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 an 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 $3 \leq Z \leq 26$ nuclei in the Lorentz gamma factor range of $10^2 - 10^5$. Design, construction and qualification tests of the new TRD as well as the low-power front-end electronics used to achieve the large dynamic range required are presented. Beam test results of a prototype TRD in the CERN SPS secondary hadron and electron beams are reported.**

***Keywords*: CREAM, TRD, balloon.**

I. INTRODUCTION

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 four times from McMurdo polar station, Antarctica, in December 2004, 2005, 2007 and recently in December 2008. It circumnavigated the South Pole three times during the first flight, which set a flight duration record of 42 days. A cumulative duration of 70 days within 13 months was achieved when the second mission completed its 28 days flight with two circumnavigations of the continent. At present the cumulative CREAM flight duration reaches 119 days. CREAM measurements continue to be carried out in a series of annual balloon flights. In the future the instrument is expected to collect almost twice the current world total of direct high-energy cosmic-ray events with a single SPB (Supper Pressure Balloon) [2] flight. A new generation transition radiation detector (TRD) is being designed to further increase the CREAM experiment's accuracy and sensitivity. Measurement of transition radiation yield [3] allows inter-calibrating the calorimeter energy measurement in a model-independent way since the TR signal only depends 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. This paper describes the new TRD construction and the prototype beam test results.

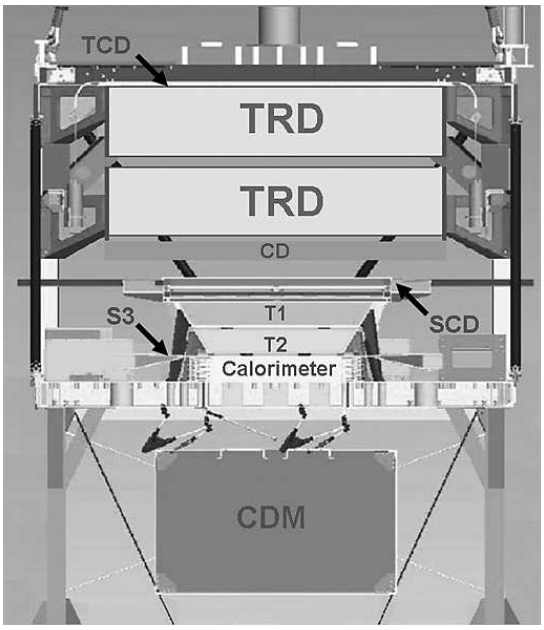
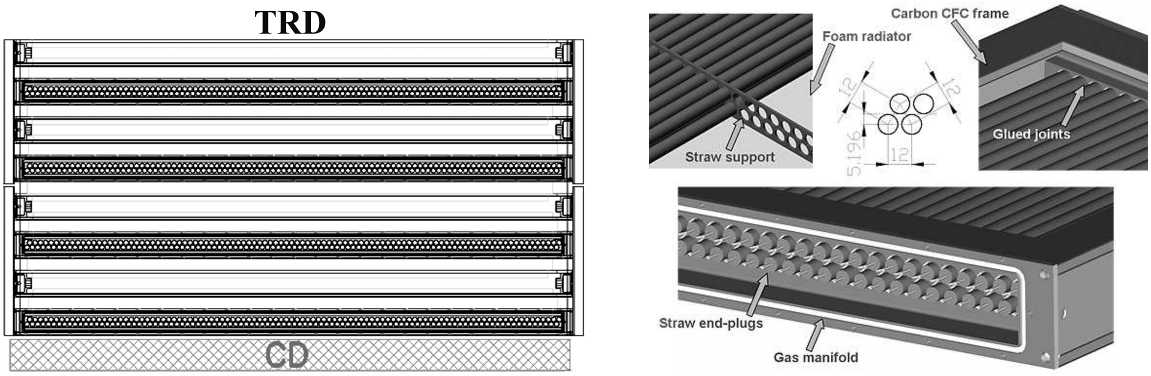


Fig. 1: TRD position in the CREAM instrument. Also shown: TCD - Time Charge Detector, CD - Cherenkov Detector, SCD - Silicone Charge Detector, T1,T2, - carbon targets, S3 - Scintillator counter, Calorimeter, and CDM - Command Data Module.

