$e^{\pm}$ Identification using the Drift Chambers and Transition Radiators of the H1 Forward Track Detector

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Abstract

The status of the operation and performance of the H1 Forward Track Detector at the HERA ep storage rings for the detection of electrons (e^-) and positrons (e^+) is reported. Events with charged particles produced at small angles ($7^o < \theta < 25^o$) relative to the incident proton beam are reconstructed using radial wire and planar wire drift chambers with an accuracy of $\sigma(p)/p^2 = 0.027\,\mathrm{GeV}^{-1}$ for momenta $p > 3\,\mathrm{GeV}$. Transition Radiation X-rays, produced in polypropylene foil radiators immediately upstream of each radial wire drift chamber, are detected in the latter as ionisation charge additional to the usual $\frac{\mathrm{d}E}{\mathrm{d}x}$ contribution. Progress towards achieving the design $\frac{e}{\pi}$ discrimination of better than 10% π contamination for 90% $e^{\pm}$ acceptance, which has been established with single tracks, in the complex multi-track environment of ep events at HERA is reported.

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1 Introduction

Electron identification and calorimeter-track matching in high multiplicity charged particle environments play an important role in the exploration of rare and potentially new physics. In this paper we report on electron/positron ($e^{\pm}$) identification for particles produced at small angles to the incident proton beam in the H1 experiment at the HERA electron proton (ep) collider [1]. This novel technique, studied in test beam [2] and now realised in a very hostile tracking environment, uses track reconstruction and energy loss measurements ($\frac{\mathrm{d}E}{\mathrm{d}x}$) enhanced by simultaneous Transition Radiation (TR) detection to discriminate between hadrons and electrons.

2 The H1 Forward Track Detector

In the forward (proton beam) direction of the H1 experiment at HERA the Forward Track Detector (FTD fig. 1) is optimised for tracking, triggering and particle identification of charged tracks. The FTD covers laboratory polar angles (θ) between 7° and 25° (cylindrical geometry: $134 < z < 254\,\mathrm{cm}$ and $15 < r < 76\,\mathrm{cm}$) with respect to the proton beam and the nominal $e-p$ interaction point. It is designed to measure charged track momenta with a precision $\sigma(p)/p^2 = 0.3\%\,\mathrm{GeV}^{-1}$ (for momenta $p \gtrsim 10\,\mathrm{GeV}$) with an angular resolution of $< 1\,\mathrm{mrad}$ in a uniform $1.2\,\mathrm{T}$ axial magnetic field. Even in the presence of a substantial Lorentz angle, the ionisation drift in the $r - \phi$ plane measures the track sagitta, and hence the most accurate co-ordinate measurements contribute directly to the momentum measurement.

The FTD consists of three identical supermodules. Each supermodule contains, in order of increasing z: a planar wire drift chamber (three modules, each with four wires, at 0°, +60° and −60° to the vertical), a multi-wire proportional chamber for fast (< 25 ns) triggering, a TR volume and a radial wire drift chamber.

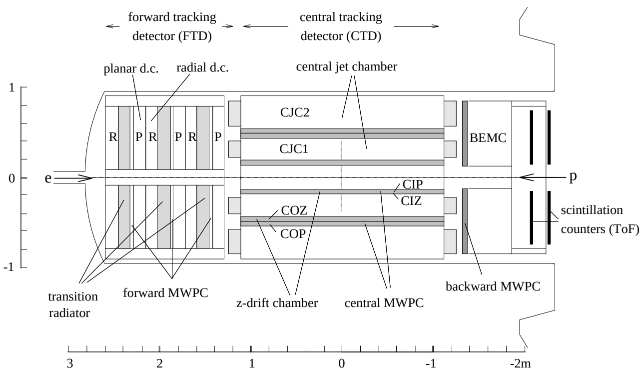

Figure 1. $r - z$ view of the tracking detectors of the H1 Detector; the positive z axis and the proton beam direction are to the left.

Transition Radiation X-rays ($\sim$ 1.5 photons per $e^{\pm}$ per radiator, $7 < E_X < 14\,\mathrm{KeV}$) are produced in the passive TR volume immediately upstream of the radial chamber. They pass through a thin mylar window and are detected on the first few sense wires of the radial chamber as a ionisation charge in addition to the $\frac{\mathrm{d}E}{\mathrm{d}x}$ contribution which forms the basis of track segment reconstruction.

Primary track multiplicities of 10 to 15 per event of mostly low momentum charged tracks, combined with a large number of secondary tracks originating from interactions in the end wall of the central tracker and the beam pipe, make the region particularly hostile for track reconstruction. The problem is exacerbated by the presence of a synchrotron radiation collimator in the beam-pipe between the second and third supermodules. Interactions between proton fragments and this collimator flood the most forward supermodule with additional secondary particles.

