Performance in flight of the CREAM-III and CREAM-IV calorimeters

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Abstract. **The Cosmic Ray Energetic And Mass (CREAM) balloon-borne experiment is designed to investigate the composition and energy of cosmic-ray nuclei. From December 2007 to January 2008 and again from December 2008 to January 2009, CREAM flew on its third and fourth flights from McMurdo, Antarctica. The payload includes a full suite of instruments, including a calorimeter constructed of 20 layers of 1 radiation-length thick tungsten plates interleaved with 20 layers of 0.5 mm diameter scintillating fiber ribbons, and used to measure the elemental energy spectra of cosmic rays up to 10^{15} eV. Improved calorimeter front-end readout electronics were introduced to reduce noise levels, and the data indicate good performance. In this paper we present the performance in flight of the CREAM-III and CREAM-IV calorimeters, including a preliminary distribution of deposited energy.**

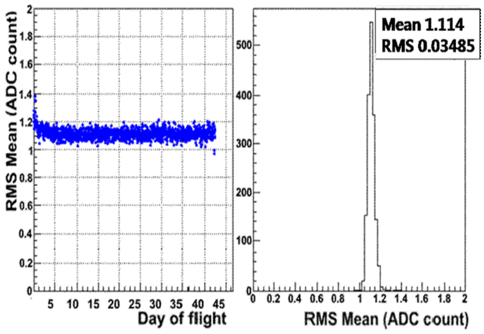
***Keywords*: Cosmic Rays, Balloon Flights and Calorimeters**

I. Introduction

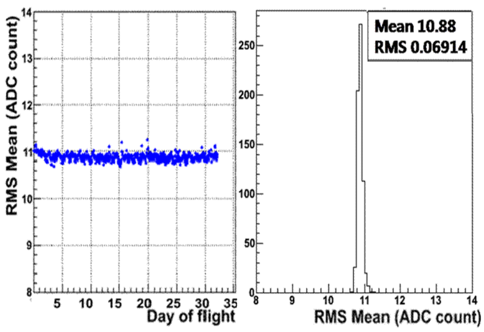
CREAM is a balloon-borne experiment to measure the composition and energy spectra of cosmic rays over the energy range from $\sim 10^{12}$ eV to $\sim 10^{15}$ eV [1, 2]. Such measurements will provide evidence for the sources of cosmic-ray particles, their acceleration mechanisms and propagation through the galaxy. The instrument consists of several detector systems: a Timing Charge Detector (TCD), a Cherenkov Detector (CD), an imaging Cherenkov Camera (CherCam), a double layer Silicon Charge Detector (SCD), carbon targets for a sampling tungsten/scintillating-fiber calorimeter (CAL) [3]. In the third flight (CREAM-III), the CherCam was added for charge measurements, and the instrument configurations of CREAM-III and the fourth flight (CREAM-IV) are identical. This paper reports on the performance of the CREAM-III and CREAM-IV calorimeters and preliminary results of the flights.

II. Calorimeter for CREAM-III and CREAM-IV

Energy measurements are made with an ionization calorimeter comprised of a stack of tungsten plates with interleaved scintillating fiber layers [3, 4]. The 50×50 cm^2 calorimeter has 20 layers of 1 radiation length (3.5mm) tungsten, interleaved with 20 active layers, each comprised of 50 fiber ribbons [5]. The 1 cm wide ribbons are each comprised of 19 cylindrical 0.5 mm scintillating fibers. A new ASIC board was designed to reduce the noise levels of the front-end electronics. The calorimeter noise was measured with pedestal runs taken automatically every hour. The pedestal noise levels were quite good and stable during the CREAM-III and CREAM-IV flights. Figure 1 (b) shows the average value of 10.88 (in ADC units) in CREAM-III. It is in good agreement with the previous measurements achieved in the lab [6]. Figure 1 (a) shows the mean noise values in all calorimeter channels of the first flight (CREAM-I). The thickness of the RMS distribution is much improved in CREAM-III compared to CREAM-I. This shows that the new electronics performed significantly better than the previous system.



(a) Average pedestal rms of CREAM-I.



(b) Average pedestal rms of CREAM-III.

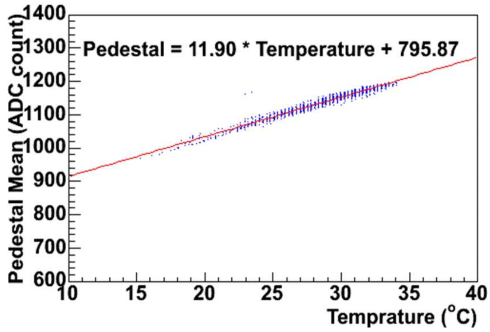
Fig. 1. Pedestal noise of 2560 channels in the CREAM-I and CREAM-III calorimeters.

