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Elemental Spectra from the CREAM-I Flight

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Abstract: The Cosmic Ray Energetics And Mass (CREAM) instrument is a balloon-borne experiment designed to measure the composition and energy spectra of cosmic rays of charge Z = 1 to 26 up to an energy of $\sim 10^{15}$ eV. CREAM had two successful flights on long-duration balloons (LDB) launched from McMurdo Station, Antarctica, in December 2004 and December 2005. CREAM achieves a substantial measurement redundancy by employing multiple detector systems, namely a Timing Charge Detector (TCD), a Silicon Charge Detector (SCD), and a Cherenkov Detector (CD) for particle identification, and a Transition Radiation Detector (TRD) and a sampling tungsten/scintillating-fiber ionization calorimeter (CAL) for energy measurement. In this paper, preliminary energy spectra of various elements measured with CAL/SCD during the first 42-day flight are presented.

Introduction

The Cosmic Ray Energetics And Mass balloon-borne experiment is designed to investigate the charge and energy spectra of cosmic-ray nuclei from hydrogen to iron at high energies, up to $\sim 10^{15}$ eV. CREAM has had two successful long-duration balloon flights, launched from McMurdo Station, Antarctica, for 42 days in 2004-2005 and 28 days in 2005-2006 [1]. In both flights CREAM employed a 20 radiation length tungsten/scintillating-fiber sampling calorimeter, preceded by a pair of graphite targets providing ~ 0.47 nuclear interaction length, to induce hadronic showers from cosmic-ray nuclei, triggering and measuring the energy of events above $\sim 10^{12}$ eV. Each of the 20 active layers was segmented into 50 one-cm-wide ribbons. Signals from these ribbons were used to reconstruct and extrapolate trajectories back to the Silicon Charge Detector of 52 $\times$ 56 pixels, for accurate charge measurement. Details of the experiment, including the TCD, CD, and TRD, have been described elsewhere [2].

Various elements have been studied by analyzing the first-flight data with CAL/SCD. The hydrogen and helium spectra are reported elsewhere in this conference [3]. In this paper, preliminary energy spectra of cosmic-ray carbon and oxygen nuclei are presented, and compared with other measurements.

Calibration

CAL was placed in one of CERN's SPS accelerator beam-lines, and exposed to electron, proton, and A/Z = 2 nuclear fragment beams to verify both the instrument's functionality and the validity of the simulation model. CAL responses to 150 GeV electrons were used for absolute calibration, which is extrapolated to the responses to much higher energy cosmic rays collected during flight [4].

First Flight

During the flight, the payload floated at an average altitude of 128,000 ft, corresponding to a residual atmosphere of 3.9 g/cm^2. The analysis in this paper has been performed with only a subset of cosmic-ray events: those CAL-triggered by requiring 6 consecutive layers to have energy deposit of greater than 50 MeV in the highest deposit ribbon, and collected for 23.7 days, when both CAL and SCD operation was stable. The live time fraction is estimated to be 75%. The dead CAL channels, noisy SCD pixels, and zero-suppression level in CAL ribbons have been taken into account in the detector simulations.

Reconstruction

The incident particle trajectory is reconstructed using χ^2 fitting of a straight line through a combination of CAL hits with highest energy deposit in each layer, in x-z and y-z, respectively. The combination is chosen by rejecting any hit that is not consistent with others to make a straight line. This trajectory is further improved by including in the fitting (1) selected CAL hits' neighbors and (2) the SCD pixel with the highest energy deposited within a circle of confusion (track extrapolation error) around the extrapolated position at SCD. This tracking algorithm has been tested with GEANT detector simulations [5]. Figure 1 shows the track extrapolation resolution at the SCD and the tracking efficiency for isotropically simulated protons within the geometry (traversing the SCD, the top of CAL and the bottom of CAL, giving a geometry factor of 0.37 $\mathrm{m^2sr}$) and CAL-triggered. The position resolution in the y-z is lower than that in the x-z because there are more dead channels in the y-z.

