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SILICON TRACKING CALORIMETER FOR ANTIMATTER SEARCH IN SPACE:FIRST EXPERIMENTAL RESULTS FROM A PROTOTYPE

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ABSTRACT

This report presents the preliminary results of the performances of a prototype of a silicon tungsten calorimeter, which has been conceived as a high-granularity tracking calorimeter for cosmic ray studies. The calorimeter contains 20 XY sampling planes interleaved with 19 showering material planes (W, 0.5 X_0 = 1.75 mm). One sensitive plane is obtained with two silicon strip detectors (Si-D) (60 x 60) mm^2 divided in 16 strips 3.6 mm wide. The strips of the two detectors are perpendicular to each other in order to provide the transverse distributions in both coordinates at each sampling. The basic characteristics of the design and the first experimental results obtained at a test beam at CERN PS for 2, 4 and 6 GeV electrons and pions are reported. The main results here presented are: the response of the calorimeter to the electron energies, the transverse shower profiles at different calorimeter depths as well as the patterns of the electron induced electromagnetic shower and those of the interacting and non interacting pions. The angular resolution has been measured for electron showers at 4 GeV.

The calorimeter performances and the adopted design criteria are also considered for possible applications to preshower detectors.

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1 - INTRODUCTION

This paper describes the design and the first experimental results of a silicon tungsten calorimeter (Si-W) characterized by high granularity.

This apparatus is a prototype tower of the calorimeter conceived for the experiment WiZard [1] to explore, in a planned space mission and in conjunction with a momentum analyzer superconducting magnet, a Transition Radiation Detector and a Time of Flight system, the primary antimatter component in cosmic rays.

A minimum ionizing particle (m.i.p.) produces about 80 electron-hole pairs per µm of detector crossed; the corresponding charge collection is a linear process not subject to instabilities or non linearity effects. These characteristics make the silicon a very interesting material for calorimetric applications. The segmentation of each silicon detector (Si-D) naturally provides a high spatial granularity to the calorimeter. The position of the shower profile is measured at each sampling plane in both X and Y coordinates.

This granularity and the good energy resolution of the silicon detectors provide the ability of measuring the shower profile for particle identification with high accuracy also in absence of the full shower containment. Indeed, the allowed weight for the mentioned space applications limits the calorimeter depth to 10 X_0, which is insufficient for full energy containment of high energy electrons (or positrons) and hadrons (pions, protons and antiprotons).

Experimental data from calorimeters based on silicon as an active material have already been previously published (see for example refs. [2] - [6]). In this paper more evidence is given to the results concerning the high segmentation and the tracking capability. This prototype calorimeter is the first built with Si-D's having an area of (60 x 60) mm^2. The detectors are fixed in a special package which, when patched to form a (50 x 50) cm^2 surface, allows a minimal dead area for the sampling planes of the calorimeter to be used in space.

The Si-W calorimeter can play a decisive role in the event definition, especially for the search of antimatter in cosmic radiation.

Moreover, the data from the first few planes of the calorimeter can be considered as a starting point for the design of a preshower detector.

2 - THE TRACKING CALORIMETER

The test calorimeter, 9.5 X_0, consists of 20 layers of X and Y pairs of silicon detectors(*) of area (60 x 60) mm^2, alternated with 19 planes of high Z material (tungsten), each of 0.5 X_0 (1.75 mm). The detector planes are equally spaced, with a pitch of 24 mm and the tungsten in the middle. All the material crossed by the incident beam before the prototype corresponds to 0.2 X_0.

The design of this prototype has been driven by the requirements, common to all experiments in space, of limited weight, low power consumption and high reliability of the detectors. Moreover, the structural constraints affect the geometrical parameters of the calorimeter and, in particular, the distance between the sensitive planes. An optimization related to the strip pitch has been obtained through a Montecarlo calculation [7]. The resulting particle identification power for the chosen segmentation corresponds to that one needed to identify matter and antimatter components in the cosmic radiation, in conjunction with the other detectors of the apparatus of WiZard.

(*) Built at Camberra (Belgium), Hamamatsu (Japan) and SGS (Italy).

Two Si-D detectors are mounted back to back with perpendicular strips, as shown in Fig. 1, to give X and Y coordinates. Their general characteristics are listed in the following table:

•Total area	(60 x 60) mm^2
•Number of strips	16
•Thickness	(380 ±15) μm
•Strip pitch	3.6 mm
•Substrate	n-type, float-zoned (FZ) Si, R ≥ 4 kΩcm
•Readout coupling	Ohmic

The two detectors are packaged on a ceramic support with an on-line pin structure. The dead area, due to the wire bonding to the ceramic support, is less than 2%. All the Si-D's used in this calorimeter prototype are analyzed before, during and after the packaging procedure, and the parameters of each strip are stored in a data-base, available for studies of ageing, radiation resistance and stability. Fig. 2 shows the results from typical measurements of the strip dark current and capacity vs. the bias voltage. Each detector assembly is mounted on a multilayer board which also carries the front-end electronics and the related wiring. The calorimeter is contained in a metallic box where one of the walls is made of a multilayer board to provide the connections of the detector's card to the outside digitizing electronics.

A schematic drawing of how the Si and W planes fit into the box is shown in Fig. 3.

Also the design of the read-out electronics [8] has been specifically developed to take into account the future application of the calorimeter for space research. It is optimized for low power consumption (15 mW/ch) and low electronic noise, i.e. ≤ 2700 electrons r.m.s. for 1000 pF. The final version of the calorimeter, where the strips of each Si-D will be connected to the neighbouring one to form the 50 cm long strips of the plane, will imply a large input capacitance. Two full scale outputs are available and give a linear response up to 25 or 400 m.i.p., respectively, for a 300 μm thickness silicon detector. This range covers the very large dynamics required in the tracking calorimeter. The read-out is performed via a multiplexing system at a maximal frequency of 1 MHz.

An analog timing-out bipolar signal allows the auto-triggering based on the amount of the energy released in a given section of the calorimeter.

For the tests at CERN the data from the front-end electronics have been digitized in a standard acquisition system, allowing the storage of a complete event, and have been transferred via VMEbus to a microcomputer system (VALET-PLUS) for recording and on-line monitoring.

