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Electron Identification in the DØ Detector

Meenakshi Narain
for the DØ Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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MEENAKSHI NARAIN
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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ABSTRACT

We present the techniques used to identify electrons in the DØ detector. The DØ electron identification algorithm is based on the full covariance matrix of energy deposits in the calorimeter cells occupied by an electromagnetic shower and information from the central tracking system. The method exploits the fine longitudinal and transverse segmentation of the DØ calorimeter to achieve excellent pion rejection. Performance criteria are derived from test beam electron and pion data and from collider data.

The DØ calorimeter is a uranium–liquid argon sampling calorimeter[1] . It is divided into three sections, the central calorimeter (CC), covering the pseudorapidity region $|\eta| < 1.2$, and two end calorimeters (EC), covering $1.2 < |\eta| < 4.0$. The electromagnetic (EM) part of the calorimeter is longitudinally segmented into four layers of 2, 2, 7 and 10 radiation lengths thickness. It is backed by the fine hadronic (FH) layers. Transversely the calorimeter is segmented into pseudo-projective towers of size 0.1×0.1 in ϕ and η space. In the third EM layer, where typically the maximum of EM showers occurs, the segmentation is $\Delta\phi \times \Delta\eta = 0.05 \times 0.05$. The central tracking system is inside the calorimeter and consists of the vertex chamber, the transition radiation detector, and the forward and central drift chambers.

Electrons are identified by detecting an electromagnetic shower in the calorimeter with an associated track in the central tracking system. The development of EM and hadronic showers is quite different so that shower shape information can be used to differentiate between electrons (and photons) and hadrons. Electrons deposit almost all their energy in the EM section of the calorimeter, while hadrons are typically much more penetrating. For example, a simple cut on the fraction of the shower energy deposited in the EM calorimeter $f_{EM} > 0.9$, is more than 99% efficient for test beam electrons with energy between 10 and 150 GeV.

To obtain the best discrimination against hadrons, we use both longitudinal and transverse shower shapes, and also take into account correlations between energy deposits in the calorimeter cells. This is done using a covariance matrix technique[2] . Given a sample of N electrons we define the covariance matrix

$$M_{ij} = \frac{1}{N} \sum_{n=1}^{N} (x_i^n - \langle x_i \rangle)(x_j^n - \langle x_j \rangle), \quad (1)$$

where x_i^n is the value of observable i for electron n and $\langle x_i \rangle$ is the mean value of observable i for the sample. If $H = M^{-1}$, we determine whether a shower k is electromagnetic by computing the covariance parameter

$$\chi^2 = \sum_{i,j}(x_i^k - \langle x_i \rangle)H_{ij}(x_j^k - \langle x_j \rangle). \tag{2}$$

By placing a cut on χ^2 we can separate EM and hadronic showers. The first three observables used to build the matrix M are the fraction of shower energy in EM layers 1, 2, and 4. For the third EM layer with the finer segmentation, we use the fraction of shower energy in each cell of a 6×6 array centered on the hottest tower. These 36 observables characterize the transverse development of the shower. To parametrize the energy and impact parameter dependence of the matrix, we also include the logarithm of the shower energy and the position of the event vertex along the beam as two independent parameters. The matrix M is thus 41-dimensional. For each of the 37 detector towers at different values of $|\eta|$, we build a matrix from Monte Carlo (MC) electrons. The MC uses GEANT 3.14 and a detailed representation of the detector geometry. By comparing the shower shape of MC electrons with showers from electron beam tests we have verified excellent agreement of the MC with the calorimeter response.

Since H is a symmetric matrix, there exists a unitary matrix U so that $H' = UHU^T$ is diagonal. Then $\chi^2 = \vec{y}H'\vec{y}^T$ and the components of the vector $\vec{y}$, which are related to the observables x by $y_i = \sum_j U_{ij}(x_j^k - \langle x_j \rangle)$, are uncorrelated variables. To avoid dominance by a single component of the covariance variable χ^2, we limit the magnitude of the diagonal elements of H' to a maximum value chosen to maximize the electron finding efficiency and hadron rejection power.

