear reactions and bremsstrahlung, are extremely rare when compared to atomic collisions. Of the two electromagnetic processes, primarily the the inelastic collisions are responsible for the energy loss of heavy particles in matter. The result of these collisions is the energy transfer from the particle to the atom evoking an excitation or ionization of the latter. Only a small amount is transferred in every collision, the large number of collisions per unit path length being responsible for the overall energy loss. The inelastic collisions are statistical in nature, occurring with a certain quantum mechanical probability. But because their number on a macroscopic scale is so large, the fluctuations in the total energy loss are small. Therefore it is meaningful to work with the average energy loss per unit path length given by the Bethe-Bloch formula:

$$-\frac{dE}{dx} = Cz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} ln \left(\frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} \right) - \beta^2 - \frac{\delta}{2} \right] \quad (1)$$

with

$$C = 4\pi N_A r_e^2 m_e c^2 \tag{2}$$

where N_A is Avogadro's number, r_e the classical electron radius, m_e the electron mass, z the charge of the incident particle in units of e, δ the density correction, Z the atomic number and A the atomic weight of the absorbing material and furthermore I is the mean excitation potential. T_{max} gives the maximum kinetic energy transfer in a single collision. For a particle with mass M and momentum $M\beta\gamma c$ this is:

$$T_{max} = \frac{2m_e c^2 \beta^2 \gamma^2}{1 + 2\gamma m_e/M + (m_e/M)^2} \tag{3}$$

In general T_{max} is approximated for $2\gamma m_e/M \ll 1$ by:

$$T_{max} = 2m_e c^2 \beta^2 \gamma^2 \tag{4}$$

Using this Eq. (1) takes the following form.

$$-\frac{dE}{dx} = Cz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[ln \left(\frac{2m_e c^2 \beta^2 \gamma^2}{I} \right) - \beta^2 - \frac{\delta}{2} \right] \tag{5}$$

The energy loss of a charged particle with mass M therefore only depends on the velocity of the particle and not on its mass. An example of the momentum dependence of dE/dx is shown in figure 1. It shows the specific ionization versus particle momentum measured in the H1 central jet chamber (CJC) at HERA runs. At non-relativistic momenta, dE/dx is dominated by the overall $1/\beta^2$ factor and decreases with increasing velocity until about $\beta = 0.96$, where a minimum is reached. Particles at this point are called minimum ionizing. Beyond the minimum, the term $1/\beta^2$ becomes almost constant and dE/dx rises again due to the logarithmic dependence of Eq. (5). This so called relativistic rise is canceled by the density corrections.

For momenta below the minimum ionizing value, each particle species exhibits a curve which, in most cases, is distinct from the other particle types. This fact can be exploited as a means of identifying particles in this momentum range.

The possibility of particle separation arises from the following identity:

$$\beta\gamma = \frac{p}{M} \tag{6}$$

Through the combined measurement of the energy loss and the particles momentum the rest mass of a particle can be determined and the particle can be identified.

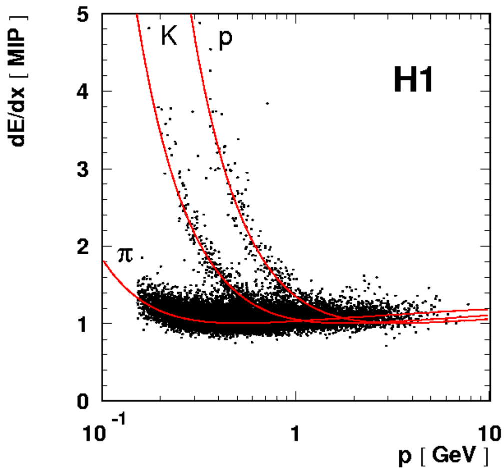

Fig. 1: *Specific ionization relative to a minimum ionizing particle versus particle momentum measured in the H1 CJC at HERA from 1996-2000. The expected mean responses of the CJCs for pions, kaons and protons are indicated*

3 The Central Jet Chambers

The H1 tracking system allows simultaneous track triggering, reconstruction and particle identification for the event topology particular to HERA electron proton collisions. The H1 detector together with the H1 reference frame is shown in figure 2. Track reconstruction in the central region is performed by two concentric drift chambers, CJC1 and CJC2, see figure 3. The chambers have strung wires parallel to the beam axis with the drift cells inclined with respect to the radial direction. Among other measurements the specific energy loss dE/dx is recorded from the signals in these chambers. The energy loss dE/dx for a given track is determined from the mean of single-hit values, excluding hits which are close to another track.

