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A New Transition Radiation Detector for the CREAM experiment

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Abstract: The Cosmic Ray Energetics And Mass (CREAM) experiment is designed to investigate the source, propagation and acceleration mechanism of high energy cosmic-ray nuclei, by directly measuring their energy and charge. Incorporating a Transition Radiation Detector (TRD) provides a model independent energy measurement complementary to the calorimeter, as well as additional track reconstruction capability. A new TRD design provides a compact, robust, reliable, low density detector to measure incident nucleus energy for $3 < Z < 26$ nuclei in the Lorentz gamma factor range of 10^2-10^5. The TRD design, R&D, construction milestones, beam test results and a progress of the final TRD integration in the CREAM instrument are reported.

Keywords: CREAM, TRD, balloon.

1 Instrument Description

1.1 Introduction

The Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne experiment to directly measure the elemental spectra from protons to iron nuclei with energies up to 10^{15}eV [1]. It has been launched already six times from McMurdo polar station, Antarctica, since December 2004. At present the cumulative CREAM flight duration reaches 162 days. CREAM measurements will continue to be carried out in a series of annual balloon flights. The future NASA Super Pressure Balloon [2] will further boost the cosmic ray data collection capability per flight. A new generation Transition Radiation Detector (TRD) is being developed to further increase the CREAM experiment's accuracy and sensitivity. Measurement of Transition Radiation (TR) yield [3] allows inter-calibrating the calorimeter energy measurement in a model-independent way since the TR signal depends only on particle charge and Lorentz gamma factor. Calibration of the TRD itself at high energy is achieved with a 100 GeV range electron accelerator beam. The TRD initial Monte Carlo study, the prototype beam tests and the construction progress were reported earlier [4, 5]. This paper describes the new TRD design, its integration and preliminary beam test results.

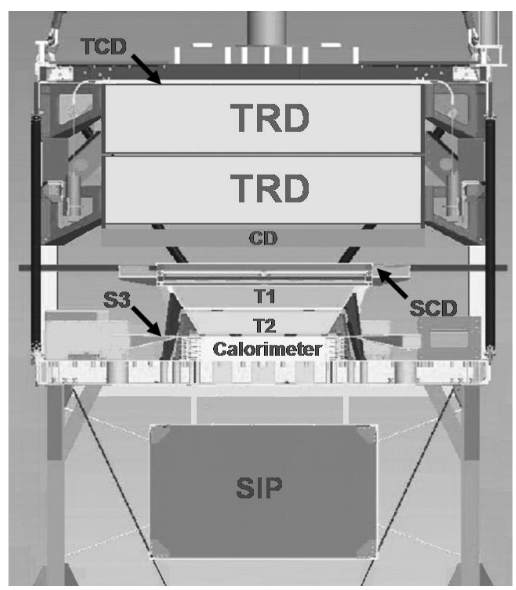

Figure 1. TRD position in the CREAM-VII instrument. Also shown in the figure: TCD - Time Charge Detector, CD - Cherenkov Detector, SCD - Silicone Charge Detector, T1,T2 - carbon targets, S3 - Scintillator counter, Calorimeter, and SIP - Support Instrumentation Package.

1.2 TRD-II Design

The New TRD (TRD-II) detector is based on gas straw technique. The 1200 mm long thin-walled gas proportional straw tubes, of 10 mm diameter, are filled with Xe/CO2 80/20% gas mixture at 1 atmosphere. The TRD consists of 8 modules (organized in two sections) with alternating orthogonal straw orientations. Each module contains 200 straw tubes arranged in dense double layers and a TR radiator made of 50 mm thick plastic foam material. The straws in the bottom layer are displaced by a straw radius respect to the top layer to remove the dead zones. The front-end readout electronics, as well as the High Voltage power elevators are placed inside the light aluminum gas manifolds at the opposite sides of each module. This solution allows avoiding exposure of a sensitive HV and readout electronics to a low ambient pressure environment (down to 3-4 mbar) at float altitude during CREAM missions. The manifolds are supported by an extremely rigid and low weight frame made of cross-winding carbon fiber reinforced composite.

