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Performance of the CREAM calorimeter module during its first flight of 42 days

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The Cosmic Ray Energetics And Mass (CREAM) calorimeter module consists of a tungsten/scintillating-fiber sampling calorimeter preceded by two graphite targets with scintillating fiber hodoscopes, and a pixelated Silicon Charge Detector (SCD). The calorimeter is designed to measure incident particle energies, and the hodoscopes are designed to provide incident particle tracking information. The calorimeter and hodoscopes both use Hybrid Photo Diodes (HPDs) with high voltage settings at 6 kV for the calorimeter and 9 kV for the hodoscopes. We describe the performance of the calorimeter module during a 42 day flight at balloon altitude (2 - 6 mbars), including HV stability, noise values as calculated from pedestal value distributions, gain variations of the electronics, and trigger. In addition, the calorimeter calibration will be discussed.

1. Introduction

The CREAM experiment was designed to be flown at the top of the atmosphere suspended under NASA research balloons to directly measure cosmic-ray spectra and abundances for nuclei from H to Fe and above, in the energy range up to ~1000 TeV [1]. The instrument is comprised of several detector systems, including a Transition Radiation Detector (TRD), a Timing-based Charge Detector (TCD) [2], and a calorimeter module. The calorimeter module (Fig. 1) is itself comprised, from top to bottom, of the SCD to measure incident particle charge, a fiber hodoscope, S0/S1, with 4 crossed layers to provide supplemental charge measurement and tracking information, a flared graphite target layer about 0.25 λ_{int} thick with a 30^{o} opening angle, to induce deep inelastic interactions with the incident nuclei, an additional fiber hodoscope, S2, with 2 crossed layers to provide another pair of tracking points, a second interaction target essentially identical to the first, but with reduced lateral dimensions to fit the smaller aperture at its location, a single layer scintillating fiber detector to provide shower flagging and reference time to the TCD, and a 20 radiation length (X_0) sampling calorimeter. On December 16, 2004, the CREAM payload was launched as a Long

Duration Balloon (LDB) payload from Williams Field, near McMurdo Station, Antarctica, and over the following 42 days collected cosmic-ray data while circumnavigating the continent three times.

2. Calorimeter module design

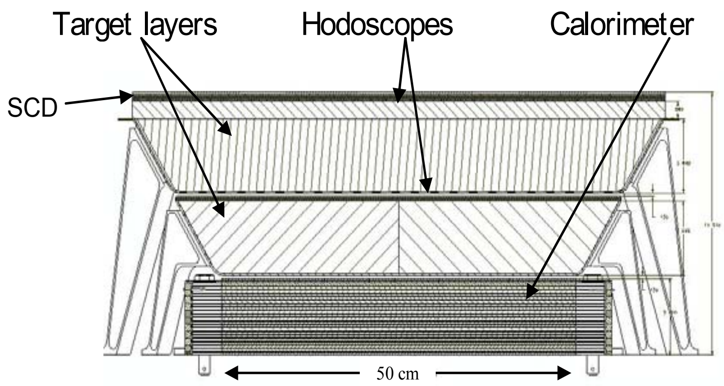

Figure 1. A cross-section view of the CREAM calorimeter module comprised of SCD, graphite targets, hodoscopes and calorimeter.

The SCD is comprised of 26 ladders, each with 7 partially overlapping sensors for full coverage of a 78×80 cm^2 area. The sensors are 380 μm thick silicon, with sixteen 2.12 cm^2 pixels in a 4×4 array, for a total of 2912 pixels. The S0/S1 hodoscope is comprised of 4 crossed layers of ~770 mm long, 2×2 mm^2 Bicron BCF-12MC scintillating fibers, with white extra mural absorber (EMA) painted on. For mechanical reasons, alternate fibers are read out on opposite ends. The non-readout end is aluminized by vacuum deposition. At the readout end, a length of 2×2 mm^2 Bicron BCF-98MC clear fiber with white EMA, is glued on, and is bent into position through a cookie against an HPD pixel. The four layers are read out alternately in X and Y. The S2, lower in the stack, covers a smaller area. The fibers in this detector are essentially the same as in S0/S1 with a length of ~630 mm. The two layers of this detector are also crossed, providing another set of X and Y measurements. The 50×50 cm^2 calorimeter has 20 layers of 1 X_0 (3.5 mm) tungsten, interleaved with 20 active layers, each comprised of 50 fiber ribbons. The 1 cm wide ribbons are each comprised of nineteen 0.5 mm round Bicron BCF-12 scintillating fibers. For similar mechanical reasons, alternate ribbons are read out from opposite ends, with the non-readout ends aluminized. The scintillation light is transferred through a UVT acrylic light guide and a jacketed bundle of clear plastic fibers to a 73-pixel HPD. The signal is optically split into low-, mid- and high-energy ranges, with progressively smaller fractions of the light signal, and with the mid- and high-range attenuated using neutral density filters with transmission coefficients of 50% and 16%, respectively. This arrangement allows the front end electronics to cover the 1:200,000 dynamic range between the smallest shower signal of interest and the highest single-ribbon signal expected in a 1000 TeV shower. The low- and mid-range signals of each ribbon are read out by separate pixels, while the high-range signals are read out in groups of five, for a total of 2200 channels. The HPD dynamic range is ~1:1,000,000, and does not constrain the readout linearity. As described in Sec. 4 below, during event reconstruction the different ranges are inter-calibrated for each ribbon separately.

