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FERMILAB-Conf-98/111-E
CDF

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April 1998

Submitted to *Astrophysical Journal* Published Proceedings of the *Lafex International School on High-Energy Physics (LISHEP-98), Session C*, Rio de Janeiro, Brazil, February 16-20, 1998

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

CDF/PUB/CDF/PUBLIC/4548

RU 98/E-09 | April 30, 1998

Proposed Forward Detectors for Diffractive Physics in CDF-II [1]

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Abstract. A program of studies on hard diffraction and very forward physics with CDF–II has been proposed, which foresees adding to CDF two very forward "MiniPlug" calorimeters designed to measure the energy and lateral position of both electromagnetic and hadronic showers. The MiniPlugs will consist of lead/liquid scintillator read out by wavelength-shifting fibers arranged in a pixel-type towerless geometry suitable for "calorimetric tracking". We present here test-beam results obtained with a 28 radiation length prototype. For positrons in the range 5-120 GeV, the energy resolution was measured to be σ/E = 18.1% / $\sqrt{E}$ + 0.6% and the position resolution 9.2 mm / $\sqrt{E}$; for charged pions in the range 10-230 GeV a position resolution of 23.9 mm / $\sqrt{E}$ was obtained.

INTRODUCTION

A program of studies on hard diffraction and very forward physics with CDF in run II foresees the re-installation of the Roman Pot Spectrometer successfully used in run 1C (1995-96) to detect leading antiprotons, and adding two forward calorimeters to cover the pseudorapidity region 3.5< $|\eta|$ <5.0. Fig. 1 (left) shows a schematic view of the three-detector Roman Pot antiproton spectrometer installed in the beam pipe during run 1C (1995-96). Each pot contained two trigger scintillation counters and two X–Y scintillating fiber arrays read out by MultiChannel PhotoMultiplier Tubes (MCPMTs). The Roman Pots were positioned about 1 m apart from one another at an average distance of 57 m downstream from the CDF interaction region along the antiproton direction. During data taking the detectors accepted antiprotons that deviated by more than 14 mm from the beam line, corresponding to $x_F < 0.95$ ($\xi = 1-x_{\bar{p}} > 0.05$). For run II these detectors will be placed closer to the $\bar{p}$ beam line and thereby gain acceptance at lower ξ-values, down to $\xi = 1 - x_{\bar{p}} \approx$0.03, where the cross-section is dominated by Pomeron exchange (see fig. 1-right for Roman Pots acceptance).

Fig. 2 shows one quadrant of the CDF–II configuration. The MiniPlugs will be placed downstream of the Plug Upgrade calorimeters within the region screened

[1] Presented at "Diffractive Physics, LAFEX International School on High Energy Physics (LISHEP-98), Rio de Janeiro, Brazil, 10-20 February 1998."

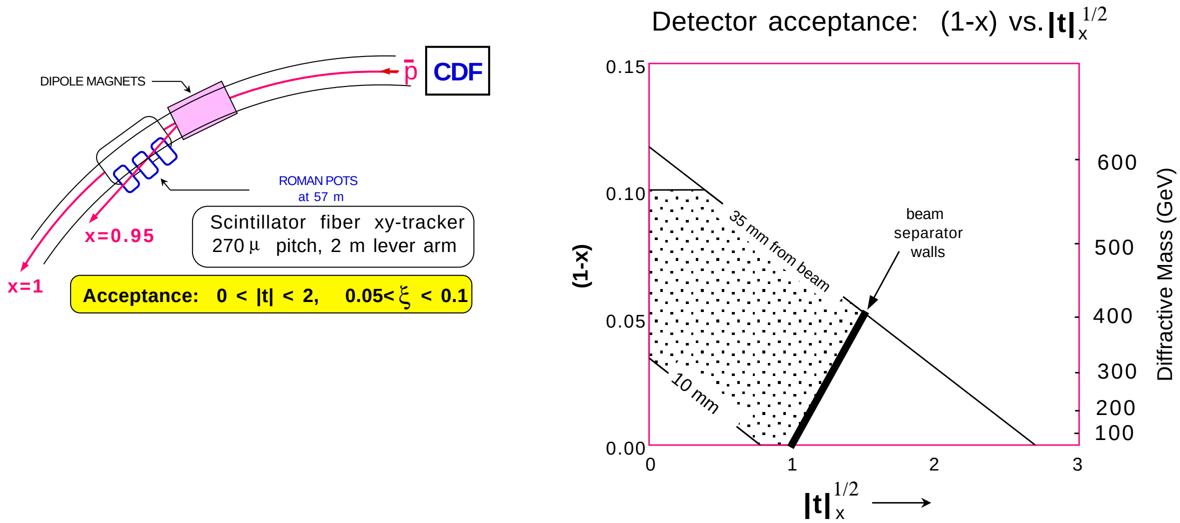

FIGURE 1. CDF Roman Pot Spectrometer for hard diffraction studies (left) and its x_F/t acceptance (right): (1-x_F) versus $\sqrt{|t|_x}$ as a function of the distance from the beam at the Roman Pot site (the distance varies linearly between the 10 and 35 mm lines).

