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Test Beam Performance of CDF Plug Upgrade EM Calorimeter

Yasuo Fukui
For the CDF Plug Upgrade Group

KEK
Japan

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

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Yasuo Fukui

KEK, Japan, e-mail: fukui@fnal.gov

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for the CDF Plug Upgrade Group[1]

Abstract. CDF Plug Upgrade(tile-fiber) EM Calorimeter performed resolution of $15\%/\sqrt{E} \oplus 0.7\%$ with non-linearity less than 1% in a energy range of 5-180 GeV at Fermilab Test Beam. Transverse uniformity of inside-tower-response of the EM Calorimeter was 2.2% with 56 GeV positron, which was reduced to 1.0% with response map correction. We observed 300 photo electron/GeV in the EM Calorimeter. Ratios of EM Calorimeter response to positron beam to that to $^{137}C_S$ Source was stable within 1% in the period of 8 months.

INTRODUCTION

In order to obtain better calorimeter data in the plug and forward/backward region ($|\eta| \geq 1$) with the shorter bunch spacing of 132 ns (than the current bunch spacing of 3500 ns) in the Fermilab Run II collider runs, the CDF group upgraded the gas sampling Plug and Forward Calorimeters with the Upgrade Plug(tile fiber) Calorimeter [1]. We calibrated a test beam module of the CDF Upgrade Plug Calorimeter at the Fermilab MTest beam line from December 1996 till September 1997.

TEST BEAM SETUP

The test beam module consists of 45 degree(ϕ) section of EM Calorimeter and 60 degree(ϕ) section of Hadron Calorimeter. Figure 1 shows a cross section of the calorimeter. The calorimeter has depth segmentation of PPS(Plug PreShower), PES(Plug EM Shower max), PEM(Plug EM), and PHA(Plug HAdron).

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1) Members of the following CDF institutions participate in the Plug Upgrade Project: Bologna U., Brandeis U., Fermilab, KEK, MSU, Purdue U., Rochester U., Rockefeller U., Texas Tech U., Tsukuba U., UCLA, Udine U., Waseda U. and Wisconsin U.

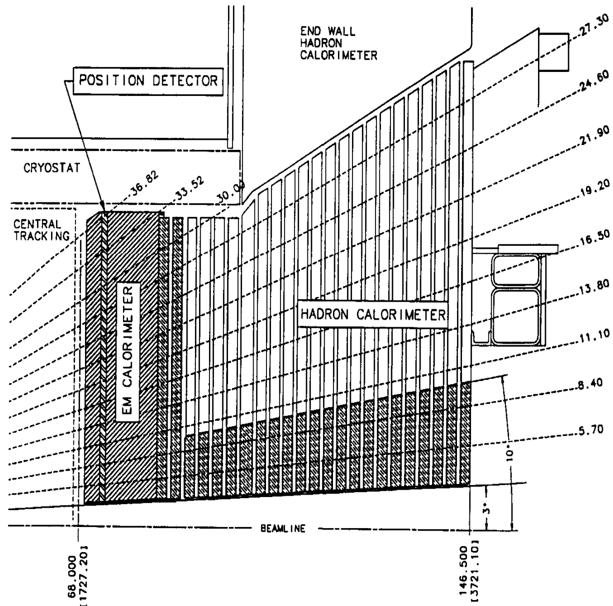

FIGURE 1. Side view of the Plug Calorimeter (cross section)

Table 1 shows parameters of the calorimeter including material and photon collection system.

