Calibration of the CREAM calorimeter with beam test data

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Abstract: The Cosmic Ray Energetics And Mass (CREAM) calorimeter (CAL) is designed to measure cosmic-ray elemental energy spectra from 10^{12} eV to 10^{15} eV. It is comprised of 20 layers of tungsten interleaved with 20 layers of scintillating fiber ribbons. Before each flight, the CAL is exposed to an electron beam. For CREAM-IV through CREAM-VI, beams of 150 GeV electrons were used for the calibration, and 100 GeV was used for CREAM-VII. For calibration purpose, we compare electron beam data with simulation results to find calibration constants with the unit of MeV/ADC. In this paper, we present calibration results, including energy resolutions for electrons and uniformity of response. We also discuss CAL calibration using various beam test data compared with Monte Carlo (MC) simulation data.

Keywords: Cosmic Rays, Beam Tests and Calorimeters.

1 Introduction

1.1 The CREAM calorimeter

The Cosmic Ray Energetics And Mass experiment was designed and constructed to push spectral measurements of individual cosmic-ray nuclei H – Fe to energies approaching the "knee" in a series of balloon flights [1]. The goal is to extend direct measurement of cosmic-ray composition to the highest energies possible using balloon flights. The CAL is a stack of 20 tungsten plates, each 1 radiation length (X_0) thick and with surface area 50 × 50 cm^2, interleaved with active layers of 1 cm wide and 50 cm long scintillating-fiber ribbons [2]. It was calibrated in the electron beam, and it displays excellent performance [6]. After refurbishment of the CREAM-III and CREAM-IV CAL, they were used for the CREAM-V and CREAM-VI flight. After recovery of the fifth flight instrument, the CAL was refurbished to prepare the CREAM-VII CAL.

1.2 Beam Test

To correctly measure energy over the wide range (10^{12} eV ~ 10^{15} eV), calibration is quite important [3]. The CAL module was placed in the H2 beam line at CERN's SPS accelerator for this purpose. The CAL calibration requires the use of accelerator beam particles of a known energy, which is limited by current technology to a few 10^{11} eV [4]. During the beam test period, data were collected at different energies and angles using beams of highly relativistic pions, protons, and electrons. For the low range calibration, the CAL was exposed to electron beams by scanning single ribbons in the x and y directions.

2 Performance during beam test

2.1 Calibration

The CREAM CAL calibration is based on identifying the ribbon with the highest signal in each layer per event [3].

By comparing the maximum ribbon signal in each layer with Monte Carlo (MC) simulations, a calibration constant, in MeV/ADC units is obtained. After applying the calibration constants for the 1000 low range readout channels, beam data showed very good agreement with the simulation results. Figure 1 shows CAL energy distributions for 150 GeV electrons from simulation and beam data.

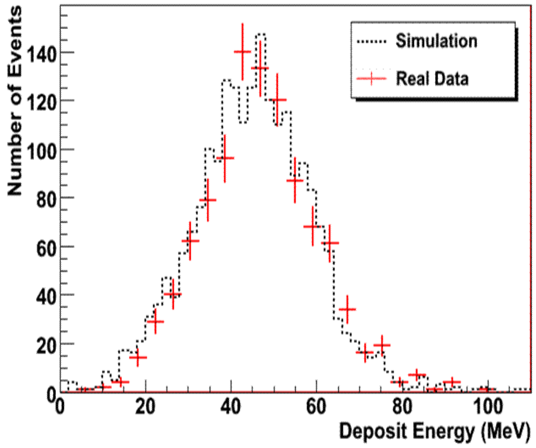

Figure 1. Energy distributions of the CREAM-III CAL for 150 GeV electron.

2.2 Linearity of Response

The dependence of the CAL measurement with the applied voltage (HV) of the photodetectors has been studied separately [8]. The HV gain correction in the range 6 kV to 10.5 kV is used to reconstruct the deposited energy of flight data. The ADC sum dependence on hybrid photo diode (HPD) high voltage was tested by changing the HV values from 3 kV to 10.5 kV at fixed beam energy. Figure 2 shows a highly linear response as expected from the HPD specs.

