Relative abundances of heavy ions measured by the CREAM Silicon Charge Detector

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Abstract: The Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne experiment for measuring high energy cosmic rays with energy up to 10^{15} eV. CREAM incorporates a sampling tungsten/scintillating-fiber calorimeter for energy measurements and a dual-layer Silicon Charge Detector (SCD) and Timing-based Charge Detector (TCD) to measure the charge of incident particles. CREAM has had two successful flights in 2004/5 and 2005/6, with a combined duration of 70 days of data. Preliminary results on the relative abundances of heavy ions measured by the SCD will be presented.

Introduction

CREAM [1, 2] is designed for direct measurement of cosmic-ray nuclei in the energy range between 10^{11} eV and 10^{15} eV from protons to iron nuclei, through a series of long duration balloon flights. Detailed investigations in this energy range will help understand features of the all-particle spectrum as well as the acceleration mechanism of high energy cosmic rays. The first flight of CREAM (CREAM-I) was carried out during the 2004/5 season, launching from McMurdo station, Antarctica. In the following season (2005/6), CREAM-II was flown. With two successful flights, 70 days of data were collected.
The CREAM-II suite included several charge detectors, including the TCD, Cerenkov Detector (CD) and a dual-layer SCD. A sampling tungsten/scintillating-fiber calorimeter, preceded by a pair of graphite targets, provided the energy measurement. The SCD is an array of DC-type silicon PIN diodes [3]. For the CREAM-II flight, the SCD was upgraded to include two layers, with a total of 4992 pixel sensors, each with a 2.1 cm^2 active area. Detailed information and flight performance of the SCD-II are described elsewhere [4].
This paper will discuss the analysis of relative abundances of heavy ions measured during the second flight of CREAM.

Event selections

Flight data for this analysis were selected from a period of stable operation. Calorimeter-triggered events were selected to study high energy events. This trigger required 6 consecutive layers, each with a signal higher than 60 MeV in at least on ribbon [5]. The total energy threshold of the calorimeter trigger is at a few TeV [6].
Shower axis reconstruction is needed to estimate the incident particle trajectories, thus at least 3 active layers per plane (X-Z, Y-Z) were required. A weighted least square fitting method was used to obtain incident particle tracks [7]. By extrapolating these tracks to the SCD planes, preliminary incidence positions on those planes can be identified. The final identification of the relevant pixels is done by selecting the pixel with the highest signal in an area defined by $\pm 1\sigma$ (standard deviation) of shower projection uncertainty. Due to the signal in the SCD being proportional to the square of their charge, primary particles with high charge have a lower probability of being mis-identified due to backscattered particles. Unstable and noisy channels in the SCD were masked to improve the reliability of the above algorithm.
After selecting the pixel measuring the incident charge, the signal is corrected for the particle's path length through the pixel based on its angle, as calculated from the calorimeter reconstruction.

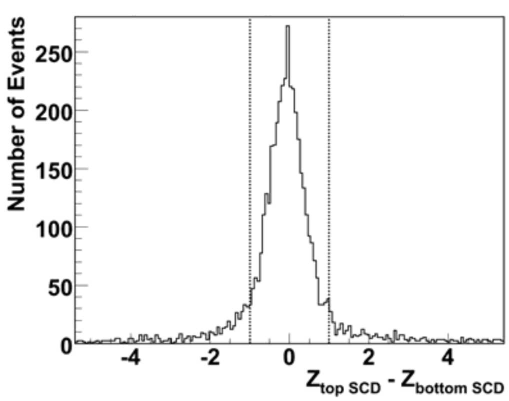

Figure 1: Distribution of the charge difference between top SCD and bottom SCD for Z>4. Data within $\Delta Z < 1$e of the distribution which indicated with broken line in the figure were selected as consistent signals.

The difference of signals from the two SCD layers was required to be less than 1e in the consistency condition. Figure 1 shows the distribution of charge difference between the top and bottom layers of the SCD for Z > 4 particles.

Analysis on the relative abundance

With the event selection described in the previous part, average charge of top SCD and bottom SCD is plotted in Fig. 2. Charge peaks from carbon (z=6) to silicon (z=14) are clearly visible. The distribution is fitted with a multi-Gaussian function. Exponential function was added for considering the effect from lower charge.
For the relative abundance study, the numbers of particles in the same energy per nucleus bin need to be estimated. To correctly define the selection range in energy per nuclei, the charge of each nucleus must be assigned. In this analysis, charge selection was done with three different levels of Z $\pm$ 0.3e, Z $\pm$ 0.4e, and Z $\pm$ 0.5e. The differences in results from the selections were used as an estimate of the systematic error. The Z value is defined based on the fitting result (Fig. 2).

