Calibration of the CREAM-III calorimeter with beam test data

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***Abstract*. The Cosmic Ray Energetics and Mass (CREAM) calorimeter 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 ribbon. In October 2006 it was exposed to high-energy particle beams of the Super Proton Synchrotron (SPS) at the European high-energy physics (CERN) lab. Beams of 150 GeV electrons were used for calibration, and the data show excellent performance. In this paper we present calibration results, including energy resolutions for electrons and uniformity of response, and we compare electron beam data with simulation results.**

***Keywords*: Cosmic Rays, Beam Tests and Calorimeters**

I. Introduction

The CREAM experiment is designed to investigate high energy cosmic rays over the elemental range from hydrogen to iron [1]. The goal is to extend direct measurements of cosmic-ray composition to the highest energies possible using balloon flights [2]. A sampling tungsten/scintillating fiber calorimeter in the instrument measures energies of cosmic-ray nuclei by looking at the scintillation signal from showers of secondary charged particles in the calorimeter volume when particles interact inelastically [3]. To correctly measure energy over the wide range (10^{12} eV $\sim 10^{15}$ eV), calibration is quite important [4]. The calorimeter module was placed in the H2 beam line at CERN's SPS accelerator for this calibration purpose. Figure 1 is a cross-section view of the calorimeter module for the beam test of the third flight (CREAM-III). From top to bottom, this module is comprised of the Silicon Charge Detector (SCD), graphite targets and the calorimeter. It was calibrated in the electron beam, and it displays excellent performance [5], but further corrections were implemented after the initial calibration [3], [6]. In this paper we compare beam data with Monte Carlo (MC) simulation data using the updated calibration constants, and we discuss energy resolutions with different energies and uniformity of response.

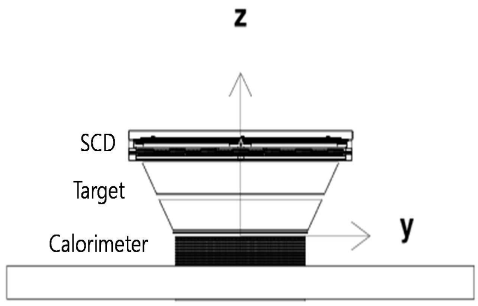


Fig. 1. Configuration of the CREAM calorimeter module.

II. Beam Test for CREAM-III

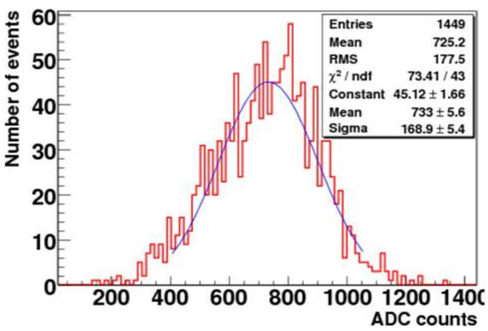
During the beam test period, we collected electron data at energies from 50 GeV to 300 GeV at 0°, 15°, 30°, 45° and 60°. In addition, proton and negative pion data were collected for energy scans and angle scans. The calorimeter has three different ranges (low, middle and high range) to cover the required dynamic range. For the low range calibration, the calorimeter was exposed to 150 GeV electron beams in CERN's H2 beam line, by scanning the calorimeter ribbons in the x and y directions.

III. Calibration Process

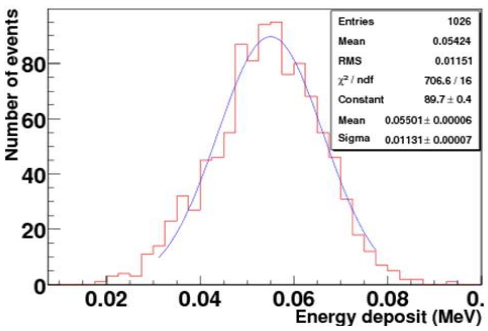
With a total of 1000 fiber ribbons in 20 layers, each with three readout ranges, calibration is of critical importance for correctly reconstructing shower energy [6]. Although the beam spot position is known with respect to the ribbons, so only those events are selected where the ribbon nominally "in the beam" actually records the highest signal. In generak this correctly selects the appropriate events. The equalization process required scanning the surface of the calorimeter with beams of 150 GeV electrons and, for each ribbon, comparing the measured signal in ADC counts for those events where that ribbon was in the middle of the beam profile, with the energy deposit from simulated 150 GeV electron events with the same incident positions.

