BEAM TEST CALIBRATION OF THE BALLOON-BORNE IMAGING CALORIMETER FOR THE CREAM EXPERIMENT

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CREAM (Cosmic Ray Energetics And Mass) is a balloon experiment designed for direct spectral and composition measurements of cosmic rays over the elemental range from proton to iron to the energy scale of 10^{15} eV. The first flight will take place at the end of 2004 from Antarctica. The instrument includes a thin ionization calorimeter designed to operate in the range of energies from a few hundred GeV to 1 PeV. Its imaging capability permits the reconstruction of the electromagnetic shower originated from the interaction of primary nuclei in the carbon target. The calorimeter has been calibrated with electron and hadron beams at CERN. The calibration procedure and preliminary beam test results will be reported.

1. Introduction

CREAM is a NASA sponsored balloon experiment designed for direct measurements of the composition and individual spectra of cosmic rays (CR) from proton to iron at energies from a few hundreds GeV up to 1 PeV. In a series of balloon flights in the stratosphere, CREAM will investigate the spectral differences between proton and He and will search for possible cut-offs in the individual spectra of light nuclei of charge Z at energies around $Z\times10^{14}$ eV, as predicted in supernova shock wave acceleration models [1]. The current understanding of the propagation of cosmic rays in the interstellar medium can be improved by accurate measurements of the relative abundances of light nuclei in the CR fluxes. The available data on the B/C

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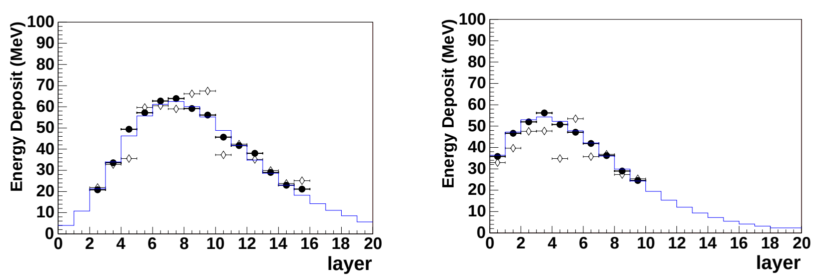
ratio can be extended by CREAM above the region of 100 GeV/n providing a quantitative test on the amount of reacceleration of CR after they leave their sources and on the rigidity dependence of their escape length in the Galaxy.
The key requirements for CREAM are excellent charge discrimination and appropriate exposure and energy resolution. The instrument has been designed to meet these requirements. Multiple measurements of the particle charge are made with a pixelated silicon charge detector (SCD), a segmented timing-based particle-charge detector (TCD) and scintillating fiber hodoscopes. Energy is measured up to 1000 TeV by two complementary techniques : a transition radiation detector (TRD) provides a measurement of the Lorentz factor for $Z \geq 3$ nuclei, while a sampling tungsten/scintillating fiber calorimeter (preceded by a graphite target and fiber hodoscopes) measures $Z \geq 1$ particles with almost energy independent resolution.
The instrument layout and expected performances are described [2,3] elsewhere. CREAM is scheduled to fly for the first time in December 2004 from Antarctica. The calorimeter to be flown on the first payload was designed and built in the US. It has been fully calibrated with high-energy electrons and protons and its response to ion fragments from a 158 GeV/n primary Indium beam was studied at CERN in a dedicated beam test. In this paper we report on the calorimeter calibration with electrons up to 200 GeV in the H2 beam line at CERN in September 2003.

2. The CREAM calorimeter module

The thin ionization calorimeter [4] is preceded by a graphite target (~ 0.46 λ_{int} and ~ 1 X_0) where a hadronic shower is initiated by the inelastic interaction of the primary nucleus. The narrow e.m. core of the shower is imaged by a fine grained 20 X_0 calorimeter [5] with an active area of 50×50 cm^2 that was constructed as a stack of 20 tungsten plates with interleaved active layers instrumented with 1 cm wide ribbons of 0.5 mm diameter scintillating fibers. Energy calibration covering the whole dynamic range of a calorimeter designed to reach 1 PeV is not possible at present accelerators, where the energy scale can be assessed only up to a few hundred GeV. Therefore, flight data will be used to inter-calibrate the calorimeter and TRD by simultaneous measurements of the energy and charge of a subset of nuclei. The energy region spanned by the beam calibration overlaps with the TRD measurements in the region 5 to 500 GeV/n where the TRD, below threshold for TR production, can still provide an energy measurement by taking advantage of the relativistic rise of specific ionization in the proportional tubes.

