Silicon Calorimeter for Cosmic Antimatter Search

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Abstract

The silicon sampling calorimeter presented is conceived as a fine grained imaging device to carry out studies of the anti-matter component in the primary cosmic radiation; it will be used in balloon payload program starting in 1993. The first sampling layer (48×48 cm^2) of this silicon calorimeter has been completed and successfully tested. We report the first results form studies performed at the CERN PS t7 beam.

The complete calorimeter contains 20 xy sampling layers (strip pitch 3.6 mm) interleaved with 19 showering material planes (tungsten 0.5 X$_0$). This allows to picture the transverse distributions of the shower in both coordinates at each sampling. The outstanding imaging capabilities reflects in high particle identification power. Preliminary results from beam tests performed with antiprotons at 3.5 GeV on a tower prototype of the calorimeter are reported.

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1. INTRODUCTION

The detector is conceived for the WiZard [1] experiment to investigate, in a planned space mission, the antimatter component in primary cosmic radiation [2]. Beside the calorimeter, the WiZard apparatus is composed of a momentum-analyser superconducting magnet with drift-chamber tracking, a transition radiation detector, and a time-of-flight system.

The main objective of the WiZard experiment is to study the antimatter component in the primary cosmic radiation. The energy spectra of antiproton and positron will be observed to study the production and propagation mechanisms [3]. The detector will be used in conjunction with a balloon experiment to study the energy spectra of the primary cosmic antimatter in different energy regions. The new calorimeter will considerably improve the performances of the existing balloon lay-out [4] as far as geometric acceptance and particle identification power are concerned. The calorimeter will deliver complementary informations to aid in particle identification with very high discrimination power.

The tasks that the imaging calorimeter will perform include: discrimination of e^+ and protons (error less than 10^{-4}), discrimination of e^- and antiprotons (error less than 10^{-3}), allow more detailed studies on antimatter candidate events and gamma conversions.

Meanwhile all the constructive details which have been set considering the final application in space will find in the balloon flight very realistic working conditions.

The allowed weight for the mentioned applications limits the calorimeter depth to about 10 radiation length (X_0), which is insufficient for the full energy containment of high-energy electromagnetic particles. The good granularity and energy resolution of the silicon detectors make them capable of measuring the transverse and longitudinal shower profiles and the tracks of the particles with high accuracy, thus allowing good particle identification also in the absence of the full shower containment [5].

2. THE SAMPLING PLANE

High longitudinal and transverse segmentation and large dynamic range are the characteristics of this detector which has a high quality track and showering-imaging capability. Beside its characteristics as a particle identifier, the calorimeter achieves good accuracy (a few mrad) in reconstructing the direction of the incoming particle [2] and can be used in the search for γ rays point-like sources in space.

The design of the detector for space applications has to satisfy the constraints of low weight, minimal power consumption, and high reliability. The

Table 1

Calorimeter characteristics

Total sensitive area	492×492 mm^2
Single detector dead area (guards, edges)	5%
Assembled plane total dead area	10%
Thickness of the Si-D per sampling	2×380 (or 300)μm
Single detector area	60×60 mm^2
Total amount detectors per plane (x and y)	$(8 \times 8) \times 2 = 128$
Pitch of the strips on the Si-D, (16 strips)	3.6 mm
Mean leakage current	10 nA cm^{-2}
Working voltage (>full depletion)	≤ 110 V
Crystal n-type, (FZ), resistivity	≥ 4 kΩ cm
Read-out coupling	ohmic
Strip capacitance	≈ 70 pF
Number of electronic channels per plane	256
Front-end power dissipation per channel	15 mW
Total input capacitance to the pre-amplifier	~ 500 pF
Mean electronic noise (7μs shaping time)	3500 ENC
Thickness of the tungsten plates	1.75 mm (0.5 X_0)
Total depth (W)	9.5 X_0
Total calorimeter thickness	35 cm

