e/π SEPARATION IN THE CDF END PLUG EM AND HADRON CALORIMETERS

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Abstract

e/π separation was studied by applying a genaralized χ^2 method on 100 GeV e^- and π^- test beam data of the CDF End Plug Calorimeters. π rejection power increases as the number of longitudinal segments of the EM calorimeter increases with or without using the information of energy deposit in the backing Hadron Calorimeter. The r. m. s. of lateral distribution of enrgy deposits in the η and φ strips of the EM calorimeter are effective to reject π's.

1. Set-up in the test beam

To study e/π rejection in the CDF End Plug region ($1.1 \le |\eta| \le 2.4$, $68 \le |z| \le 146.5$ in.), 100 GeV e^- and π^- beam were injected into the End Plug EM Calorimeter[1] with the backing End Plug Hadron Calorimeter[2] in the M-Bottom beam line at Fermilab. Δp/p of the momentum tagging system[3] in the beam line was 0.47 % for 100 GeV beam. After inserting 7.8 X_0 lead block at the upstream collimator in the beam line, contamination[4] of e^- in π^- beam was estimated to be reduced to less than 3.5×10^{-6}.

The End Plug EM and Hadron calorimeters are gas sampling calorimeters which consist of 34 layers of 0.5 X_0 lead and proportional chambers and 20 layers of 0.3 λ_0 iron and proprotional chambers, respectively. Energy resolution of the End Plug EM and the End Plug Hadron calorimeters are $\approx 24\ \%/\sqrt{E}$ and $\approx 132\ \%/\sqrt{E}$.

The End Plug EM Calorimeter has three longitudinal pad segments (2.5 X_0, 12 X_0, 2.5 X_0). The lateral segmentation of the pad towers of the EM and Hadron Calorimeters are $\Delta\eta=0.09$ and $\Delta\phi=5°$. The e^- and π^- beam simulated particles comming from the origin of the CDF detector with the η of 1.6 (23 ° in the polar angle). The r. m. s. of the incident beam spread in radial and phi (azimuthal angle) directions were around 1 cm at the upstream end of the EM calorimeter. Five by five towers of pads in the η and φ were used to collect energy deposits. The second longitudinal pad segment of the EM calorimeter has interleaved η and φ strip layers (5 X_0 in total) in its upstream end. Tower sizes of the η and φ strips are $\Delta\eta=0.02$ and $\Delta\phi=30°$ and $\Delta\eta=0.64$ and $\Delta\phi=1°$, respectively. The End Plug Hadron Calorimeter has a single longitudinal pad segment with the total thickness of 6.0 λ_0.

The data taking system in the test beam line consisted of the RABBIT system[5] (the CDF front end electronics system), the CAMAC system, and the MULTI data aquisition program[6].

2. Data analysis

In order to reject pions from electrons, R. Engelmann et. al.[7] used a covariant matrix which describes energy deposits and their correlations for electron showers in longitidinal and lateral elements of their calorimeter. By using energy deposits in calorimeter elements as variables, the covariant matrix depends strongly on the incident energy and the position of the electron beam. These dependence can be reduced by using ratios of energy deposits in longitudinal segments of the EM and Hadron calorimeters and the r. m. s. of lateral distribution of energy deposits in the η and φ strips of the EM calorimeter.

By reconstructing beam momentum with PWC's in the beam line, 1,223 e^- events were selected for this analysis. 4,978 π^- evnts survived the momentum reconstruction and μ^- cut which was made on energy deposits in the EM and the Hadron calorimeter.

By using the electron events, a covariant matrix element is defined as;

$$M_{ij} \equiv \frac{1}{N} \sum_{n=1}^{N} (X_i^{(n)} - \langle X_i \rangle)(X_j^{(n)} - \langle X_j \rangle)$$

where, N, $X_i^{(n)}$ and $\langle X_i \rangle$ are the total number of electron events, the i-th variable for n-th electron event, and the average of the i-th variable for all electron events. For the k-th event (e^- or π^- event) tested, a single variable ζ_k is defined as;

$$\zeta_k \equiv \frac{1}{N_{DOF}} \sum_{i,j=1}^{L} (X_i^{(k)} - \langle X_i \rangle)(M^{-1})_{ij}(X_j^{(k)} - \langle X_j \rangle)$$

where, N_{DOF} and L are the number of degree of freedom and the total number of variables, and the matrix M^{-1} is the inverse matrix of the M. $X_i^{(k)}$ and $\langle X_i \rangle$ are the i-th variable for k-th event (e^- or π^- event) tested, and the average of the i-th variable for all the electron events. The variables X_i are;