3. Calorimeter calibration with electron beams

The first step of the calibration procedure was the equalization of the response of individual calorimeter channels. Data were taken by steering 150 GeV electrons onto the center of each ribbon and scanning the calorimeter in both views. Ribbons connected to the same Hybrid Photo Diode



(a) (b)

Figure 1. Average longitudinal shower development with 150 GeV electron beam data (the solid line is the prediction from simulations) : (a) with no absorber ; (b) with 5 X_0 Pb absorber in front of the target (*diamonds* : before; *circles* : after channel equalization).

(HPD) in a layer were first equalized to their average response. In a second pass, the equalization was improved by summing the signals in groups of 3 ribbons and taking into account their relative contribution to the lateral development of the shower weighted with the gain of the respective HPDs. The energy response of each layer was then determined by fitting the longitudinal distribution of the shower at a given beam energy as shown in Figure 1(a) for 150 GeV electrons. A second set of electron data at the same energy were taken with a Pb absorber (5 X_0) in front of the target. The resulting shift in the position of the shower maximum was found to be in good agreement with expectations and allowed calibration of the relative response of the first 2 layers of the calorimeter (Figure 1b).

A third data set was taken rotating the calorimeter by 180 degrees. In this configuration, the beam impinged on the bottom layer of the calorimeter and a tungsten absorber of thickness 2 X_0 had to be added in front of the beam to compensate both for the absence of the target (1 X_0) and for the thickness of the Al bottom plate. Addition of a further 5 X_0 Pb absorber resulted in a longitudinal distribution (Figure 2) with shower maximum on layer 16, which allowed calibration of the last 4 layers of the calorimeter. A single set of calibration constants turned out to fit all longitudinal distributions taken at different energies. Data taken at electron energies

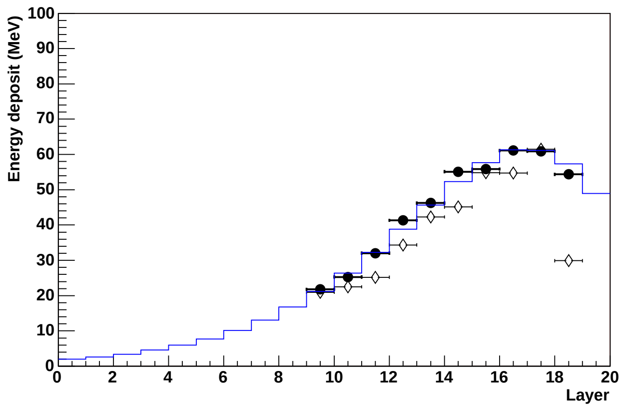


Figure 2. Average longitudinal shower development with 150 GeV electrons impinging on the bottom calorimeter layer preceded by a 5 X_0 Pb absorber (*diamonds* : before; *circles* : after channel equalization).

50, 100, 150, 200 GeV are shown in Figure 3 where the slope from the linear fit $(4.2 \pm 0.3)10^{-3}$ provides the ratio between the visible energy in the calorimeter and the beam energy. This was found to be in agreement with the expected calorimeter sampling fraction from simulations. The absolute energy scale offset is consistent with zero within errors.

