Performance of Preshower and Shower-maximum Detectors

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Abstract. We constructed a set of prototype preshower and shower-maximum detectors to be attached in front of the main calorimeter. The performance of the detectors were studied in combination with a lead/plastic-scintillator calorimeter module using high energy beams up to 100 GeV at a test beam facility at Fermilab.

INTRODUCTION

A high performance calorimetry is required for future linear collider experiments to fully achieve the physics research [1]. To this purpose we constructed a compensated hadron calorimeter test module with tile-fiber read out techniques and carried out performance tests at KEK and Fermilab [2,3]. In addition to excellent energy resolutions, the calorimetry should have good electron identification capability, good photon identification capability against π^0, and good position resolution for photons and electrons. We constructed a preshower detector (PSD) and a shower-maximum detector (SMD) using the same tile-fiber readout techniques as the hadron calorimeter. They were tested in combination with the hadron calorimeter test module at Fermilab. A detailed report can be found elsewhere [4].

DETECTOR AND EXPERIMENTAL SETUP

The hadron calorimeter test module has a cross section of 1000×1000 mm^2 and divided into the front part (FCAL) and the rear part (RCAL) [3]. The FCAL has a 5×5 tower structure, while the RCAL does not. The PSD and the SMD [4] are designed to have an effective cross section of 200×200 mm^2 to cover the front surface of the central FCAL tower. The tile-fiber readout techniques are employed for each detector.

The PSD consists of six layers of lead absorber (4 mm thick) and plastic scintillator (1 mm thick) plates in a sandwich structure. The total thickness of the PSD is 4.3 X_0 and 0.14 λ_I. The scintillation light of three successive layers is fed to a PMT, resulting in two super-layers. The SMD, to be positioned between the PSD and the FCAL, has two scintillator layers orthogonal to each other. Each SMD layer consists of twenty scintillator strips with a dimension of $200 \times 10 \times 5$ mm^3. The scintillation light from each strip is individually fed into a pixel of multi-anode PMTs.

The test was carried out at the MT6 test beam facility at Fermilab in September 1999. The beam parameters were tuned so that we had either electron-rich or pion-rich beams at each energy point. For this study we set the nominal momentum at 50, 75, and 100 GeV, where good electron and pion samples were obtained. However, the measured momentum showed some discrepancy from the nominal momentum. There were four single-wire drift chambers (SWDC's) which determined the particle trajectory and momentum. There was a counter, called SRD, to detect the synchrotron radiation from electrons passing through the magnetic field of the bending magnet. The trigger was made by two trigger scintillation counters. Another scintillation counter, called TPSD, was placed in front of the PSD. When a 50 mm thick iron block was placed in front of the TPSD, the signal was used to efficiently remove electrons.

ANALYSIS AND RESULTS

The TPSD and the SWDC information are used to select single-track events. The muon component in the beam is removed using the last super-layer of the RCAL. An event in electron samples is required to have a good hit in the SRD.

The total energy deposit E_{tot} is then calculated. The resolutions are expressed as $\sigma_E/E = (24.4 \pm 0.5)\%/\sqrt{E} \oplus (0.0 \pm 1.9)\%$ for electrons, and $\sigma_E/E = (44.8 \pm 0.2)\%/\sqrt{E} \oplus (0.0 \pm 0.4)\%$ for pions, respectively, and consistent with those obtained by the hadron calorimeter without the PSD and the SMD in front [3]. For further analysis the total energy is required to be in the region $\mu_E - 3\sigma_E < E_{tot} < \mu_E + 3\sigma_E$, where μ_E and σ_E are the results of a Gaussian fit. The contamination in the electron (pion) samples is estimated to be less than 0.02 (0.01) %.

Once a selection for electron identification is defined, the electron efficiency (ϵ_e) and the pion rejection factor (r_π, inverse of the pion efficiency ϵ_π) are calculated as $\epsilon_e = N_e^{sel}/N_e^{tot}$ and $r_\pi = 1/\epsilon_\pi = N_\pi^{tot}/N_\pi^{sel}$, respectively, where $N_{e(\pi)}^{tot}$ and $N_{e(\pi)}^{sel}$ are numbers of total and selected events in the electron (pion) sample.

Figure 1 shows the distributions of cut parameters : (a) R_{PS2}, the ratio of the energy deposit in the second PSD super-layer to the total energy, (b) the S value, representing the lateral shower spread, calculated only from the FCAL towers as $S = \sqrt{\sum_i d_i^2 E_{FC}(i)/\sum_i E_{FC}(i)}$ where $E_{FC}(i)$ is the energy deposit in the i-th tower of the FCAL, and d_i is the lateral distance of the tower from the central tower, and (c) the D value, representing the longitudinal depth of the shower, calculated from the PSD, FCAL, and RCAL as $D = \sum_j z_j E_j/E_{tot}$, where z_j denotes the longitudinal depth of the j-th detector component from the front surface of the PSD and E_j

is the energy deposit in it. A combination of two or more variables improves the pion rejection factor. Figure 1(d) shows the scatter plot of D value and R_{PS2} as an example. Numerical values of the pion rejection factors are listed in Table 1.

