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A silicon array for cosmic-ray composition measurements in CALET

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电荷分辨

The CALorimetric Electron Telescope (CALET) mission is proposed for a long exposure observation of high energy cosmic rays and gamma radiation, taking advantage of the JEM-EF facility on the International Space Station. The instrument is optimized for the search of nearby sources of acceleration of cosmic ray electrons in the TeV energy range. Its large collection power also allows for precision studies of the elemental composition of VHE nuclei and of their spectral features. The charge identification of the incoming particle is performed by a double-layered array of pixelated silicon sensors, covering a seamless sensitive area of the order of 1 m^2. The conceptual design of the array and its front-end electronics are presented.

1. Introduction

The CALorimetric Electron Telescope (CALET) is designed to achieve high precision measurements of the cosmic ray (CR) electron spectrum in the range from GeV to about 10 TeV and high energy resolution measurements of gamma rays in the range 20 MeV to TeV. The physics goals and the layout of the experiment are described in more detail elsewhere.[1]

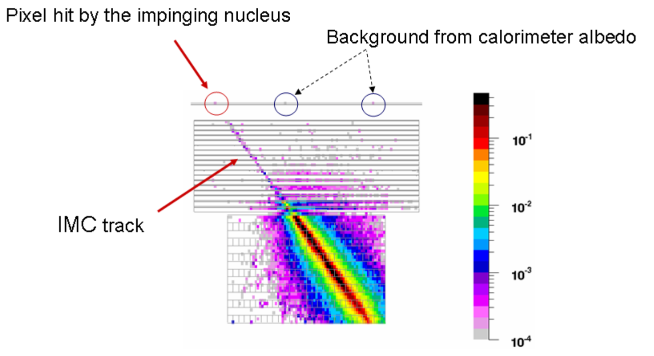

Fig. 1. Fluka event simulation : a 1 TeV/n Carbon nucleus interacting in CALET

Being a non-magnetic instrument, CALET has to provide an adequate electron-proton separation taking advantage of the very small granularity and fine sampling of the Imaging Calorimeter (IMC) - that covers the first 4 radiation lengths - and is followed by a 27 X_0 BGO calorimeter (TASC). A discrimination power in excess of 10^5 against hadron induced showers is required.
Though not optimized for hadrons, CALET will be able to identify cosmic ray nuclei with individual element resolution and measure their energies in the range from about 1 TeV to the PeV scale (Fig. 1). This will allow to extend to higher energies the present data on the secondary-to-primary ratios and cosmic ray composition from direct measurements and to verify the findings of balloon (ATIC,[2] CREAM,[3] TRACER[4]) and space missions (AMS, PAMELA).

2. Identification of cosmic ray nuclei

The residual systematic uncertainty on the subtraction of the irreducible background due to the atmospheric overburden at flight altitude sets an effective limit to the highest energy points of the Boron-to-Carbon ratio (B/C) obtainable with measurements on balloons. On the other hand, experiments in space are free from this limitation and CALET is expected to measure B/C up to several TeV/n, thus providing information about the rigidity dependence of the diffusion coefficient, an essential ingredient to discriminate among different propagation models, and to infer the slope of acceleration spectra at the source.

An important requirement for a direct measurement of CR composition is the ability to identify individual chemical elements in the cosmic ray flux. The Z^2 dependence of the specific ionization loss of an ultra-relativistic nucleus of charge Z in a thin silicon sensor can provide a sufficient charge discrimination capability, provided the electronics noise is kept sufficiently low. A pixel geometry has been chosen to isolate the ionization signal generated by the incoming particle, in the presence of albedo particles due to backscattering from the calorimeter. This background may strongly degrade the track reconstruction performance of the apparatus. In order to provide an unique assignment of the pixel hit

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by the incoming cosmic ray, the detector segmentation has to match the track reconstruction accuracy of the instrument. The fine granularity of the IMC (Fig. 1) allows the determination of the track parameters and the extrapolation of the trajectory to the silicon plane with millimiter accuracy.

3. The conceptual design of the Silicon Array

The baseline configuration of the Silicon Array (SIA) proposed for CALET is a mosaic of PIN diodes, arranged in 12 ladders, covering a sensitive area of about 1 m^2 with no dead regions. Each sensor has 64 pixels of dimension 11.25 $\times$ 11.25 mm^2, with inter-pixel distance of 0.1 mm. In order to achieve a seamless active region over the whole array, the sensors are overlapped in both dimensions (along each ladder and along the orthogonal direction).

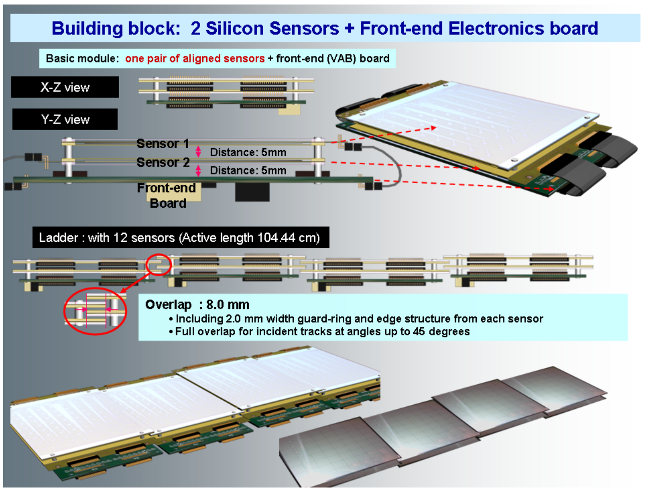

Fig. 2. Detector concept: two layered silicon sensors as building block of the array

The SIA detector consists of two layers of sensors for a total of 288 units. This allows to have two independent measurements of the charge of the same particle with a great benefit in terms of background rejection and increase in the purity of the data sample when a single cosmic ray element is selected. The sensors are produced from 6″ wafers of 500 micron thickness with high resistivity (not less than 10 kOhm·cm). They are specified to have a full depletion voltage below 80 V and a dark current per pixel typically lower than 2 nA.