3. Performance of calorimeter and hodoscope

During the 42 day flight, the calorimeter and hodoscopes operated quite satisfactorily. Although the payload was not pressurized, and the ambient pressure was 2 – 5 Torr, at pressures for which the corona and tube high-voltage discharges take place at the lowest E-field levels, the calorimeter module HV systems were mostly stable. One supply out of 8 in the calorimeter was slightly unstable during the first 6 days of the flight, but from that point on was stable at 6 kV along with the other seven. Of the 11 hodoscope HV supplies flown, six were stable at 9 kV, with the others at somewhat reduced settings. The bias voltages for

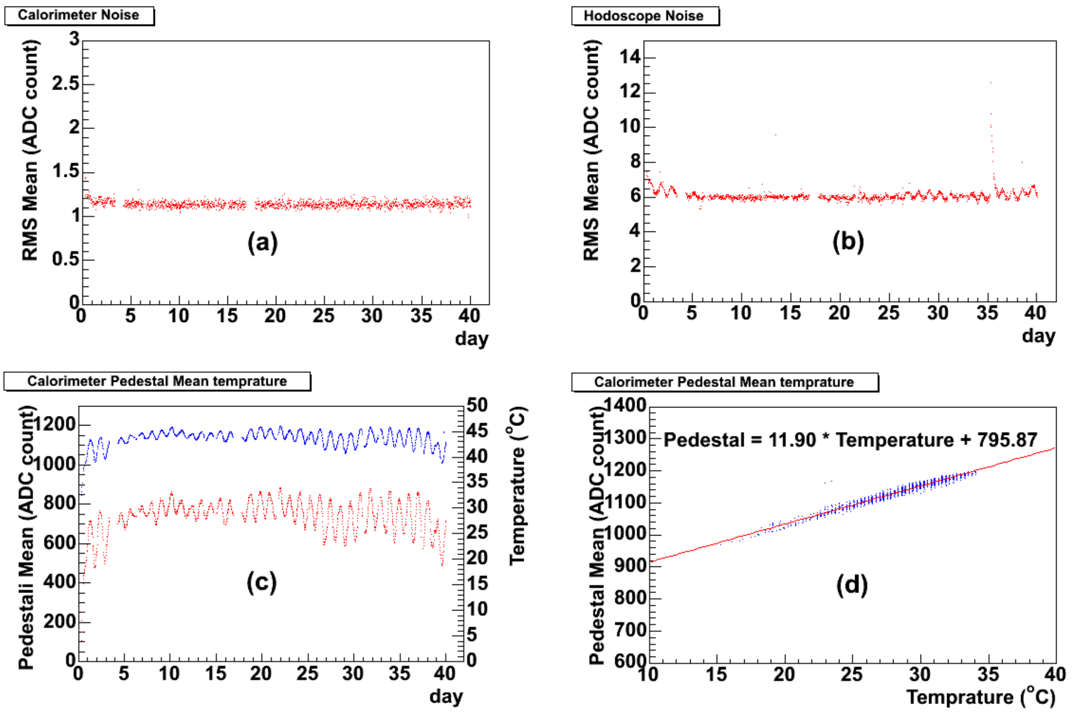

Figure 2. Pedestal noise in the calorimeter (a) and hodoscopes (b) during the flight; (c) pedestal mean values and temperature for one calorimeter MB; (d) correlation between temperature and pedestal mean values in the MB.

