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ENERGY AND POSITION RESOLUTION OF SILICON CALORIMETER
USED IN THE UA7 EXPERIMENT

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ABSTRACT

The performances of a compact 4 inches in diameter, 20 radiation lengths Silicon/Tungsten calorimeter have been evaluated using electron and pion beams up to 100 GeV at the CERN SPS. The energy and position resolutions have been found respectively $(25\%/\sqrt{E} + 1.1\%)$ GeV and $3.8 \text{ mm}/\sqrt{E}$.

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1. INTRODUCTION

The aim of the UA7 experiment was to measure production cross section of photons and π^0 's in the fragmentation region at the CERN $\bar{p}p$ collider [1]. This requires compact Silicon/Tungsten calorimeters able to be installed inside "Roman pots" giving access to the photons emitted inside the beam pipe. The basic properties of these calorimeters have already been investigated in the lower energy region (< 5 GeV) [2,3], however, no study has been made beyond.

The most accurate absolute energy calibration is obtained in the UA7 experiment by reconstructing the π^0 mass. This implies good resolutions both in energy and position of the photon showers by adequate longitudinal and transverse segmentation. The information on the position resolution for such a calorimeter will also be important for future application of silicon calorimetry such as forward photon tagging in big accelerators and for cosmic gamma ray telescope around GeV region in satellites.

In this paper we present energy and position resolutions together with e/π separation obtained with our calorimeter. In the last part of the paper, an experience obtained during UA7 data taking is described.

2. EXPERIMENTAL SET-UP

The test experiment has been performed using the CERN SPS secondary beam line X7, with incident electrons and hadrons in the energy range between 5 and 100 GeV. The telescope (fig. 1) consists of a 4 scintillator hodoscopes, 2 horizontal and 2 vertical proportional wire chambers with 2 mm wire spacing. This leads to a beam position resolution in front of the calorimeter of 720 μm in both vertical and horizontal directions. The momentum spread of the beam was 1.2%. Electron/hadron separation has been obtained by two Cerenkov counters placed upstream. In addition five radiation lengths of tungsten have been placed behind the calorimeter to take into account of back scattering.

3. THE CALORIMETER AND READ-OUT SYSTEM

The test calorimeter is made with 20 radiation lengths in total of tungsten plates (fig. 2(a)). The longitudinal shower development is observed at 11 sampling points. The structure of the silicon wafer is shown in fig. 2(b). Four of them were segmented into strips, 5 mm wide for the X (horizontal coordinate) and Y (vertical coordinate) placed respectively at 6 and 10 radiation lengths. The strip width was 11 mm for the front Y plane and for the 45° oriented U-plane placed at 8 radiation lengths.

The shower signal is amplified by the linear preamp and shaping amplifiers, sent to a LeCroy 2281 ADC system and recorded using the LEP Aleph data acquisition system. The calibration of the preamplifier and ADC system is made by injecting a test pulse in front of the preamplifier. The test pulse itself is calibrated by a standard condensor, known within 1%.

The energy deposit in the Silicon has been calibrated using 976 KeV electrons from decay of isotope Bi(207). The thickness uniformity of each silicon wafer was better than 25 µm by construction. The absolute thickness varies from .8 to 1.2 mm and the depletion depth has been adjusted from one wafer to the other within 10% by a smooth fitting to the showers themselves.

4. RESULTS

The energy loss by the incident electrons in the front wafer is shown in fig. 3(a). Clear separation from the p.destal measurement is observed and the measured energy is in agreement with our Monte-Carlo calculation for one minimum ionizing particle.

The longitudinal electron shower development can be fitted by the following formula [2,3]:

$$N(t) = a f\left(\frac{t-t_0}{t_m}\right)$$

where:

$N(t)$ is the deposited energy in units of energy deposited by minimum ionising particles.

t = depth in radiation length

t_o = shower start

t_M = shower maximum

and the function $f(x)$ is defined by

$$f(x) = x^c \exp[b(1-x) + d(1-x^2)]$$

with:

$$a = 15. E^{.92}$$

$$b = 1.86 + .96 \ln E - .025 \ln^2 E$$

$$c = 2.03 + .72 \ln E$$

$$d = (c - b)/2$$

$$t_M = 4.26 E^{.15}$$

and E is the shower energy in $\text{GeV}^{(*)}$.

Fig. 4(a) represents the energy resolution of the calorimeter of tungsten plates. The data points agree well with the Monte-Carlo prediction $25\%/\sqrt{E} + 1.1\%$ [2]. The constant term comes from the limited number of the tungsten plates.

