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THE SHOWER-MAXIMUM DETECTOR FOR CDF II

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The Shower-Maximum Detector(SMD) of the CDF Plug Upgrade EM calorimeter has been tested at the 1996 - 97 test beam. Calibration of the SMD has been performed using both beam positron response and wire-source data, with both calibrations agreeing to within 5% . The e^+ position resolution was studied by fitting the shower profile to find its center and comparing it with the projected track from the drift chambers. A position resolution of $(38/E + 0.4)\,mm$ for positrons in the energy range $10 - 180\,GeV$ has been obtained.

1 Introduction

The upgrade program of CDF includes the replacement of the forward gas calorimetry with electromagnetic and hadronic calorimetry using a scintillator-tile sampling calorimeter, read out by wave-length shifting (WLS) fibers. To measure the position of $e^{\pm}$ and γ showers, and separate $e^{\pm}$'s and γ's from π^0's, a position sensitive shower-maximum detector (SMD) has been placed inside the EM section of the plug calorimeter at a depth of approximately 6 radiation lengths. This paper studies the performance of the SMD at the 1996-97 test beam program, particularly its position resolution.

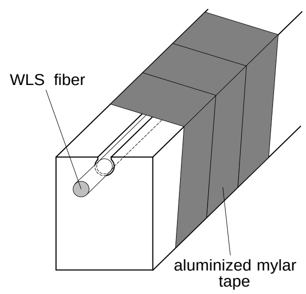
2 Detector Description

The shower-maximum detector [1] is divided into eight 45° sectors, each covering the region from $11\,cm$ to an outer radius of $130\,cm$ from the beam axis. Each sector contains two layers (U and V) of $5\,mm$ wide scintillator strips. The U and V layers are held together by two 1/8" thick lexan covers, and inserted into the fifth sampling slot within the EM calorimeter.

The two scintillator layers U and V are aligned at $+22.5°$ and $-22.5°$ with respect to the simmetry axis of the 45° sector, to provide a two-dimensional position measurement. The scintillating strips are $6\,mm$ thick and have lengths varying beetween 5 and $100\,cm$. The principle of the strip design is shown in Fig. 1. A "ball groove" in each strip ($0.89\,mm$ in diameter) accepts a WLS fiber ($0.83\,mm$ in diameter) which guides the light through the optical connectors mounted near the outer perimeter of the sector to clear fibers, which carry the

[a] 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.

light to the Multi-Channel PhotoMultiplier Tubes (MCPMTs) placed at the rear of the plug calorimeter. The strips are wrapped in reflective aluminum tape. Groups of 10 strips are taped together and subsequently treated as one unit, the so called "megastrip". The megastrips are placed in the lexan covers using separators that keep the megastrips parallel to one side of the 45° sector. The placement of the U and V strips in a 45° sector is shown in Fig. 1(right plot). One 45° sector of SMD has been mounted in the EM section of the plug calorimeter that was tested at the 1996-97 CDF test beam .



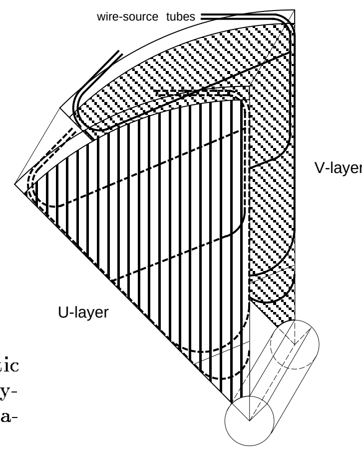


Figure 1: Strip design(left plot) and schematic view(right plot) of the SMD scintillator-strip layers in a 45° sector, and the wire-source calibration tube arrangement.

3 SMD Calibration

A strip-to-strip calibration of the SMD has been performed in two ways: by using the e^+ beam data and the wire-source calibration data.

3.1 e^+ Beam Calibration

For e^+ beam calibration data from ϕ scans have been used. In each stand position of the scan the e^+ beam hit 5 – 6 strips in each U and V layer. To find the strip-to-strip calibration the response of the strip with the maximum responses for each event was used. Data from different exposures to ϕ scans have been superimposed and the mean value of the maximum response from different events for each strip was used as the strip calibration constant.

3.2 Wire-Source Calibration

There are four sets of wire source tubes crossing the 45° sector. They are located at the back side of the rear laxen panel. The arrangment of wire-source calibration tubes is shown in Fig. 1.