EM1/EM,
EM2/EM, η/EM, φ/EM, σ_η, σ_ϕ,
EM3/EM, and
HAD/EM,

where, EM1, EM2, EM3, η, φ are energy deposits in the first, second, and the third longitudinal pad tower segments and the η and φ strips of the EM calorimeter, and EM≡EM1+EM2+EM3. HAD is the energy deposit in the pads of the Hadron calorimeter, and σ_η and σ_ϕ are r. m. s. of lateral distribution of energy deposits in the η and φ strips of the EM calorimeter. Table 1 lists the averages and r. m. s. of the variables for 100 GeV e^- events.

Table 1 : Averages and r. m. s. of the varaibles for 100 GeV e^- events

variable	average	r. m. s.
EM1/EM	0.050	0.020
EM2/EM	0.909	0.024
EM3/EM	0.041	0.018
HAD/EM	0.021	0.043
η/EM	0.207	0.034
φ/EM	0.191	0.026
σ_η (cm)	2.70	0.16
σ_ϕ (cm)	2.76	0.11

The effectiveness of longitudinal segmentation of the EM calorimeter was studied by choosing sets of various variables in five cases as follows;

(1) 1 longitudinal segment in the EM calorimeter
HAD/EM
(2) 2 longitudinal segments in the EM calorimeter
(i) EM1/EM+[EM2+EM3]/EM+(HAD/EM)
(ii) EM3/EM+[EM1+EM2]/EM+(HAD/EM)

(3) 3 longitudinal segments in the EM calorimeter
EM1/EM+EM2/EM+EM3/EM+(HAD/EM)

(4) 3 longitudinal segments and the η and ϕ strips in the EM calorimeter
EM1/EM+EM2/EM+EM3/EM+η/EM+ϕ/EM+(HAD/EM)

(5) 3 longitudinal segments and the η and ϕ strips in the EM calorimeter and the r. m. s. widths
EM1/EM+EM2/EM+EM3/EM+η/EM+ϕ/EM+ σ_η+σ_ϕ+(HAD/EM)

where "+(HAD/EM)" means with/without HAD/EM.

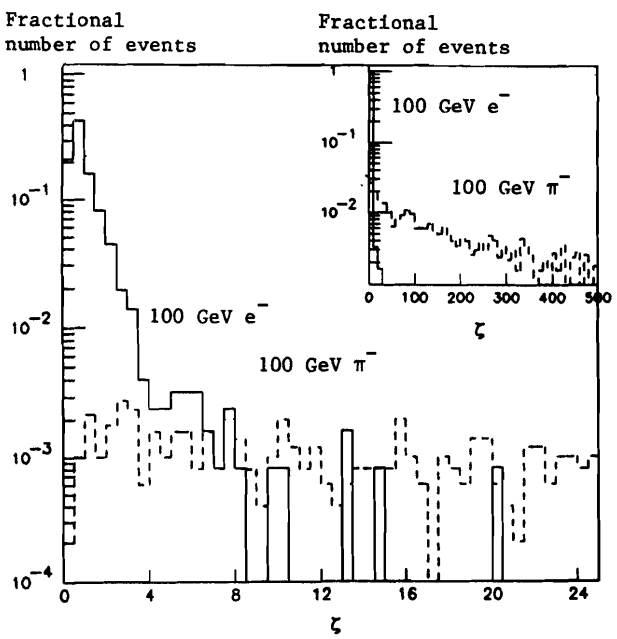

Figure 1 Fractional number of events as a function of the ζ

In Figure 1, as an example, the fractionnal number of events is shown as a function of the ζ for 100 GeV e^- and π^- events for the case (3) with the set of variables of ;
EM1/EM+EM2/EM+EM3/EM+HAD/EM,
where, the "fractional number of events" is the ratio of the number of events devided by the total number of events.
The solid lines represent the fractional number of events for electrns and the dotted lines for pions. The inserted smaller figure shows the same distribution with a larger range of the ζ. The averages of the ζ for 100 GeV e^- and π^- events in Figure 1 are 1.13 and 149, respectively.