4 Systematic Dependences of the dE/dx Measurement

As described in [4], the result of the dE/dx measurement of a track shows dependences upon the following parameters:

- the polar angle θ
- the charge of the ionizing particle

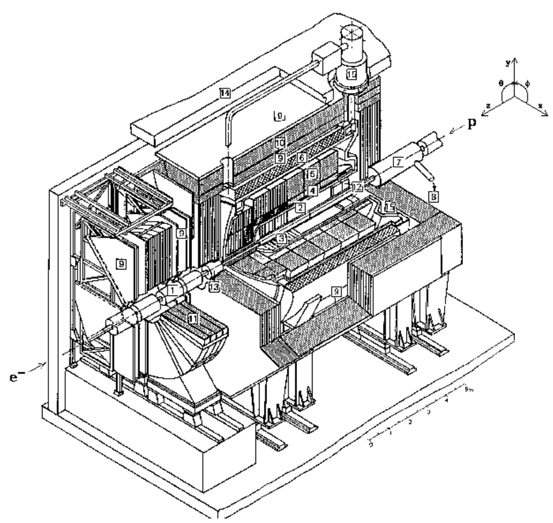

Fig. 2: *Schematic layout of H1 Detector, showing the H1 reference frame*

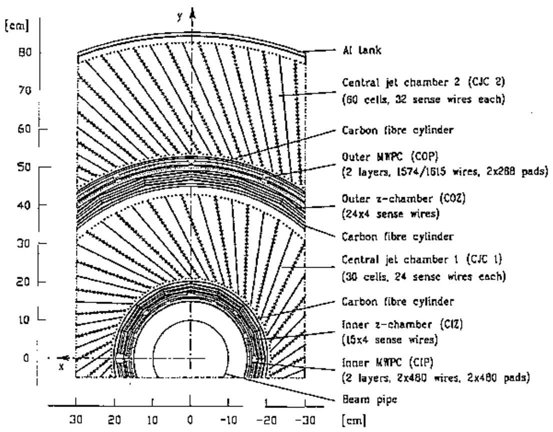

Fig. 3: *The CJC drift chambers at H1*

The reason for the systematic dependence on the polar angle can be explained by screening and saturation effects. During the gas amplification positive ions are produced. These ions cause a shielding of the electric field of the signal wires and therewith a decrease in the gas amplification. The magnitude of this effect depends on the density of the electron distribution that reaches the signal wire. It should be strongest for tracks with $\cos(\theta) = 0$. For these tracks electrons that were produced in the primary ionization all reach the signal wire at roughly the same time.

The different behavior of the dE/dx measurement for positive and negative tracks can be explained by the asymmetric structure of the CJC (Fig. 3) in the $r\phi$ -plane. The CJC-drift

Sector	ϕ	Name
ϕ_1	$45° \leq \phi \leq 135°$	up
ϕ_2	$-45° \leq \phi \leq 45°$	left
ϕ_3	$135° \leq \phi$ or $\phi \leq -135°$	right
ϕ_4	$-135° \leq \phi \leq -45°$	low

Tab. 1: *Definition of the ϕ sectors*

cells are inclined 30° respective the radial axis. This leads to different behavior with regard to the measurement of negative and positive particles. Negative particles wind against the signal wire plane, while positive particles follow tracks tangential to the signal wire plane. Therefore e.g. the following physical values are different for positive and negative tracks [4].

