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Nuclear Physics B (Proc. Suppl.) 150 (2006) 272–275
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
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Performance of CREAM Calorimeter: Results of Beam Tests

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The Cosmic Ray Energetics And Mass (CREAM), a balloon-borne experiment, is under preparation for a flight in Antarctica at the end of 2004. CREAM is planned to measure the energy spectrum and composition of cosmic rays directly at energies between 1 TeV and 1000 TeV. Incident particle energies will be measured by a transition radiation detector and a sampling calorimeter. The calorimeter was constructed at the University of Maryland and tested at CERN in 2003. Performance of the calorimeter during the beam tests is reported.

1. Introduction

CREAM (Cosmic Ray Energetics And Mass) is a balloon experiment selected by NASA to extend the range of direct cosmic-ray (CR) composition measurements up to the energy scale of $\sim 10^{15}$ eV. Experimental data above 100 TeV are essential to validate theoretical models predicting a rigidity dependent acceleration limit by supernova shock waves [1–3]. In this energy region, CREAM will search for the onset of cutoffs in the spectra of light nuclei and will also investigate possible spectral differences between proton and He.
Measurements of secondary-to-primary ratios are believed to be the key to clarify the history of cosmic rays during their propagation in the interstellar medium. One of the science goals of CREAM is to extend the available data on the B/C ratio above the region of 100 GeV/n in order to test the validity of reacceleration models and to quantify the rigidity dependence of the escape length from the Galaxy.
To overcome the statistical limitations due to the low fluxes involved at high energy, CREAM has been designed as a multi-flight ULDB (Ultra Long Duration Balloon) mission. Unambiguous identification of the incoming nuclei from proton to Iron (and above) is provided by multiple measurements of the particle charge with a pixelated silicon charge detector (SCD), a segmented timing-based particle-charge detector (TCD) and scintillating fiber hodoscopes. Energy is measured up

0920-5632/$ – see front matter
doi:10.1016/j.nuclphysbps.2004.08.040

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 thin ionization calorimeter measures Z $\geq$ 1 particles with almost energy independent resolution.
The CREAM instrument layout and expected performances are described in [4,5] and references therein.
The first CREAM payload is scheduled for flight in December 2004 from Antarctica. The response of the calorimeter to protons of energy from 150 to 350 GeV and the results of a dedicated test carried out at CERN in November 2003 with ion fragments from a 158 GeV/n primary Indium beam will be reported in this paper.

2. The calorimeter module

The CREAM calorimeter module is comprised of the SCD, scintillator fiber hodoscopes, a graphite target [6] and a 20 radiation-length tungsten-scintillation-fiber calorimeter. The primary nucleus interacts inelastically in the target ($\sim$ 0.46 λ_{int}) generating secondaries. Neutral pions initiate an electromagnetic shower whose axis is reconstructed by the finely segmented imaging calorimeter, projected backwards and matched with the SCD pixels in order to provide an unambiguous measurement of the primary charge by discriminating against pixels affected by backscattering from the calorimeter. The target is divided into two elements. The top two hodoscopes (S0, S1) are positioned just above the upper section (T1) of the target and below the SCD. A third hodoscope (S2) is located between the upper and lower target sections. The hodoscopes provide dE/dx measurements and combined tracking capability with the TRD proportional tubes.
The calorimeter layout and construction technique is described elsewhere [7–9].

3. Calorimeter response to protons

The calorimeter was fully calibrated with electrons ranging from 50 to 200 GeV at CERN in 2003 as reported in [9]. During the beam test, data were also collected with proton beams.

