Charge identification of heavy ions with a pixelated silicon array telescope

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Introduction

An accurate measurement of the charge of cosmic-ray ions allows the identification of the chemical elements in the Cosmic Ray (CR) spectrum. This is a specific requirement for the present and the next generation of experiments (balloon-borne or space-based), designed to provide direct measurements of the elemental composition and of the individual spectra of cosmic rays.

Arrays of silicon detectors have been successfully operated as charge identifiers both in the ATIC (Panov,2006) and in the CREAM (Park, 2005) balloon missions, where they achieved an adequate discrimination capability to tag individual elements, with excellent charge resolutions (for instance 0.3-0.4 electron charge units for the elements from C to Si in ATIC).

In the framework of the MATRIX project – funded by the Istituto di Fisica Nucleare (INFN) – our group developed pixelated silicon sensors prototypes (with large pixels of size ~ 1 cm x 1 cm). Produced from 6” wafers of high resistivity (not less than 10 kΩ cm) with 500 micron thickness, they have been successfully tested with atmospheric muons and particle beams (Marrocchesi,2007),(Kim,2007) achieving a S/N around 8 with Z = 1 ultra-relativistic particles.

CALET (Calorimeteric Electron Telescope) is an international collaboration (Torii,2003),(Torii,2006) being considered as part of the utilization plan for the Exposure Facility attached to the Japanese Experiment Module (JEM-EF) on the International Space Station (ISS). As member of the CALET team, our group partecipated in Phase-A studies of the mission and developed the concept (Marrocchesi,2008) of a double-layered Silicon Array (SIA) for cosmic-ray composition measurements, providing single-element identification up to Fe and above,.

CALET can extend the available data on cosmic-ray composition and on secondary-to-primary ratios to higher energies allowing to discriminate among different propagation models and to derive the acceleration spectra at the source. In particular, CALET can extend the energy reach of the current data (Ahn,2008) on the Boron-to-Carbon (B/C) ratio, up to several TeV/n (**Figure 1**).

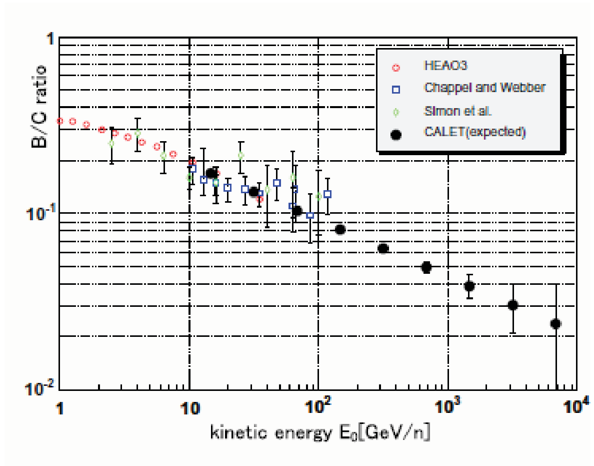

Figure 1: Compilation of B/C measurements and comparison with CALET expectations.

In this letter, we propose to perform beam test measurements at GSI in order to assess the charge discrimination capability of a (reduced size) prototype array with relativistic heavy ions. The dynamic range of the front-end electronics (not less than 10^3 MIP) allows measurements of ultra-relativistic cosmic-ray from Z = 1 to Z = 30 and above. The assessment of the charge resolution for sub-Fe and Fe is one of the primary goals of the proposed test.

The Silicon Array (SIA) detector for CALET consists of a mosaic of PIN diodes, covering a sensitive area of about 1 m^2 with no dead regions. The sensors are pixelated on one-side with 64 pixels of dimension 11.25 x 11.25 mm^2, with inter-pixel distance of 0.1 mm.
The baseline configuration of the SA consists of two layers of sensors organized in 10 ladders. In order to achieve a seamless active region over the whole array, the sensors are overlapped in both dimensions (parallel and orthogonal to the ladder axis).

