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H and He spectra from the 2004/05 CREAM flight

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Abstract: The balloon-borne Cosmic Ray Energetics And Mass (CREAM) payload flew for a record-breaking 42 days during the 2004/05 Antarctic season. The instrument incorporates a tungsten/scintillating-fiber sampling calorimeter and graphite targets to measure energies of incident cosmic-ray nuclei. A finely segmented Silicon Charge detector (SCD) located above the targets is used for charge measurement. The position of the primary particle in the SCD is determined by a backward extrapolation of the reconstructed shower axis in the calorimeter. The flight data have been analyzed using the latest calibration of the calorimeter. The energy spectra of protons and helium nuclei, as well as their ratio, are presented in this paper.

Introduction

CREAM is a balloon-borne experiment to measure the composition and energy spectra of cosmic-ray nuclei in the energy range ~10^{11} –10^{15} eV from protons to iron [1]. The first Long Duration Balloon flight of CREAM payload was from McMurdo Station, Antarctica on Dec 16, 2004, lasting a record-breaking 42 days and circumnavigating Antarctica three times. During the flight, 48.9 GB of data were collected, archived on-board, and transmitted to the ground in near real-time [2]. In this paper we present preliminary energy spectra of protons and helium nuclei, as well as their ratio, as measured by the CREAM calorimeter and SCD during this flight. We also discuss the current status of the analysis.

The CREAM Calorimeter Module

The CREAM instrument has several detectors for redundant charge identification, namely a Timing Charge Detector (TCD), a Cherenkov Detector (CD), and an SCD. CREAM also has redundant energy measurements using a Transition Radiation Detector (TRD) and a sampling calorimeter [3]. This paper describes an analysis of data solely from the calorimeter and SCD. The calorimeter, designed to measure the energy of cosmic-ray nuclei above 100 GeV, consists of twenty tungsten plates, each 50.1×50.1× 0.35cm^3 interleaved with twenty layers of 0.5 mm diameter scintillating fibers. The fibers are arranged into fifty 1 cm wide ribbons per layer, each read out independently. Two 9.5 cm thick graphite targets (~0.5

interaction lengths) precede the calorimeter to initiate showers and allow a calorimetric energy measurement. Hodoscopes, comprised of crossed layers of 2 mm square plastic scintillating fibers, are positioned between the targets (2 layers, S2) and above the targets (4 layers, S0/S1) for tracking and additional charge measurement. The two fiber layers in each hodoscope are oriented orthogonal to each other. The SCD, mounted above S0/S1, consists of 380 µm thick Si sensors, each segmented into a 4×4 array of pixels, with 2912 pixels covering an area of 779×795 mm^2.
The calorimeter was calibrated at CERN with a 150 GeV electron beam. A beam of A/Z=2 nuclear fragments extended the calibration up to 8 TeV [4, 5]. The SCD was calibrated using the same nuclear fragment beam [6]. The performance of both the calorimeter and the SCD was stable during the flight [7]. Events triggered by the calorimeter were collected throughout the flight, with all temperatures, bias voltages and high voltage levels monitored continuously.

Analysis

Event Selection

In selecting events for analysis, data is excluded from periods of parameter tuning, as well as a few days following the major solar flare of January 20, 2005. The calorimeter trigger selects high energy shower events in an unbiased manner by requiring 6 consecutive layers, each with at least one ribbon recording more than 60 MeV. For each event, the shower axis is reconstructed. This reconstructed trajectory is required to traverse the SCD active area and the bottom of the calorimeter active area. The calorimeter energy was reconstructed from the ribbons with the highest energy deposit in each layer and its neighbors [8]. The reconstruction requires at least three layers per side. The extrapolated position resolution from calorimeter tracking extrapolated to the SCD is about 1.0 cm in the flight data.

Charge Determination

In this analysis, the SCD is used for charge identification of the high energy events triggering the calorimeter. A 7×7 pixel area centered on the extrapolated position at the SCD is scanned for the highest pixel signal. The signal in that pixel is then corrected for the reconstructed incidence angle. In counting the numbers of protons and helium nuclei, two separate methods are used. Between 1 TeV and 10 TeV, where there are enough events per energy bin for accurate fitting, the SCD signal is plotted separately for each of five energy bins, and the number of protons and helium nuclei is determined by calculating the areas under the Landau fits for the two peaks. Above 10 TeV the sample of events is too small for accurate fitting. For this region we define a cut value and count the entries below the cut as protons, and those above the cut as helium nuclei. To determine this cut value, the SCD signal is plotted for events with reconstructed energy between 1 TeV and 10 TeV (Fig. 1). The proton and helium peaks are fitted with Landau curves, and the SCD signal where the curves cross each other is defined as the cut value. The SCD signal is then plotted for events with energy above 10 TeV, and those events with SCD signal below the cut value units are counted as protons, while those above the cut value are counted as helium nuclei.
Further work is in progress and is intended to improve the accuracy of charge assignment. This includes adding the selected SCD pixel to the tracking algorithm and using the more accurate angles for better angle corrections to the SCD signal.