Table 2
Packaging specifications

Supporting board :	Ceramic (Al_2O_3) 96% , thickness 0.025".
Metallic circuit on the supporting board:	The circuit allows the connection of strips, guard, and substrata to the corresponding pins. a base of Mo/Mg, a layer of Ni ($2+3\mu m$) and a final Au sheet ($0.5-1.$ μm) are used. The connections from the detector to the substrata are realized with ultrasonic bonds.
Pins:	There are 34 pins having 0.45 ± 0.05 mm diameter and 3.5 ± 0.1 mm length, they are completely imbedded in the ceramic, in the upper part, and soldered to the circuit (Cu/Ag).
The lower detector:	Is glued (Down-Corning RTV31450) to the supporting board the stripes are centred on the bonding holes and the detector is perfectly aligned to three edges of the ceramic. Stripes, substrata and eventually. guard, are bonded through the supporting board to the pins (the wire is Al/Si 33 μm diameter).
The upper detector:	The two detectors are glued back to back with conductive epoxy (Epotek H20E), the stripes are aligned to the related bonding pads. The two detectors are perfectly aligned.The edge of detector where the bonding will be realized is coated (H70E resin), then the bonding executed and the bonding self coated (H70E).
Finishing:	The packaging is coated on the most exposed upper part with silicone resin (General Electric RTV615)

geometrical parameters of the calorimeter (like the distance between the sensitive planes) are affected by the structural constraints imposed by the unusual stress occurring in different phases of the flight. The transverse granularity was chosen for the aim of the WiZard apparatus through Monte Carlo calculations [5].

The complete detector, whose characteristics are reported in table 1, consists of 20 layers of silicon detectors alternated with 19 planes of tungsten.

One sensitive module is composed of two Si detectors, each having a volume of ($60\times60\times0.38$) mm^3, mounted back to back with an on-line pin structure and perpendicular strips to give x and y coordinates, each detector has 16 strips 3.6 mm wide [2]. In our application the detectors are hold in a special package which, when patched to form large surfaces, allows a minimal dead area for the sampling planes of the calorimeter. The details of that packaging are given in table 2, the used materials are approved by NASA for space applications. A drawing of the detector module is given in Fig. 1.

The packaged silicon detectors are assembled on a multilayer board, which also carries the front-end electronics and the related wiring. The strips of each detector are connected to the neighbouring one to form single strips 50 cm long.

The design of the readout electronics has been specifically developed to take into account the future application of the calorimeter in space research. Two full-scale outputs are available and give, a linear response up to 25 or 400 minimum ionizing particles, respectively. The readout is performed by means of a multiplexing system at maximal frequency of 1 MHz.

