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The CREAM-III Calorimeter

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Abstract: After successful recovery of the first CREAM (Cosmic Ray Energetics And Mass) instrument during the 2004/5 Antarctic campaign, the calorimeter was refurbished for a third flight, planned for December 2007. In this CREAM-III calorimeter, the optics were replaced with multi-clad fiber ribbons to enhance the light signal, and new readout electronics boards reduce noise even further than the previous low-noise version. These improvements allow increased sensitivity to low energy showers. A new assembly structure has also been fabricated for ease of recovery. This refurbished calorimeter was calibrated at a CERN test beam in October 2006, and is now being integrated with the rest of the CREAM detector suite. The construction of the calorimeter and tests of its optical and electronic components will be discussed.

Introduction

Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne investigation to directly measure the elemental spectra of protons to iron nuclei with energies up to ~ 10^{15} eV [1]. Two successful flights from McMurdo Station, Antarctica have been accomplished with a total of 70 days duration, collecting 117 GB of data [2].
After the recovery of the second flight instrument, a refurbishment of the first calorimeter was started, to prepare the CREAM-III calorimeter. The basic design of the calorimeter [3] has not changed, but several improvements were made in the design, based on experience from the first two flights. To increase the sensitivity of the calorimeter to low energy showers, the single-clad scintillating fibers were replaced with multi-clad fibers as the active components of the calorimeter. This change is expected to increase the collected light signal by ~ 60%. The ASIC board design was improved to reduce the front-end electronics noise level by replacing a few components. The mechanical design of the first calorimeter allowed recovery of the tungsten absorber as well as the optical sensors and electronics, but not the optics. The mechanical structure was redesigned for the third flight, allowing safe recovery of all calorimeter elements. The new calorimeter is designed to be separated into five independent assemblies. Special recovery trays will protect the optics during recovery operations.
After refurbishment of the calorimeter in September 2006, the calorimeter module including the refurbished Silicon Charge Detector (SCD-II), carbon targets and scintillating fiber trigger counter S3, was shipped to CERN for a beam calibration. During the beam run, the calorimeter and the SCD-II were successfully calibrated with good resolution and uniform position response.
This paper describes performance of the new ASIC board and beam test analysis and results.

Performance of the new ASIC board

From previous flight experience we learned that biasing the reference voltage in the ASIC board does not increase the linear dynamic range of the

VA-HDR2 chip, since the linear region is only about a quarter of the full range. Since this reference voltage was originally designed to maintain a stable pedestal value at varying temperatures, using it to shift the center point of the range increased the pedestal drift rate as a function of temperature. In the new ASIC board, the reference voltage was returned to its initial function. In addition, the 12 bit ADC chip was replaced with a 16 bit chip, addressing a problem of missing bit behavior in the old design and improving the resolution. Since the data format was already based on 16 bit data to accommodate other detector systems, this did not increase event record size. After these modifications, a full set of the new ASIC boards were fabricated. Figure 1 shows a distribution of pedestal RMS noise (in ADC units) for all 2560 calorimeter readout channels. Except a small excess at the low end, we see the plot follows a Gaussian distribution, indicating a well controlled noise level. The mean value of 10.9 ADC units is fairly consistent with the previous board, but the 0.5 unit RMS width of the distribution (~5%), shows a 10-fold improvement relative to the previous version. This improvement will allow lower sparsification thresholds to be used in suppression of “empty channels” given telemetry bandwidth limits. These lower thresholds will improve the sensitivity of the calorimeter to lower energy showers.

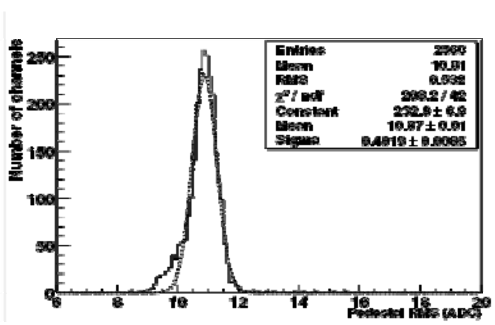

Figure 1: Pedestal RMS distribution of all 2560 channels.