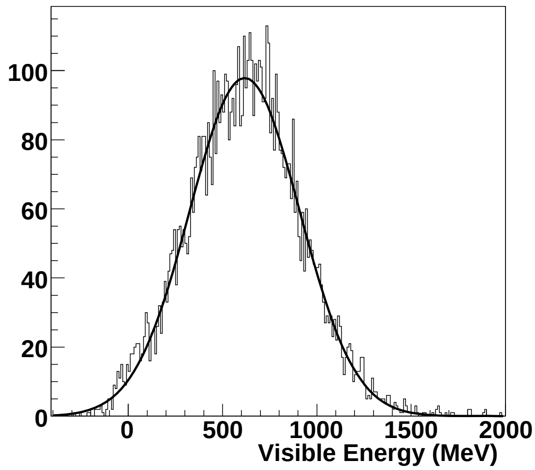

Figure 1. Total visible energy in the calorimeter for 350 GeV protons interacting in the target.

Events interacting in the target were selected by requiring a significant energy deposit in the first three layers of the calorimeter. The total visible energy in the calorimeter for 350 GeV protons is shown in Figure 1 where the mean value is consistent with a visible energy fraction of $\sim$ 0.15 %. An energy resolution of 68%, 53%, 46% was found at 150, 250, 350 GeV, respectively.

4. Calorimeter response to relativistic ions

In order to study the calorimeter performance with Z > 1 nuclei, a dedicated beam test was performed at CERN where ion fragments with A/Z = 2 and a kinetic energy of 158 GeV per nucleon were selected by tuning the H2 beam line as described in [10] .

The whole calorimeter module was read-out and incoming ions were identified taking advantage of the excellent charge resolution provided by SCD [11] as shown, for example, in Figure 2 in the range from B to Ne and in Figure 3 in the Fe region range(V to Ni).

The elemental composition of the beam fragments was extracted from the SCD data with an unbinned likelihood fit. The charge resolution was found to be close to 0.1 charge units for He and $\sim$ 0.3 for Fe. The response of the calorimeter

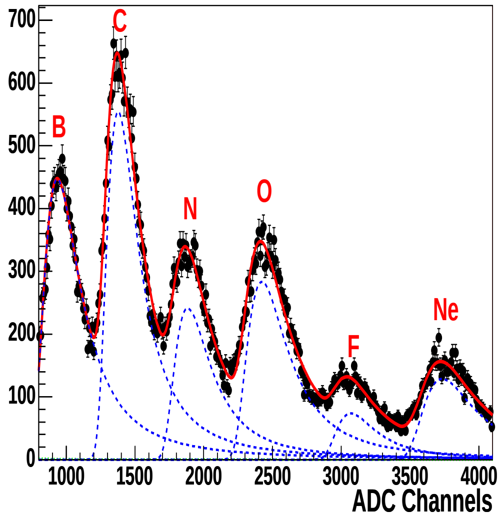

Figure 2. Unbinned likelihood fit of the beam elemental composition from B to Ne

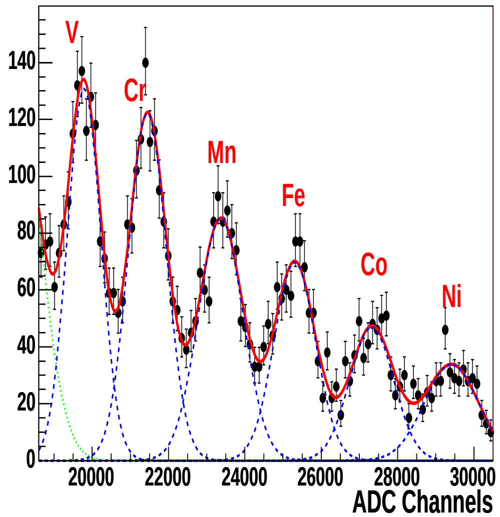

Figure 3. Unbinned likelihood fit of the beam elemental composition from V to Ni

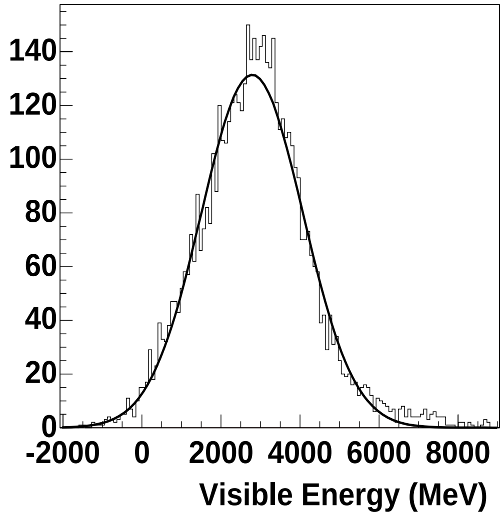

Figure 4. Visible energy (MeV) in the calorimeter for Carbon.