3 - EXPERIMENTAL RESULTS

The prototype of the WiZard Si-W tracking calorimeter has been exposed to the PS Test Beam T7 at CERN, where a magnetic channel can select negative or positive charged particles of momentum between 1 and 8 GeV/c ($\Delta p/p = \pm 1\%$).

The beam geometry and the arrangement of the counters are shown in Fig. 4. The dimensions of the beam spot at the calorimeter entrance were defined by a circular counter S_2 of 1 cm in diameter. The trigger was provided by the following logical combination

$$C_1 \, C_2 \, S_1 \, S_2 \, \bar{S}_3$$

of the S_i scintillators and the C_i Cerenkov counters. This logic allowed the identification of electrons and pions and opened the sequence of the read-out electronics.

Data have been collected in different runs at beam energies of 2, 4 and 6 GeV. The transverse and longitudinal energy containments for this prototype at these values, as obtained from a Montecarlo calculation, can be deduced from Table I where the respective percentage of leakage is given.

TABLE I - Calculated transverse and longitudinal leakage at three energies 2, 4 and 6 GeV.

	Leakage	
E_{inc}(GeV)	Longit. (% of E_{inc})	Transv. (% of E_{inc})
2	6.5	31
4	9.3	29
6	11.5	29

The calibration of the correspondence between the collected electric charge and the energy loss of a m.i.p. crossing a Si-D has been obtained for each plane from the charge distribution corresponding to the energy deposited by non interacting pions in all the strips. The calibration matrix has been obtained strip by strip by moving the prototype in the two transverse directions with respect to the beam by means of a remote controlled mechanical support.

The typical response of the strips to a m.i.p. is given in Fig. 5 where the distribution of the m.i.p. energy loss is given in units of ADC channels. From this figure it is also possible to evaluate a signal-to-noise ratio of better than 20 for the present input capacitance of 80 pF.

The total charge released in the calorimeter by electrons at different energies (expressed in m.i.p. units) is given in Fig. 6 compared with the Montecarlo simulation. The response of the calorimeter, in this energy range, is linear as expected. In fact, from Tab. 1 it is possible to deduce that the calculated difference in the response due to the transverse leakage at the three energies cannot be more than 2% and that the variation for the longitudinal leakage, at the same energies, is not higher than 5%.

Fig. 7 shows the energy resolution of the calorimeter for the three energies (2, 4, 6 GeV) compared with the expected values as computed by Montecarlo simulation. In this simulation, the beam enters into the calorimeter exactly at its center and only the sampling fluctuations have been considered excluding any other source of noise.

The total energy released by the electron shower is measured with a fine transversal and longitudinal segmentation due to the high granularity of the calorimeter. Fig 8 shows the longitudinal development (experimental and simulated) of the showers initiated by 2 GeV electrons; the energy released is sampled over the 20 sensitive planes. Here the Montecarlo simulation gives the absolute values of the energy released in each plane in m.i.p. units.

Fig. 9, represented as a Lego plot, simultaneously shows the longitudinal and the transversal energy distributions for 2 GeV electrons. The energy released in each of the 20 sensitive planes is sampled over the 16 strips per plane. From this plot it is also possible to see that the electron beam was impinging on the calorimeter at the central area of the first plane.

The tracking calorimeter increases the discrimination power between electrons and hadrons, even in the absence of the full energy containment, by sampling the shape of the shower development at each sensitive plane. In Fig. 10, the transverse shower profiles for 4 GeV electrons are shown at the calorimeter depths of 2, 4, 6 and 8 X_0's for the horizontal strips.

The same information also allows the measurement of the electron directions. As an example, Fig. 11 displays the distribution of the differences between the two centers of gravity $<x>_i$ of the transverse profile of the electromagnetic shower, as measured in the first and in the last plane. The ratio of this difference to the distance d between the two planes is:

$$R = (<x_{20}> - <x_1>) / d = (-2 \pm 20) \text{ mrad}.$$

This value of R confirms, within the error, the relative alignement between the beam direction and the calorimeter axis. The dispersion provides the resolution in the angular measurements of the electron shower of the calorimeter. This demonstrates the pointing capability of the detector to match tracks or to point to sources of photons.

Fig. 12 shows the distribution of the differences between the centers of gravity of the transverse shower profiles for two contiguous planes (24 mm apart) around the shower maximum for electrons of 4 GeV initial energy. The mean value of this difference is in agreement, within the errors, with the alignment; the width of the distribution is related to the accuracy of the determination of the position of the center of gravity of the shower maximum. The sigma of this distribution, simulated around the center with a Gaussian, is of the order of 1 mm, corresponding to about 1/4 of the dimension of the strip.

The same analysis, applied to two contiguous sensitive planes after 2 X_0, provides information concerning the possible use of the first part of the calorimeter as a preshower detector. The origin of the shower induced by 4 GeV electrons is measured in the transverse direction with an accuracy of about 2 mm, as one can infer from Fig. 13.

The Si-W tracking calorimeter also reconstructs the event patterns giving further information about the nature of the particle interaction. Some examples of event reconstruction for 2 GeV/c momentum particles are reported in Figs. 14 a)-b), where the difference between the pattern of the shower induced by electrons and pions is clearly visible. The numbers in the position of the Si-D strips indicate the energy released by the particles crossing the strip in m.i.p. units.

CONCLUSIONS

The preliminary test on the single tower of the full silicon tracking calorimeter has shown the good capability of this instrument to give detailed information on the shape of the shower development. This is used for the discrimination among differently interacting particles, as required in the antimatter space research program. This result has been achieved through the good energy resolution of the calorimeter coupled to its high granularity. The calorimeter can measure the direction of the photon induced shower with an accuracy of a few mrads and can be used as a directional detector in the search of point-like sources in space.

The preshower capability of the first part of this calorimeter has been also experimentally proven.

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We would like to thank L. Andreanelli and F. Bronzini, of the University "La Sapienza" of Rome, for their effort in producing a high precision automatic mechanical support for the calorimeter. We would also like to thank the CERN PS machine staff and, in particular, the PS Coordinator R. Landua. Finally, our warm appreciation goes to K. Batzner for his help in the beam set-up.

