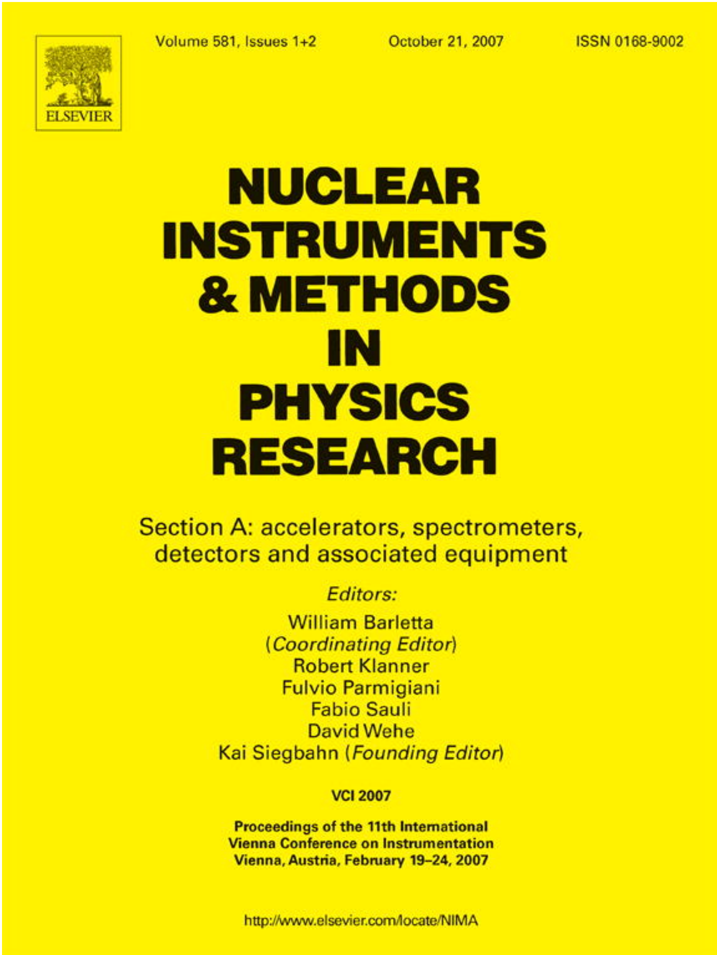
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Beam test of a dual layer silicon charge detector (SCD) for the CREAM experiment

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Abstract

The Cosmic Ray Energetics and Mass (CREAM) balloon-borne experiment is designed for direct measurement of high-energy cosmic rays. The experimental goal is to measure single-element fluxes of all cosmic-ray nuclei from hydrogen to iron with energies up to the "knee", or spectral index change near 10^{15} eV, observed in the all-particle spectrum. The dual layer Silicon Charge Detector (SCD) was designed to provide precise charge measurements. Each SCD layer has an active area of 77.9 cm × 79.5 cm and consists of 156 silicon sensors mounted on 24 ladders. Each sensor contains a 4 × 4 array of single-sided DC type silicon pixels with an active area of 2.1 cm^2. The detector was flown on the second CREAM flight (December 2005–January 2006) and recovered successfully. The SCD was refurbished for the third CREAM flight and tested with high-energy electron and hadron beams at CERN. This paper reports on the performance of the SCD during the beam test.

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Keywords: Silicon sensor; Silicon charge detector; Cosmic ray

1. Introduction

The all-particle spectrum of cosmic rays generally follows a power law distribution with characteristic kinks. One of the kinks, or slope changes, located near 10^{15} eV is referred to as the "knee". The supernova remnant (SNR) acceleration model predicts a dependence of the acceleration limit on the charge number (Z) of cosmic-ray nuclei [1]. Direct measurements of cosmic-ray particles with energies up to the knee region provide tests of the acceleration model.

Cosmic Ray Energetics and Mass (CREAM) is a balloon-borne experiment for the measurement of elemental spectra from hydrogen (protons) to iron in the energy range between 10^{12} and 10^{15} eV [2]. Analysis of CREAM data will investigate the origin, propagation and acceleration mechanism of high-energy cosmic rays. CREAM-I was flown in Antarctica from December 2004 to January 2005 with a record-breaking Long Duration Balloon (LDB) flight of 42 days [3]. The second flight of CREAM (CREAM-II) collected data for 28 days from December 2005 to January 2006 [4].

2. The silicon charge detector (SCD)

The design goal of the SCD is to measure the charge of incident particles from protons ($Z = 1$) to iron nuclei ($Z = 26$) with a charge resolution of ~0.2 [5]. A single layer SCD (SCD-I) was constructed for the first flight of the CREAM experiment [6,7]. For the second flight, the SCD was upgraded to a dual layer device.