The fast shaping circuit for the trigger output was tested with charge pulses. Figure 2 shows the change in rate for a trigger channel as the threshold value is changed. For a charge pulse, the trigger rate changes from 100% (26 Hz here) to 0% (0 Hz) which ideally would follow a step function behavior, but given trigger circuit noise follows a somewhat more gradual transition. The trigger behavior curve was fitted with a step function convoluted with a Gaussian function. The sigma of the Gaussian function is the noise level of the trigger circuit.

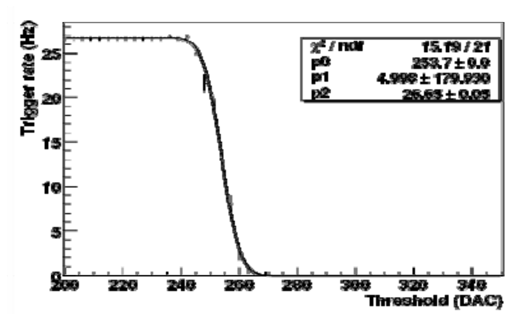

Figure 2: Trigger rate vs. threshold for a trigger channel in the new board.

A distribution of trigger noise values for all 1280 trigger channels was plotted (Fig. 3). The new circuitry displays a 2-fold improvement in the mean value compared with the previous board. Although the final trigger noise level cannot be determined until the flight, we expect the above improvement to permit lower trigger threshold levels, increasing the CREAM calorimeter sensitivity to lower energy events.

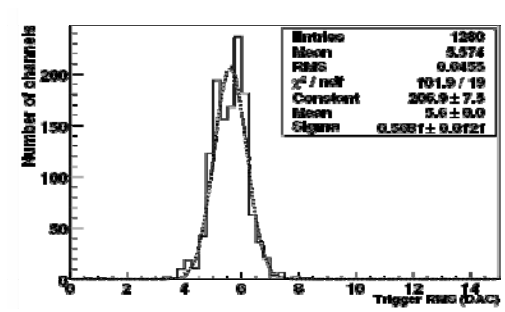

Figure 3: A distribution of trigger noise values in DAC counts for 1280 trigger channels.

Reverting the use of the ASIC reference voltage drastically reduced the pedestal drift with temperature. Figure 4 shows the change in pedestal mean value of one channel as a function of temperature from 5 ^{o}C to 35 ^{o}C in a thermal chamber. The slope of 1.4 ADC/^{o}C is only ~ 1% of the slope measured with the old boards. Given the temperature change rate of ~ 1°C/hr observed in the first two flights, measuring pedestals every hour with these boards will achieve < 1.5 ADC unit pedestal drift. This level would be 7 times better than achieved with the previous boards, collecting pedestal data once every 5 minutes. The improved pedestal stability will allow finer sparsification, reducing event record sizes. This reduction in event record size will allow higher event transfer rates, which will be useful with the higher trigger rates expected for the lower energy data.

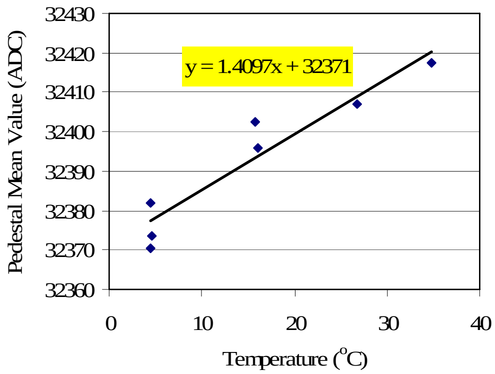

Figure 4: Pedestal mean value as a function of temperature showing a 1.4 ADC/°C slope.

Performance during beam calibration

Figure 5: Refurbished CREAM calorimeter before integration of the refurbished SCD-II.

Following optical components fabrication, the CREAM-III calorimeter was assembled in September, 2006 (Fig. 5). The new mechanical structure is comprised of five sets of sub-frames for safe recovery including optical components.

The calorimeter module was exposed to 150 GeV electron beams at CERN's H2 beam line, calibrating the calorimeter ribbons by scanning in the x and y directions. Calibration constants were obtained for 1000 ribbons using the same method as in previous calibration runs [3]. Preliminary calibration constants are shown in Fig. 6.