II. NEW TRD CONCEPT AND MECHANICAL DESIGN

The TRD detector is based on gas straw technique. The 1200 mm long straws, of 10 mm diameter, hold a Xe/CO_2 80/20% gas mixture at 1 bar pressure. Working temperature range is from -10^oC to +40^oC. The TRD consists of 8 modules (organized in two sections) with alternating orthogonal straw orientations, each comprised of a double straw layers (200 straws per module) and a radiator made of 50 mm thick Ethafoam-220 polyethylene foam material. Ethafoam-220 is optimal for a large Lorentz factor sensitivity range, with a high saturation limit. The next generation CREAM TRD is designed with 10 mm diameter



(a) TRD cut view (b) TRD module structure

Fig. 2: TRD cross section and structural elements

straw tubes to improve particle tracking over the previous 20 mm tube design, thereby enhancing charge identification in the silicon charge detector (SCD). The improvement over the TRD tracking accuracy will also reduce uncertainties of particle path-length corrections for the signals in TRD and other CREAM sub-detectors. The aluminum alloy gas manifold boxes offer good thermo-conductivity and serve as a housing for the front-end electronics, ASIC, and HV distribution boards. The gas manifolds are supported by composite CFC frames, to minimize the TRD weight and straw plane thermal stress. The straws are made of 36 μm thick aluminized Mylar film using an ultrasonic welding process. The straws then are tested at 3 bar overpressure for the weld quality and gas leaks, required to be less than 0.01mbar/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 of two sets of support brackets. A cross section of the TRD showing straw plane structural elements, radiator blocks and gas manifolds is shown in the Fig. 2. The elements of the detector are tested at maximum stress with a required margin (Fig. 3) and results are compared with ANSYS finite-element modeling. An example of an ANSYS calculation is shown in Fig. 4.

A. TRD front-end, DAQ and housekeeping electronics

The TRD front-end readout electronics contain a simple FPGA-based sequencer, driven by the CREAM Master Trigger (CMT), to control the ASIC hold, sample analog multiplexer, serial ADC and clear logic. The front-end performs zero-suppression (data sparsification) and sends significant data to the main DAQ board. The front-end electronics designed to cope with a large Transition Radiation signal range. It provides a good signal-to-noise ratio per channel, as well as a low cross-talk and coherent noise levels required, yet must have a large dynamic range, sufficient to cover high Z (up to 26) ion signals.

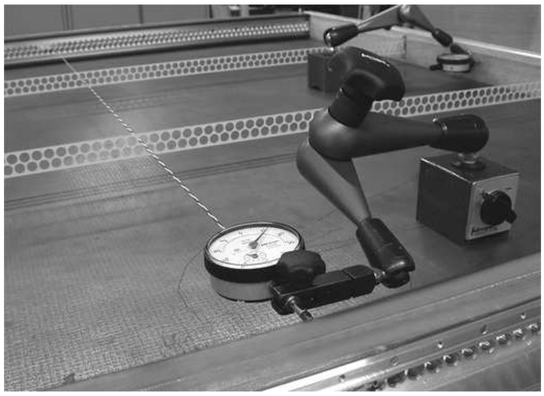


Fig. 3: Structural static test of the TRD module frame

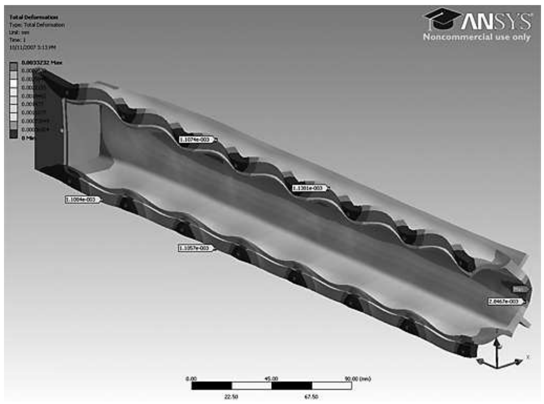


Fig. 4: TRD gas manifold finite-element model

Compact new electronics will replace the bulky VME based electronics box of the CREAM-I TRD. The ASIC we chose is the 32-channel VA32-HDR14, produced by Ideas SA, Norway. This ASIC has an input noise level (single straw) of: 5200e + 13.6 pF $\times$ 5e/pF = 5270e (0.844 fC) and 15pC maximum input charge which