The energy resolution of thin calorimeters, designed for very high energy measurements with protons and heavier nuclei, is dominated by fluctuations in the electromagnetic fraction of the hadronic shower, initiated in the low-Z target. Therefore, at TeV energies, photon statistics is relatively unimportant and the sampling fraction can be kept below 1%. The situation is the opposite at beam test energies of a few hundred GeV where, with such a

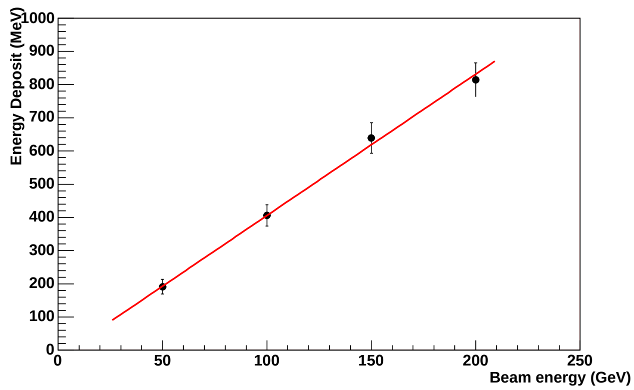


Figure 3. Electron data in the range 50 to 200 GeV. The slope from the linear fit is consistent with a calorimeter sampling fraction of the order of 0.5%. The intercept is compatible with zero within the error.

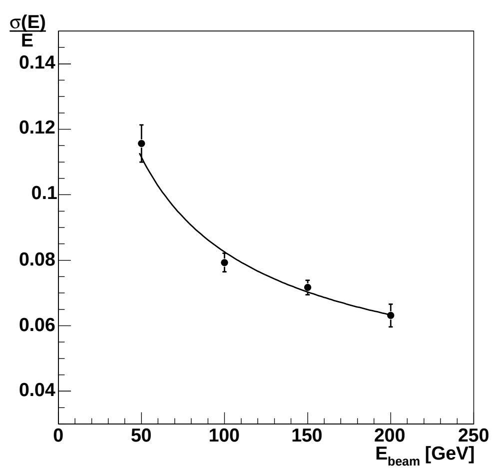
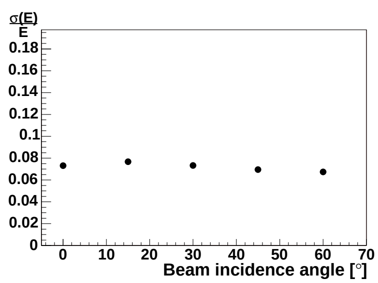


Figure 4. Energy resolution for electrons from 50 to 200 GeV.

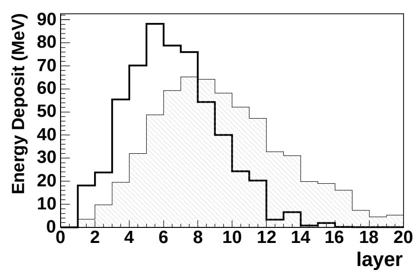
small sampling fraction, the energy resolution is significantly affected by photon statistics. This was confirmed by the data.

The energy resolution of the calorimeter for electromagnetic showers is shown in Figure 4 as a function of the electron beam energy. The electron energy resolution was fitted by the sum in quadrature of two terms:

$a(E[TeV])^{-1/2}$ + b , with a = (2.4± 0.4)% and b = (3.2± 2.4)%. The fitted value of the first parameter is consistent with a previous measurement [6] made in the electron energy range 5 to 100 GeV with a reduced scale calorimeter prototype read-out by photomultipliers.
Electron data at 150 GeV were taken with the calorimeter tilted with respect to the beam direction by 15°, 30°, 45°. The energy resolution in Figure 5(a) was found to be independent of the tilting angle θ as expected at this energy where the e.m. shower is well contained within the calorimeter depth. The number of radiation lengths traversed by a track in the calorimeter stack scale as $1/\cos\theta$. Therefore, the position of the shower maximum at 45° is expected to be reduced by a factor $\sqrt{2}$ as shown in Figure 5(b).



(a)



(b)

Figure 5. Angular scan with 150 GeV electrons : (a) energy resolution vs. tilting angle; (b) longitudinal shower development at 0° (empty) and 45° (filled) tilt angle.

4. Acknowledgements

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