A. Event Selection

The calorimeter calibration is based on identifying for each event the ribbon in each layer having the highest signal in that layer [4]. There are several steps is this process. First, we must find the ribbon with maximum signal in each layer. Next, we must select events at the expected ribbon positions. Last, we must find the signal distributions in all 20 layers with selected events. As seen in Fig. 2, the mean measured signal for a typical ribbon was 733 ADC units, while the simulated energy deposit for that ribbon had a fit mean of 56.01 MeV. This gives rise to a calibration constant of 0.07641 MeV/ADC count. Figure 2 (a) shows the distribution of ADC counts for the maximum ribbon of a layer, and Fig. 2 (b) shows the distribution of energy deposit in the same ribbon.



(a) 150 GeV electron beam data.



(b) Simulation data.

Fig. 2. Distributions of Gaussian mean with selected events at the expected ribbon position.

Although the ribbon hit by the beam particle normally has the highest signal, different channels have different light yield, light collection and light transmission efficiencies, because they are read out with different hybrid photo diodes (HPDs) having different quantum efficiencies and gains, with different ASIC gains, etc [4]. Therefore, it is possible that the ribbon with highest signal would have a lower overall gain, to the point of not recording the largest signal in the layer for most events. To correct for this selection bias and increase the sample of events used in the calibration, one needs to modify the selection by making a less stringent requirement than that the ribbon signal be higher than all other ribbon signals in the layer for that event.

B. Calibration Constants

The calibration constants for the CREAM-III calorimeter were calculated by comparing data from X and Y scans with 150 GeV electron beams to MC simulations based on GEANT [4]. Calibration constants were obtained for 1000 ribbons using the same method as in previous calibration runs [3]. The updated calibration constants are as shown in Fig. 3. It shows the distribution of the 1000 equalization constants obtained through the above process [6].

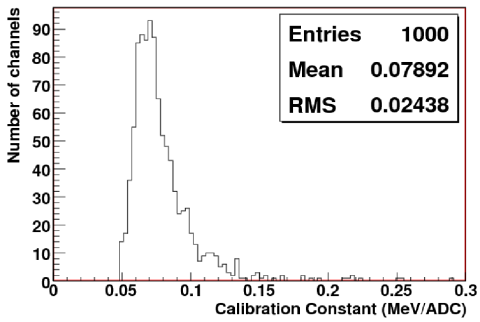


Fig. 3. A distribution of calibration constants for the CREAM-III calirometer.

IV. Comparison of Beam Test Data and Simulations

This calibration was verified by applying the calibrations derived from the procedure to other data-sets [4]. Using GEANT, detailed beam test data were simulated with a variety of energies, incident positions and angles.

A. Longitudial Shower

Figure 4 shows the longitudinal shower profile for three configurations. This results in an energy deposit too low to be of use in calibrating the ribbons of the first and last few layers when using 150 GeV electrons [6]. To address calibration of the first layers, 2.5 cm thick lead bricks were place in front of the graphite targets for a second scan to move the shower maximum closer to the top of the calorimeter. To calibrate the last few layers, the detector was rotated such that the beam was incident through its bottom, and the same lead bricks were placed before the aluminum honeycomb pallet holding the stack. The longitudial profile of both measured and simulated 150 GeV electron showers is shown in Fig. 4. The comparison shows that the simulations acculately reproduces the rising and falling slopes, the overall peak location. and the energy deposited in the lowest calorimeter layers of the experimental measurements. The data points were found to be consistent with the simulations.