PPS is a scintillator layer with the same $\eta - \phi$ segmentation of PEM with a structural iron plate as an radiator. PES(Plug EM Shower max) is made of two layers of arrays of thin scintillator bars with 22.5 degree crossing angle of bars in two layers placed at the depth of EM shower maximum. EM Calorimeter covers $1.1 \leq \mid \eta \mid \leq 3.5$, and Hadron Calorimeter covers $1.3 \leq \mid \eta \mid \leq 3.5$. ϕ segmentation($\Delta\phi$) is 7.5 degree at $\mid \eta \mid \leq 2.1$ and 15 degree at $\mid \eta \mid > 2.1$ in both EM and Hadron Calorimeter. Momentum tagging system of the MTest beam line gives $\Delta p/p$ of 0.2 %. FWHM beam size is 2.5 cm in horizontal and 1.3 cm in

TABLE 1. EM Calorimeter parameters

Segmentation	$\sim 8 \times 8 \ cm^2$
Total Channels	960
Thickness	21 X_0, 1 λ_0
Density	0.36 ρ_{Pb}
Samples	22 + Preshower
Active layer	4 mm SCSN38 (EM), 10 mm BC408 (PreShower)
Passive layer	4.5 mm Pb
Photo tube/Gain	R4125/2.5×10^4(EM), R5900-M16/1×10^5(PreShower)
Light Yield (pe/MIP/tile)	~ 5
Non-linearity	≤ 1 %
Resolution	$15\%/\sqrt{E} \oplus 0.7\%$

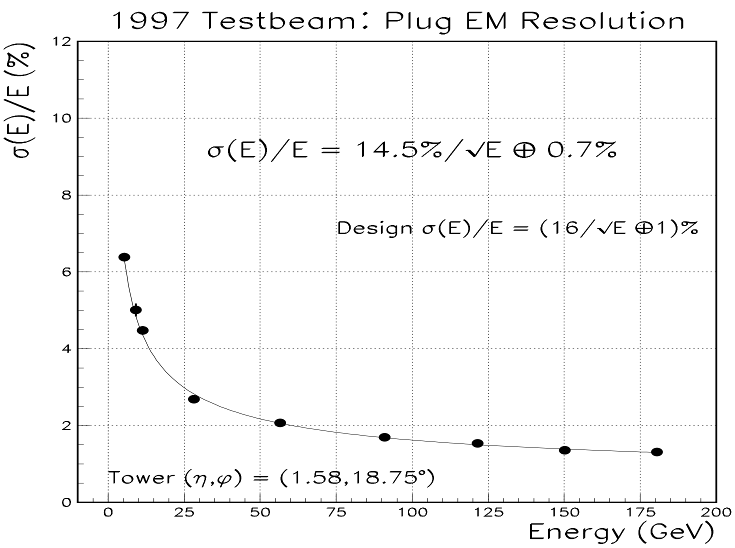

FIGURE 2. EM Energy Resolution as a function of e^+ beam energy

vertical.

RESPONSE TO ELECTRONS

Energy Resolution

Figure 2 shows Energy Resolution (σ(E)/E) of (PPS and PEM) as a function of beam energy with e^+ beam at the center of a reference tower. (PPS and PEM) energy was summed up in a $3(\eta) \times 3(\phi)$ tower window around a reference tower with beam. We obtained $(14.5 \pm 0.2\%)/\sqrt{E} \oplus (0.7 \pm 0.1\%)$ in the reference tower, and $(14.6 \pm 0.2\%)/\sqrt{E} \oplus (0.8 \pm 0.1\%)$, and $(15.8 \pm 0.2\%)/\sqrt{E} \oplus (0.4 \pm 0.2\%)$ in two other towers. Measured stochastic terms and constant terms are smaller than the *Design Values* of $16\%/\sqrt{E} \oplus 1\%$.

Linearity

Figure 3 shows non-linearity $[\equiv (EM(e)/p - 1)]$ of response of (PEM and PPS) and non-linearity of PEM alone as a function of e^+ beam energy at the center of a reference tower of the test beam module. By using PreShower response, we can reduce the non-linearity significantly at beam energy of 56 GeV or below. Energy scales were calculated to be 1.46 pC/GeV on (PPS and PEM) response to e^+ beam at 56 GeV in the reference tower in a reference run.