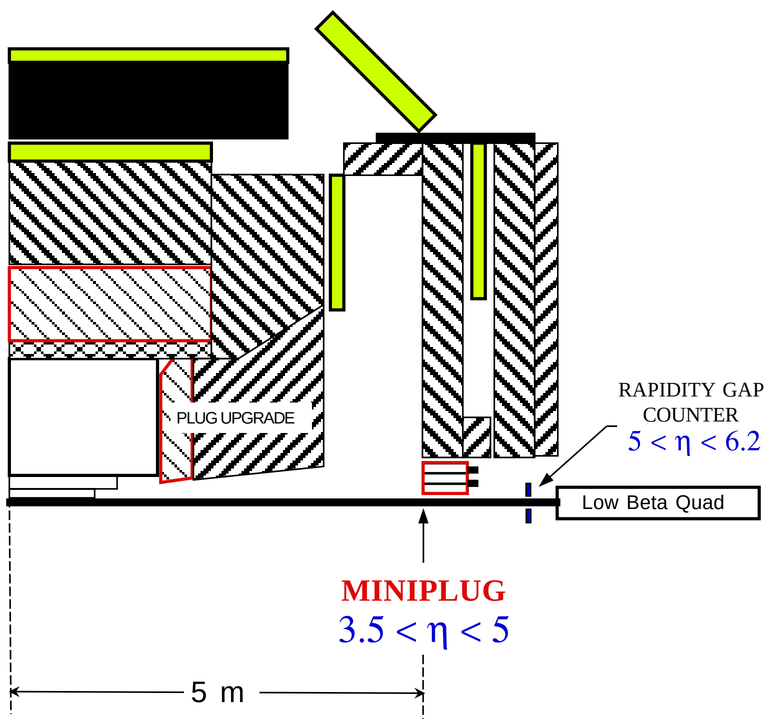

FIGURE 2. Schematic view of CDF in Run II showing the position of the MiniPlug.

by the muon toroids, extending the calorimetry coverage all the way down to the beam pipe.

The physics topics to be addressed by the MiniPlugs include studies of hard diffraction, searches for centauros and disoriented chiral condensates (see the review by Zheng Huang [1] and references therein), and forward jet production. The latter can probe both the small-x and large-x regions of the proton structure function, which are of great interest. The x-value of the interacting partons can be obtained from the jet η for a given E_T^{jet}. At $\sqrt{s}$ =1.8 TeV, the cross sections for symmetric (same η) jets of E_T^{jet} =5 GeV are given in fig. 3 for same–side (SS) and opposite–side (OS) dijet events. For η =5 the MiniPlugs allow the measurement of x_{min} =$4{\cdot}10^{-5}$ and x_{max} = 0.4(0.8) for SS(OS) dijets.

The MiniPlug design combines a low cost construction with an efficient and high resolution position determination. MonteCarlo predictions of the MiniPlug expected performance and results obtained from a test of a MiniPlug protype in a test beam at the Brookhaven National Laboratory in 1994 are described elsewhere [2,3]. The following sections describe the prototype design and the results obtained in a Fermilab test beam in 1997.

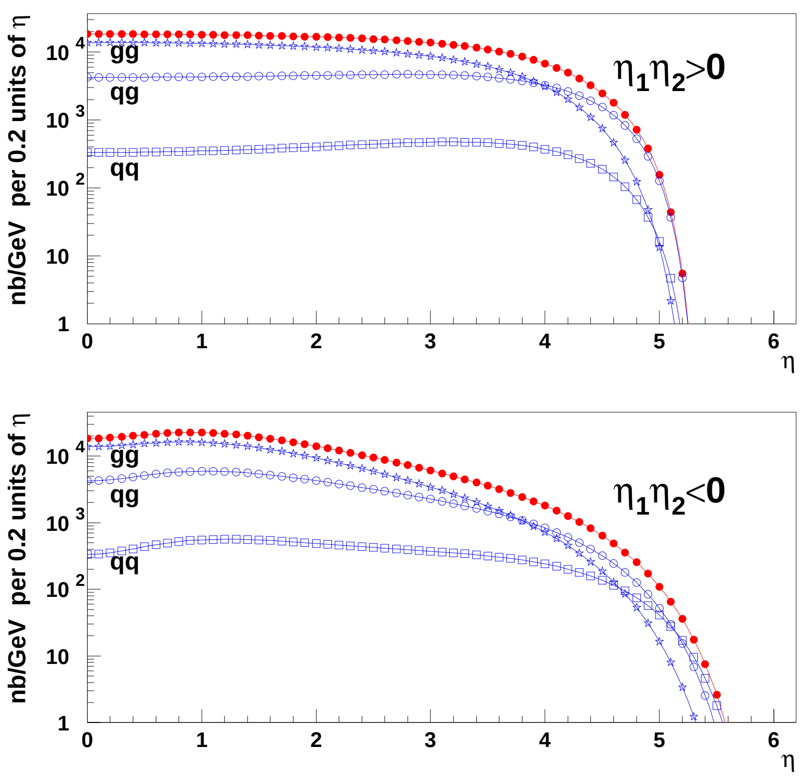

FIGURE 3. Cross section versus η for symmetric (same η) dijet production of E_T^{jet} =5 GeV: (top) same-side jets ($\eta_1\eta_2$ >0); (bottom) opposite-side jets ($\eta_1\eta_2$ <0).