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

The picture in fig. 2 shows the assembled sampling layer the copper sheet covers the front end electronics for the x and the y sampling disposed on two edges of the plane.
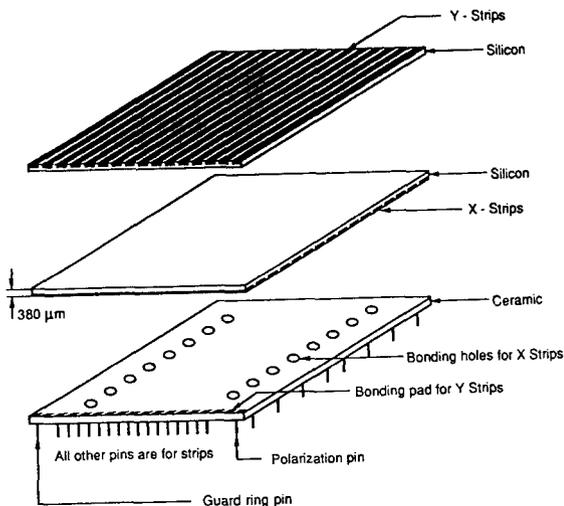
Fig. 1 - Drawing of the x y Si detector module showing how the two detectors are held on the ceramic plate.
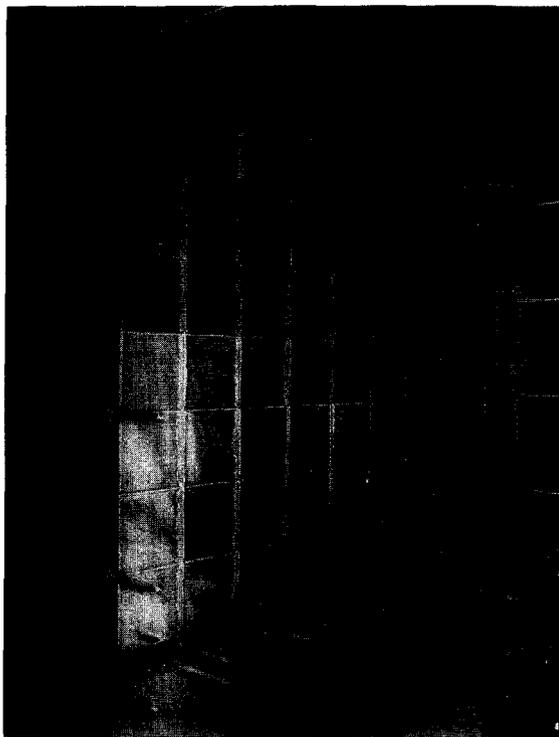
Fig. 2 - Picture of the sampling plane in the test beam area. Visible are the 48 x y detector packaging already assembled on the multilayer board, on two edges covered by copper screens are the pre-amplifiers.

3. RESULTS

3.1 The sampling layer has been exposed to the PS Test Beam t7 at CERN, the beam geometry and the arrangement of the telescope counters were the same used for an extensive study of the calorimeter behaviour described in ref. [2]. Two Cerenkov counters for the identification of electrons and pions were used.

Data from the front-end electronics have been recorded by a standard acquisition system, allowing the storage of a complete event, and have been transferred via VME-bus to a microcomputer system (VALET-PLUS) for recording and on-line monitoring.