The signals from each straw tube are readout by a single channel of the VA32HDR11 front-end ASIC chips The 32-channel VA32HDR11 chips have 50 pC effective input range, enabling over 12bit signal resolution relative to 5 σ of electronic noise, and low power consumption.

The straw tubes are fabricated out of very thin (35 μm) aluminized Mylar film by an ultrasonic welding to allow easy penetration by the relatively low-energy transition radiation x-rays. The straws then were tested at 3 bar overpressure for the weld quality and gas diffusion rate, required to be less than 0.01 mbar/min at 1 bar.

Figure 1 shows a general layout of the CREAM instrument. Two mechanically independent TRD sections are mounted in the upper part of the instrument by two sets of support brackets. The plastic Cherenkov Detector (CD) which produces the relativistic particles trigger signal is mounted underneath the TRD using common support brackets. The top honeycomb plate of the TRD serves as a support for the Timing Charge Detector (TCD). All the rest of the CREAM detectors is mounted on the large aluminum honeycomb pallet at the bottom of the CREAM science compartment. The pallet houses also the onboard science computers, the trigger electronics, the readout and power electronics of the detectors as well as the TRD gas distribution system. In the Figure 2 the CAD model of the TRD-II and its system boxes installed on the pallet is displayed. The instrument support structure elements as well as the TCD and CD detectors are also shown. Two larger boxes on the left and the right of the pallet are the TRD gas distribution boxes. Each box controls the gas pressure in 4 modules of one of the TRD sections. It contains the gas solenoid valves and pressure sensors so that the sections of the TRD can be operated independently. The TRD modules have their own gas replenishment and venting lines and can be sealed in case of the accidental pressure drop in the module. The other two smaller boxes shown on the pallet are the TRD Low Voltage (LV) system box and the central TRD Event Builder (EB) and housekeeping (HSK) system box. The EB/HSK box is the main TRD interface to the CREAM data acquisition system.

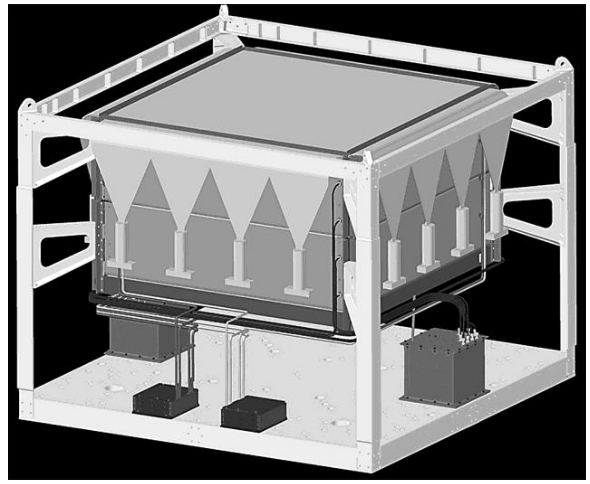

Figure 2. CAD model of the TRD-II.

The TRD front-end readout electronics contain the Actel Igloo FPGA-based sequencer, driven by the CREAM Master Trigger Box (MTB), to control the ASIC sample and hold, the analog multiplexer, serial ADC and clear logic. Each TRD module performs zero-suppression (data sparsification) and sends significant data to the EB board. The front-end electronics designed to cope with a large signal range sufficient to cover high Z (up to 26) ion signals.

The central EB/HSK box is connected to the CREAM Science Flight Computer (SFC) by a double redundant USB 2.0 interface. It receives commands for the front-end and housekeeping systems and builds the TRD event. The housekeeping system sets the low and high voltages, reads the temperature and pressure sensors and controls the latching valves of the TRD gas system.