THE MINIPLUG PROTOTYPE

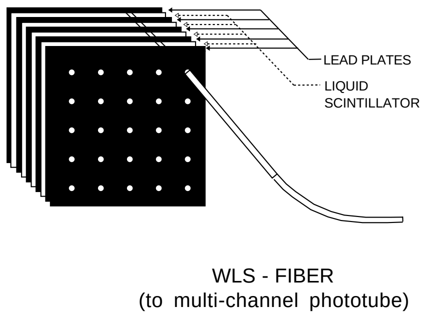

FIGURE 4. Conceptual design of a MiniPlug calorimeter.

The "MiniPlug" is a calorimeter designed to measure the energy and, without using any shower maximum detector, the lateral position of both electromagnetic and hadronic showers initiated by high energy particles incident at small angles relative to the detector axis.

A MiniPlug consists of a set of parallel lead plates immersed in liquid scintillator. The scintillation light is guided by wavelength–shifting (WLS) fibers to multichannel photomultiplier tubes (M-CPMT's). The fibers are inserted in holes drilled in the lead plates as shown in fig.4, and are arranged in a unique *towerless* geometry (no boundaries between the fibers) suitable for "calorimetric tracking" of particles in the very forward region of collider experiments in a moderate luminosity environment like that of CDF at Fermilab.

The fiber pulse–height centroid provides the position of the shower initiating particle. As interacting hadrons release on average 1/3 of their energy in the form of π^0's, a 2–3 interaction-length deep "tracking calorimeter" can be used to measure the energy and position of both electrons/photons and hadrons. A set of fibers which do not sample the first 24 radiation lengths of the detector can be used to tag the hadrons.

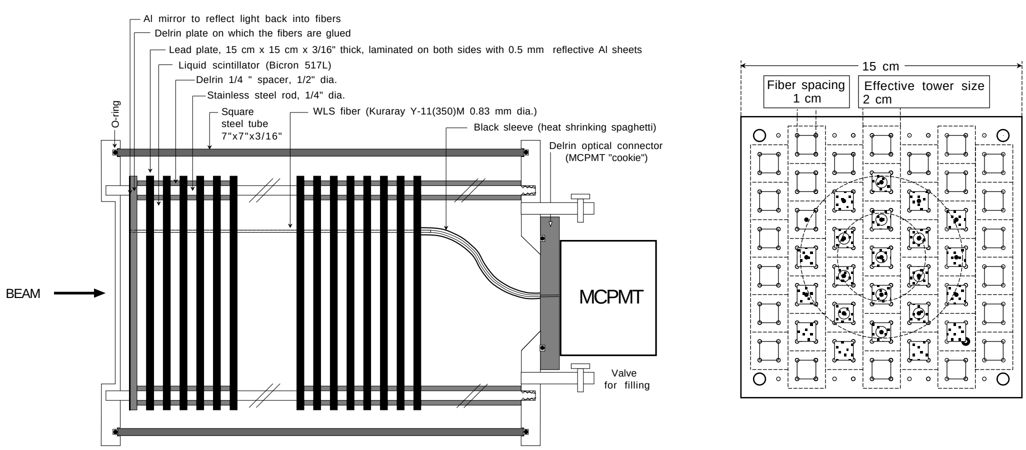

FIGURE 5. Left: Schematic side view of a MiniPlug prototype. Right: Front view. Each group of four fibers in a square is read by the same MCPMT channel. All the squares were instrumented at the 1997 test beam, as well as the single fibers at the center of the squares, as indicated (the shaded squares are those instrumented at the BNL test beam [3]). The x-direction in the text corresponds to the vertical direction in this view.

A schematic view of a MiniPlug prototype is shown in fig.5. The prototype consists of 30 parallel lead plates, with dimensions 15 cm x 15 cm and 4.8 mm thick, spaced 6.4 mm apart. The plates were laminated with 0.5 mm thick aluminum sheets of 86% reflectivity glued on the lead with epoxy. Multiclad WLS Kuraray Y–11(350)M fibers with a 0.83 mm diameter are inserted into an array of aligned holes through the entire depth of the detector. The holes have 1 mm diameter and were drilled through the lead–aluminum plates with a CNC machine. The whole plate/fiber assembly was immersed in mineral oil based Bicron 517L liquid scintillator. The MiniPlug prototype comprised about 28 radiation lenghts or about 1 interaction length.

The prototype was housed in a square steel tube between two 0.5″ thick aluminum flanges. O–rings in grooves in the flanges provided the sealing for the liquid scintillator. A 2.5″ diameter hole in one of the flanges allowed the fibers to be guided to a black delrin "cookie" that served as an optical connector to the MCPMT. The cookie had 64 holes to match the MCPMT photocatode glass face. A reflective aluminum sheet was pressed against the far-ends of the fibers to reflect the light back into the fibers.

Fibers were grouped as shown in fig.5(right), with four fibers in the corners of a square being read by one MCPMT channel providing what in the following we will call for simplicity a "tower" with a size of 2 cm x 2 cm. The fibers in the centers of the squares were read individually. In a final design of a calorimeter of $\approx$ 58 radiation lenghts or $\approx$ 2.0 interaction lengths, these single fibers will penetrate the calorimeter only through a certain distance from the back, stopping short of reaching the first 24 radiation lengths. In this way they will not be sensitive to electron/photon showers and therefore will provide a "*hadron tag*". In the present prototype the fibers were brought all the way to the front of the calorimeter to test the idea of tagging hadrons with one fiber per "tower".