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Each SCD layer has an active area of 77.9 cm × 79.5 cm, with a total of 156 silicon sensors. Each sensor is a 4 × 4 array of single-sided DC type pixels fabricated from a single 380 μm thick high resistivity wafer. The active area of each pixel is 2.1 cm^2, optimized to reduce the albedo effect from back-scattered particles produced by shower development in the calorimeter below the SCD. Each pixel in the sensor is connected to the front-end electronics through wire bonding and a flexible PCB attached on the front surface of the sensor. The CR-1.4A ASIC was chosen for analog data processing with a wide dynamic range and good linearity [8]. Seven sensors are integrated in each analog board (ladder). In order to avoid dead area between sensors, these are attached to angled mechanical frames which allow overlapping between sensors by tilting them by an average of 2°.

For CREAM-II, 48 analog boards with 4992 pixel sensors were incorporated in the SCD. Dual layers provide reliable charge information with improved resolution through redundant measurement. In addition, the redesigned front-end electronics for the dual layer SCD show better performance with reduced electronics noise, enhancing the signal-to-noise ratio. Clean separation of signal from noise is important in collecting the dominant proton data in high-energy cosmic rays and also in reducing the telemetry bandwidth needed.

The dual layer SCD exhibited excellent performance during the CREAM-II flight. CREAM-II landed on January 2006 after 28 days of flight and the SCD was successfully recovered as shown in Fig. 1, with most of its components found to be in good condition. After refurbishment and reassembly for the next flight, the SCD was brought to a test beam at CERN in October 2006 for a post-recovery performance test and detailed calibration. The SCD was scanned with 100 GeV/c electrons and 150 GeV/c pions in the H2 beam line at the SPS.

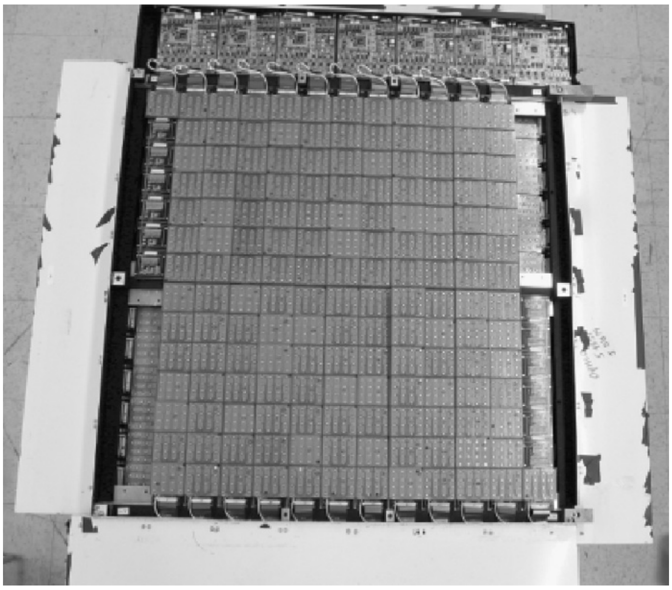

Fig. 1. Dual layer SCD after recovery. Nearly all parts were recovered without damage.

3. Beam test

3.1. Beam test setting and procedure

The SCD was integrated into the calorimeter module. The calorimeter module contains a sampling tungsten-scintillating fiber calorimeter, with twenty 1 radiation length tungsten absorbers interleaved with twenty thin active layers of scintillating fiber ribbons, preceded by two graphite targets [9]. The SCD was installed atop the upper target. A non-flight CREAM DAQ system was used for the beam test to accommodate the high event rate available [10]. Both beam and random triggers were combined in the CREAM master trigger board. The beam trigger was provided by a coincidence of signals from scintillation detectors installed in front of the SCD along the beam line. The random trigger was generated in the CREAM calibration board for readout monitoring and pedestal subtraction.

The beam was used to scan the SCD channels by changing the vertical and horizontal position of the table holding the instrument, allowing the beam spot to light up different positions on the instrument's face. The scanning was performed such that at least one pixel sensor from each 4 × 4 array was exposed to the beam, with a total of 41% of SCD pixels exposed to the beam.

3.2. Results

Fig. 2 shows the general response of a pixel sensor after pedestal subtraction. The signal to noise (S/N) ratio was calculated using the most probable value (MPV) obtained from the Gaussian-convoluted-Landau fit with the signal

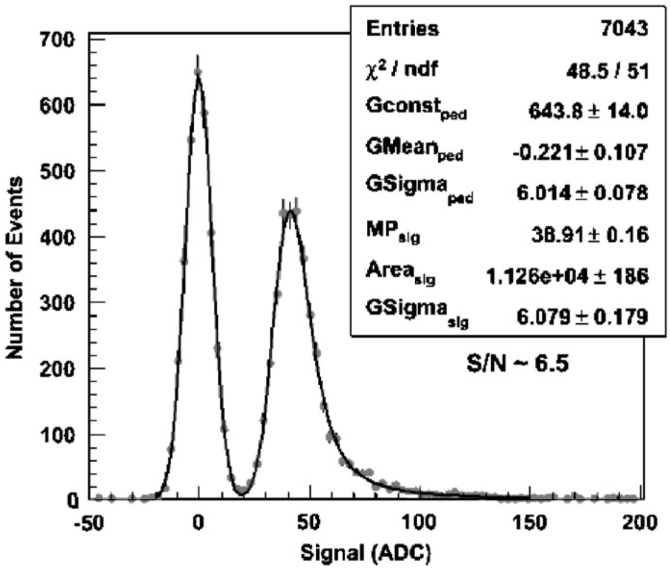

Fig. 2. Signal from one pixel sensor (in top SCD).