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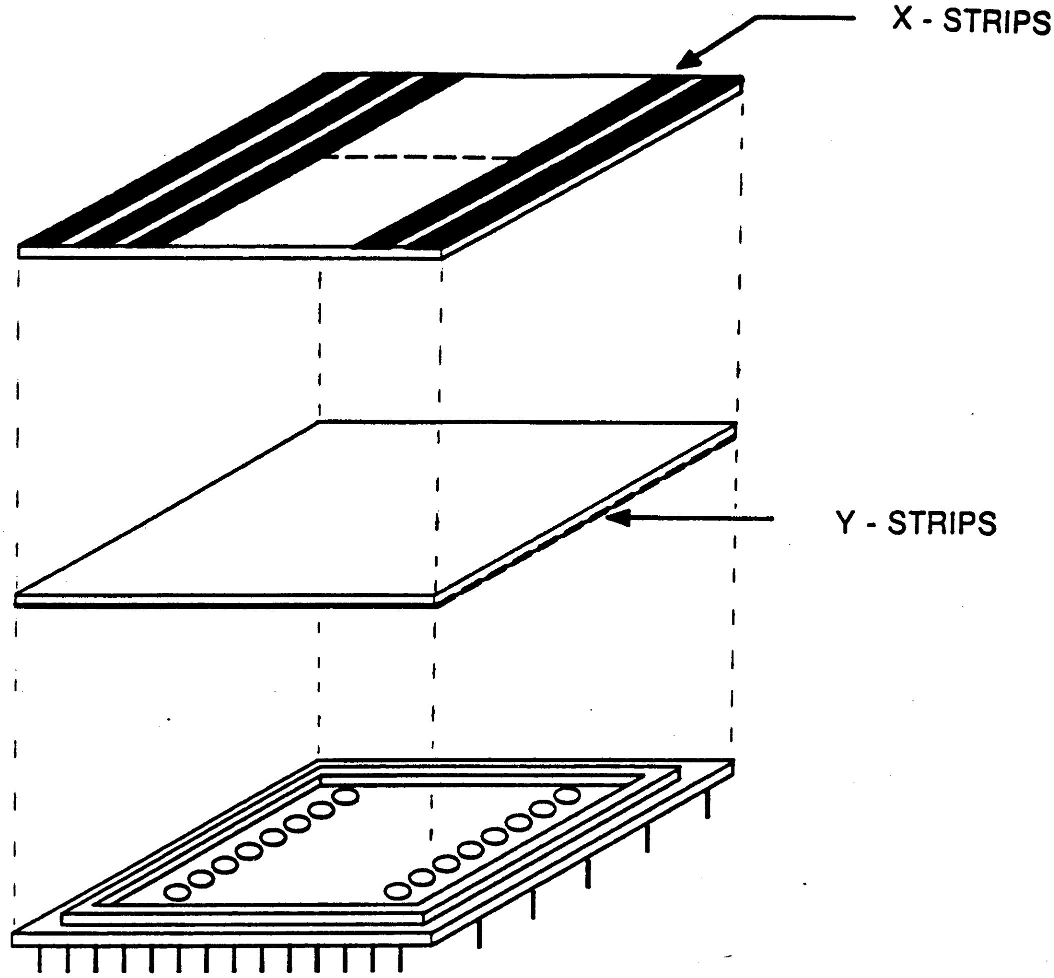

FIG. 1 - Exploded view of the lay-out of the packaging of two detectors with perpendicular strips.