III. Performance of the CREAM-III Calorimeter

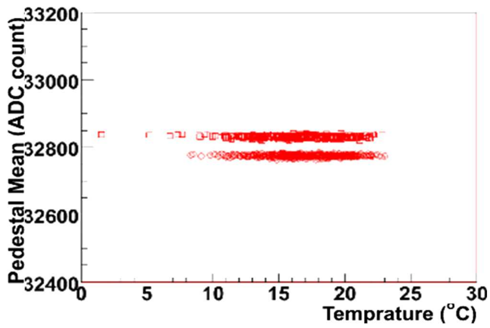
CREAM-III was launched from McMurdo on December 19, 2007 and flew over Antarctica for 29 days. During the flight, the calorimeter performed excellently. CREAM-III collected much more data than previous flights, especially for the lower energy range, since the trigger threshold per channel was reduced from $\sim$ 60 MeV to $\sim$ 12 MeV. The calorimeter module HV systems were stable at 6 kV throughout the flight. The bias voltage for all Hybrid Photo Diode (HPD) boxes was stable at 60 V. It verified that the refurbished HPDs worked properly. In addition, the readout electronics operated very quietly. During the flight, calorimeter temperatures were within the operational range of 10 °C – 31 °C. In CREAM-I, pedestal values measured every 5 minutes showed a clear correlation with temperature for one calorimeter motherboard, as shown in Fig. 2(a). By improving electronics for CREAM-III and CREAM-IV, we were able to remove the temperature dependence of pedestals, as seen in Fig. 2 (b). It allowed us to measure the pedestal once an hour.

IV. Performance of the CREAM-IV Calorimeter

CREAM-IV flew again over Antarctica from December 19, 2008 to January 7, 2009. During the 20 day flight, the calorimeter module HV systems ($\sim$ 6 kV) and bias voltage ($\sim$ 60 V) were stable as during the CREAM-III flight. The calorimeter remained in a temperature range of 8 °C – 31 °C, and the maximum excursion in a single day was $\sim$ 12 °C. The average pedestal noise during the flight remained stable around the value of 11.08 ADC units. Sparsification thresholds were automatically adjusted as pedestal runs were performed every hour [5].



(a)



(b)

Fig. 2. Correlation between temperature and pedestal mean values of the (a) CREAM-I calorimeter, and (b) CREAM-III (open circles) and CREAM-IV (open squares) calorimeters.

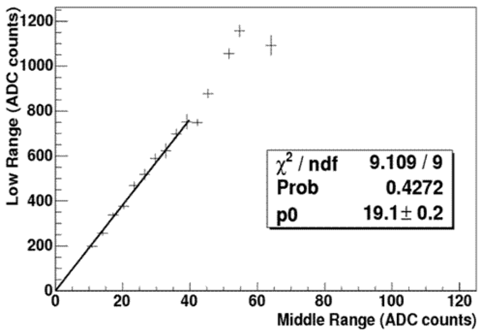
V. Data Analysis

A. Calorimeter Trigger

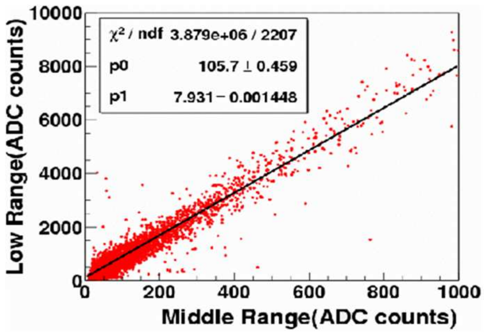
During the flight, the calorimeter trigger required 6 consecutive layers with at least 1 ribbon in each layer above a fixed threshold value, as described below. It used the same algorithm as for CREAM-I and CREAM-II.

1) CREAM-III Calorimeter Trigger: The threshold value was set to 18 DAC counts, which corresponds to $\sim$ 12 MeV of energy deposit. Compared to CREAM-I with a threshold of $\sim$ 60 MeV, this is a great improvement. The overall calorimeter trigger rate was $\sim$ 0.5 Hz during the CREAM-III flight. About 5×10^4 calorimeter trigger events were collected each day, and we accumulated over 1.3×10^6 events during the flight, representing a 30-fold increase in statistics compared to the previous exposures for CREAM-I, made possible by the lower threshold.