The MiniPlug prototype was read with a Hamamatsu H–5828 MCPMT as 45 "towers" and 19 single fibers (fig.5). A good transverse uniformity in response has been obtained on beam tests by integrating the signal over a radius encompassing several towers around a Seed Tower (the tower with the largest pulse height). The radius is determined by the effective attenuation length of the liquid scintillator, which depends on the number of reflections. Bench measurements yielded an effective attenuation length of 20 mm for a scintillator thickness of 6 mm [3].

The Hamamatsu H–5828 MCPMT was tested and calibrated at Rockefeller with a green LED signal illuminating all the 64 photocathode pixels. The LED was embedded in a lucite "light mixer" bar, which distributed the light uniformly among 64 clear 1 mm dia. fibers. These fibers guided the light to a delrin cookie, which was optically coupled to the MCPMT. The response variation of the light mixer was measured by reading the light from each hole of the light mixer cookie using a fiber coupled to a regular PMT prior to gluing all 64 fibers, and was found to be uniform within $\pm$ 5 %. Our test results agree with the Hamamatsu specifications within $\pm$10%. The measurement was repeated after rotating the MCPMT by $+90^o$ or -90^o, so that in the new position each channel was illuminated by a different fiber. The difference of the two responses for each channel was found to be consistent with the light variation over the 64 fibers.

TEST BEAM SETUP

The MiniPlug prototype was moved to the MT6 test beam area at Fermilab in May 1997, where it was exposed to electron, hadron and muon beams. Sets of drift chambers before and after the bending magnets were used to measure the momenta of the particles. The momentum resolution of these drift chambers was ±0.5%. The position measurement had an error of 290 μm in both directions perpendicular to the beam for each chamber.

All the MCPMT channels were read out using custom CDF electronics, which have been described in detail elsewhere [4]. The beam was directed into the central tower of the calorimeter and the energy of the particle was obtained by the ADC count sum of the Seed Tower and the adjacent towers within a circle of radius 3, 5, 7 or 8 (all towers) cm. Sets of data were also taken with the MiniPlug shifted by ± 1 tower perpendicular to the beam, and at angles of 0, 3 and 10 degrees between the beam and the calorimeter axis.

A $\pm 1.5\ \sigma$ cut on a gaussian fit to the momentum spectrum of the beam particles was applied at each nominal beam momentum. The trigger scintillation counters provided a beam with dimensions of about $1/2'' \times 1''$.

CALIBRATION AND LINEARITY

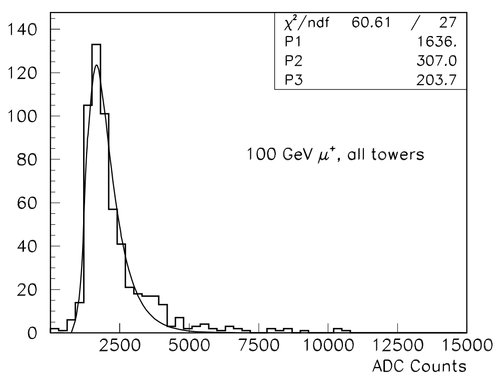

FIGURE 6. The integrated signal from all the towers for 100 GeV muons, fitted with a Landau function.

The response of the MiniPlug calorimeter to positron, hadron and muon beams was studied with the MCPMT high voltage set at 1.8 KV, where the gain was $\approx 0.6 \times 10^6$. Fig.6 shows the signal for 100 GeV muons (the real momentum from the drift chambers was actually 117 GeV - in the following we will always refer to the nominal value of the momentum), fitted with a Landau distribution. When the energy was summed over all the towers of the prototype, the light yield was found to be 110 pe's/GeV (positrons) and 55 pe's/MIP (muons), equivalent to 1.8 pe's/MIP/layer. If we considered only the single Seed Tower, we obtained ≈ 13 pe's/MIP or ≈ 0.43 pe's/MIP/layer. The relation between the average ADC count sum over all the MiniPlug towers and the beam momentum is shown in fig. 7 for positrons in the range 5–120 GeV (left) and for pions in the range 10–230 GeV (right). For the positrons the deviation of each point from a linear fit is better than 1.5%. Good linearity was observed also for ADC sums over smaller circles around the Seed Tower, down to a radius of 3 cm.

For the pions interacting in the MiniPlug, the energy resolution is found to be about 43 % independent of pion energy (see below). However, as seen in fig. 7, the mean values are still fitted very well with a straight line and, apart from the measurement at 230 GeV, the points are within 4% from the linear fit. We notice

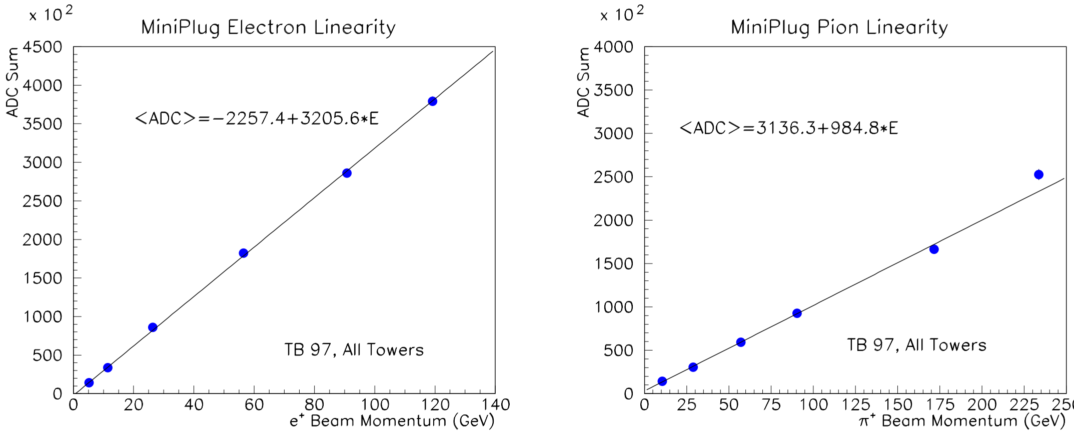

FIGURE 7. The relation between ADC counts and beam momentum for positrons in the range 5–120 GeV (left) and pions in the range 10–230 GeV (right).

from these plots that the energy released by the pions is about one third of the positron energy for the same beam momentum, as expected.