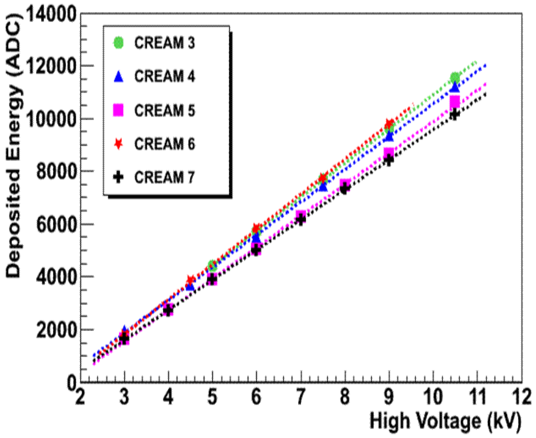

Figure 2. CAL energy vs. high voltage.

2.3 Electron Energy Scan

After the calibration, electrons with different energies were injected into the CAL to test its performance [6]. Calibrated energy sums were plotted for electron beam events with energies from 50 GeV to 200 GeV, incident on the central region of the CAL [3]. During the energy scan, the CAL was kept at a fixed position with the beam impinging on the center at normal incidence [8]. CAL energy was calculated from the sum of the 5 ribbons centered on the beam for different beam energies [8]. Figure 3 shows energy distributions from electron beam runs exhibiting good linearity.

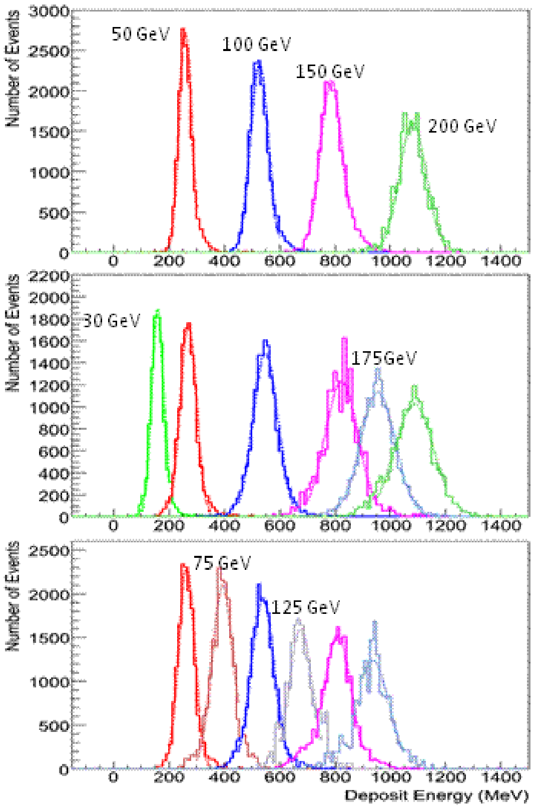

Figure 3. Signal sum distributions of the CREAM-III, CREAM-V and CREAM-VII for different electron beam energies.

3 Calibration Results

3.1 Energy Resolution

To optimize the signal to noise ratio, the energy resolution was assessed in comparison to the number of ribbons summed over per layer, with the best resolution obtained for 5 ribbons per layer (total of 100 ribbons) [7]. With this method, the CAL reconstructed energy resolution was plotted against the electron beam energy as shown in Figure 4 (a) and (b).

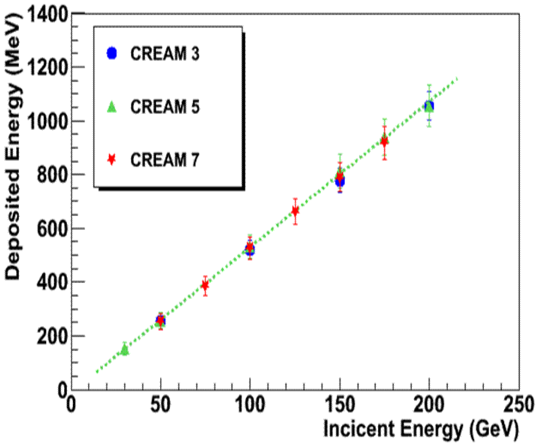

Figure 4 (a). CAL energy vs. electron beam energy.