After correction for the losses due to the limited number of radiation lengths (1% at 10 GeV/c, 3.2% at 100 GeV), the linearity of the calorimeter is better than 1%.

The position resolution reduced for the beam position uncertainty is shown in fig. 4(b) as a function of energy. It can be expressed by $3.8 \text{ mm}/\sqrt{E}$. This dependence is in good agreement with the Monte-Carlo calculation described in ref. [2].

(*) The longitudinal electron shower development is equally reproduced by the formula given by the Particle Data group [4], with the appropriate normalization coefficient: $N(t) = 110 E (b^a/\Gamma(a+1)) t^a e^{-bt}$. A good approximation is also given by $N(t) = 6.5 E^{0.03 t} e^{-bt}$.

The longitudinal energy deposition has been fitted for both electrons and pions using the above formula leaving the parameter t_0 free, where t_0 is the starting point of the shower. The t_0 distributions for electrons and pions are shown in fig. 5 after a 2.5 GeV energy and a large χ^2 cuts. Only 2% of electron showers will start after four radiation lengths, whereas only 13% of pions interact before. By applying a four radiation length cut to the data, the rate of hadrons which would fit electrons has been found $(7.6 \pm 1.3)\%$, $(7.0 \pm .9)\%$, and $(5.8 \pm .5)\%$ respectively at 20, 50 and 100 GeV incident energy.

5. PERFORMANCES DURING UA7 DATA TAKING

A similar calorimeter with longitudinal segmentation every radiation length has been used for the first time in a physics experiment UA7. According to our Monte-Carlo extrapolation, the corresponding energy and position resolution will be respectively $(17/\sqrt{E} + 1.1)\%$ GeV and $(3.0 \text{ mm}/\sqrt{E} + .1)\text{mm}$. This is confirmed by the width of the π^0 peak shown in fig. 6. A typical double photon event is also shown in fig. 7.

In fact the absolute calibration obtained by the π^0 mass had to be readjusted over the whole data taking period due to radiation damage. During normal collider operation the expected total dose is two orders of magnitude less than the radiation damage (10^{13} single charged particles/cm²) obtained by isotope radiation. But the main damage occurred during beam losses and machine setting up. The decrease of the gain arose from the increase of the leakage current due to radiation and insufficient voltage supplied to the silicon wafers. When we increase the supply voltage after UA7 data taking, this tendency has recovered. The increase of leakage current happens due to a change of the quasi-intrinsic part of the silicon into P-type semiconductor.

6. CONCLUSIONS

The Silicon/Tungsten calorimeters used in the test experiment have shown good energy and position resolution amounting to respectively $(25/\sqrt{E} + 1.1)\%$ GeV and $3.8 \text{ mm}/\sqrt{E}$. This type of calorimeters will be suited for future use in forward photon tagging or cosmic ray telescope in the GeV region transported by satellite.

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FIGURE CAPTIONS

- Fig. 1 The layout of the experimental line at X7B. The beam centre is adjusted to come to the centre of 4 inch. tungsten calorimeter.
- Fig. 2 (a) The schematic view of 20 radiation length Silicon/tungsten test calorimeter. The longitudinal development of the showers is measured at 11 sampling points. The silicon wafer is put every two radiation lengths and X, Y, U-strips are respectively at 6, 10 and 8 radiation lengths from the first plane respectively.
- (b) The structure of 4 inch. silicon wafer. X and Y direction are segmented in 5 mms wide strips.
- Fig. 3 (a) Energy deposited by single electrons in the front silicon wafer showing clear separation from noise measurement.
- (b) The calculated number of detectable electrons created by the electron shower as a function of the depth in radiation lengths at various energies together with the experimental data points.
- Fig. 4 (a) The energy resolution of the test calorimeter is given by as a function of incident electron energy. The curve corresponds to the Monte-Carlo prediction.
- (b) Position resolution of the present calorimeter. Lower points are for X-direction (5 mm distance) and upper points correspond to the U-chamber (1.1 cm distance). The position resolution of the beam ($\sigma = 0.72$ mm) has been reduced from those data. The curve is the Monte-Carlo prediction.
- Fig. 5 Starting point distribution for electron and pion induced showers. Both incoming energies are 100 GeV. The minimum shower energy (threshold energy) is set to > 2.5 GeV.

FIGURE CAPTIONS (Cont'd)

Fig. 6 The double photon mass spectrum showing a clear π^0 peak.

Fig. 7 A double photon event from π^0 decay in the 4 inch. Si/W calorimeter.

Fig. 1

Fig. 2

Fig.3

Fig. 4

Fig. 5

Fig. 6

Fig. 7