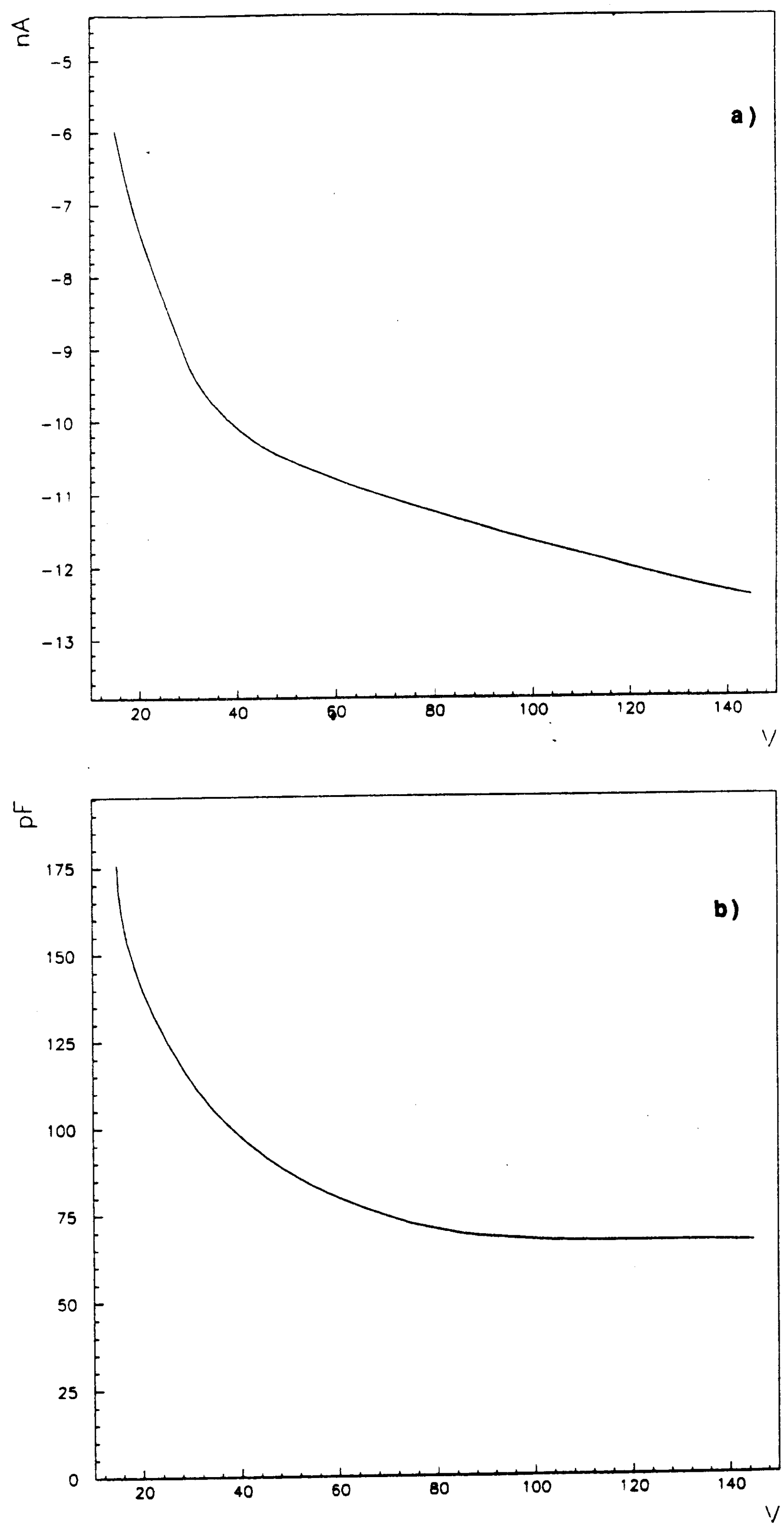

FIG. 2 - **a)** Typical Current-Voltage characteristics for a (3.6 x 58) mm^2 area strip; **b)** Typical Capacity-Voltage curve, showing the on-set of full depletion.

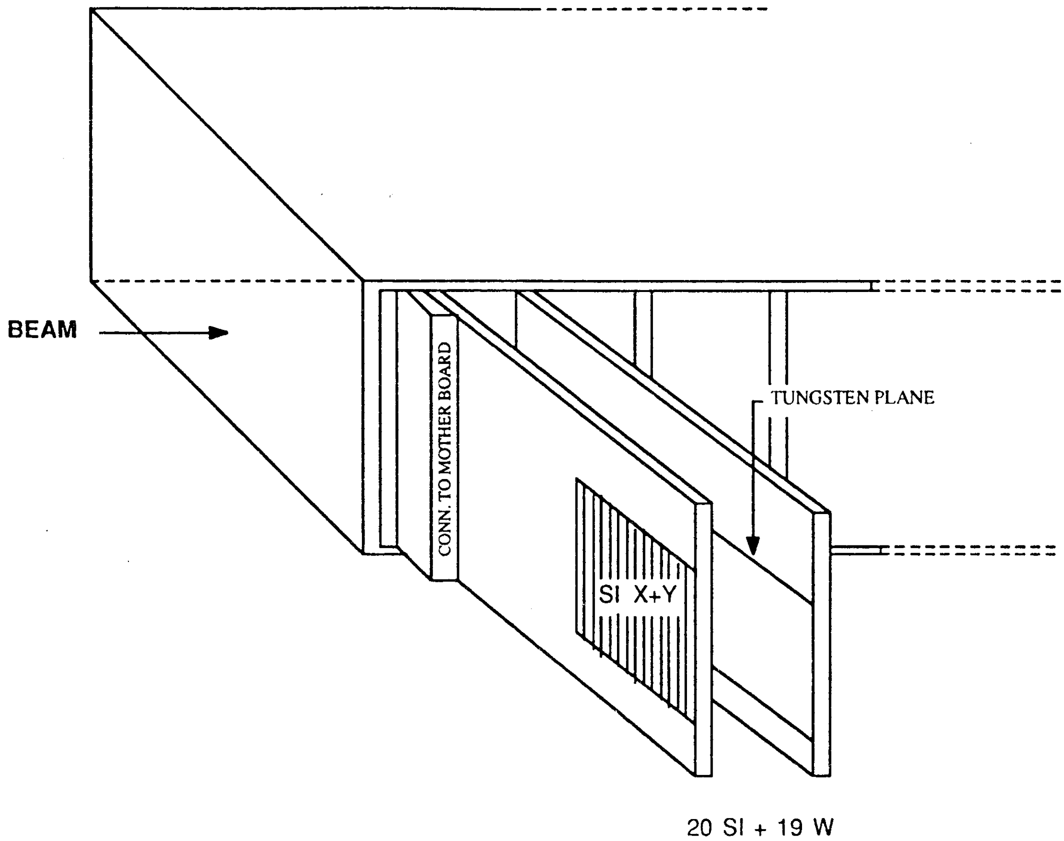

FIG. 3 - Pictorial view of the sequence of the sensitive Si-D's and the shower tungsten planes of the calorimeter into the test box.

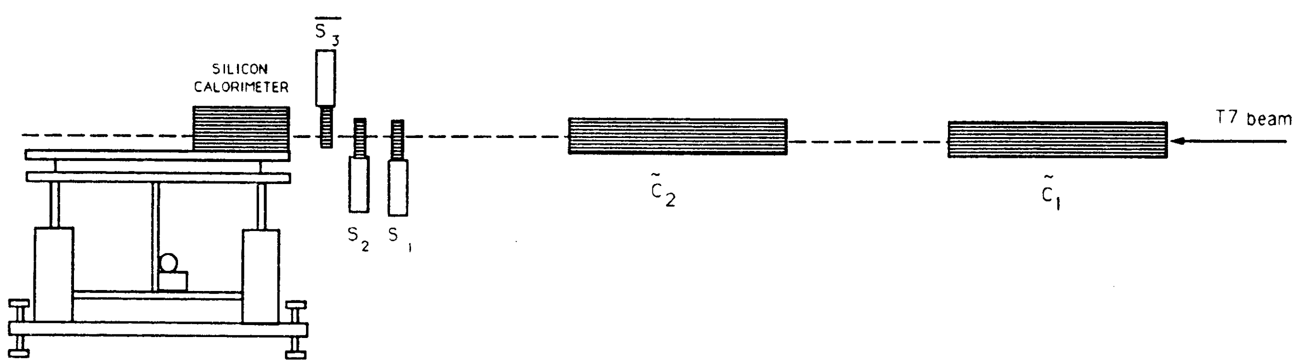

FIG. 4 - Schematic view of the arrangement of the beam set-up.