2 Calibration

2.1 Beam Test Setup

The TRD-II construction was finished by the beginning of October 2010. After long term qualification tests (leak rate test at high pressure, HV test, readout system test on cosmic moons and with ^{55}Fe gamma source) the TRD was moved in the SPS secondary beam line (H2B) for the calibration. The beam calibration was done together with the CREAM calorimeter and SCD. In the Figures 3,4 the beam test setup is shown. The TRD was placed on the large scissor moving table upstream of the rotation fixture holding the CREAM pallet with the calorimeter and SCD. Two double layer Silicone Beam Trackers (SBT) were installed in the beam line and connected to the CREAM readout system. During the data taking the MBT was distributing the trigger signals and the event numbers (time stamps) for software synchronization of the individual detectors. The TRD readout system was also triggered by the MBT and receiving the event-numbers which allowed detecting the same beam particle seen by all other CREAM detectors and recording all measured signals as a single event. Therefore the SBT accurate tracking information as well as the particle energy measured by the calorimeter was available for the

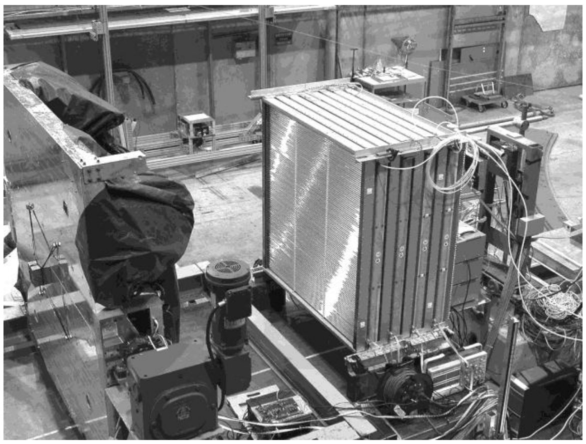

Figure 3. TRD setup in the test beam line. View from downstream respect to the beam.

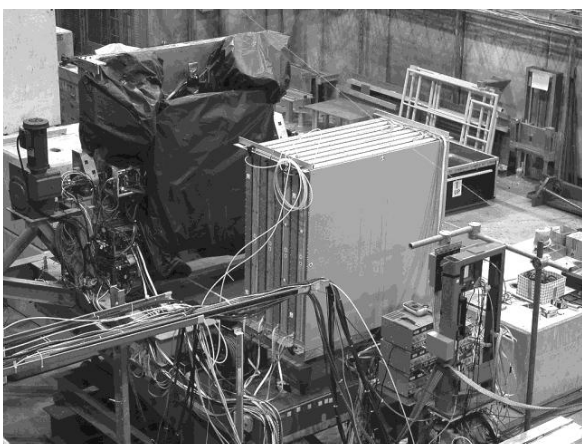

Figure 4. TRD setup in the test beam line. View from upstream respect to the beam.

TRD beam data analysis and reconstruction. The energy measurement by the calorimeter was needed for the particle identification and the electron beam contamination suppression based on good e/h separation provided by the CREAM calorimeter. Perfect particle identification is essential for the TRD signal response calibration as a function of the particle Lorentz gamma factor. This calibration consisted in a series of runs at different beam momentum with hadrons and electrons. For the hadron beams the negative beam polarity (secondary beam charge) was chosen to remove a proton contamination obtaining almost 100% pion (π-) beam. The tertiary electrons and positrons from converter are partially contaminated by hadrons and muons and the amount of contamination is different at different beam momentum. The cleanest tertiary beam was obtained for positrons. However a residual contamination can only be removed using the calorimeter response. Sufficient statistics of the TRD events was collected at different HV with Xe/CO2 80/20% gas mixture after initial hold delay scan. The lateral scans with 1 cm pitch were also performed to study the detector uniformity and its spatial resolution.

2.2 Beam Test Results

The data collected during the beam-line calibration test is shown in the Figure 5. The TRD response measured at different beam momentum and particle mass covers a large Lorentz gamma factor range. A contribution due to ionization energy losses in the gas was calculated for the TRD response and plotted as a dashed line. It represents a logarithmic relativistic ionization plateau. The rise of the data points above log10(γ) ~ 3 is due to the onset of transition radiation production. The solid line represents a polynomial fit to the data. The preliminary beam results confirm our previous Monte Carlo calculations [4,6,7] and the measurements obtained with the prototype [5]. The calibration will be further improved by applying the track passage corrections, based on the SBT data.