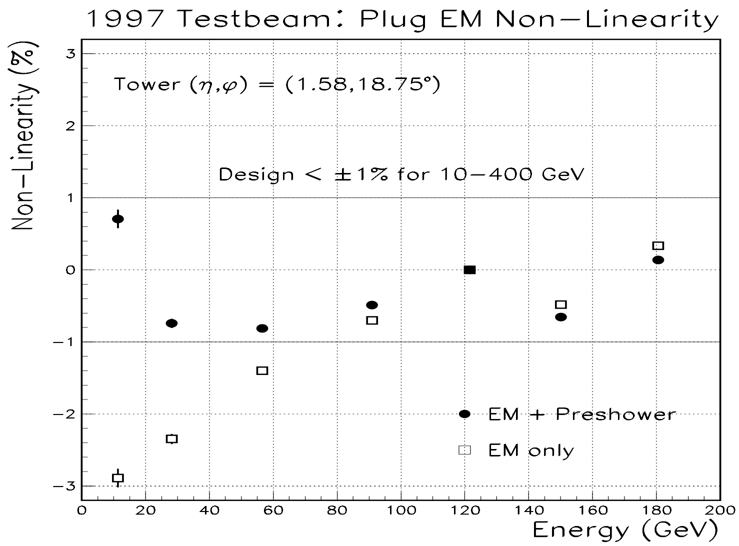

FIGURE 3. Non-Linearity as a function of e^+ beam energy

PreShower channel weight was adjusted in order to achieve our *Design Goal* of obtaining less than or equal to 1 % of non-linearity with a beam energy range from 10 GeV to 400 GeV. Non-linearity of (PPS and PEM) is normalized to e^+ beam at 120 GeV in the figure.

Response Uniformity

Inside four towers, we measured uniformity of the PEM response to e^+ beam at 56 GeV by moving the Upgrade Plug Calorimeter with respect to the beam in small steps in η and ϕ with overlapped beam area. Incident beam position was reconstructed by using the ShowerMax detector(PES). Figure 4 shows normalized response of PEM as a function of normalized η and ϕ inside and on tower boundaries of four towers, and an average of those four responses in normalized η and ϕ. In the figure, tower boundaries correspond to η or ϕ at $\pm$ 0.5. ϕ direction was reversed in two towers so that we obtain the same configuration of WLS(Wave Length Shifter) fiber routing inside a tower as that of the reference tower.

Normalization was done at the center of the tower. Size of the each bin in $\eta \times \phi$ was around 1 cm $\times$ 1 cm where EM(e)/p was fitted to a Gaussian with around 100 momentum reconstructed e^+ beam events to obtain an average PEM response in a bin. The average of the normalized response of PEM in normalized η and ϕ in four tower was used as a response map of the PEM. EM response is highest around boundaries where WLS fibers exit from tiles, and lowest at four corners of tiles as

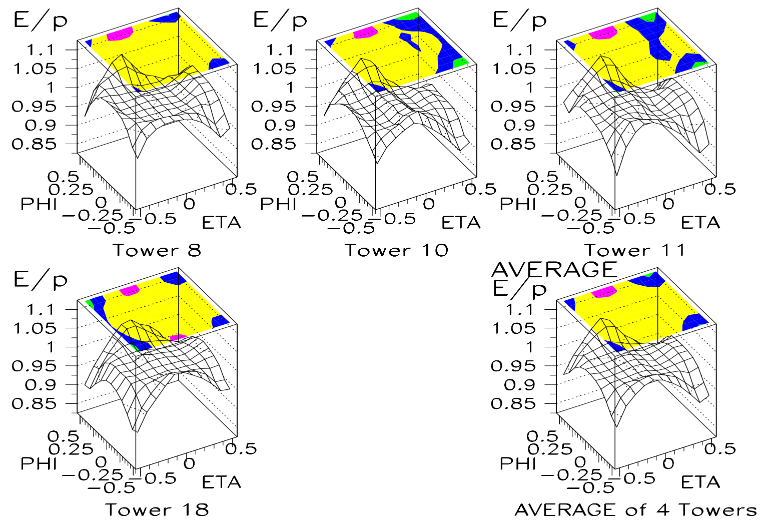

FIGURE 4. Normalized EM response to e^+ beam inside 4 towers and the average EM response in normalized η and ϕ