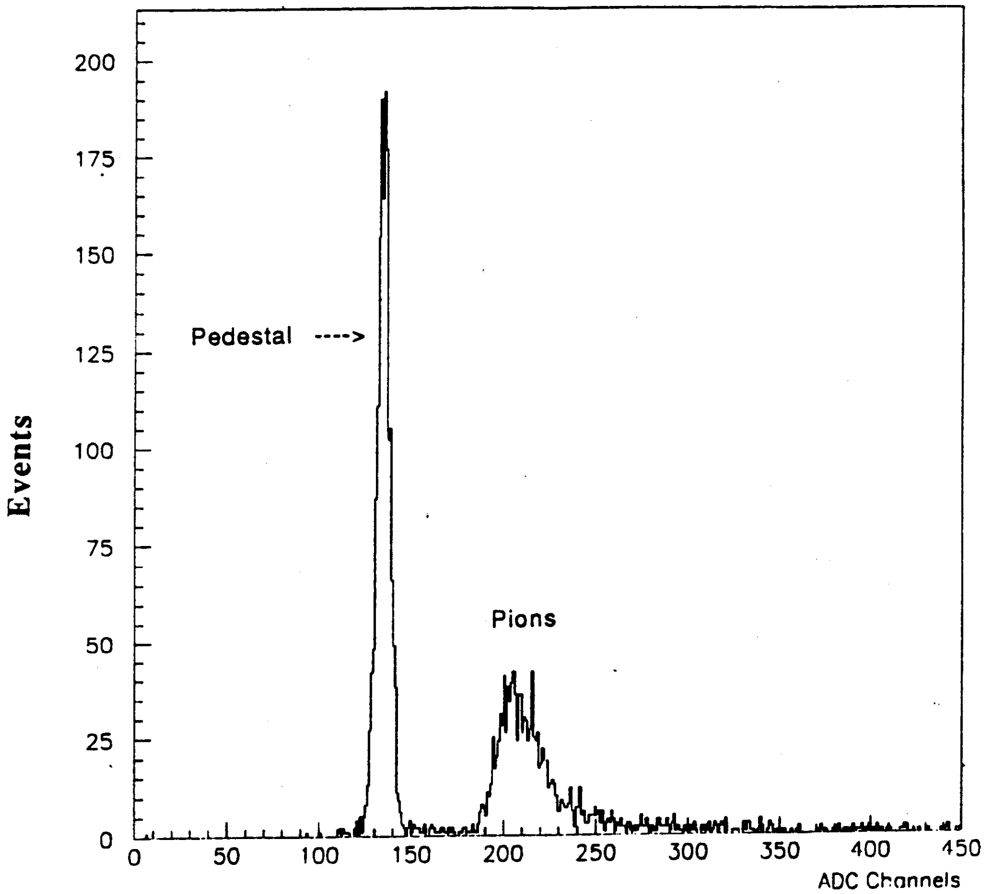

FIG. 5 - Energy loss distribution for 2 GeV pions crossing a single Si-D.

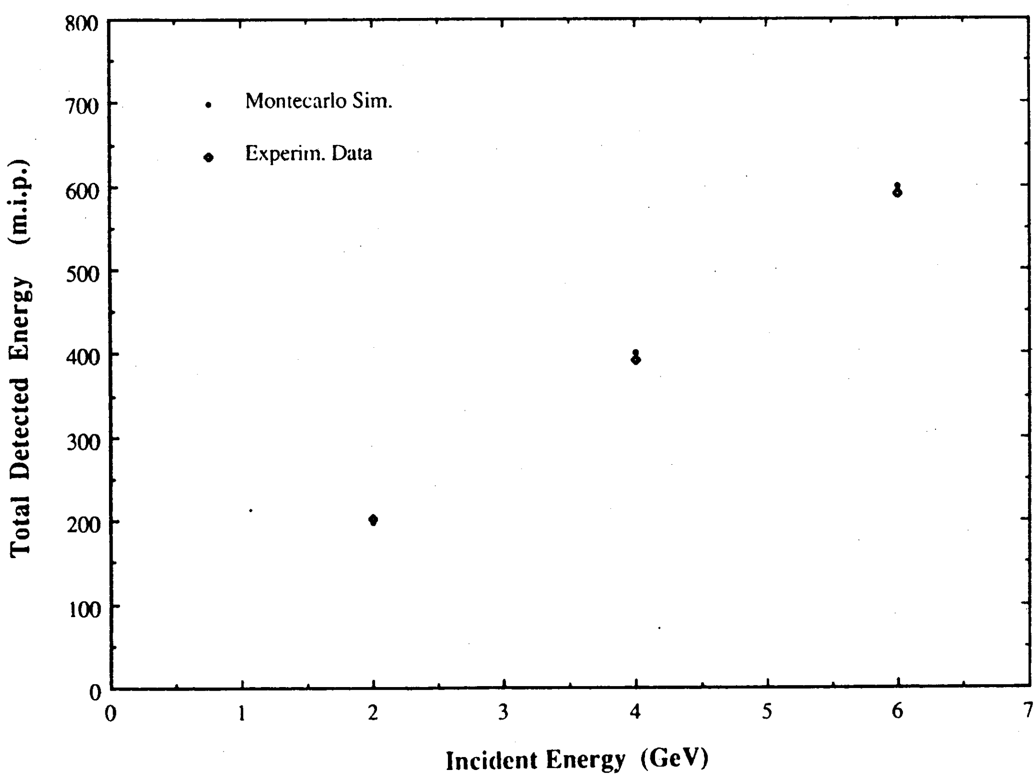

FIG. 6 - Energy linearity plot for 2, 4, 6 GeV electrons. The collected total mean charge Q is given in m.i.p. units versus the particle energy.