- for negative tracks the angle between the track and the normal to the drift direction is in the average smaller than for positive tracks
- positive tracks show a broader distribution with regard to the drift length in the CJC
- positive tracks cover a longer distance on the average in one drift cell than negative tracks

These values show a dependence on the curvature of the track, i.e. the momentum. The higher the momentum of a particle the smaller the curvature of the particles track. On that score it is to be expected that for increasing momentum the difference between positive and negative particles will decrease.

To obtain a better resolution of the dE/dx measurement one has to correct for these dependences.

To describe these systematic dependences with respect to the charge, dE/dx and θ, the following procedure is applied. For a certain period of data taking (e.g. the run range 367283-367293) all pion tracks which fulfill the conditions: $Dcap_{track} < 0.5cm$ and $length_{track} > 10cm$, are gathered for the dE/dx measurement. Only central tracks are taken. These restrictions are imposed on the data to ensure high quality measurement of dE/dx. The cut on the length of the track is equivalent to a cut on the number of single-hits. $Dcap_{track}$ is the distance from the origin of the track to the interaction point.

This cut thus ensures that the tracks considered emerge from the interaction point. According to their momentum they are sorted into 11 momentum bins. In a third step they are also sorted according to θ into 8 $\cos\theta$ bins, the corresponding ϕ sector (see table 1) and their charge. To obtain the mean dE/dx for a certain bin a Gaussian fit is done to the dE/dx distribution. The center of the Gaussian is taken as the mean dE/dx value. The θ bins are chosen according to the limited geometric acceptance of the CJC, so that only bins with enough entries are displayed.

The so obtained distribution in θ is fitted with a quadratic function with the three free parameters a,b and c:

$$f = a + b\cos(\theta) + c\cos^2(\theta) \tag{7}$$

The parameter a corresponds to value of the fitting function for $\cos\theta = 0$, the parameter b to the asymmetry of the function in the interval $-1 \leq \cos(\theta) \leq 1$, and c to the curvature.

Figure 4 shows an example of how the mean dE/dx value varies with $\cos(\theta)$. However the dependency varies with the momentum and the charge of the pion. For low momenta positive pions show a positive curvature which diminishes and turns into a negative curvature for higher momenta. Negative pions exhibit a negative curvature almost over the whole range, only for the lowest momentum bin the curvature is slightly positive.

The parameters a,b and c are shown in figure 6. Parameter a demonstrates a different behavior for negative and positive pions. The differences amount up to 3 %. Parameter b shows no systematic dependence on the momentum for both negative and positive pions. Over the whole range the asymmetry is very small. Within the error b is compatible with zero. With respect to parameter c positive and negative pions show a similar behavior as for the parameter a. Though the differences are more severe over the whole momentum range.

To correct for these effects the uncorrected dE/dx is multiplied by the following factor for every momentum bin:

$$\frac{a}{a + c * \cos(\theta)^2} \tag{8}$$

An example of the corrected dE/dx versus $\cos(\theta)$ distribution is shown in figure 5. It shows that after the correction the $\cos(\theta)$ dependence has reduced.

Figure 7 shows the corrected data plotted over the uncorrected data. It shows that the corrected data has a smaller deviation from expected value than the uncorrected data.

5 Conclusion

The ionization loss measurement in H1 CJC for the HERA-2 data shows the expected dependences on track parameters. The dependence of the dE/dx measurement on $\cos(\theta)$ of a track is flatter than that in HERA-1 data before calibration [4]. These dependences are corrected for in a similar way as described in [4]. The resulting dE/dx distribution shows flat behavior against $\cos(\theta)$. To obtain an optimal description of the measured dE/dx values, that in particular accounts for the described dependences, one could perform a multi-dimensional fit to the data.

References

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[2] W.R. Leo, Techniques for Nuclear and Particle Physics Experiments, Springer-Verlag.

[3] K. Kleinknecht, Detektoren für Teilchenstrahlung, Teubner Studienbücher: Physik.

[4] J. Steinhart, 'Die Messung des totalen $c\bar{c}$-Photoproduktions-Wirkungsquerschnittes durch die Rekonstruktion von Λ_c Baryonen unter Verwendung der verbesserten dE/dx Teilchenidentifikation am H1 Experiment bei HERA', Ph.D thesis, 1999, Universität Hamburg (in German), available from http://www-h1.desy.de/publications/theses_list.html.