For a threshold, ζ_0, π rejection power and electron efficiency are defined as;

$$\pi \text{ rejection power} \equiv \frac{\text{number of incident } \pi}{\text{number of } \pi \text{ events with } \zeta \le \zeta_0}$$

$$\text{electron efficiency} \equiv \frac{\text{number of electron events with } \zeta \le \zeta_0}{\text{number of incident electron}}$$

By changing ζ_0 in the ζ distribution for the e^- and π^- events, the π rejection powers were obtained as a function of electron efficiency for the cases (1) through (5) as shown in Figure 2.

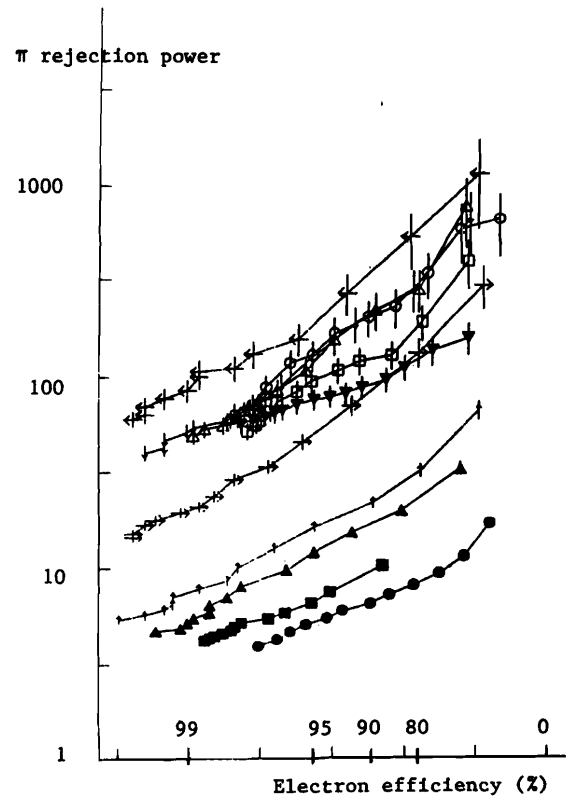

Figure 2 π rejection power as a function of electron efficiency for 100GeV e^- and π^- events. Marks are assigned to the following sets of variables

Marks	Sets of variables
←	EM1, EM2, EM3/EM +η+ϕ +σ_η+σ_ϕ +HAD/EM
↓	EM1, EM2, EM3/EM +η+ϕ +HAD/EM
Δ	EM1, EM2, EM3/EM +HAD/EM
◻	EM3, [EM1+EM2]/EM +HAD/EM
O	EM1, [EM2+EM3]/EM +HAD/EM
▼	HAD/EM
→	EM1, EM2, EM3/EM +η+ϕ +σ_η+σ_ϕ
↑	EM1, EM2, EM3/EM +η+ϕ
▲	EM1, EM2, EM3/EM
■	EM3, [EM1+EM2]/EM
●	EM1, [EM2+EM3]/EM

Without using the variable HAD/EM, the π rejection power increases as the number of the longitudinal segments of the EM calorimeter increases. The lateral shower width information gives the π rejection power an additional factor of around 2. By using HAD/EM, the π rejection powre is improved by a factor around 10. Although the π rejection power increases as the number of the lateral segments of the EM calorimeter increases, the difference in the π rejection powers among cases (1) through (5) are much smaller than those without using HAD/EM. Thus the HAD/EM information is very effective in rejecting π's, and only electron-like events can survive with this information.

3. Conclusion

On 100 GeV e^- and π^- test beam data, a generalized χ^2 method was applied to reject π's by using variables of ratios of energy deposits in longitudinal segments of the EM and Hadron calorimeters and r. m. s. of lateral distribution of enrgy deposits in the η and ϕ strips in the EM calorimeter. The π rejection power increases as the number of longitudinal segments in the EM calorimeter increases with or without information of energy deposit in the Hadron calorimeter. In cases without using the information of energy deposit in the Hadron calorimeter, by adding the information of energy deposits in the longitudinal segments of the EM calorimeter, the π rejection power is more improved than in cases with the Hadron energy deposit information. After using all information on energy deposits in the EM and Hadron calorimeters, the r. m. s. of lateral distribution of energy deposits in the η and ϕ strips of the EM calorimeter are still effective in rejecting π's, which have broader lateral distribution of energy deposits in the η and ϕ strips of the EM calorimeter than electrons.

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