to relativistic nuclei was studied by selecting individual elements with SCD charge cuts and requiring that the hadronic interaction had occurred in T1. The latter selection was made with topological cuts using the cluster information of the S2 hodoscope. The visible energy in the calorimeter for a selection of C nuclei interacting in the graphite target is shown in Figure 4. The energy resolution is close to 46 % for a total particle energy of $\sim$ 1.9 TeV.

The energy measured by the calorimeter (in MeV) is plotted in Figure 5 as a function of the ion mass number A. The measured energies are consistent with the expected value of 158 GeV per nucleon and a visible energy fraction of 0.15%. Results (cross markers) of a full MonteCarlo simulation (FLUKA 2003.1b with DPMJET-II.53 [12,13]) of the calorimeter module for ^{4}He, ^{16}O, ^{30}P, ^{52}Fe are consistent with the beam test data (filled circles) as shown in Figure 5.

A selection of 700 Fe events is shown in Figure 6 where the visible energy in the calorimeter is plotted for ion data and compared with the simulation (solid line). The two distributions are in agreement and are consistent with an energy reso-

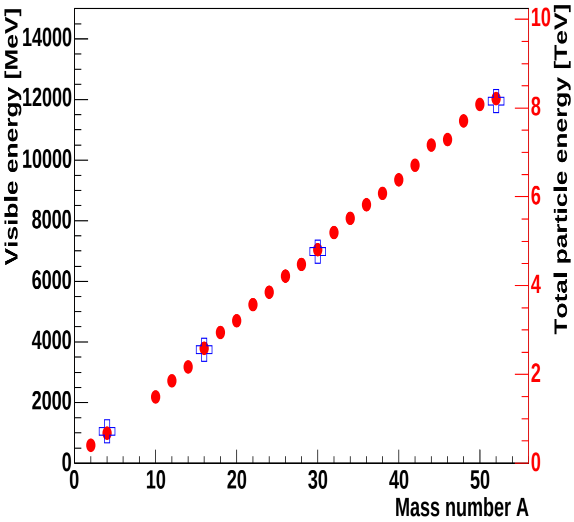

Figure 5. Total visible energy in the calorimeter (left scale) and total particle energy (right scale) for heavy ion fragments versus mass number A (data : filled circles; simulation : cross markers).

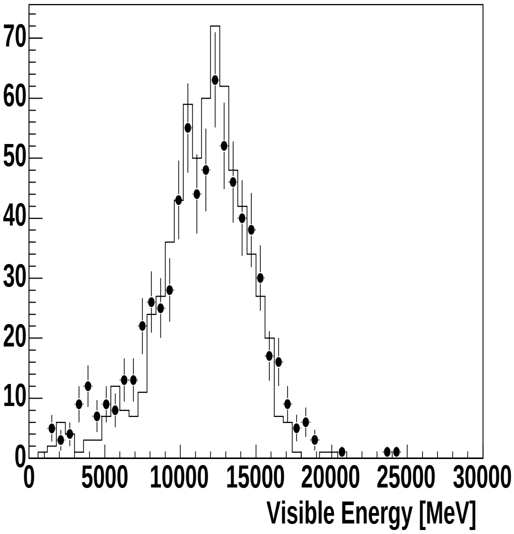

Figure 6. Visible energy (MeV) in the calorimeter for Iron (data : filled circles ; MC simulation : solid line)

lution of $\sim$ 21% for Iron at a total particle energy of $\sim$ 8.2 TeV.

5. Acknowledgements

This work was supported by NASA grants in the US and by INFN in Italy. The authors greatly appreciated the support of CERN for the beam test facilities and operations.

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