ELECTRON ENERGY RESOLUTION

We studied the energy resolution at six different energies of the positron beam, from as low as 5 GeV up to 120 GeV. In fig.8 the σ/E in percentage is plotted for the different energies. The data are well fitted by a resolution function σ/E = 18.1% / $\sqrt{E}$ + 0.6%. All the towers formed by a group of four fibers were used in this measurement. When the ADC counts were summed over a circle of smaller radius, the stochastic term did not change appreciably, but the constant term increased, especially for low energies, due to leakage outside the circle.

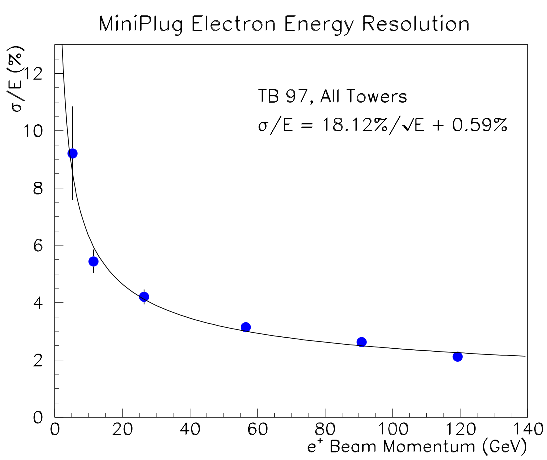

FIGURE 8. MiniPlug energy resolution for positrons of momentum in the range 5–120 GeV.

ELECTRON POSITION RESOLUTION

The position of a particle can be measured from the “Center of Gravity” (CoG) of the shower profile. A typical lego plot for ADC counts over the X–Y plane of the MiniPlug is shown in fig.9 for single events from a 50 GeV positron, a 50 GeV pion and a 100 GeV muon.

We studied several algorithms in order to optimize the position resolution and minimize the well known systematic effect of the finite detector segmentation when

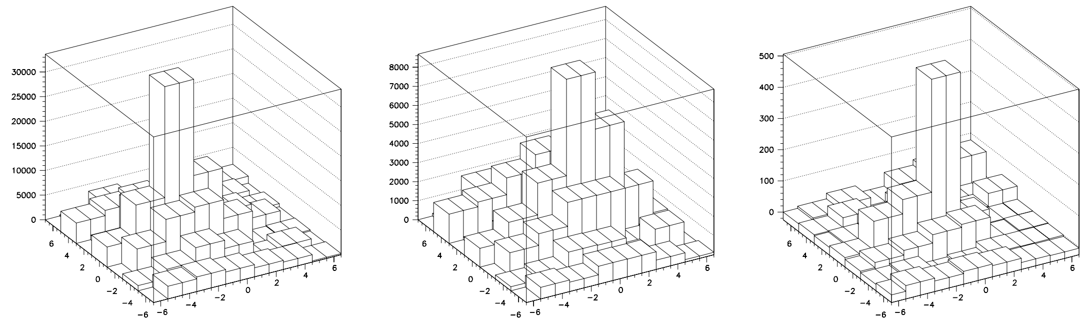

FIGURE 9. Typical single event ADC count distributions in the MiniPlug for a 50 GeV positron, a 50 GeV pion and a 100 GeV muon (from left to right).

using a small number of towers. The best results were obtained by using a corrected CoG over a raw of five towers only, with the Seed Tower signal weighted by a factor 0.3, or by using over three towers the form:

$$< x >= x_{Seed} + (1/\mathrm{R1} - 1/\mathrm{R2}) \;/\; [2(1/\mathrm{R1}+1/\mathrm{R2}-2)] \cdot \mathrm{W}$$

based on a Lorentzian lineshape fit to the shower profile, where R1 and R2 are the signal fractions Q_{-1}/Q_{Seed} and Q_{+1}/Q_{Seed}, respectively, and W is the tower effective size (2 cm). These two methods gave very similar results. Fig.10 shows the bi–dimensional position (R) reconstructed by the MiniPlug relative to the Beam Chamber position for 50 GeV positrons. The standard deviation of this distribution of residuals is 1.15 mm. In fig. 11(left) we plot the position resolution for positrons in the range 5–120 GeV, where a weighted CoG over five towers was used. The points are well fitted with the function σ = 9.2 mm / $\sqrt{E}$. With a Lorentzian lineshape over three towers we find $\sigma = 9.5\mathrm{mm}/\sqrt{E}$, as shown in fig.11(right).