shown in the figure. We can obtain transverse uniformity of PEM response of 1.0 % inside a reference tower with e^+ beam at 56 GeV with the response map correction, where the transverse uniformity of PEM response was 2.2 % without response map correction. *Design Value* of inside a tower response of EM was less than 2.5 %.

Response Stability

Figure 5 shows the response of EM Calorimeter (E/p) to 56 GeV e^+ beam as a function of time in the day number of 1997, as well as estimated EM response to beam based on the response of EM Calorimeter to $^{137}C_S$ Source. Data points covers almost 8 months in 1997. RMS of ratios of EM response to 56 GeV e^+ beam to EM response to $^{137}C_S$ Source is 0.4 % in the period when both EM response to 56 GeV e^+ beam and EM response to $^{137}C_S$ Source increased around 4 %. The Ratio of the calorimeter response to beam to that to wire source allows us to bring the energy scale(pico Coulomb/GeV) into B0 collision hall where the Plug Upgrade Calorimeter will be used in the Run II.

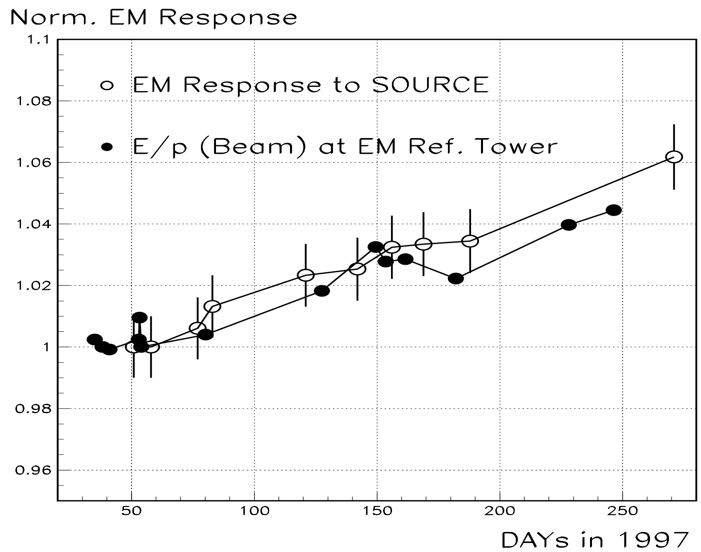

FIGURE 5. Normalized EM response to e^+ Beam and Source as a function of DAY number in 1997

CONCLUSION

The response of the PreShower and the EM Calorimeter ($\Delta\varphi = 45\,\mathrm{deg}$) to e^+ beam are better than or equal to the *Design Values.*

We obtained Energy Resolution of $14.5\%/\sqrt{E} \oplus 0.7\%$, where *Design Value* was $16.0\%/\sqrt{E} \oplus 1.0\%$.

On response linearity, the *Design Goal* of (Non-linearity ≤ 1 % in the energy range of 10 - 180 GeV) was achieved.

RMS/meam of transverse response uniformity inside a tower was measured to be 2.2 % without response map correction, and $\approx 1\%$ with response map correction, where the *Design Goal* was ≤ 2.5 %.

We observed 5 photo electrons/MIP (150 GeV μ beam), where greater than 3 was expected as the *Design Value.*

RMS/mean of the ratio of the EM Calorimeter response to e^+ beam to the response to ${}^{137}C_S$ Source was 0.4 % in a period of 8 months, which shows the accuracy of the energy scale calibration of the EM calorimeter with the beam.

REFERENCES

1. The CDF II Collaboration, *The CDF II Detector Technical Design Report*, FERMILAB-Pub-96/390-E.