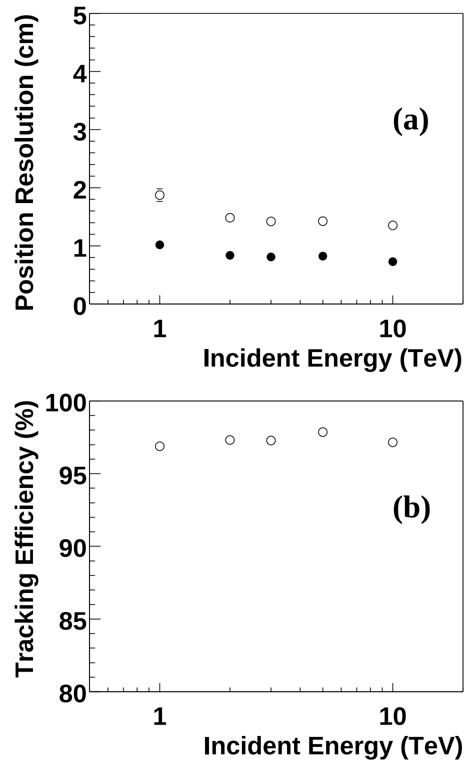

Figure 1: Simulated results of CAL/SCD tracking for protons within the geometry and CAL-triggered: (a) track extrapolation resolution at the SCD, in x-z (filled circles) and y-z (open circles), (b) tracking efficiency.

To determine incident particle charge, the reconstructed trajectory is extrapolated back to the SCD, and the highest energy deposit within the circle of confusion is corrected for path-length. The charge is extracted by taking the square root of the corrected signal. In Fig. 2, a preliminary charge distribution measured by the CREAM CAL/SCD shows various elements, including boron, carbon, nitrogen and oxygen. Multiple asymmetric Gaussian functions were applied to parameterize each element, with an exponential function to account for background, the sources of which are still being investigated, including nuclear interactions in the upper detectors and/or support structure before the incident particle reaches the SCD. The contributions from each element and the background are also shown with dashed and dot-dashed lines in Fig. 2.

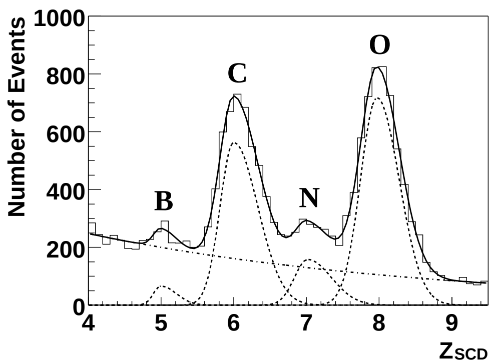

Figure 2: Preliminary charge distribution measured by the CREAM CAL/SCD for all energies. Overall fitting results (solid line) and the contributions estimated for each element (dashed lines) and background (dot-dashed line) are also shown.

Absolute Flux Determination

The distribution of energy deposit is divided into 4 bins per decade, and for each bin, the number of carbon/oxygen nuclei is estimated by the area of the corresponding asymmetric Gaussian function. To obtain a distribution of incident energy, a detailed study of deconvolution is still in progress, including energy dependence and resolution effects. In this paper, a 0.13% average ratio of energy deposit to incident energy is used for energy conversion, based on preliminary Monte Carlo studies.

To obtain the differential flux (F) at the top of the atmosphere, the number of incident particles ($N^{\rm inc}$) in each bin of size ΔE, is normalized by

$$F = \frac{N^{\rm inc}}{\Delta E} \times \frac{1}{\mathrm{GF} \cdot \varepsilon \cdot T \cdot \eta}, \qquad (1)$$

where GF is the geometry factor (0.37 $\mathrm{m}^2\mathrm{sr}$), ε is a correction for various inefficiencies, T is the live time (17.8 days), and η is a correction for atmospheric attenuation. Inefficiencies from the CAL-trigger, CAL dead channels, and tracking are taken into account in ε. Energy-dependent efficiencies for carbon and oxygen are shown in Fig. 3. η is estimated to be 86.3% and 85.1% for carbon and oxygen, respectively, by calculating the probability of particles within the geometry to survive the atmospheric overburden.

