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TESTBEAM RESULTS FOR THE CDF END PLUG HADRON CALORIMETER [a]

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Preliminary testbeam results for the CDF Tile-Fiber End Plug Upgrade Hadron Calorimeter (Hcal) are presented. Data were taken at incident momentum range of 5 to 230 GeV/c during 1996-7. The discussion of the π-p energy response difference is motivated by the proton contamination in the hadron beam. Three effects which result in the π-p response difference are studied. Measurements of the π-p energy response were done at 5.4 and 13.3 GeV/c. The data agree with a calculation based on the three effects. The calculated proton contamination correction is applied to all the hadron data. The linearity and resolution of Hcal to pions are presented. The $\frac{e}{h}$ parameter is extracted from the measurements of the response of Hcal to pions and positrons.

1 Introduction

The CDF End Plug Upgrade Hadron Calorimeter (Hcal) is a sampling calorimeter composed of iron sheets (2 inches thick) and plastic scintillating tiles (6mm thick) using a projective tower geometry. The tiles are read out by wavelength-shifting fibers embedded in the scintillating tiles. There are 23 layers in depth for a total thickness of about $7\lambda_I$ (interaction length) at normal incidence [1].

The 1996-7 Plug Upgrade testbeam module consists of a 45° EM calorimeter (Ecal) followed by a 60° Hcal segment. The 15° section of Hcal which doesn't have Ecal in front is used to measure the response to electrons.

The hadron beam is a positive polarity secondary beam. The momentum of the beam can be tuned from 5 GeV/c to 230 GeV/c. The proton faction (f_p) is listed in Table 1 versus momentum. The f_p values at 5.4 GeV/c and 13.3 GeV/c are from a direct measurement. At higher energy, f_p values are from a calculation using DECAY-TURTLE. The calculation has a relative error of at least 40% [2].

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p	$f_p(\%)$	$\frac{E(\pi)}{E(p)}$			$\frac{E(\pi)}{f_\pi*E(\pi)+f_p*E(p)}$
GeV/c		Avail. E.	F_{π^0} Eff.	Int. Leng. Eff.	
5.4	14.7 ± 2.8	1.189	1.038 ± 0.005	1.005 ± 0.002	1.029 ± 0.005
13.3	5.7 ± 0.7	1.073	1.030 ± 0.004	1.007 ± 0.004	1.006 ± 0.001
28.7	5.9	1.033	1.028 ± 0.004	1.004 ± 0.003	1.004 ± 0.001
57.9	9.6	1.016	1.025 ± 0.003	1.003 ± 0.002	1.004 ± 0.001
90.3	15.3	1.010	1.023 ± 0.003	1.002 ± 0.002	1.005 ± 0.001
171.3	29.9	1.005	1.020 ± 0.003	1.002 ± 0.002	1.008 ± 0.003
231.5	40.7	1.004	1.019 ± 0.002	1.001 ± 0.002	1.010 ± 0.003

Table 1: Beam composition, π-p response difference and p contamination correction factor

2   Proton contamination correction

The response of the calorimeter to pions and protons at the same momenta is different because of three effects:

- The available energy effect. The available energy [3] is the energy which is available to be deposited in the calorimeter as ionization. For protons it is the kinetic energy, and for pions it is the total energy. Therefore the ratio of the expected energy response of pions to protons with momenta P is $\frac{E(\pi)}{E(p)} = \frac{\sqrt{P^2+m_\pi^2}}{\sqrt{P^2+m_p^2}-m_p}$.

- The F_{π^0} effect. On average, proton interaction have a smaller fraction of energy going into π^0's than pion interaction. This difference has a consequence that protons produce a smaller signal than pions of the same energy in a non-compensating calorimeter. It can be estimated in terms of $\frac{e}{h}$ as follows: $\frac{E(\pi)}{E(p)} = \frac{F_{\pi^0}(\pi) \times \frac{e}{h} + F_h(\pi)}{F_{\pi^0}(p) \times \frac{e}{h} + F_h(p)}$. Groom's power-law formula $F_{\pi^0} = 1 - (E/E_0)^{m-1}$ is used [4]. For pions E_0=0.96 GeV,m=0.816 and for protons E_0=2.62, m=0.814. Because the e/h measurement depends on the correction factor we applied to the data, iteration method is used here. $\frac{e}{h}$=1.43 $\pm$ 0.05 is the final number put in the calculation.

- The interaction length effect. Pions have longer interaction length than protons. This difference may also contribute to π-p response difference when Ecal(Pb) is followed by Hcal(Fe).

The calculated π-p response difference from each effect is listed in Table 1 (column 3-5) versus momentum. The ratio of the response for a pure pion beam and a pion beam with a proton contamination can be calculated as

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$\frac{E(\pi)}{f_\pi * E(\pi) + f_p * E(p)}$. The result is listed in column 6 of Table 1. In the calculation, we used the beam composition and the $\frac{E(\pi)}{E(p)}$ which is simply the multiplication of the ratio from three different effects. The ratio $\frac{E(\pi)}{f_\pi * E(\pi) + f_p * E(p)}$=1.029 at 5.4 GeV/c means that the p contamination shifts the response down by 2.9%. The correction is also significant at high energy. We apply the proton contamination correction to all the hadron data. The numbers in Column 6 of Table 1 are the correction factor to obtain the response for a pure pion beam.