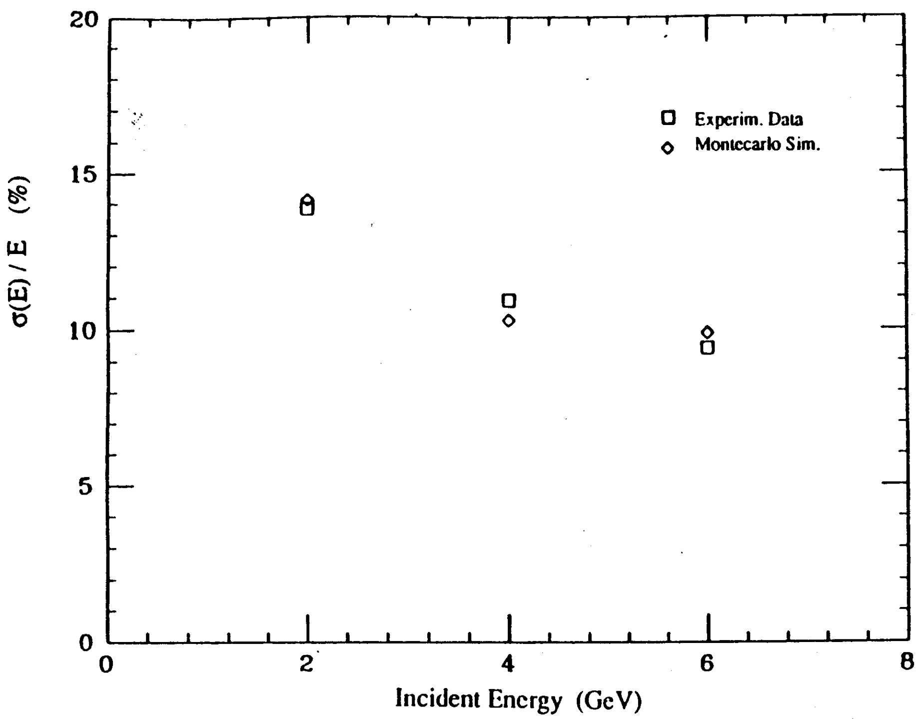

FIG. 7 - Energy resolution for the measured energies (2, 4, 6 GeV) compared with Montecarlo simulation.

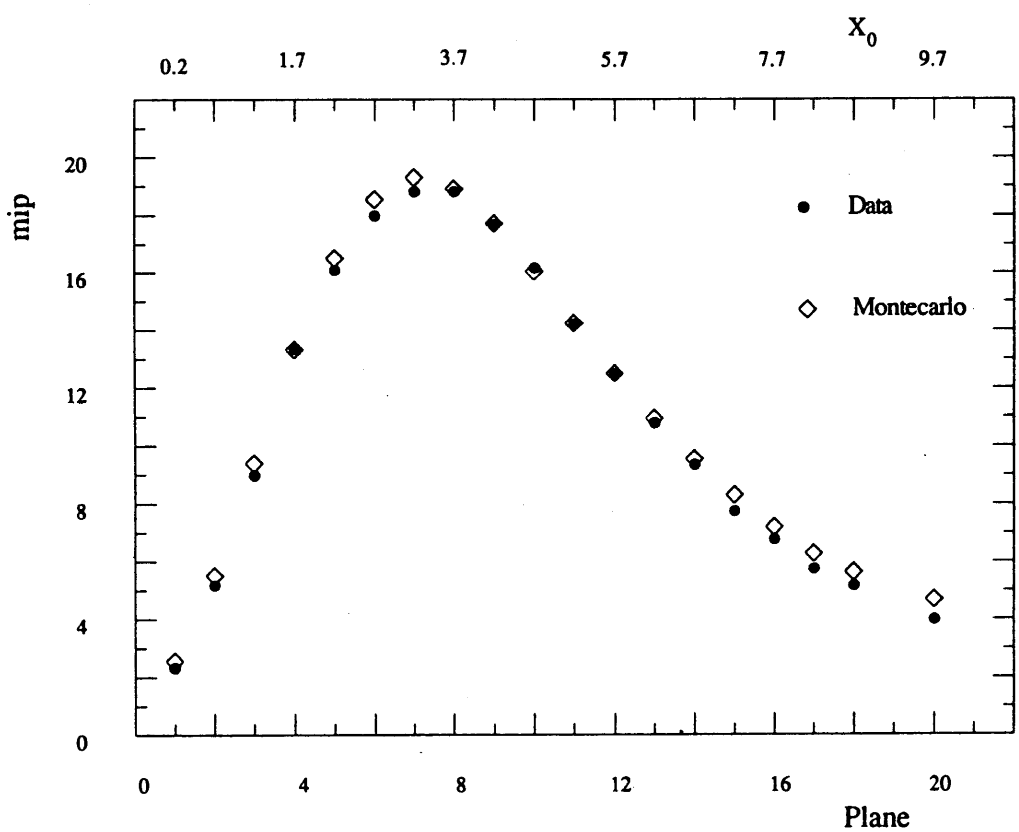

FIG. 8 - Longitudinal development (experimental and simulated) of 2 GeV electron shower. The energy is sampled over 20 sensitive planes.

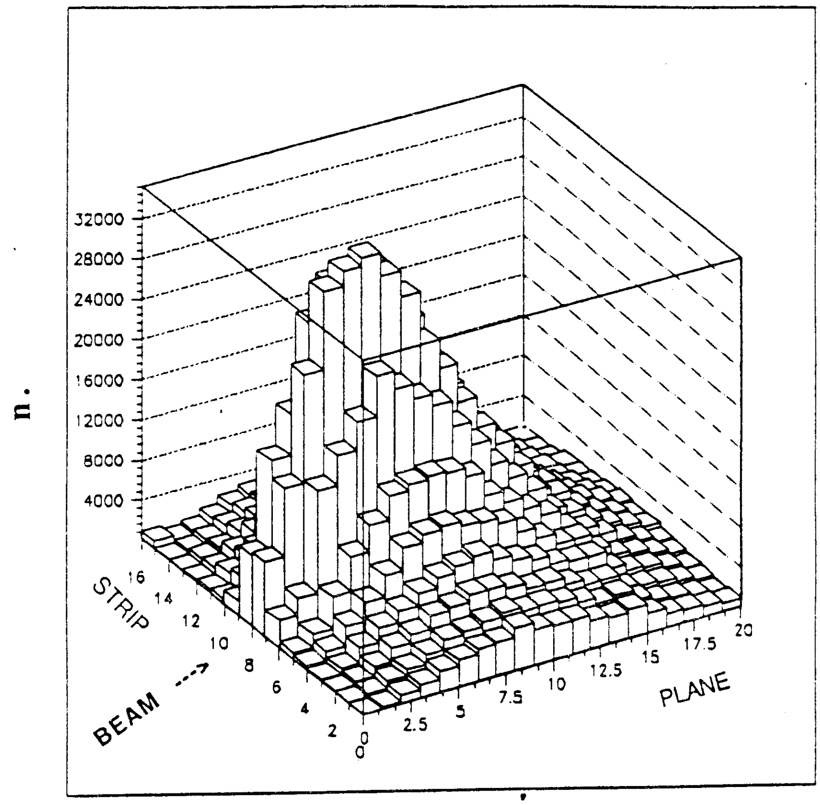

FIG. 9 - Lego plot of the longitudinal and transversal energy distributions for 2 GeV electrons.