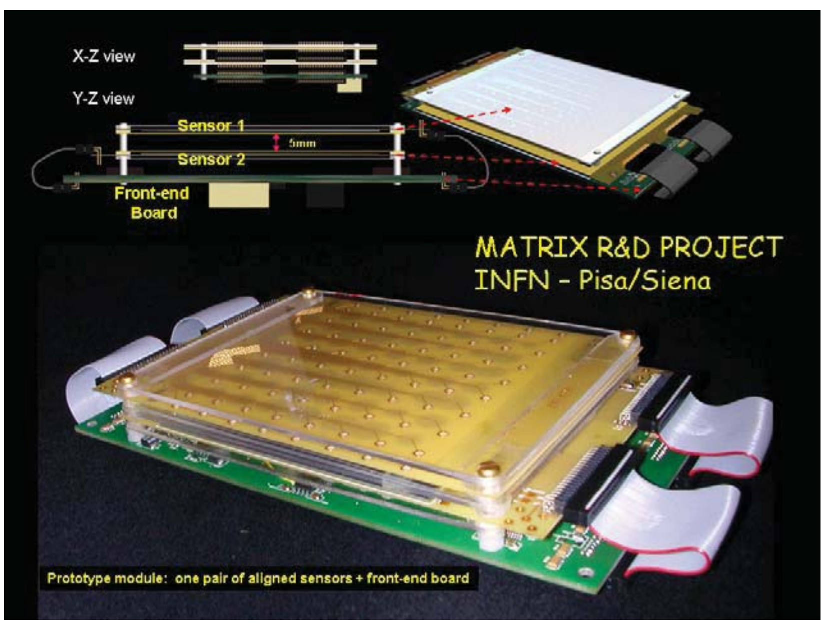

Figure 2: Prototype of a basic module of the Silicon Array: two pixelated silicon sensors are mounted on top of the front-end electronics board (128 channels).

The two layers are mechanically arranged in one unit. An innovative 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. Along each ladder, sensors are mounted in pairs (see **Figure 2**) for a total of 20 sensors. The mechanical arrangement of each pair of sensors allows an accurate knowledge of the relative position of the respective pixels.

Beam requirements

We would like to use a mixed beam with ions of different Z to check the linear response and resolution performance of our detector along its whole dynamic range. A similar test facility was provided in the past to experiments like GLAST and AMS at GSI.
A fragments run at the FRS would probably be the best opportunity (for istance: a ^{58}Fe beam tuned to N=Z).
We would like to underline our need to collect enough statistics to study the instrument charge resolution in the Fe and sub-Fe regions.

Experimental requirements for the beam test

We plan to test a reduced-scale prototype of the silicon array for CALET. The beam test layout includes: one pair of X-Y silicon strip detectors (to accurately define the beam position), preceding a telescope of 4 pixelated silicon sensors, followed by a second pair of X-Y silicon strip detectors.

An external trigger will be provided by the coincidence of scintillator counters positioned up(down)-stream the telescope. The small sized equipment under test (contained in a light-tight box of about 40 cm x 40 cm) should be relatively easy to install on the beam line.

The readout is performed by dedicated front-end electronics and digitizers connected via a 30 m long optical fiber to a USB-2 port into a laptop outside the beam area.

Previous experience with similar measurements at CERN

In the framework of the CREAM balloon experiment (Seo, 2004), we partecipated in the beam test of the silicon pixel array (SCD) at CERN using (A/Z=2) Indium beam (158 GeV/u) fragments at the SPS.
The mixed beam configuration turned out to be extremely useful to study the response of the detector array. An example of individual element separation obtained – at that time – is shown in **Figure 3** (Ahn, 2007).

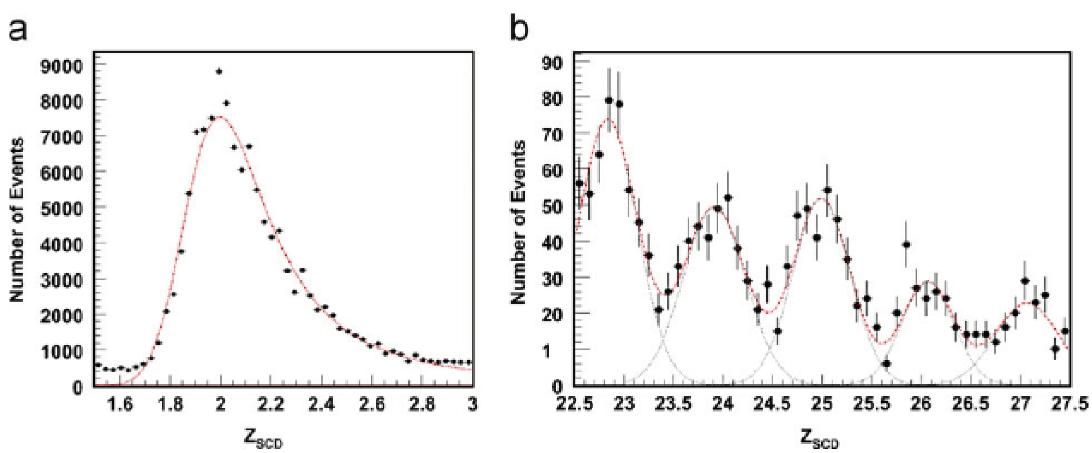

Figure 3: CREAM SCD at CERN with 158 GeV/u fragments : (a) Z=2 ; (b) $23 \leq Z \leq 27$.

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