3 Radial Wire Drift Chambers and Transition Radiator

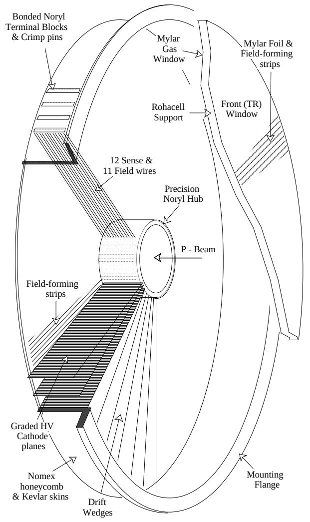

Figure 2. Schematic of a radial wire drift chamber in the H1 FTD.

Each radial chamber (fig. 2) contains 48 wedge shaped cells [2]. Planes of wires and segmented cathodes extend radially from the beam. A uniform drift field is maintained by copper cathode strips mounted on thin paper epoxy printed circuit boards which run parallel to the beam axis. The field is closed at the back of the cell by 17 HV graded strips, of varying lengths, which run parallel to the 12 stablohm ($50\,\mu$m) sense wires. Mounted on the front of each chamber is a thin ($50\,\mu$m) gas-tight mylar window which provides the support for the field forming strips (Al) while allowing the passage of X-rays.

The TR volume contains 400 foils of polypropylene ($19\,\mu$m) spaced regularly over a depth of 96 mm. The foils are held at a distance of $\sim 230\,\mu$m from each other by a lattice of indentations on their surface.

In the first three years of HERA operation (1992–94) the radial chambers were filled with Ar:C_2H_6 (50:50). The drift field and the sense wire surface field were $1.2\,\mathrm{kV\,cm^{-1}}$ and $170\,\mathrm{kV\,cm^{-1}}$ respectively. During the last two weeks of the 1994 data taking period, the radial chambers were filled with He:C_2H_6:Xe 40:35:25 (X-ray absorption length $\sim$ 4 cm, radial chamber sense wire spacing 1 cm). The ideal gas for the TR volume is He but the need to ensure HV stability of the front field closing strips, which reside inside the TR volume, requires that it is filled with an X-ray transparent quenching gas He:C_2H_6 (70:30). When operating with He:C_2H_6:Xe, the drift field is $1.0\,\mathrm{kV\,cm^{-1}}$ and the sense wire surface field is $157\,\mathrm{kV\,cm^{-1}}$.

4 Track Reconstruction

In both the radial and planar chambers the ionisation deposition is recorded as a function of time in 8-bit, non-linear, flash ADC's. The data are sampled every 9.6 ns (10 times in every HERA bunch crossing interval). The maximum difference of consecutive ADC samples determines the time of the leading edge of a pulse to one FADC time bin. This precision is refined by weighting the adjacent samples. The drift co-ordinate is then determined using a time-to-distance relation extracted from the data with typical resolutions of $\sim 185\,\mu$m and $\sim 205\,\mu$m in the radial and planar chambers respectively.

Reconstruction in the FTD [3] uses track models based on straight lines in either $\phi - z$ or $r - z$ which are a good approximation to a helix and allow vector segments to be linked across modules to form tracks. The final stage of reconstruction exploits Kalman filtering [4] to extract the optimal track parameters.

For data taken in 1993, the momentum resolution for tracks measured in the FTD with (without) inclusion of an event vertex is $\sigma(p)/p^2 = 0.027\,(0.054)\,\mathrm{GeV}^{-1}$ for $p > 3\,\mathrm{GeV}$. This is dominated by multiple Coulomb scattering for $p \lesssim 5\,\mathrm{GeV}$ and is equivalent to $\sigma(p)/p^2 = 0.007$ $(0.07\,\mathrm{GeV}^{-1})$ for $p \gtrsim 10\,\mathrm{GeV}$. The track reconstruction efficiency varies with laboratory polar angle (θ) between at least 50% at $\theta = 8°$ and at least 82% at $\theta = 15°$ for events with 4 or more tracks.

5 Charge Calibration

A pre-requisite for any analysis of energy loss is a detailed understanding of those parameters, both time independent and time dependent, which affect the measurement of ionisation deposition. Time independent variations mainly arise from mechanical effects (geometric/electrostatic), track length and differences in electronic pre-amplifier response. The geometric/electrostatic effects include an asymmetry in charge collection resulting from the wire stagger, a slight radial dependence and a drift time correction which may be due to diffusion. Time dependent factors include slight differences in gas composition, temperature and atmospheric pressure. The dominant temporal effects are introduced by variations in HERA operating conditions. In fig. 3 the mean charge deposition for the three radial chambers is shown as a function of H1 run number. Variations in mean charge of up to 12% per supermodule are observed during one electron fill.