The spectrum produced by pions at 4 GeV in a single stripe is shown in fig. 3 where the minimum
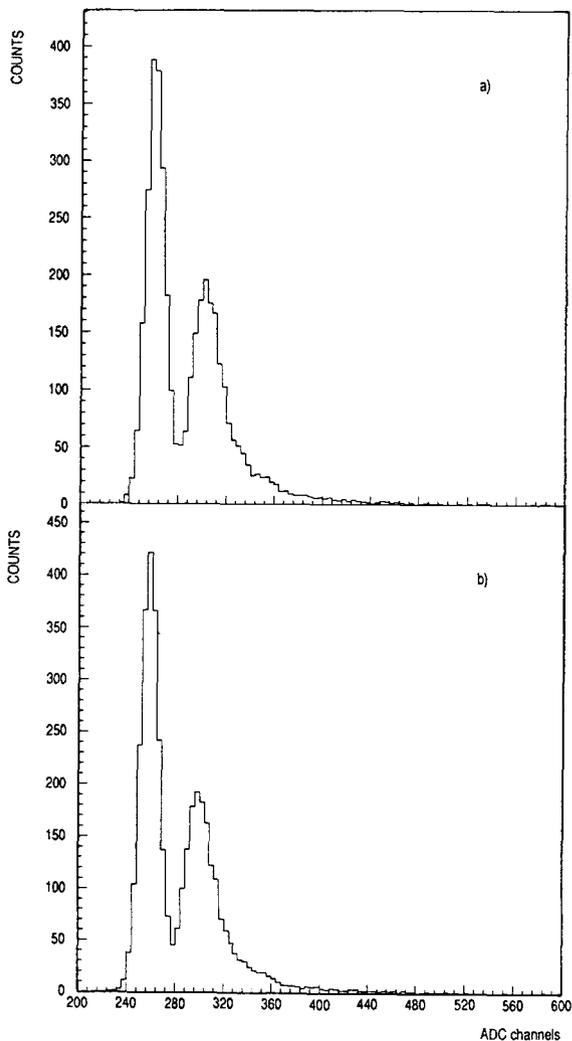
Fig. 3 - The minimum ionizing peak from 4 GeV pions, fig. 3a x sampling fig. 3b y sampling.
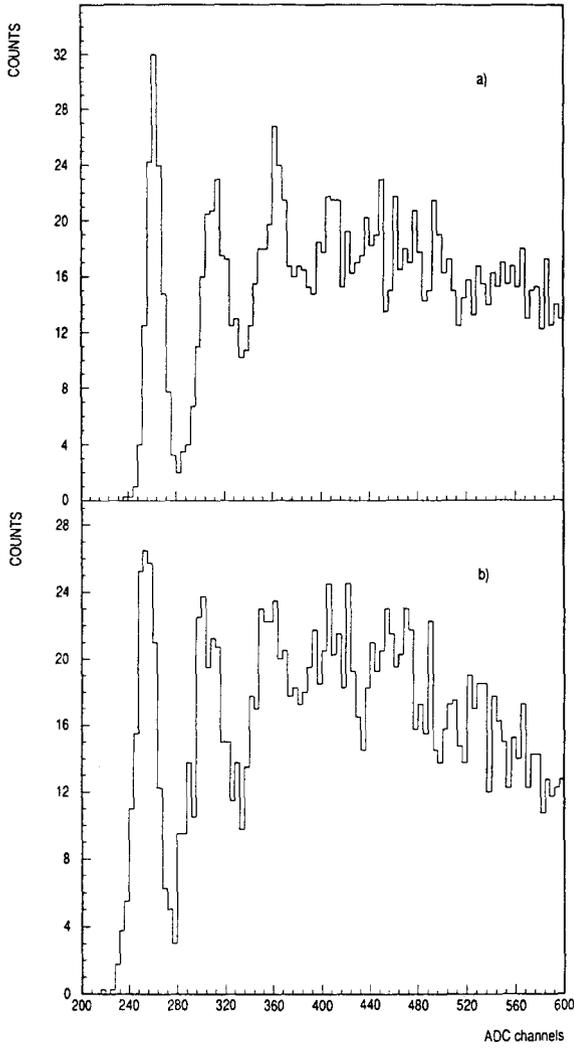
Fig. 4 - The spectrum induced by 4 GeV electrons impinging on a 4X0 tungsten converter placed immediately before the calorimetric plane. One can distinguish peaks from one and more ionizing particles, fig. 4a x sampling fig. 4b y sampling.

Fig. 5 - The image of antiprotons converting in the tower calorimeter (20 X_0, 20 y x sampling) is reported. Fig. 5a shows one event resulting from Monte Carlo simulations for antiprotons at 3.5 GeV, fig. 5b one event from the data taken at the same energy in the beam. The two dimensional histograms report the energy released by the interacting particle at each sampling in the 16 stripes for both x and y projections. The numbers represents the total energy released in each stripe in arbitrary units.

ionizing peak is visible well separated from the noise (note that the detectors used for this test are 300 microns thick). Fig. 4 shows the spectrum from the same strip when 4 GeV electrons are selected from the beam, in order to raise the conversion probability for the electrons 4 X0 of tungsten were added in front of the plane at approximately 4 cm. Well visible is the first minimum ionizing peak together with the spectrum produced by differently showering events, the second and the third ionization peak are also visible.