all HPDs were stable at 60 V, and the readout electronics operated very quietly. Figures 2 (a) and 2 (b) show the mean noise levels in all calorimeter and hodoscope channels, respectively, as measured in pedestal runs throughout the flight. The mean calorimeter noise value of ~1.15 ADC counts is comparable to the best achieved in the lab at full atmospheric pressure. The hodoscope readout electronics also proved extremely quiet and stable, except for a period of several hours on January 20, 2005 when an extremely large solar flare occurred [3]. During the flight, the calorimeter and hodoscope remained in a temperature range of 15C – 35C, well within their operational limits. As expected from our experience in beam tests, the pedestal values varied with the ambient temperature. Figure 2 (c) shows the time variation of the pedestal mean values and temperature for one calorimeter motherboard (MB). A very clear correlation between the two is shown in Fig. 2 (d). To assure proper sparsification thresholds and pedestal subtraction despite this thermal drift, pedestal runs were performed every five minutes throughout the flight, leading to a pedestal value drift of less than 1 ADC count between two consecutive pedestal runs. Sparsification thresholds were automatically adjusted as needed following each pedestal run. The performance of the SCD is reported elsewhere in this conference [4].

4. Calorimeter trigger and preliminary energy reconstruction

The calorimeter trigger was designed to generate a trigger signal whenever a set of N consecutive calorimeter active layers (N = 4, 6, 8, or 10, adjustable by command) each observed a signal exceeding a threshold that could be adjusted separately per half-layer by command. During the flight, the trigger was set to require at least 6 consecutive layers, with a threshold of ~60 MeV. This provided nearly 100% efficiency for showers of protons above 3 TeV (estimate based on MC study). Figure 3 (a) shows a preliminary result of the calorimeter energy deposit distribution for events recorded with a calorimeter trigger. The energy deposit was reconstructed using a preliminary set of calibration constants from beam calibration, LED-based HV gain corrections, and flight measurements of the ratios between different optical ranges. Figure 3 (b) shows an example of such a ratio of mid- and low-range signals for one ribbon. Such plots were used to inter-calibrate the different ranges for each ribbon, providing measurements from the mid-range wherever the low-range was saturated.

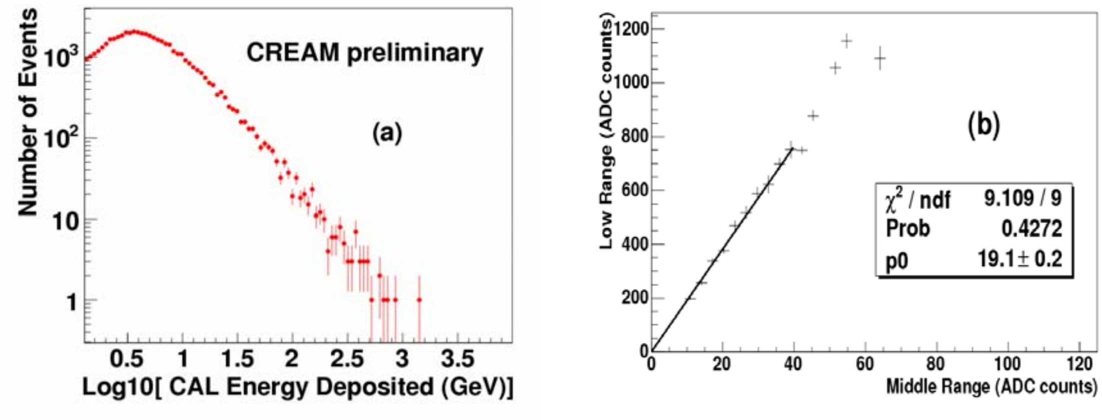

Figure 3. (a) Preliminary distribution of reconstructed calorimeter energy deposit for calorimeter triggers during flight; (b) an example of the mid-range vs. low-range signals measured in flight from the same ribbon, with a fit of the linear region.

5. Conclusions

The CREAM calorimeter module worked very well unpressurized, in a weak vacuum, during CREAM's 42-day maiden flight. Electronics noise levels were low. Bias and high voltage values for the calorimeter were very stable until termination. A significant amount of high-energy data was collected and analysis is in progress.

6. Acknowledgements

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