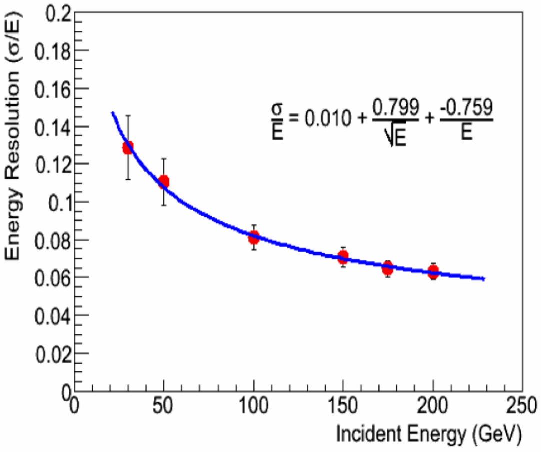

Figure 4 (b). CAL energy vs. energy resolution of CREAM-V.

3.2 Uniformity of Response

CAL response uniformity with respect to the beam was also studied at the incidence point [6]. Electron data were collected by steering 150 GeV electrons onto the center of each ribbon and scanning the CAL in both views. The CAL response as a function of beam position in the X direction of both measured and simulated data is shown in Figure 5. The data points were found to be consistent with the simulation.

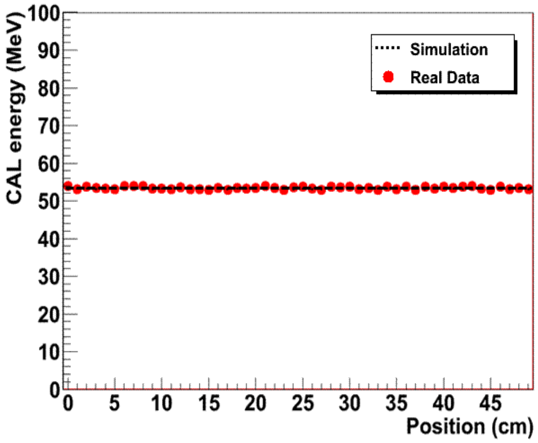

Figure 5. CAL response of ribbons in a layer of CREAM-IV.

Utilizing a fine scan, with a pitch of 2 mm, the reconstructed energy measurement was assessed as a function of beam position. Figure 6 shows energy sums of 5 ribbons per CAL layers after calibration. As shown in Figure 6, the measured energy is independent of incident position [7].

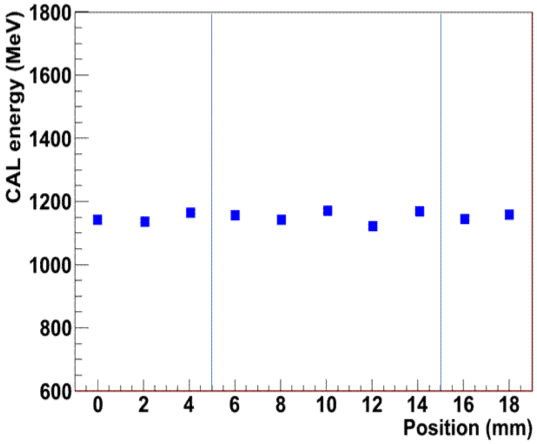

Figure 6. CAL energy with respect to the electron beam injection points of CREAM-VI.

3.3 Systematic Uncertainty

Several components contribute to systematic uncertainty in the CREAM CAL energy measurement [3]. For comparison, calibration was carried out with both 100 GeV and 150 GeV electron beams. Applying the results of these different calibrations to the same data, taken for 175 GeV, is shown in Figure 7.

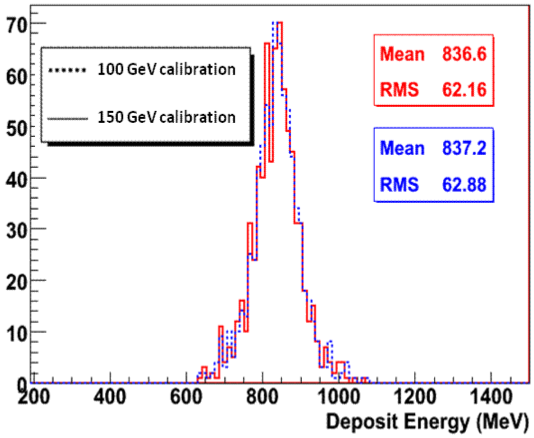

Figure 7. Comparison of signal sums using 100 GeV and 150 GeV calibrations for CREAM-VII.

4 Conclusion

The CREAM CAL was designed to measure the spectra of high-energy cosmic-ray nuclei [5]. The results show good agreement with simulations, and they verify that the detector has an electron resolution sufficient for calibration. During the beam test, the CAL was successfully calibrated with good resolution and uniform position response.

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