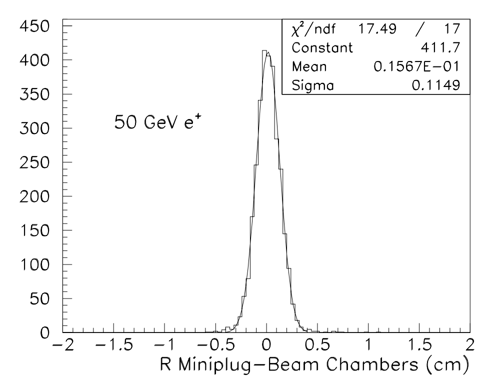

FIGURE 10. Position resolution for 50 GeV electrons.

RESPONSE TO PIONS

The MiniPlug prototype is only one interaction length deep. Thus, the ADC count distribution obtained with a pion beam shows a MIP–like Landau peak at low counts for pions traversing the entire calorimeter and a Gaussian tail mainly due to the energy deposited by the photons from π^0's created in the primary interaction. The response to 25 GeV pions is shown in fig.12.

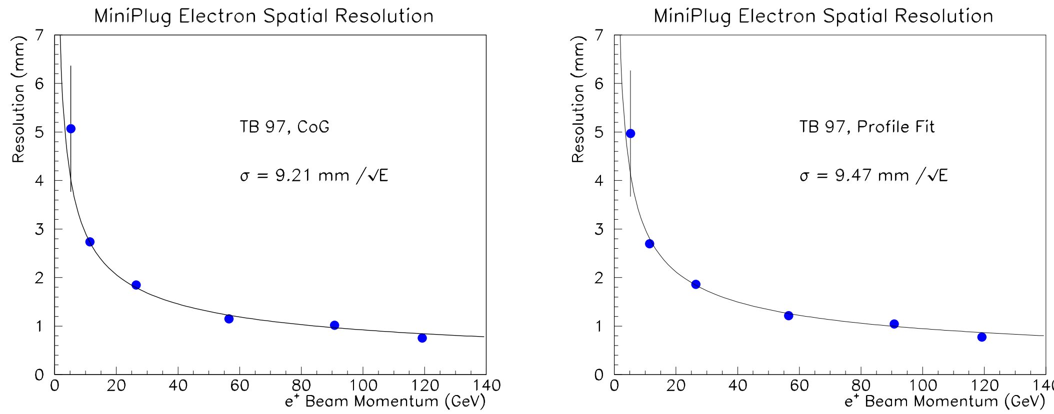

FIGURE 11. MiniPlug position resolution for positrons in the range 5–120 GeV. Similar results were obtained by using either a weighted CoG over five towers (left) or a Lorentzian lineshape fit over three towers (right).

To study the energy resolution, we applied a cut, for each pion beam energy, to reject the Landau peak in the Seed Tower ADC spectrum, and selected the events entirely due to interacting pions. Results for these events are shown in fig.13: the energy resolution is about 43%, constant over a momentum range from 10 to 230 GeV. The resolution is dominated by fluctuations in the neutral/charged pion ratio. In the final design with two interaction lengths, a GEANT simulation predicts an energy resolution of ≈30% for interacting pions.

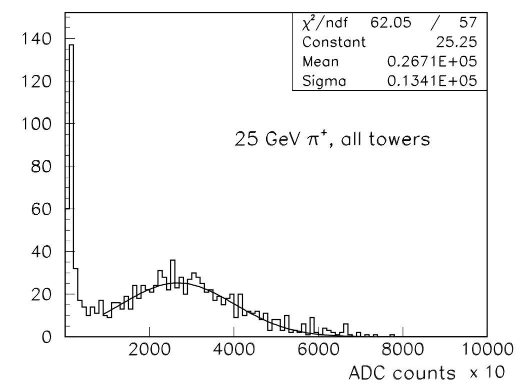

FIGURE 12. MiniPlug response to 25 GeV π^+. The MIP–like response to non–interacting pions at low ADC counts is followed by a Gaussian tail for interacting pions.

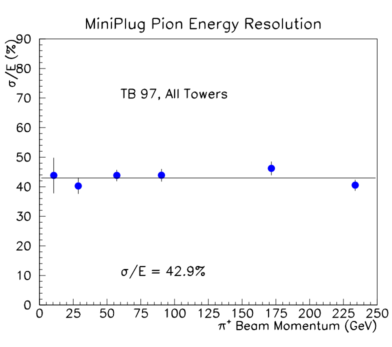

FIGURE 13. The MiniPlug energy resolution for interacting pions is constant over a momentum range from 10 to 230 GeV.

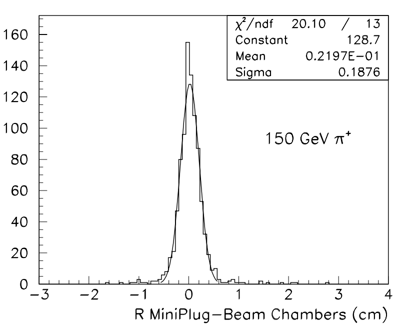

FIGURE 14. Position resolution for 150 GeV pions.

We also studied the position resolution for interacting pions. A typical residual distribution is shown in fig.14 for 150 GeV pions; the resolution is 1.88 mm. Over the entire momentum range 10–230 GeV the resolution was found to be 23.9 mm / $\sqrt{E}$ using the weighted CoG technique (fig.15, left) and 24.2 mm / $\sqrt{E}$ using a Lorentzian profile fit over three towers (fig.15, right).