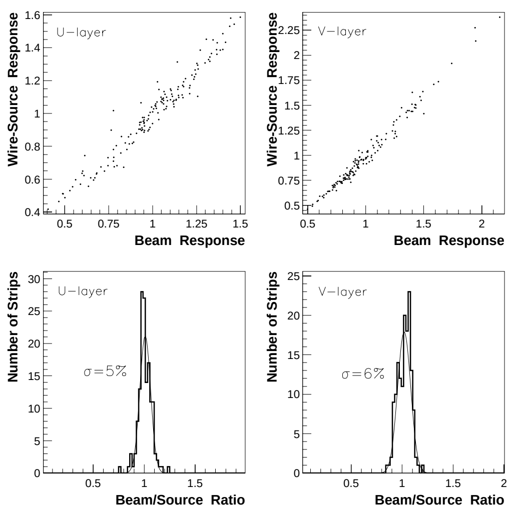


Figure 2: The correlation(top) and ratio(bottom) between the beam and wire-source calibration constants.

During the SMD "sourcing", all strips were scanned sending a wire with a ^{137}Cs source through the source calibration tubes. The current read out from each chanel of the MCPMT provides the strip-to-strip calibration. The data from the first tube (close to the outer radius), which crosses the most of the strips in each layer, have been used for strip calibration. Fig. 2 (top) shows the correlation between the two calibrations. The r.m.s. variation (botom plots) is about $5-6\%$, which is an acceptable precision for the determination of the calibration constants and satisfies our design requirement of $\leq 10\%$.

4 Energy Response

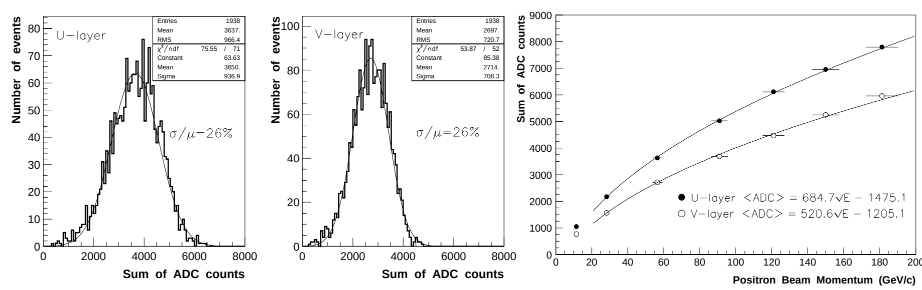


Figure 3: ADC distribution for 57 GeV positrons(right plots) and the relation(left) between ADC counts and beam momentum for positrons in the range 10 - 180 GeV.

The response of the SMD to positrons has been studied in the range $10-180\,GeV$. The relation between the SMD response, ADC count sum over 7 strips of each layer, and beam momentum is shown in Fig. 3(right plot). The strips were calibrated by using the beam calibration constants. The ADC distribution for $57\,GeV$ positrons is shown in Fig. 3(left plots); in this case the positron energy resolution is about 26%.

5 e^+ Shower Profile

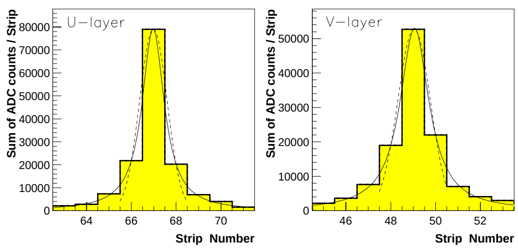


Figure 4: Average shower profile distribution for 57 GeV positrons. The solid line is a Lorentzian fit to 3 strips extrapolated to 9 strips; the dashed line corresponds to a Gaussian fit.

By superimposing a number of positron events which hit a nerrow region ($2\,mm$ by $2\,mm$) within the center of one strip in each of the U and V layers, we determined an average shower profile. The obtained shower profiles are shown in Fig. 4. The profile distribution of the V layer, which is downstream of the U layer, is wider because the shower particles diverge after leaving the lead in front of the U layer. As follows from these plots, about 50% of the energy is contained in the central strip and 80% in the center 3 strips.

6 e^+ Position Resolution

The main purpose of the SMD is to determine the position of the $e^{\pm}$'s and γ's showers. To determine the position resolution from the test beam data, the position of the incident positron reconstructed from SMD data was compared with the position measured by a set of tracking chambers.

6.1 Position Reconstruction Algorithms

Three different methods were studied for the reconstruction of the position of the incident positron.

- *Energy weighted method.* This most simple approach uses energy weighted average for 7 strips (highest central strip and 6 adjacent) to determine the position of the positron track. This method was rejected because of the poor track-shower determination.

- *3-strip analytical fit.* This algorithm uses the strip with highest response and the two neighboring strips to fit their ADC values to shape functions, which can be evaluated analytically in the case of 3 parameter functions. The shape functions used in this fit are discussed below.

- *5-strip fitting.* This method uses five strips in fitting by shape function.