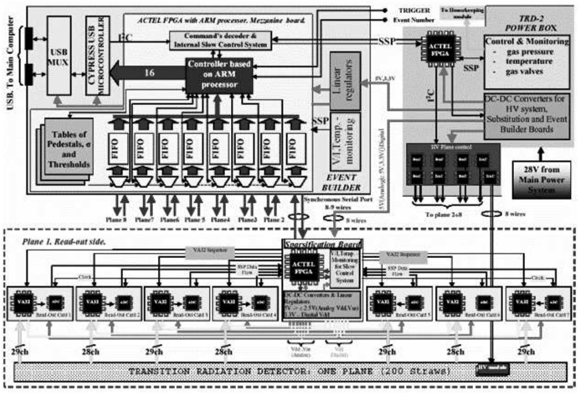


Fig. 5: TRD electronics block diagram

Fig. 7: TRD prototype at the SPS test beam area.

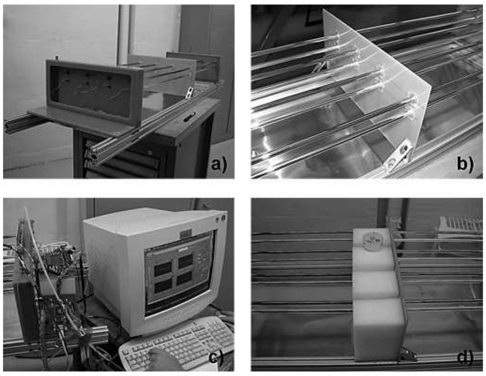


Fig. 6: TRD prototype construction (a)&(b), readout electronics (c), and calibration with the ^{55}Fe radioactive gamma source (d).

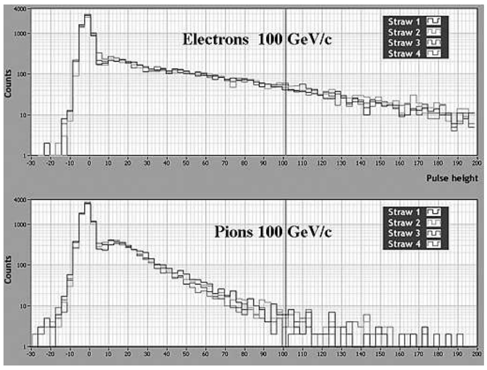


Fig. 8: Measured TRD signal pulse height spectra of the 100 GeV electron (top) and 100 GeV negative pion (bottom) SPS secondary beams.

satisfies the dynamic range and noise requirements. If the sparsification threshold is set at 5 sigma of the pedestal, the dynamic range is equal to: 15 000 fC / (0.844 fC $\times$ 5) = 3550. Results of beam tests and tests with ^{55}Fe gamma source, obtained with two different ASIC types (VA32-HDR14 and Gassiplex-1.5 [4], used for comparison), show generally good agreement with the expected front-end signal response and noise levels. Figure 5 shows the TRD electronics block diagram. The main DAQ board is connected to the CREAM Science Computer 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. In total the TRD has 1600 data readout channels.

B. *Solutions for the TRD operation constraints*

The CREAM instrument science payload works in an ambient pressure of 2-4 mbar at balloon flight altitude ($\approx$ 40 km). To solve the thermal and low pressure constraints, the front-end electronics (which dissipates a large part of the TRD power) and the HV system are located inside the gas manifolds of each TRD module. This solution allows the most sensitive part of the electronics to be maintained at normal (1 bar) pressure, and at the working temperature of the gas mixture. The front-end ASIC chips are thus protected from potential corona discharges and are located as close as possible to the straw tube detectors. The aluminum gas manifolds provide sufficient thermal conductivity to the support brackets and transfer the dissipated electric power to the CREAM gondola structure. The pre-mixed working gas is stored on-board in a thermo-insulated gas bottle connected to the TRD gas distribution system.