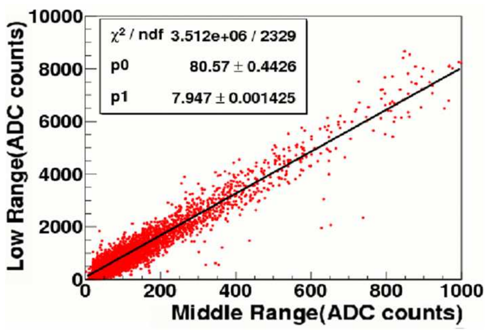
2) CREAM-IV Calorimeter Trigger: The threshold value was set to 16 DAC counts, also corresponding to $\sim$ 12 MeV of energy deposit. The trigger conditions were therefore essentially the same as for CREAM-III. During the flight, about 4.8×10^4 calorimeter trigger events were collected each day for a total of $\sim 9\times 10^5$ events.



(a)



(b)



(c)

Fig. 3. Examples of the low range signal as a function of middle range signal measured in flights for the (a) CREAM-I, (b) CREAM-III and (c) CREAM-IV calorimeters, respectively.

B. Energy Reconstruction

The deposited energy was reconstructed using calibration constants from CERN beam calibrations, LED-based HV gain corrections, and flight measurements of the ratio between different gain ranges [5]. The wide dynamic range of the calorimeter is divided into 3 sub-ranges (low, middle and high range, respectively) with different gains, chosen to match the dynamic range of the front-end electronics with a total of 2560 channels [7]. Light from each ribbon is channeled out by 48 black jacketed clear fibers, with 40 thin fibers for the low range, 5 for the middle range and 1 for the high range. Figure 3 shows an example of the low range as a function of middle range signals from one ribbon, for the CREAM-I, CREAM-III, and CREAM-IV calorimeters, respectively. For CREAM-I the gain ratio was 19.1, whereas for CREAM-III and CREAM-IV the ratio had been adjusted to 8 (the experimentally realized value of 7.9 is in good agreement with this goal). Such ratio values were used to inter-calibrate the different gain ranges for each ribbon, to compensate for situations when the low range saturated [5].

C. Preliminary Results

Cosmic rays traverse the TCD, CherCam, and SCD, and then develop a shower in the calorimeter. The calorimeter measures shower energy resulting from a nuclear interaction in the carbon target. Figure 4 shows the preliminary distribution of the total energy deposit in MeV in the calorimeter for shower events recorded with a calorimeter trigger [3]. These events were individually scanned, and all primary charge species are included in the distribution. The calorimeter trigger distribution shows a clear power-law feature, expected from the energy dependence of the differential cosmic-ray spectrum, even before applying any calibrations. The power-law behavior is visible in the right-hand side of the distribution (beginning at about 1000 MeV). In the case of CREAM-II, the value marking the onset of power-law behavior was approximately 3000 MeV [7]. Below 1 GeV, the effect of the trigger efficiency threshold is apparent in Fig. 4. The calorimeter energy threshold and other instrumental effects are responsible for the shape of the curve on the lower-energy side, with a deviation from a pure power-law [5]. The energy deposit was reconstructed by applying calibration constants, HV gain corrections, and accounting for the ratios between different gain ranges. After converting the energy deposited in the calorimeter to the parent cosmic-ray energy, the all-particle spectrum is expected to exhibit power-law behavior, following a trend similar to that of Fig. 4.

VI. CONCLUSIONS

CREAM had successful flights from McMurdo, Antarctica during the 2007/08 season for CREAM-III and again during the 2008/09 season for CREAM-IV. The calorimeters operated well for the entirety of both flights. With improved readout electronics, the pedestal noise levels were reduced, allowing significant amounts of data to be collected. Initial data from the calorimeter in the CREAM-III and CREAM-IV flights indicates

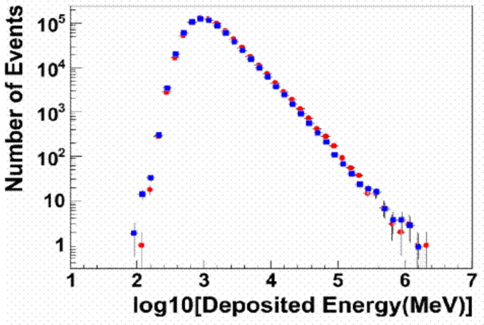


Fig. 4. Preliminary distribution of calorimeter energy deposits from CREAM-III (filled circles) and CREAM-IV (filled square) data.

satisfactory operation of the detectors in flight. Further detailed analysis is currently in progress to improve our preliminary energy spectrum analysis.

VII. ACKNOWLEDGEMENTS

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