The last approach was studied for different shape functions and it was found that this method is very sensitive to the fluctuations of the energy deposited in the tail strips, which are significant because of the fluctuations of light yield in these strips.

The *3-strip analytical fit* gave a more precise track-shower match and was adopted for position determination. Lorentzian lineshape function was used for fitting, and the mean value μ of this function was taken as the position of the incident particle. If E_1, E_{max} and E_2 are the energies measured by the 3 strips, and x_{max} is the center of the strip with maximum response, then the mean value of a Lorentzian fit to the center three strips is given by the simple analytical formula

$$\mu = x_{max} + \frac{E_{max}(E_2 - E_1)\Delta}{2[E_{max}(E_2 + E_1) - 2E_1E_2]}$$

where Δ is the strip width. This shape function has also been successfully used in the determination of shower profiles in the MiniPlug [2] calorimeter.

A Gaussian function was also studied for track position reconstruction. For Gaussian 3-strip fitting the reconstructed position is

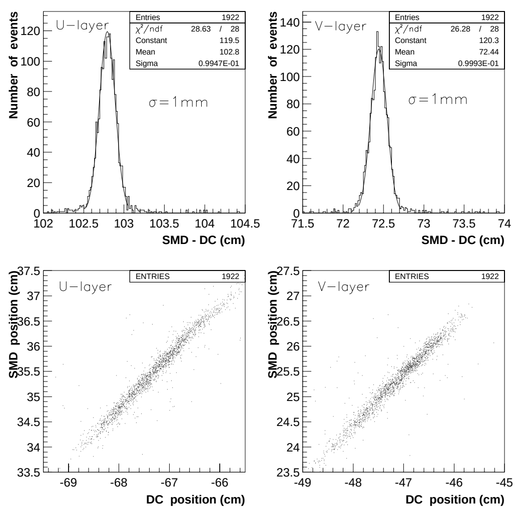
$$\mu = x_{max} + \frac{\Delta \log\left(\frac{E_{max}}{E_1}\right)}{2\log\left(\frac{E_{max}^2}{E_1E_2}\right)}$$

As shown in Fig. 4, the Lorentzian lineshape describes the e^+ shower profile better in both U and V views. The position resolution using the Lorentzian fit also provides a more reliable result.

6.2 Results of position resolution studies

The position of an incident particle extracted from the SMD response using the Lorentzian algorithm is determined in natural SMD coordinates, along the U and V axes, which are perpendicular to the strips in the corresponding layer. So, to compare this position with the measurement by the SWDCs it is necessary to transform the SWDC positions to U and V coordinates. The angle between the SMD and the SWDC coordinate systems was estimated from the knowledge of the test beam stand position and was then corrected by minimizing the spread of SMD–DC distribution for both U and V directions. Fig. 5 (top) shows the distribution of the difference between the position reconstructed by the SMD and the extrapolated SWDC position to the SMD plane for 57 GeV positrons. The standard deviation of this distribution is $1mm$.

The SMD position resolution for positrons in the range $10 - 180\,GeV$ is shown in Fig. 5(right plot). The points are well described by the function $\sigma = (38/E + 0.4)\,mm$. The uncertainty in the SWDC projection was $110\,\mu$. This uncertainty increased to $140\,\mu$ after extrapolation to the SMD plane, but its contribution is still too small (less than 2%) to influence significantly the SMD resolution.



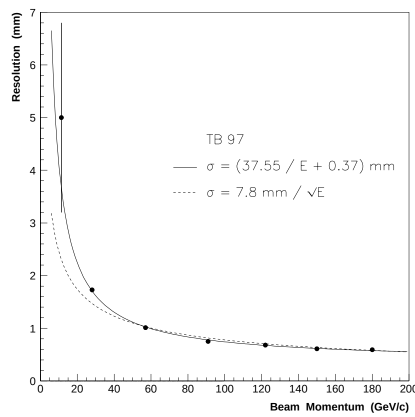


Figure 5: Top left: SMD position resolution for 57 GeV positrons. Bottom: The correlation between the SWDC's and SMD's position. Right: SMD position resolution for positrons in the range 10 - 180 GeV.

7 Conclusions

The Shower Maximum Detector has been calibrated with a precision of 5%, which satisfies the technical requirements. Test-beam results show good performance and an electromagnetic shower position resolution of $(38/E + 0.4)\,mm$.

References

1. The CDF Detector for Tevatron Run II, Technical Design Report, The CDF II Collaboration, FERMILAB-Pub-96/390-E (October 1996).
2. K.Goulianos, S.Lami, A.Solodsky. MiniPlug Calorimeter Performance at the 1997 CDF Test Beam, CDF Note 4279.