III. TRD PROTOTYPE AND BEAM TEST RESULTS

The TRD performance was studied and optimized using dedicated Monte-Carlo models [5], [6], [7] and the simulation results were compared to the TRD prototype beam test data. The prototype for the beam test (Fig. 6) was designed with four layers of 10 mm, 1200 mm long straws with two different types of metallization: aluminum and gold. The straws were arranged in two horizontal planes shown in Fig. 6a,b. Four layers of the

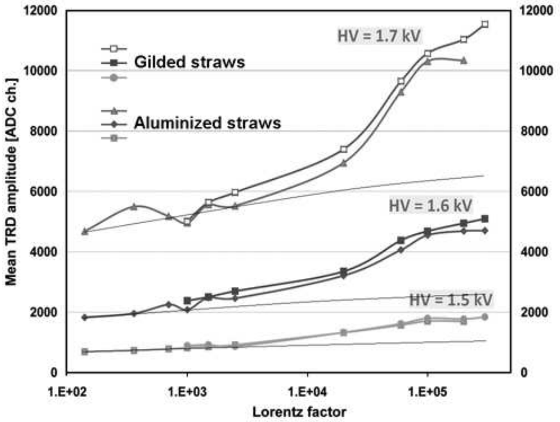


Fig. 9: TRD signal versus a particle Lorentz factor.

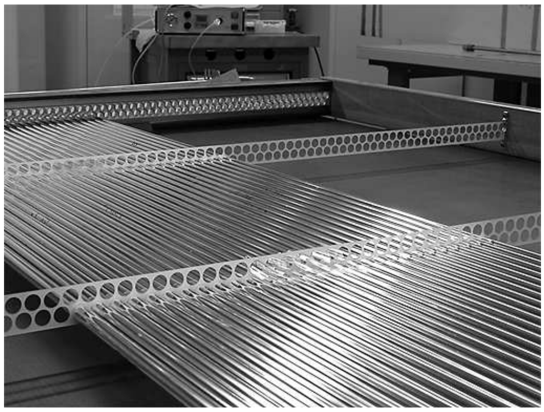


Fig. 10: Production of the TRD modules

Ethafoam-220 radiator were mounted between the straw rows (Fig. 6d). The two gas manifolds housed the HV distribution and signal front-end circuitry. The readout electronics was using VA32-HDR14 ASIC's and an Altera FPGA-based sequencer with sparsification board. The data were transferred to the TRD DAQ computer (Fig. 6c) using the USB 2.0 interface, as required for the CREAM sub-detectors. Figure 7 shows the TRD prototype installed at the SPS North Area H2 test beam line. Singly charged particle beams, both electrons and hadrons with different energies, were tuned to cover a large Lorentz gamma factor range. Since the Transition Radiation intensity depends on particle charge and gamma factor only, this allows the use of electrons, pions and protons of various momenta to extend the Lorentz factor range from 10^2 to $5{\times}10^5$. An example of measured TRD pulse height spectra below (100 GeV/c pions) and above (100 GeV/c electrons) the Transition Radiation threshold is shown in Fig. 8. No significant Transition Radiation photons accumulation with the plane number was observed. The measured TRD prototype performance both for detection efficiency and response versus gamma factor confirmed the Monte-Carlo predictions. A very high signal saturation gamma value, in excess of 10^5, was demonstrated. Figure 9 shows the TRD response versus particle gamma factor for three different HV values. The normalized ionization plateau curves are also shown. After the analysis of the prototype beam test results a decision to decrease each module radiator thickness from 60 mm to 50 mm was taken.

IV. Conclusion

Based on previous CREAM flight experience, a new generation TRD was designed for the CREAM instrument, incorporating improvements in both spatial and signal resolution, compact, low-power front-end electronics, fast USB 2.0 interface to the CREAM Science Computer and a low noise HV system. A full straw size TRD prototype was fabricated and tested in the CERN SPS beam. The beam test demonstrated excellent TRD prototype performance and confirmed the Monte-Carlo predictions. The TRD manufacturing is in progress (Fig. 10).

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