A further temporal decrease in gain (not shown in the figure) is observed on the first two sense wires of the radial chambers. This is probably due to accumulation of ionic charge on the mylar window inside the chambers.

Individual ionisation measurements are corrected both for time independent and for time dependent variations. Time dependent parameters are determined from the data and are applied run-by-run. Time independent corrections are determined from both data and from test pulses injected directly into the pre-amplifiers.

In this way the resultant run-to-run pulse integration variation can be controlled to better than 3%.

6 Data Analysis and Results

In this analysis only well measured tracks with at least two planar track segments and a minimum of 24 out of a possible 36 hits recorded in the radial chambers are used. A primary vertex requirement was not applied. Monte Carlo simulations show that this sample contains $\sim 10\%\ e^{\pm}$'s (mainly γ conversions). The data are categorised as either $e^{\pm}$ or hadrons according to the following crite-

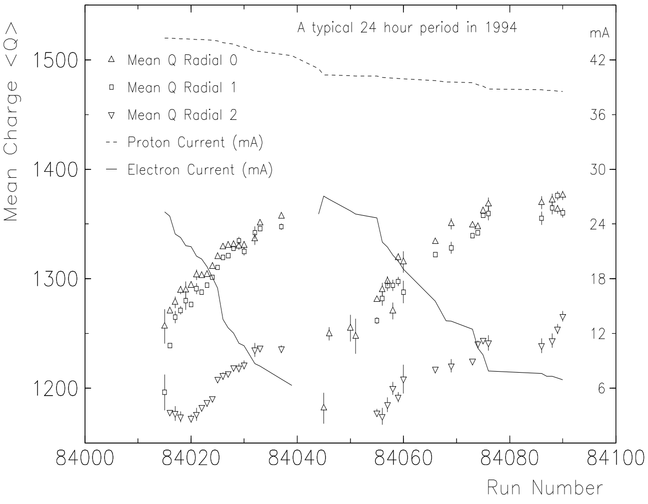

Figure 3. Variation of mean pulse integral for 3 FTD radial chambers as a function of run number; also shown are the HERA electron and proton beam currents for the same periods.

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Candidate $e^{\pm}$'s from γ conversions in the passive material in front of the FTD were identified as pairs of oppositely charged tracks whose extrapolations intersect in the r-ϕ plane. The e^+e^- pair must have an invariant mass less than 150 MeV and $\cos\alpha_{r-\phi} > 0.65$, where $\alpha_{r-\phi}$ is the opening angle in the $r-\phi$ plane. Monte Carlo studies indicate that the purity of the $e^{\pm}$ sample selected in this way is greater than 96%.

Electrons, not identified as pairs, are rejected fom the hadron sample using a χ^2 technique which exploits the different shower characteristics of the hadrons and electrons in the H1 liquid argon calorimeter [5]. Monte Carlo studies indicate that the purity of the hadrons selected in this way is greater than 98% for $p > 1\,GeV$. The χ^2 technique was also applied to the $e^{\pm}$ sample extracted from γ conversions. This reduces the hadronic contamination in this sample by another factor of 10.

Fig. 4 shows the mean scaled energy loss ($\frac{\mathrm{d}E}{\mathrm{d}x}$ in arbitary units) as a function of the signed momentum for both electrons and hadrons. $\frac{\mathrm{d}E}{\mathrm{d}x}$ is estimated by using the mean of only the smallest half of the collected charges, the so-called truncated mean. The hadron sample shows qualitatively the expected behaviour, namely a decrease to a minimum with some evidence for a "relativistic rise", but it is not yet quantitatively understood. The $e^{\pm}$ sample shows no momentum dependence, as expected for a species which has reached the Fermi plateau.

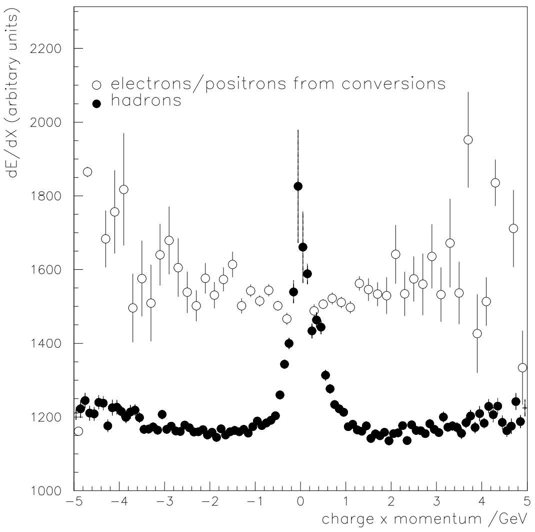

Figure 4. $\frac{\mathrm{d}E}{\mathrm{d}x}$ (arbitary units) as a function of signed track momentum; the data are shown with statistical errors and which are not the r.m.s deviation of the parent distribution.