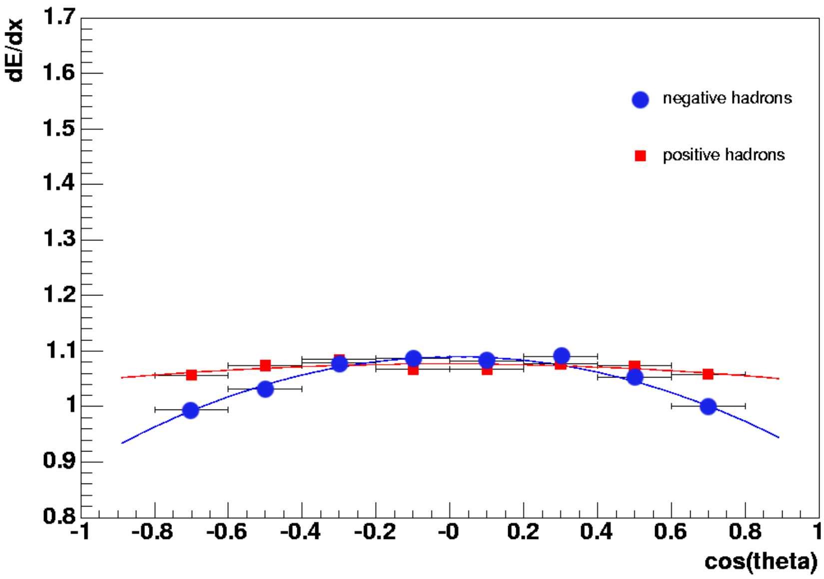

Fig. 4: *dE/dx against* $\cos\theta$ *for pions detected in the upper sector for the momentum bin with log10(p/[GeV])=-0.575.*

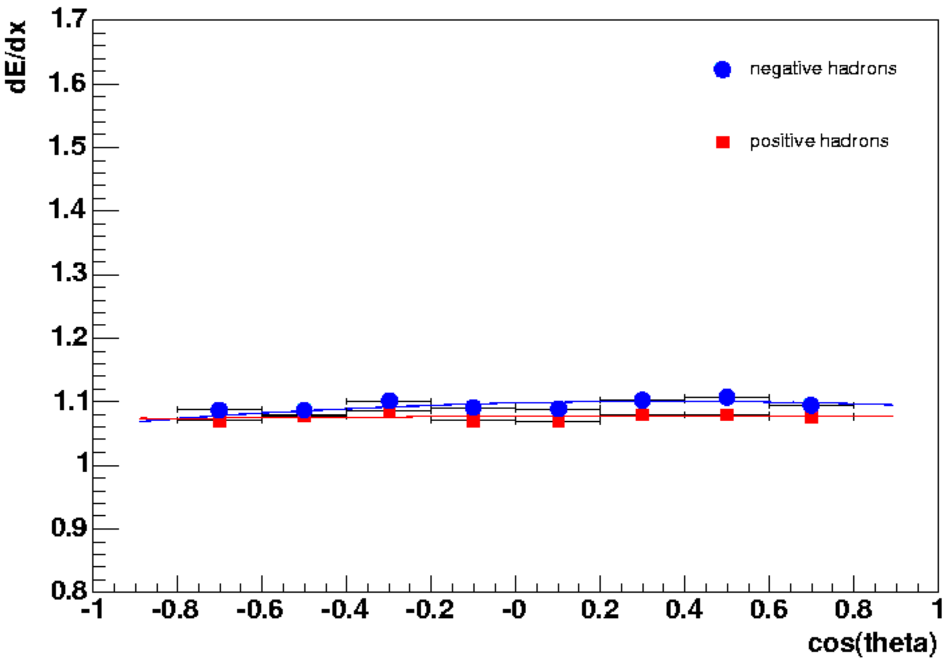

Fig. 5: *The corrected dE/dx against* $\cos\theta$ *for pions detected in the upper sector for the momentum bin with log10(p/[GeV])=-0.575.*