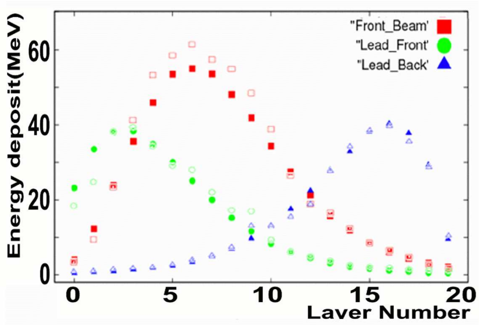


Fig. 4. Mean longitudinal profile of 150 GeV electrons – data (open symbols) and simulation (solid symbols).

B. *Energy Distribution*

A mean calibration constants of about 0.079 MeV/ADC counts was obtained in the beam test for the CREAM-III flight calorimeter. After applying the calibration constants for the 1000 low range readout channels, the beam data showed very good agreement with the simulation results, as shown in Fig. 5.

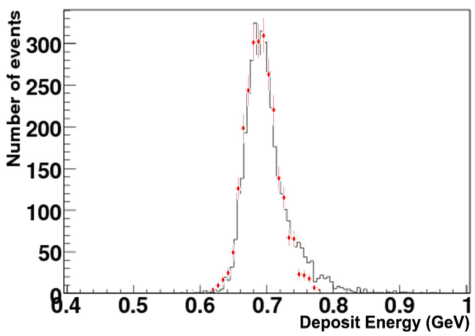


Fig. 5. Calorimeter energy distribution for 150 GeV electrons from simulations and beam data.

V. CALIBRATION RESULTS

Utilizing a fine scan, with a pitch of 0.2 mm, the reconstructed energy measurement and resolution were assessed as a function of beam position [6]. As a result of the calibration procedure, 1000 calibration constants were determined, using exclusively the 150 MeV electron data [7].

A. *Energy Calibration*

Calibration energy sums were plotted for electron beam events with energies of 50, 100, 150 and 200 GeV incident on the central region of the calorimeter [4]. During the energy scan, the calorimeter was kept at a fixed position with the beam impinging on the center at normal incidence. The calorimeter energy was calculated from the sum of the 5 ribbons centered on the beam for the four different beam energies [7]. Figure 6 shows the energy resolution as a function of energy after calibration [5].

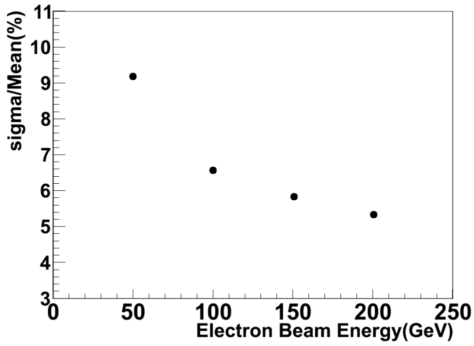


Fig. 6. Calibrated calorimeter resolution for different electron beam energies.

B. *Uniformity of Response*

The calorimeter response uniformity with respect to the beam was also studied incidence point [5]. As shown in Fig. 7, the measured energy is independent of incident position within ± 3 %. Further, the variations between different positions do not coincide with ribbon boundaries, and are thus most likely statistical in nature [6].

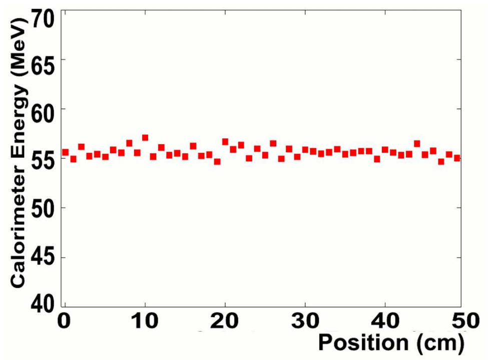


Fig. 7. Calorimeter energy with respect to the electron beam injection points.

VI. CONCLUSIONS

The CREAM calorimeter was designed to measure the spectra of high-energy cosmic-ray nuclei. The calorimeter was placed in a CERN electron beam for calibration and test of its performance. By comparing the maximum ribbon signal in each layer with MC simulations, a calibration constant in MeV/ADC units was obtained. The results show good agreement with simulations, and they verify that the detector has an electron resolution sufficient for calibration, and is uniform down to a 2mm pitch [6].

VII. ACKNOWLEDGEMENTS

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