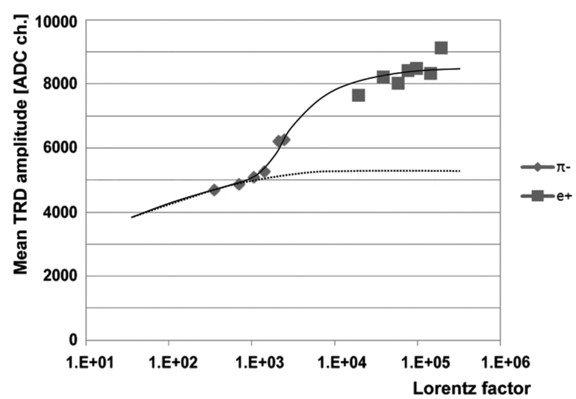

Figure 5. TRD response measured in the test beam at CERN as a function of the particle Lorentz factor. Solid line is a polynomial fit to the data, dashed line is the calculated ionization loss contribution. Preliminary data.

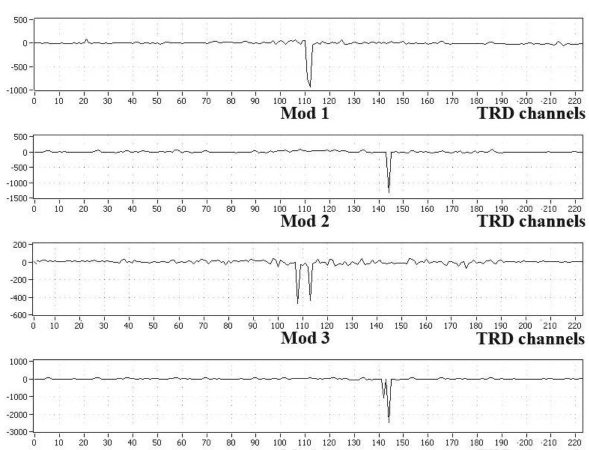

Figure 6. Single TRD event during the lateral position scan. First section hits are shown.

The Figure 6 shows the TRD event display with the channel mapping conversion applied. That singe event is a typical TRD amplitude profile (hit profile) and was recorded during the lateral position scan. The exact knowledge of the particle path length in the gas straw tube has direct impact on the ultimate energy resolution achievable with the instrument. Using the SBT and a second-level likelihood fit which takes into account the tube geometry, impact parameters, and energy deposition distributions allows to check the TRD spatial resolution expected to be ~1 mm. The beam data analysis is in progress.

3 Integration and further tests

After the beam calibration the TRD-II was shipped to the IPST, University of Maryland and the mechanical fit-check pre-integration with the CREAM instrument support structure was performed. The bottom CD detector was also integrated. The check went through without a hitch thanks to the excellent mechanical precision of the TRD and the instrument support structure (Figure 7). The high pressure leak test (72 hours long) and the cosmic muon data taking (functionality test) were successfully accomplished again, proving that the detector supported well the transportation.

Next tests include the thermo-vacuum test, the house-keeping and gas distribution systems tests and the end-to-end TRD flight systems test. The preflight preparation includes many more standard NASA qualification tests to be performed by the individual detectors and by the complete instrument. The CREAM-VII flight preparation is in progress.

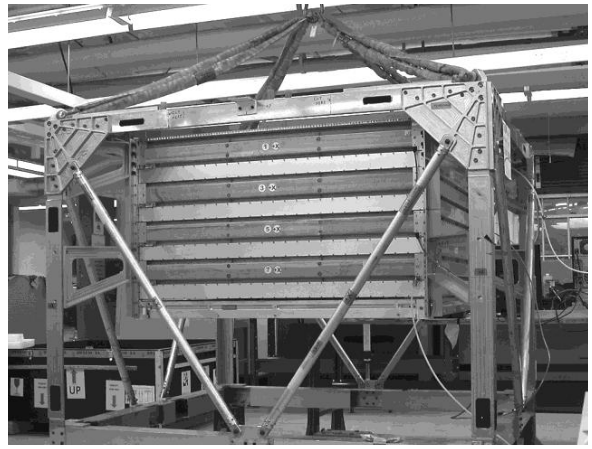

Figure 7. TRD-II mechanical pre-integration in the CREAM-VII instrument at UMD. The CD detector is also mounted.

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