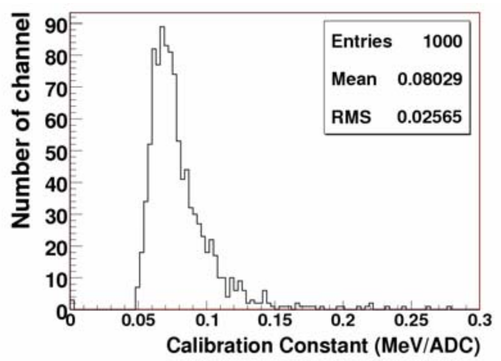

Figure 6: A distribution of calibration constants for the CREAM-III calorimeter.

After the calibration, electrons with different energies were injected into the calorimeter to test its performance. Figure 7 shows four distributions of ADC sums from electron beam runs at 50, 100, 150 and 200 GeV exhibiting good linearity.

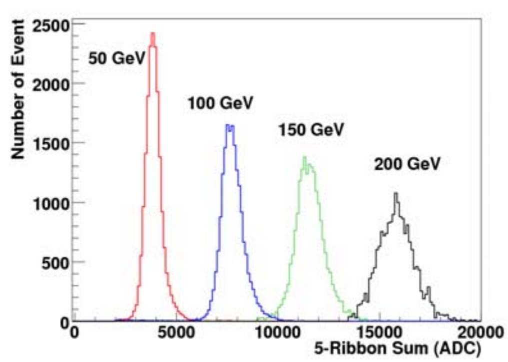

Figure 7: Signal sum distributions for 4 different electron beam energies.

Figure 8 shows the raw energy resolution as a function of energy, before calibration. These preliminary resolutions already show an improvement over the previous calorimeter resolution after calibration [3].

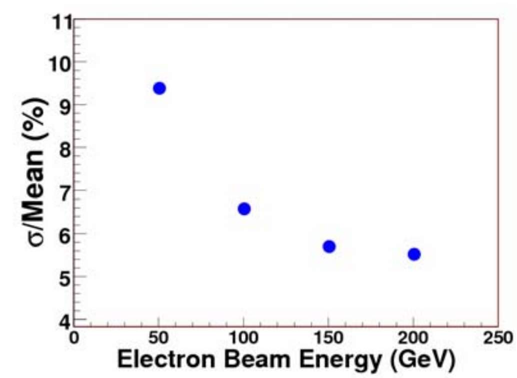

Figure 8: Un-calibrated calorimeter resolution for different electron beam energies.

The calorimeter response uniformity was also studied with respect to the beam incidence point. Figure 9 shows ADC sums of 5 ribbons per calorimeter layer as a function of X position. Even before calibration, and including the edges where some side leakage occurs, the energy sum displays a RMS width of only ~ 4%.

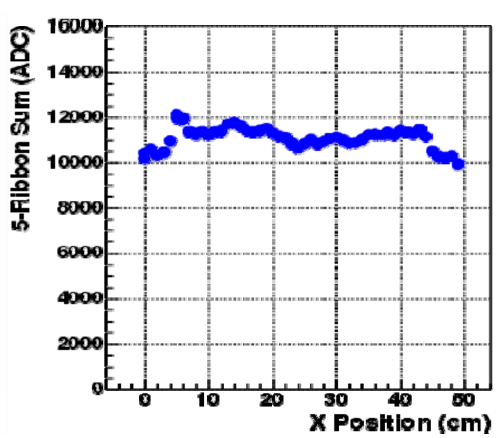

Figure 9. Calorimeter response as a function of beam position in the X direction. .

The ADC sum's dependence on HPD high voltage was tested by changing the HV values from 5.1 to 10.5 kV. The result shows a highly linear response as expected from the HPD specs.

Conclusions

After a successful recovery of the CREAM-II instrument, a refurbished calorimeter was assembled for the third flight, with improvements in optics, electronics and mechanical structure, based on experience of two previous flights. The calorimeter was calibrated at a CERN beam test and displayed excellent performance. Further studies are underway for calibration using both the conventional method as well as a new method utilizing data from an independent beam tracker [4]. The refurbished SCD-II was also calibrated by exposing each sensor to an electron beam [5]. A separate study of backscatter from the calorimeter, and its effects on charge measurement is presented elsewhere in this conference [6].

Acknowledgements

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