The use of the truncated mean reduces the sensitivity to the TR signal because the additional ionisation deposition from the TR X-rays gives a large enhancement over the normal ionisation deposition on only a few wires. In fig. 5 are shown the mean of the first 6 charges in z in each supermodule for tracks with $p > 2\,\mathrm{GeV}$. There is a clear distinction between the distributions for the electron and hadron samples. In fig. 6 the integrated spectra are shown in which the resulting $\frac{e}{\pi}$ discrimination is quantified. Also shown are results from test beam measurements [6] for single charged particles. In multi-particle $e-p$ operation in HERA, the discrimination achieved is not yet as good as for isolated charged particles in a similar momentum range.

A complete understanding both of $\frac{\mathrm{d}E}{\mathrm{d}x}$ and of TR $\frac{e}{\pi}$ discrimination is dependent on a better understanding of the determination of ionisation charge from the FADC pulse integral spectra.

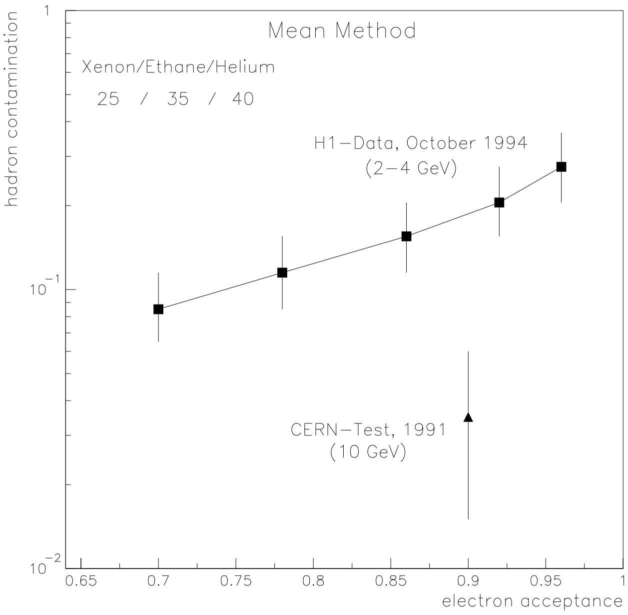

Figure 6. Hadron contamination as a function of $e^{\pm}$ acceptance determined from the pre-selected samples of hadrons and $e^{\pm}$ described in the text.

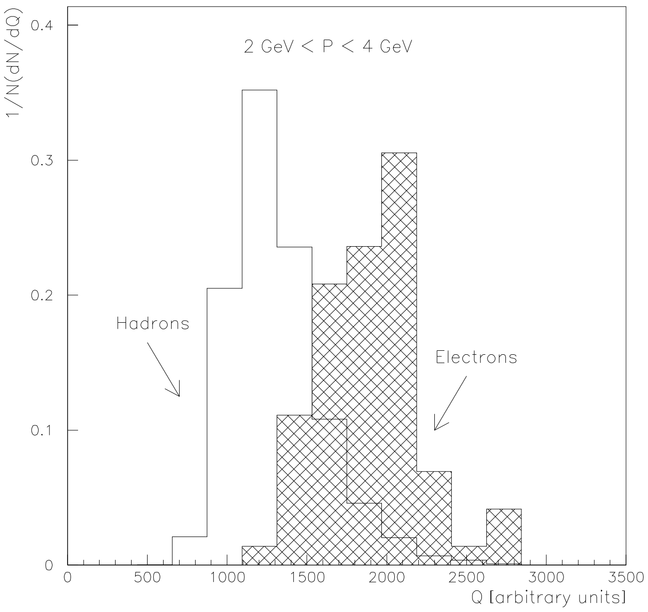

Figure 5. Mean of the ionisation charge deposition on the first 6 charges in each radial chamber (18 charges in total); the hatched distribution corresponds to sample of $e^{\pm}$ (see text).

7 Conclusions

First $\frac{e}{\pi}$ discrimination using simultaneous track reconstruction and Transition Radiation detection has been demonstrated for forward charged particles produced in high energy $e-p$ interactions at HERA. To date, for 90% electron acceptance a hadron contamination of 20% is achieved, about a factor of 5 worse than for single particle measurements in a test beam. The reasons for this difference continue to be investigated as improvements in the operation, calibration and off-line data analysis proceed.

Acknowledgments

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