A first generation of sensors with smaller pad size (1 cm $\times$ 1 cm) were manufactured and successfully tested with atmospheric muons and particle beams[5,6] achieving a S/N close to 8 for Z = 1 ultra-relativistic particles. A second generation of sensor prototypes, implementing the CALET pixel geometry were produced at the end of 2007. Their electrical characterization showed a full depletion voltage below 30 V and leakage current around 0.5 nA.

Along each ladder, sensors are mounted in pairs for a total of 24 sensors (Fig. 2). The mechanical arrangement of each pair of sensors allows an accurate knowledge of the relative position of the respective pixels. The SIA is mechanically divided in two halves: a lower section (Fig. 3), where 6 (odd numbered) ladders are arranged and an upper section that provides the mechanical support for the remaining 6 (even numbered) ladders. The upper section is mounted on top of the lower one after a 180° rotation. This design allows to achieve a complete overlap of all sensors, while providing two independent measurements of the charge of the incoming cosmic ray at all angles within the acceptance of CALET.

The current design allows for assembly/disassembly operations of the silicon array to be carried out with sufficient precision and reproducibility in the sensors position, as well as the possibility to easily replace a given sensor and/or one or more readout cards, a feature of great value during the commissioning of the detector.

The readout of the two layers is integrated into the mechanical structure. All the electronics cards are placed on the upper and lower surfaces of the detector in a symmetric way. This simplifies the design of the cooling system and minimizes temperature gradients across the instrument.

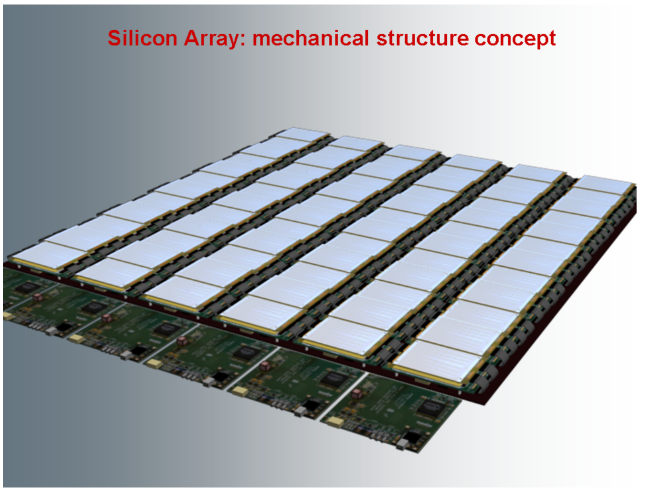

Fig. 3. Artist's view of the integrated assembly of the lower module of the Silicon Array

4. The readout architecture

Each pair of sensors (128 channels) is readout by a dedicated board (VAB) hosting 4 chips of the VA family. The front-end chip VA32-HDR14 (a sample-and-hold, low-noise, low-power, large dynamic range ASIC with multiplexed readout of 32 channels) was first developed for CALET in collaboration with IDEAS (Norway). A later version HDR14.2, with epitaxial layer protection against SEE effects, and optimized for positive charge inputs, was developed under the support of INFN.[7]

The VAB board implements a sequencer for the readout of 4 VA chips with 16 bits digitization, using 4 independent ADC integrated circuits. The 12 VAB boards of each ladder are readout by a Ladder Controller (LAC) that formats the sub-event with no sparsification. The LAC also supervises the distribution of physics and calibration triggers (Fig. 4). Gain calibrations of individual channels are performed by each VAB under the control of the LAC by using a charge injection facility built into the ASIC.

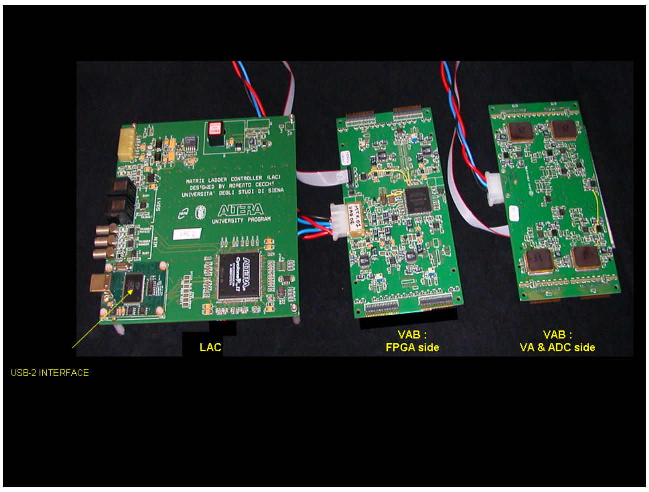

Fig. 4. Prototype of LAC board connected to two VAB boards

The global readout and sparsification of the 12 event fragments from the LAC boards is done by a ReadOut Controller (ROC) interfaced to the main DAQ. Redundance will be implemented for the flight version. The ROC reads the LAC boards, assembles the event fragments and applies a sparsification threshold. A suitable scheme of event buffering is implemented in the ROC. A number of control (e.g.: hold-signal delay, gain calibrations) and housekeeping functions (e.g.: temperature sensors readout, pedestal monitoring) is performed by the LAC under the control of the ROC.

5. Acknowledgements

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