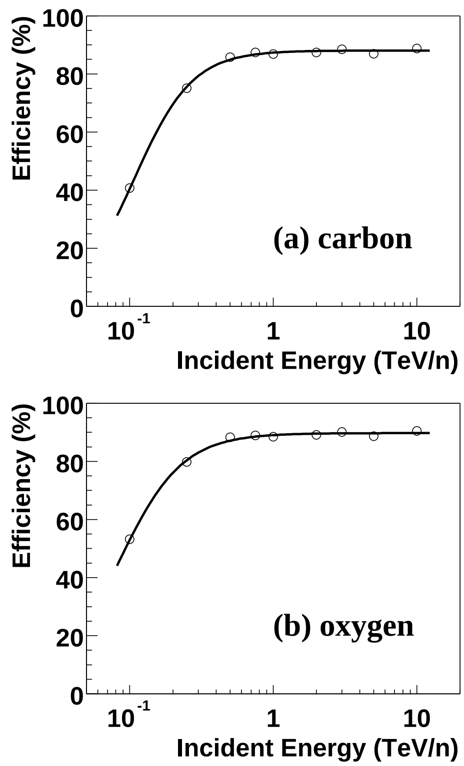

Figure 3: Energy-dependent efficiencies from the CAL-trigger, CAL dead channels and tracking, for (a) carbon and (b) oxygen.

Results

Figure 4 shows the preliminary energy spectra of carbon and oxygen, extracted by the CREAM CAL/SCD analysis of the first-flight data (filled circles). Also shown in the plots are the measurements of HEAO (open stars) [6], CRN (open crosses) [7], and CREAM Hi-Z (open circles) [8] analyses. The preliminary results reported here are in good agreement with those other observations. Additional work is in progress to improve the current results, including full deconvolution, improved live time estimate, and addressing the effects of secondary particles from interactions in the upper detectors and structure.

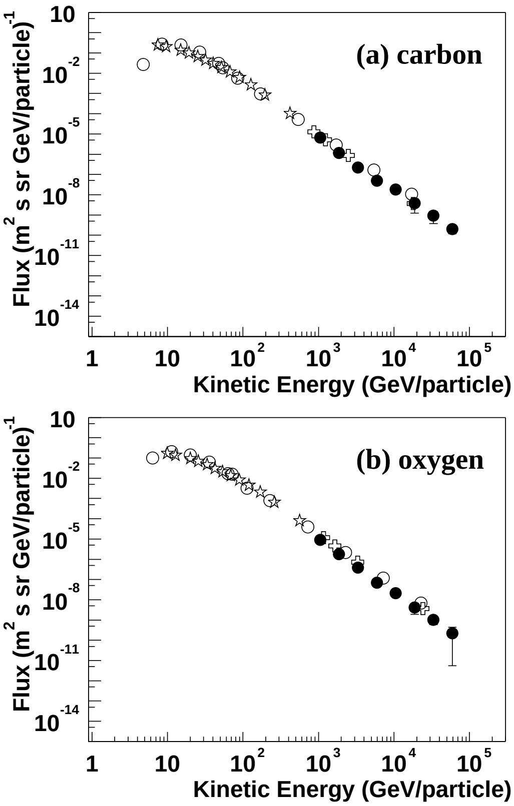

Figure 4: Preliminary energy spectra of (a) carbon and (b) oxygen measured by the CREAM CAL/SCD (filled circles) compared with other measurements. Open stars, crosses, and circles represent the measurements of HEAO, CRN and CREAM Hi-Z analyses, respectively.

Summary

Preliminary energy spectra of carbon and oxygen measured by the CREAM CAL/SCD, along with the procedure of reconstruction and normalization, have been presented. The results are in agreement with other observations and extend the energy range to near 100 TeV/particle. An analysis work is still in progress of the elemental spectra of other cosmic-ray nuclei, including neon, magnesium, silicon, and iron.

Acknowledgements

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