Figure 1 shows the distributions of χ^2 for showers from test beam electrons and pions with an energy of 25 GeV. The two distributions are clearly separated. In general, the observables defining the matrix are not normally distributed. For example, this is true for the energy deposited in the layers due to the exponential nature of longitudinal shower development. Therefore the covariance parameter χ^2 does not necessarily follow a χ^2 distribution. To compare with collider data, we have superimposed on figure 1 the distribution of χ^2 for electrons from W-boson decays, which have been identified using a missing transverse energy tag. It agrees well with that obtained from electron beam tests.

The calorimeter position resolution is important when matching tracks in the central tracking system to showers in the calorimeter. We calculate the shower centroid ($\vec{x}_{cog}$) using a weighted center of gravity method[3] ,

$$\vec{x}_{cog} = \frac{\sum_i w_i \vec{x}_i}{\sum_i w_i}, \quad w_i = \max\left\{0, \left(w_0 + ln\frac{E_i}{E_{tot}}\right)\right\}, \tag{3}$$

where E_i is the energy in calorimeter cell i, E_{tot} the total energy of the shower, $\vec{x}_i$ the position vector of cell i, and w_0 is a parameter that is tuned to optimize the position resolution. Using electrons from beam tests, we find the position resolution in CC and EC to be about 1.5 mm to 2.0 mm. This is confirmed by our electron sample from W decays.

Since DØ does not have a central magnetic field, e^+e^- pairs from photon conversions are not separated and are often reconstructed as a single track with an accompanying shower. To discriminate conversions we measure the ionization per unit path length (dE/dx) in the drift chambers. Figure 2 shows the distribution of dE/dx for reconstructed tracks in the central drift chamber that correspond to reconstructed EM clusters in the calorimeter. The lower peak is from minimum ionizing particles, while the second peak is due to conversions that have been reconstructed as single tracks. Thus conversion electron pairs can be eliminated with good efficiency by using the measured value of dE/dx.

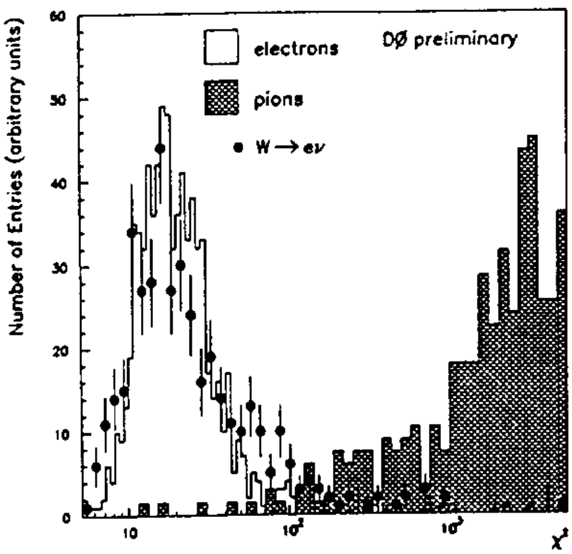

Figure 1. Distribution of χ^2 from test beam electron (open histogram) and pion (hatched histogram) showers, and electrons from W decays (data points).

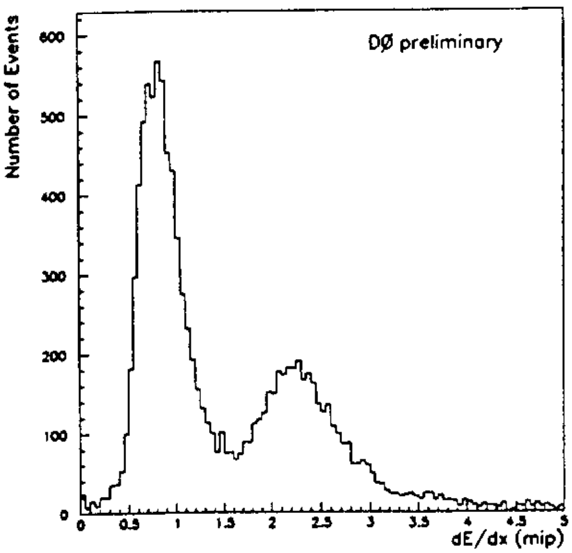

Figure 2. Distribution of dE/dx for single tracks in the central drift chamber.

In summary, using a covariance matrix method we have developed a powerful technique for electron identification which has been tested on electrons from beam tests and collider data. This algorithm has been implemented as a part of the standard DØ reconstruction software.

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References

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