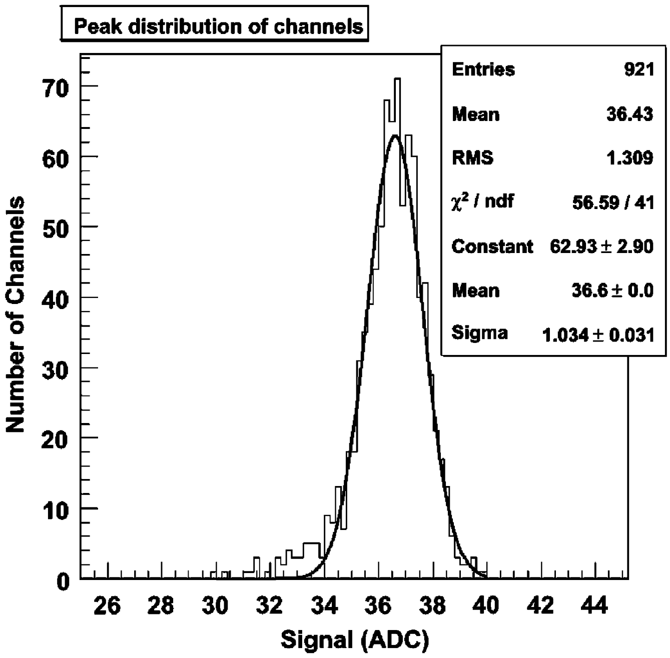

Fig. 3. Peak distribution of channels in the SCD. Peak value was defined by the MPV of the fitted curve.

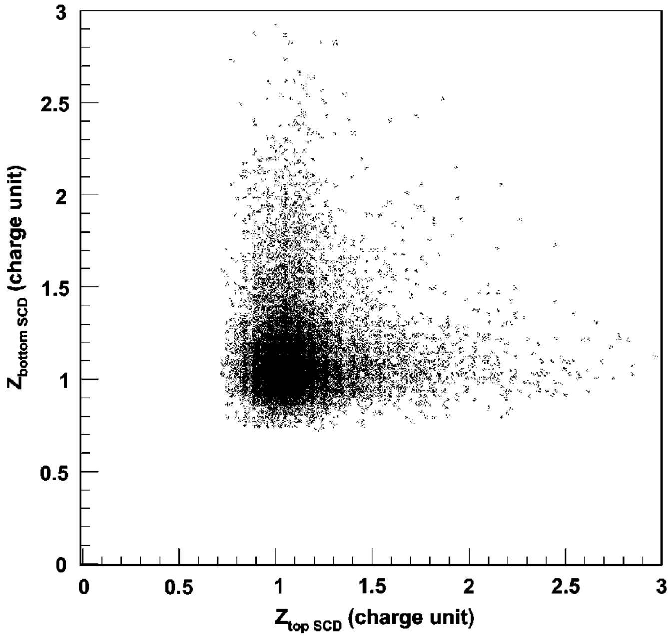

Fig. 4. Signal comparison between top SCD and bottom SCD (signals with value higher than the pedestal mean value +3 sigma were selected in each layer).

and the sigma value obtained from the Gaussian fit of the pedestal distribution. The average S/N ratio was measured to be 7.0.

Defining the channel gain by the MPV from the signal fit curve, the gain non-uniformity in the SCD was found to be 2.8% for stable sensors (see Fig. 3).

Signals from the two layers were compared in Fig. 4. Charge resolution (defined as the ratio of the standard deviation value calculated from FWHM and the peak location of the signal fit) was measured to be 0.11 in both layers. By taking average of signals from two layers, the resolution is improved to 0.08.

4. Conclusions

The dual layer SCD recovered from the CREAM-II flight was tested with high-energy particles at CERN's H2 beam line for flight requalification and calibration. The test showed the SCD has excellent charge resolution, satisfying the requirements of the next CREAM flight. The gain non-uniformity was found to be 2.8% and the dual-layer charge resolution was measured to be 0.08. The calibration data will serve as a reference for data analysis of the next flight. The CREAM-III payload, with the dual layer SCD integrated, is planned to be launched on December 2007 in Antarctica.

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