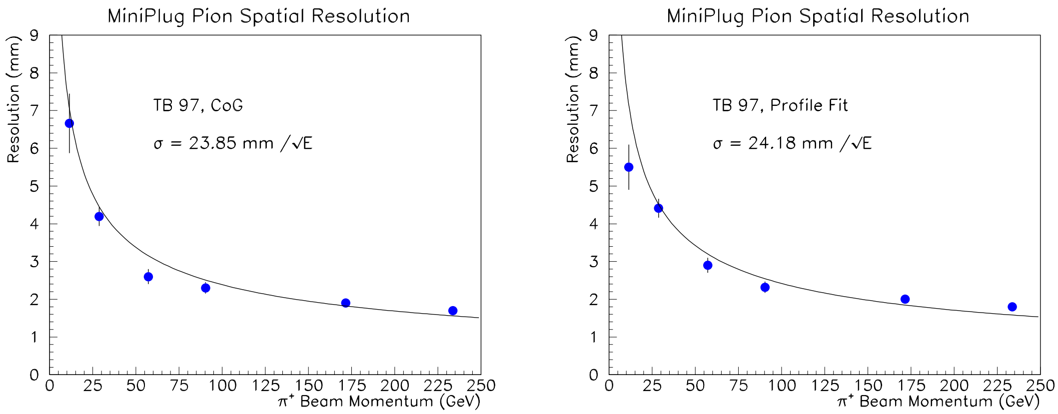

FIGURE 15. MiniPlug position resolution for pions in the range 10–230 GeV. A weighted Center of Gravity technique over five towers (left) or a Lorentzian profile fit over three towers (right) was used to determine the position.

THE MINIPLUGS IN CDF-II

Two MiniPlugs have been proposed for CDF-II to be placed in the forward region about 5 meters from the center of the detector (fig.2). The MiniPlugs will cover about two units in pseudorapidity, extending the Plug coverage all the way down to the beam pipe. In fig.16, four test beam events, two from 50 GeV pions and two from 50 GeV electrons, are displayed in an X–Y LEGO plot whose dimensions are approximately those of the final MiniPlug design. This plot illustrates that the MiniPlug can be used to count several individual particles and measure their energy.

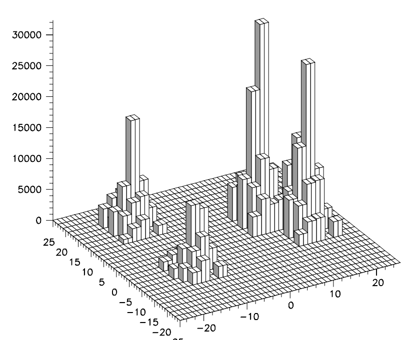

FIGURE 16. Two 50 GeV pions and two 50 GeV electrons from TB data have been mixed on an X–Y plane of about the size of the final MiniPlug.

Jet Energy Resolution

We have recently studied [5] the jet energy resolution of the MiniPlug calorimeters in the CDF–II configuration of fig.2 using a simulation based on the GEANT MonteCarlo program [6].

Each MiniPlug module comprised about 58 radiation lenghts and 2 interaction lenghts. The jets were produced in $\bar{p}p$ collisions at $\sqrt{s}$ =1.8 TeV using the HERWIG [7] MonteCarlo program. The jet energy resolution was studied by passing individual particles of a jet through the MiniPlug module and summing the response to each particle of the jet.

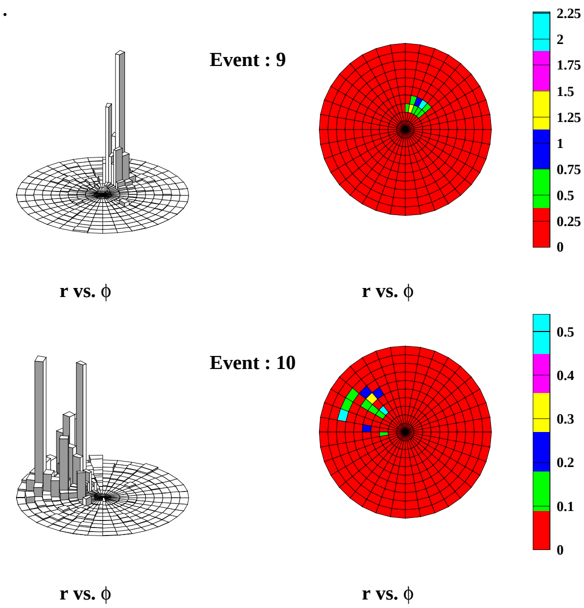

FIGURE 17. MiniPlug response to jets. For each event an isometric lego plot (left) and color-coded front view (right) are shown.

Fig. 17 shows the MiniPlug response to typical jets. For each event an isometric lego plot (left) and color-coded front view (right) are shown. For convenience in representation, the impact point of a particle was expressed in polar coordinates r and ϕ relative to the center of the MiniPlug front surface. Fig. 18a shows the distribution of the incident jet energy. The distribution of the number of particles in a jet is presented in fig. 18b. Fig. 18c shows the percent fraction of the initial jet energy registered in the scintillator; from this distribution we evaluated the jet energy resolution to be $\sigma/E = 29.2\%$. The z-position of the first shower vertex, the average longitudinal shower profile and the average transverse shower profile are shown in figures 18d, 18e, and 18f, respectively.