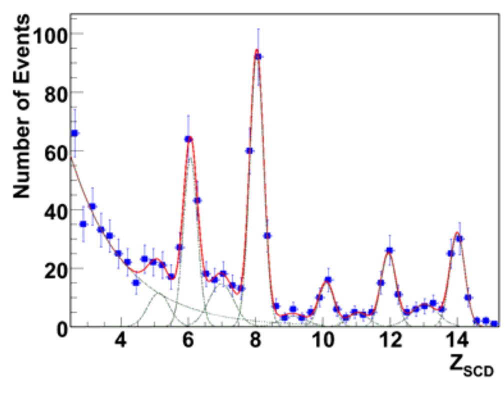

Figure 2: Subset of charge distribution using the average of signals from the top and bottom SCD layers after event selection and consistency requirements. The distribution is fitted with a multi-Gaussian function with exponential function.

Overlap between charge peaks caused contamination from neighboring charges. In each charge selection levels, the ratio between the summation of overall influences and the pure amount of selected charge was calculated by using the parameters of a fitting function. By using these ratios, rough estimation of contamination effect was done.

To compare the abundance of different elements with the same energy per nucleus, the numbers of particles in each bin was counted. To avoid bias due to energy-dependence of the trigger efficiency at low energy, the energy per nucleus threshold for the abundance study was determined by the lowest charge of interest. In this report, the threshold was set at ~400 GeV/n to assure full efficiency for carbon.

The incident particle energy was reconstructed by assuming the energy deposit in the calorimeter active layers was 0.15% of the full incident energy. The uncertainty due to this energy calculation is not included here. The deposited energy was calculated using the three energy ranges in the calorimeter readout to avoid bias due to energy readout saturation.

The average air burden during the CREAM flight was measured as ~3.9 g/cm^2. A preliminary correction for interactions in the atmosphere above the instrument was done using the cross sections reported by Westfall [8]. Since this is a ratio of different elements, the effect for spallation corrections is estimated to be less than 5%. Figure 3 shows the carbon to oxygen ratio superposed on results from earlier experiments.

Relative abundances were calculated for the elements with large enough samples in the energy region selected above. Figure 4 shows the relative abundances of carbon, nitrogen, oxygen, neon, magnesium to silicon.

Conclusion

CREAM-II data on the carbon-oxygen abundance ratio and the relative abundances of particles from carbon to silicon above 400 GeV/n were found to be in good agreement with earlier measurements at lower energies except magnesium.

This work is very preliminary. Detailed investigation will continue to improve the understanding of our data and the nature of cosmic rays.

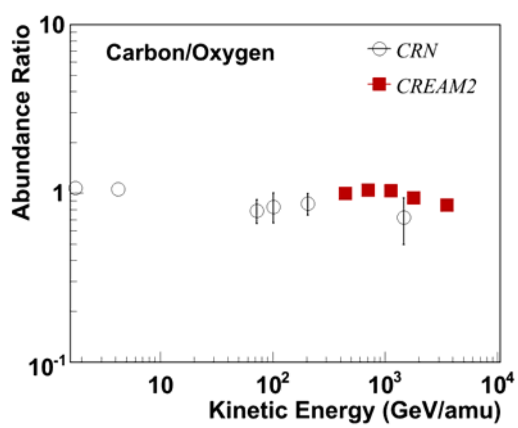

Figure 3: Abundance ratio of carbon and oxygen. Results are plotted from CRN [9] and CREAM-II (this work, filled rectangles).

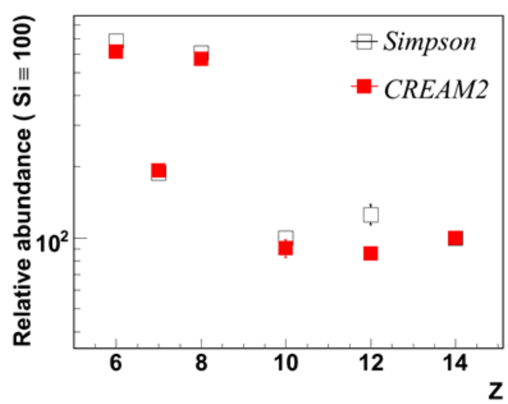

Figure 4: Abundances for C, N, O, Ne, Mg and Si normalized to 100 for Si. Simpson [10] and CREAM-II (this work, filled squares) are plotted. Simpson data are at an average energy range of 1~2 GeV/n. CREAM-II data are at energies above 400 GeV/n.

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