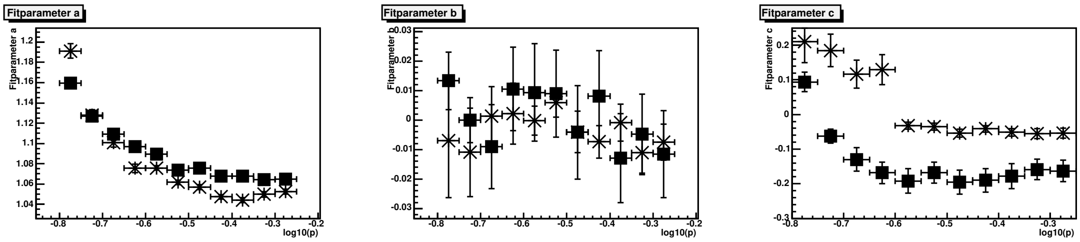

Fig. 6: *The fit parameters a,b and c from the fit of a quadratic function to the distribution of dE/dx in the upper sector against* $\cos(\theta)$ *for positive (aterisk) and negative (square) pions, plotted against the mean of the corresponding momentum bin*

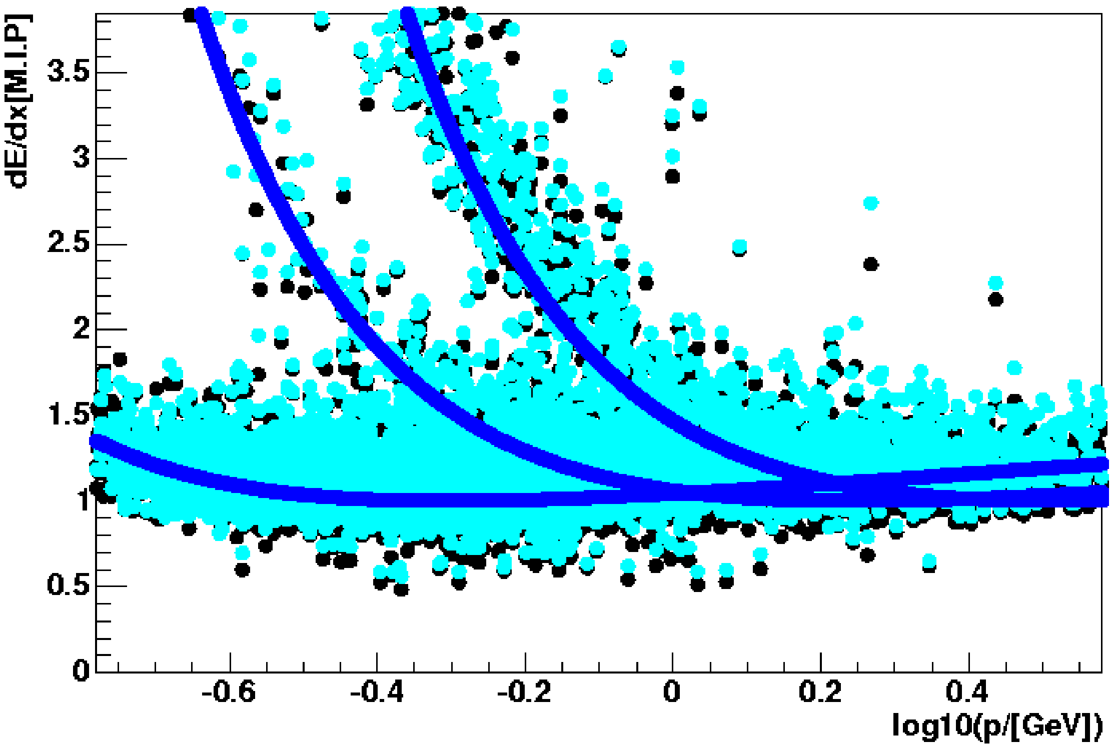

Fig. 7: *dE/dx versus momentum in the upper sector plotted for the uncorrected data(dark) and the corrected data(bright). The expected mean response of the CJCs for pions, kaons and protons are indicated(line)*