Measurements of π-p response difference were done at 5.4 and 13.3 GeV/c. An isobutane Cerenkov counter was used to separate pions and protons. The measured difference in the response to pions and protons of $(22.9 \pm 7.4)\%$ and $(11.4 \pm 3.0)\%$ is consistent with the expectation of $(24.0 \pm 0.6)\%$ at 5.4 GeV/c and $(11.3 \pm 0.6)\%$ at 13.3 GeV/c, respectively, and indicates that the calculation based on three effects is reliable.

3   Results

3.1   Linearity and Resolution

The response of the calorimeter to pions is extracted after the application of the proton contamination correction. Fig. 1 shows the linearity (upper left plot) and resolution (upper right plot) of Hcal for pions. The plots show the response of Hcal to pions which are minimum ionizing in Ecal, and the response of the combined Ecal+Hcal system to pions interacting in either Ecal or Hcal. The energy resolution for the MIP-in-Ecal pions is: $\sigma(E/p) = (74\% \pm 1.\%)/\sqrt{E} \oplus 3.8\% \pm 0.3\%$. The energy resolution for pions interacting in Ecal or Hcal is: $\sigma(E/p) = (68\% \pm .7\%)/\sqrt{E} \oplus 4.1\% \pm 0.2\%$.

3.2   e/h from data taken with Hcal only

The $\frac{e}{h}$ value is extracted by fitting the π/e response ratio for Hcal versus beam momentum (from 13 to 230 GeV/c) using the equation[5], $\frac{\pi}{e} = \frac{1+(e/h-1)\times F_{\pi^0}}{e/h}$. In addition to the proton contamination correction, a longitudinal containment correction is applied to the π/e values shown in figure 1 (lower plot). The extracted value of e/h depends on the functional form for F_{π^0}, with Wigmans' form $F(\pi^0) = 0.11 * ln(E)$ [5] yielding $\frac{e}{h} = 1.35 \pm 0.01$ with $\chi/ndf \simeq 1.7$, and Groom's power-law form $F(\pi^0) = 1 - (\frac{E}{0.96})^{-0.184}$ [4] yielding $\frac{e}{h} = 1.43 \pm 0.015$ with $\chi/ndf \simeq 1.1$. Both parameterization are consistent with the measured π/e response ratio at 5.4 and 8.0 GeV/c.
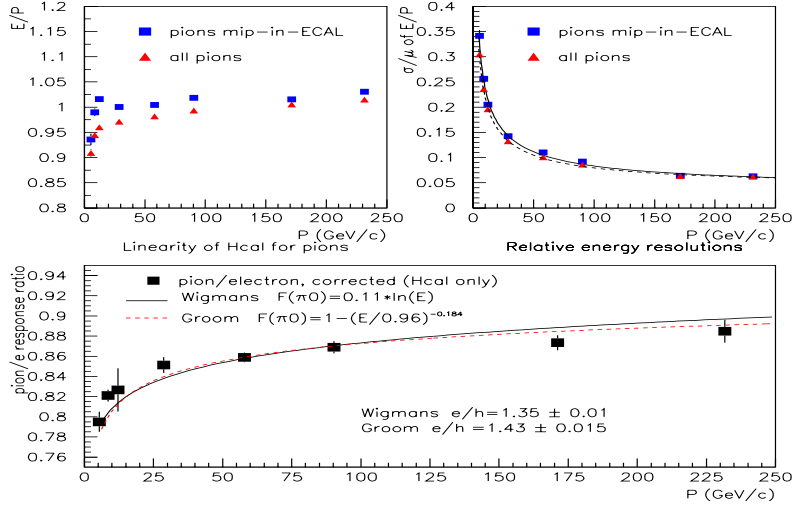
Figure 1: Performance of the CDF End Plug Upgrade Hcal (TestBeam 97, Preliminary)

4 Summary

The observed difference in the response of the calorimeter to protons and pions at momenta of 5.4 and 13.3 GeV/c agrees with a calculation based on three effects. In the momentum range of 5 to 230 GeV/c, all three effects result in a lower response for protons. The π-p response difference becomes smaller with increasing momentum. The available energy effect dominates at low energy. It decrease much faster than the F_{π^0} effect. The F_{π^0} effect in a non-compensating calorimeter dominates at high energy. The interaction length effect is small compared to the other two effects. The π-p response difference should be included in Monte Carlo simulation. The energy resolution for incident pions is $\sigma(E/p) = (74\% \pm 1.\%)/\sqrt{E} \oplus 3.8\% \pm 0.3\%$ which satisfies the design requirements. The extracted e/h value is 1.35±0.01, and 1.43±0.01 for the Wigmans' and Groom's F_{π^0} forms, respectively.

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