3.2   A tower prototype of the calorimeter [2] having a sensitive area of 60 × 60 mm and 20 x y sampling layers was used to study the antiprotons interacting in the calorimeter. The pictured interaction was then compared to Monte Carlosimulation. The experimental lay-out reported in [2] was completed by a time of flight system; this

together with the two Cerenkov detector allowed the identification of the 3.5 GeV antiprotons delivered by the CERN PS t7 beam. The tower calorimeter self was implemented with showering layers of 1 X_0 for a total of 20 X_0 . In fig. 5 a we report the simulated interaction of the antiprotons in the calorimeter, in this case the interaction produces two π^0, visible are the x and y projections for the 20 sampling layers. In fig 5 b we show a real event, antiproton candidate, selected using time of flight and Cerenkov detectors as particles identifiers.

4. CONCLUSIONS

A calorimeter sampling layer made of large silicon detectors produced with planar technology has been constructed and successfully tested. Combining the good energy resolution of the calorimeter and its high longitudinal and transverse granularity, it will be possible to carry out a detailed study of the primary cosmic antimatter energy spectrum in a balloon borne experiment. Able to operate in stand alone mode or in conjunction with the magnetic spectrometer foreseen for the experiment WiZard this detector allows identification of differently interacting particles, as required in the antimatter space research programme.

References

[1] R.L. Golden et al., Nuovo Cimento **105B** (1990) 191 .

[2] G. Barbiellini, G. Basini, V. Bidoli, M. Bocciolini, M. Boezio, F. Bongiorno, F. Massimo Brancaccio, M.T. Brunetti, M. Candusso, M. Casolino, F.Celletti, A. Codino, C. De Fabritiis, M.P. De Pascale, F. Fratnik, M. Grandi, A. Incicchiti, M. Menichelli, M. Miozza, A. Morselli, A. Perego, P. Picozza, D. Prosperi, M. Ricci, I. Salvatori, P. Schiavon, P.Spillantini, D. Prosperi, A. Vacchi, and N. Zampa.
"Silicon Imaging Calorimeter Prototype for Antimatter Search in Space".
Submitted to Nuclear Instruments and Methods in Physics Research.

[3] G.D. Badhwar, R.R. Daniel, R.L. Golden, S. Horan, J.L. Lacy, B.G. Mauger, S.A. Stephens, and J.E. Zipse.
"Evidence for the Existence for Cosmic-Ray Antiprotons",
Phys. Rev. Letters, vol. 43, pp. 1196-1199 (1979).
T. Bowen, R.L. Golden, J. Llyoid-Evans, A. Moats, J.F. Ormes, S.J. Stochj, S.A. Stephens and R.E. Streimatter.
"Experimental Limit on Low Energy Antiprotons in the Cosmic Radiations".
Adv. Spac. Research, vol. 9, pp. 65 (1989).
G. Basini, M. Candusso, F. Massimo Brancaccio, M. Ricci, M. Bocciolini, P. Spillantini, Yi. F. Wang, F. Bongiorno, M. P. De Pascale, A. Morselli, P. Picozza, C. De Marzo, O. Erriquez, G. Barbiellini, A. Vacchi, P. Galeotti, G. Ballocchi, M. Simon, P. Carlson, P. Goret, R. L. Golden.
"Matter-Antimatter Space Spectrometer for Cosmic Ray Studies" Nuovo Cimento, **105B**, 779 (1990)

[4] G. Basini,V. Bidoli, F. Bongiorno, E. Bonaviri, F. Massimo Brancaccio, A. Buccheri, M. Candusso, M. Casolino, F.Celletti, A. Codino, M.P. De Pascale, R.L. Golden, C. Grimani, R. Hull, B. Kimbell, M. Menichelli, A. Morselli, F. Ormes, P. Picozza, M. Ricci, I. Salvatori, P. P.Spillantini, S.A. Stephens, R.E. Streitmatter and S. Stochaj.
"Performance of a Balloon Borne Magnetic Spectrometer for Cosmic Ray Studies",
Nucl. Instru. and Methods **A306** (1991) 266-377.

[5] M. Meschini et al., Nuovo Cimento **102B** (1988) 523.