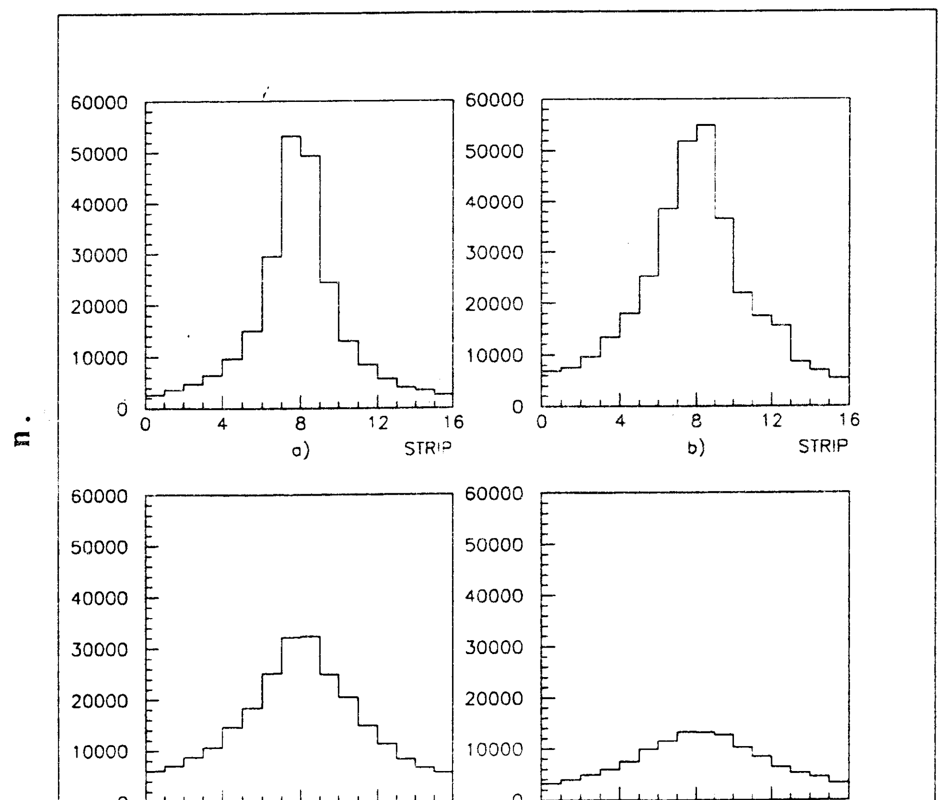

FIG. 10 - Transverse shower profiles for 4 GeV electrons at the calorimeter depths: a) $2X_0$; b) $4X_0$; c) $6X_0$; d) $8X_0$.

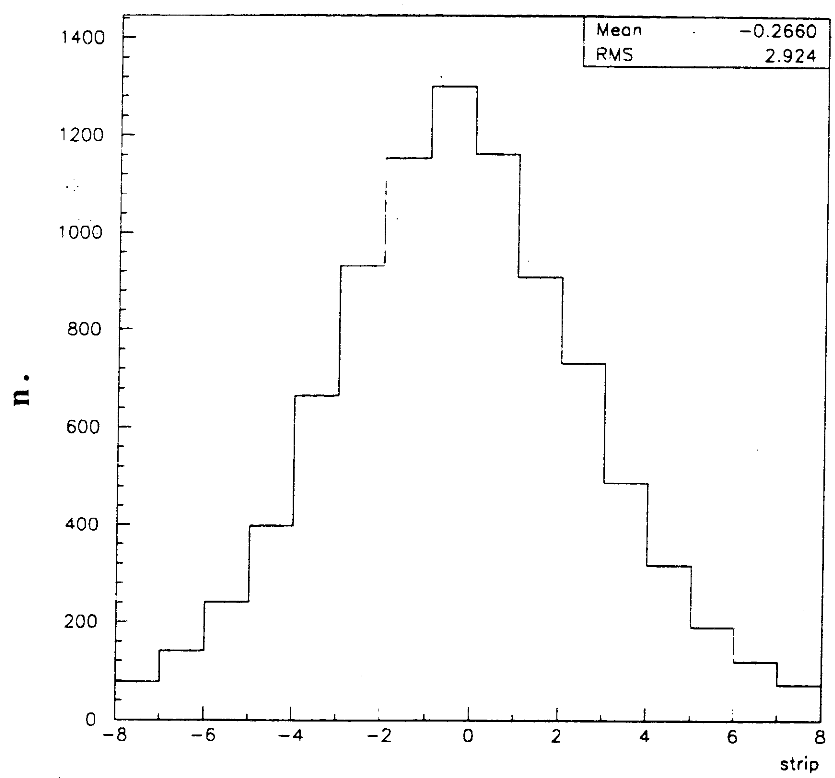

FIG. 11 - Distribution of the difference between the centers of gravity of the energy shower profiles of the first and the last plane of the calorimeter for 4 GeV electrons.

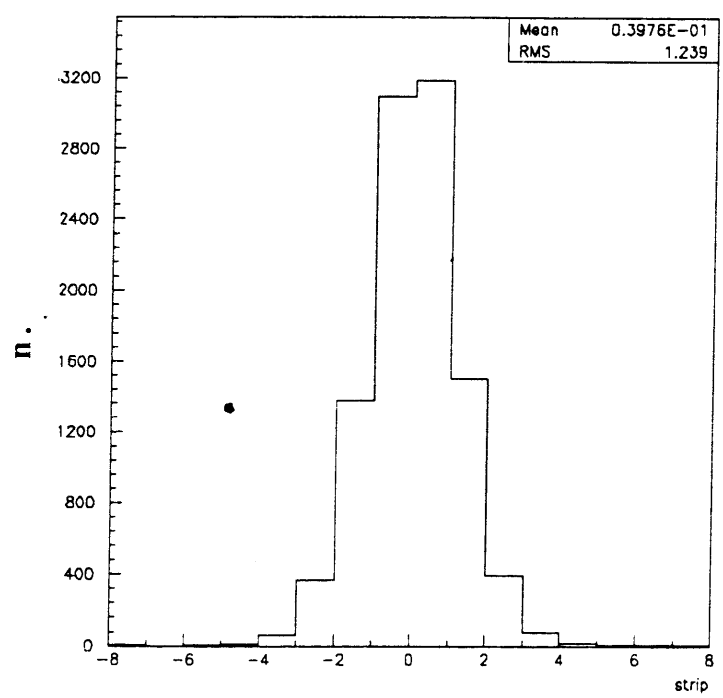

FIG. 12 - Distribution of the difference between the centers of gravity of the energy shower profiles for two contiguous planes around the shower maximum for 4 GeV electrons.