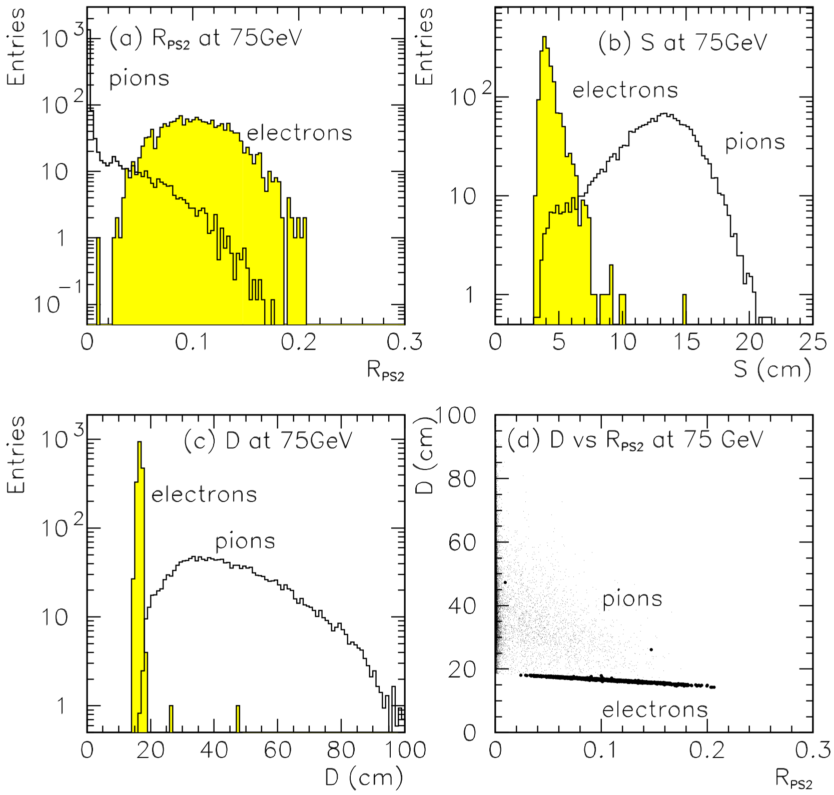

FIGURE 1. Distributions of cut variables for electron identification.

TABLE 1. Pion rejection factors.

Method	R_{PS2}			S			D		
ϵ_e (%)	90	95	98	90	95	98	90	95	98
r_π at 50 GeV	21.9	15.6	12.2	33.2	21.3	13.3	828	571	502
r_π at 75 GeV	19.6	16.0	12.1	43.8	30.2	20.5	1001	719	629
r_π at 100 GeV	18.9	12.3	10.3	43.6	31.3	19.8	984	820	703
Method	S and R_{PS2}			D and R_{PS2}			D and S		
ϵ_e (%)	90	95	98	90	95	98	90	95	98
r_π at 50 GeV	473	312	180	1274	1104	720	1183	828	753
r_π at 75 GeV	657	487	343	1258	1162	944	1510	1162	888
r_π at 100 GeV	984	656	281	1640	1406	1406	984	820	656

The incident position of an electron can be determined by the energy deposits in the SMD with various methods such as energy-weighting and analytical methods. Among the methods we have used, the best performance is obtained by the 3-strip analytic method using the Lorentzian line-shape function. The position calculated by the SMD is compared with that determined by the SWDC (x_{SWDC}). The correlation plot and the distribution of the difference are shown in Fig. 2. The position resolution is summarized in Table 2. The resolution of the position determined by the SWDC is estimated to be less than 0.2 mm at the PSD surface. Therefore the influence to the SMD position resolution is negligible. The resolution is typically 2∼3 mm and well described by the formula $(37.7 \pm 2.5)/\sqrt{E} - (1.75 \pm 0.28)$ mm in the energy region 50 GeV $< E <$ 100 GeV. We consider the intrinsic resolution of the scintillator strips should be a little better, as we suffered from the saturation and crosstalk effects of the multi-anode PMTs.

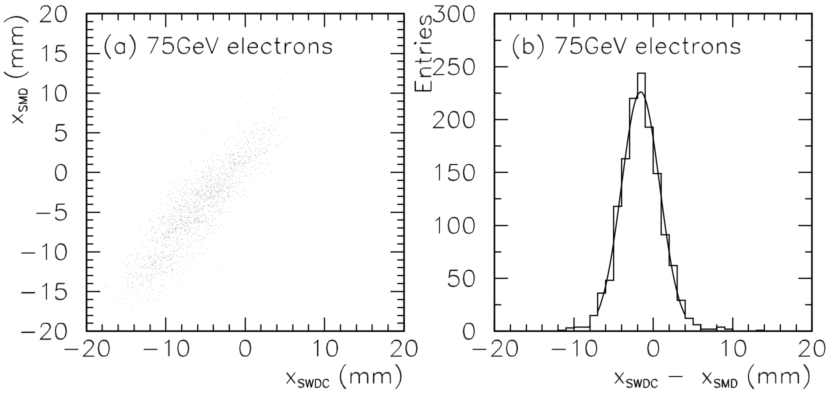

FIGURE 2. The scatter plot and difference of the positions measured by the SMD and the SWDCs.

TABLE 2. The electron position resolution of the SMD.

measured energy	$\sigma_{\Delta x}$ (mm)	$\sigma_{\Delta y}$ (mm)
55.3 GeV	3.31 ± 0.09	3.20 ± 0.12
83.0 GeV	2.49 ± 0.05	2.42 ± 0.07
101.1 GeV	1.97 ± 0.09	1.84 ± 0.08

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