Results for the jet E_T resolution in the MiniPlug are presented in fig. 19. Fig. 19a shows the initial jet E_T distribution. The reconstructed jet E_T is plotted in fig. 19b. Fig. 19c shows the percent fraction of the initial jet E_T reconstructed in the MiniPlug, which yields a jet transverse energy resolution of 30.6% for $< E_T^{jet} >= 4.9$ GeV.

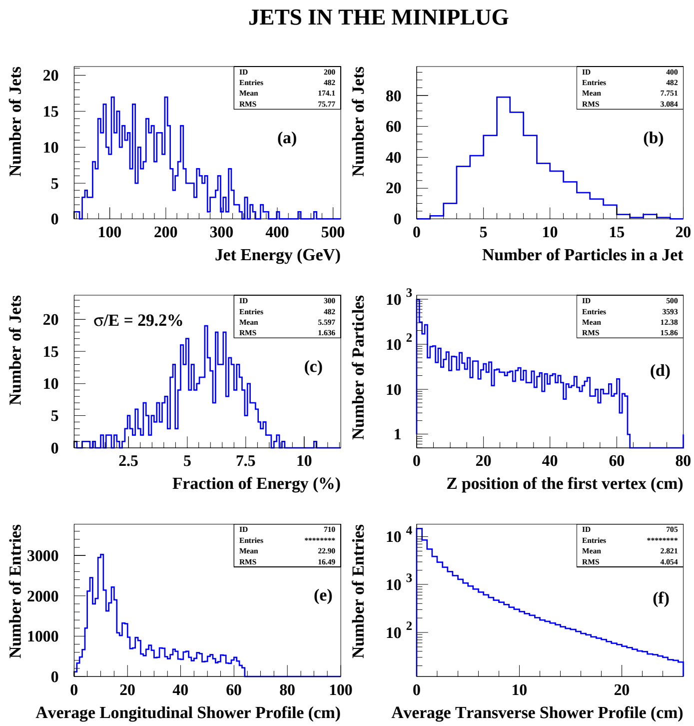

FIGURE 18. Distributions for jets incident on the MiniPlug.

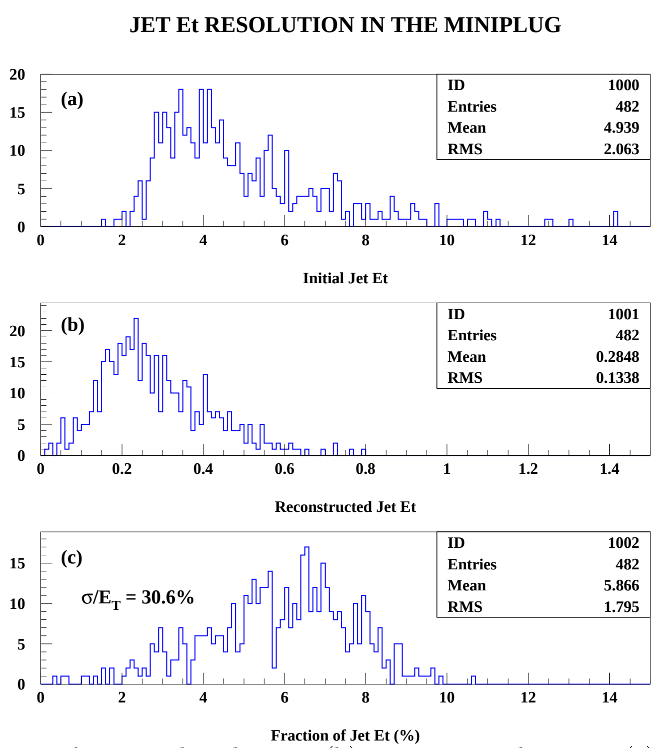

FIGURE 19. (a) Initial jet E_T distribution, (b) reconstructed jet E_T, (c) fraction of the initial jet E_T reconstructed in the MiniPlug.

CONCLUSIONS

We successfully tested a prototype of the proposed CDF–II MiniPlug Calorimeter. The response to positrons in the range 5–120 GeV and to charged pions in the range 10–230 GeV shows good linearity, which for positrons is better than 1.5%. The energy resolution was measured to be σ/E = 18.1% / $\sqrt{E}$ + 0.6% for electromagnetic showers. Our main goal of measuring with high precision the lateral position of both electromagnetic and hadronic showers has been achieved with resolutions of 9.2 mm / $\sqrt{E}$ for positrons and 23.9 mm / $\sqrt{E}$ for pions.

REFERENCES

1. Zheng Huan, "Disoriented Chiral Condensate", HEP-PH/951366 (1995).
2. S. Bagdasarov and K. Goulianos, "Calorimetric Tracking of High Energy Particles", Proc. IVth Int. Conf. on Calorimetry in HEP (1993), 524.
3. S. Bagdasarov, K. Goulianos, A. Maghakian, Q.F. Wang, *Nucl. Instrum. Methods* A **372**, 117 (1996).
4. G. Drake et al., *Nucl. Instrum. Methods* A **269**, 68 (1988).
5. S. Bagdasarov, "Monte Carlo Studies of Particle and Jet Energy Resolution of the MiniPlug Calorimeter", CDF internal note 4448 (1998).
6. R. Brun et al., GEANT Detector Description and Simulation Tool, CERN Program Library, W5013, 1994.
7. G. Marchesini et al., Comp. Phys. Comm. (1992) 465.