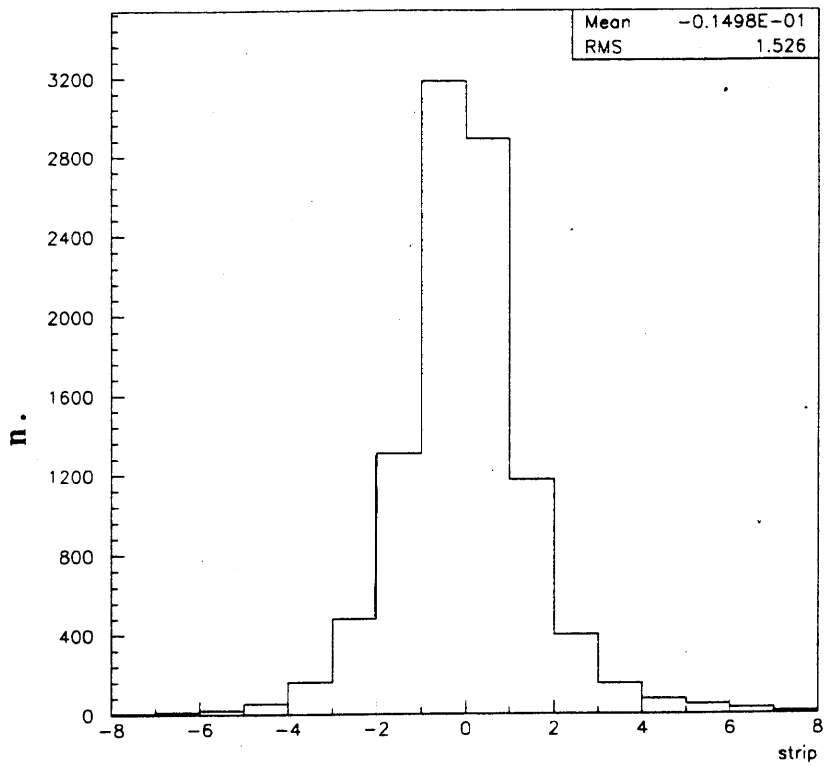

FIG. 13 - Distribution of the difference between the centers of gravity of the energy shower profiles of two contiguous planes after 2 X_0 for 4 GeV electrons.

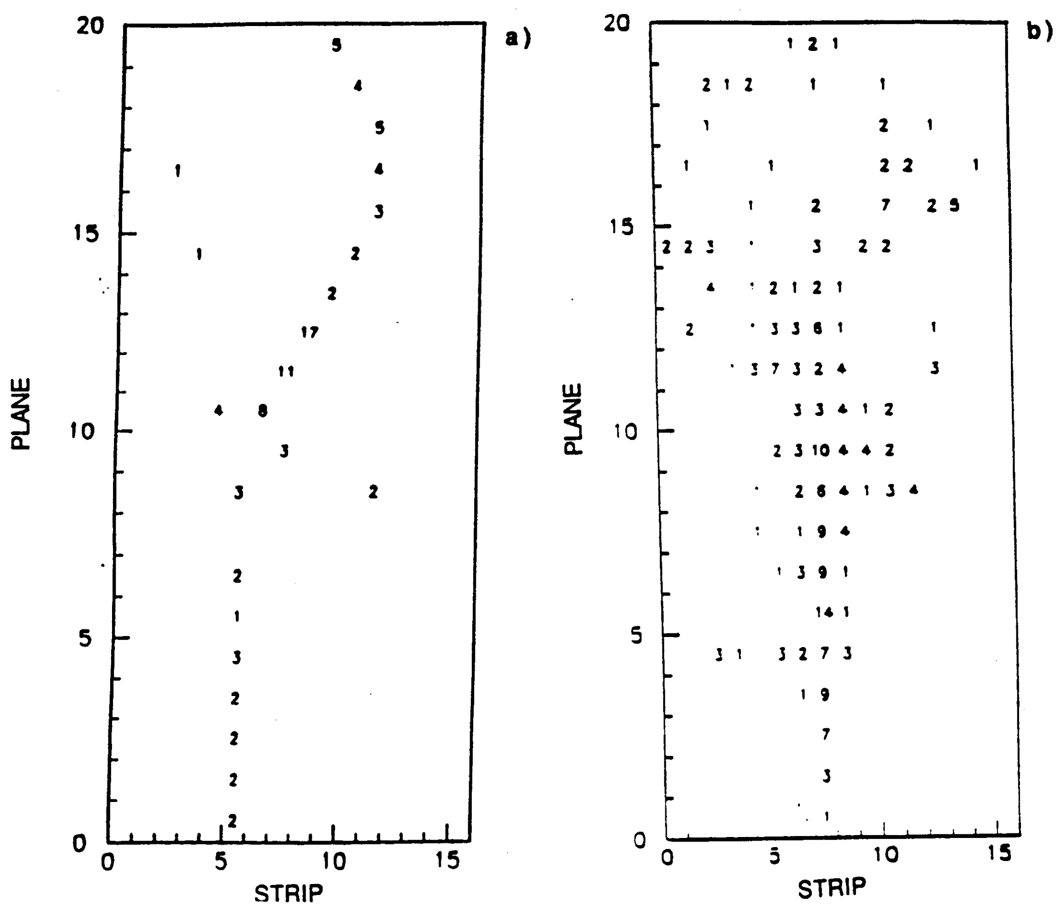

FIG. 14 - Examples of pattern reconstruction for 2 GeV/c particles: a) interacting pion; b) electromagnetic shower, Numbers are given in m.i.p. units.