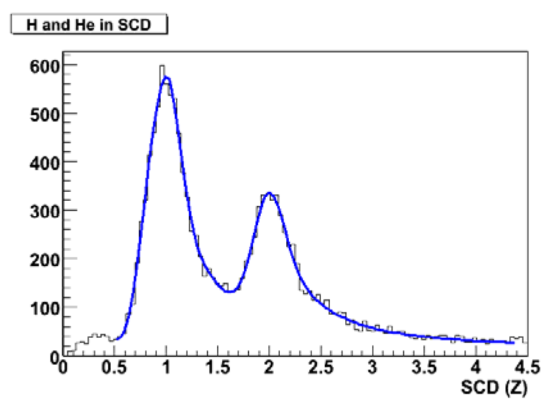

Figure 1: SCD charge distribution with energy between 1 to 10 TeV after event selection. The charge resolution is about 0.19e for protons and 0.18e for helium nuclei.

Energy Assignment

To accurately reconstruct spectra, one should deconvolve the response of the detector from the effects of the incident spectrum, using a matrix that describes the probability of having incident energy in any one bin, given a measured energy in any other bin. In this preliminary study a simpler method was used. A GEANT/FLUKA 3.21-based Monte Carlo [9, 10] simulation study determined the ratio between incident particle energy and the energy deposit in the calorimeter, for incident energies between 1 TeV and 50 TeV. The ratio was found to be fairly constant at 0.13% between 3 TeV and 50 TeV. This average value is used to reconstruct the incident energy from the deposited energy. Further simulations are being carried out to extend the study to higher energies, and improve the incident energy reconstruction by adding energy deconvolution and accounting for potential energy-dependent leakage effect at very high energies.

Absolute Flux Determination

The numbers (ΔN) of proton and helium events were calculated in each energy bin (ΔE) from the SCD signal distribution (see Fig. 1). The differential fluxes (F) can be written as follows:

$$F = \frac{\Delta N}{\Delta E \cdot GF \cdot \varepsilon \cdot (1+\delta) \cdot T \cdot \eta}$$

where GF is the geometry factor, ε is the efficiency, δ is the background, T is the live-time and η is the survival fraction for atmospheric attenuation and instrument material. The raw GF value was calculated by requiring that the reconstructed trajectory traverse the SCD and the bottom of the calorimeter. The efficiencies (ε) for protons and helium nuclei are obtained from the trigger and reconstruction efficiencies calculated MC simulations. For protons, the trigger efficiency is calculated from fits to the MC distributions. Above 10 TeV, the proton trigger efficiency is about 71%. For helium nuclei, the trigger efficiency is calculated based on proton simulations correcting for the higher interaction probability for helium nuclei. The helium efficiency is higher than the proton efficiency due to higher interaction probability in the carbon targets. Above 10 TeV, the helium trigger efficiency is about 94%. The reconstruction efficiencies are about 97% for both protons and helium nuclei. Simulations show no significant energy dependence for these efficiencies. The background (δ) is the percentage of the events satisfying trigger and reconstruction conditions, although its track is not in geometry [11]. It is calculated from MC simulations. At 10 TeV, the background for protons is 4% and for helium nuclei is 4%, with no significant energy dependence. T is calculated from the length of the selected data range (~24 days) using an estimated live-time fraction, 75%. Further work on the live-time fraction estimate for the first flight is expected to reduce uncertainties. The flux was corrected for the attenuation loss due to the air depth ($3.9 g/cm^2$) as well as the instrument material above the SCD. η is the survival fraction for atmospheric attenuation and instrument material.

Results

Preliminary CREAM proton and helium spectra were obtained from the first flight data. Several improvements are currently in progress including further corrections to the energy deconvolution, extending the spectra below a few TeV by applying corrections in the range where the trigger efficiency is energy-dependent, energy-dependent shower leakage corrections at very high energies, etc.

Figure 2 shows the CREAM proton and helium spectra (red circles) superposed on spectra from previous experiments (AMS [12, 13], BESS [14], RUNJOB [15], JACEE [16], IMAX [17], CAPRICE [18], Ryan et al. [19], ATIC-1 [20] and ATIC-2 [21]). Although some corrections are not included yet, the proton spectrum follows a power law without significant feature up to ~100 TeV and shows resonable agreement with those of ATIC-1, RUNJOB and JACEE. The CREAM helium spectrum shows better agreement with those of ATIC-2 and JACEE, than with those of ATIC-1 and RUNJOB. Above ~30 TeV statistics are limited.

The preliminary CREAM ratio of protons to helium nuclei is about 12.2 ± 2.6 at 13 TeV. JACEE reported 12.1 ± 3.6 at 10 TeV [16], while earlier measurements at energies about two decades lower reported ratios nearly twice as high. Ryan et al. reported 26 ± 3 at 40 – 100 GeV [19] and LEAP[22] and CAPRICE[18] reported ratios of ~20 at 100 GeV. Although still preliminary,

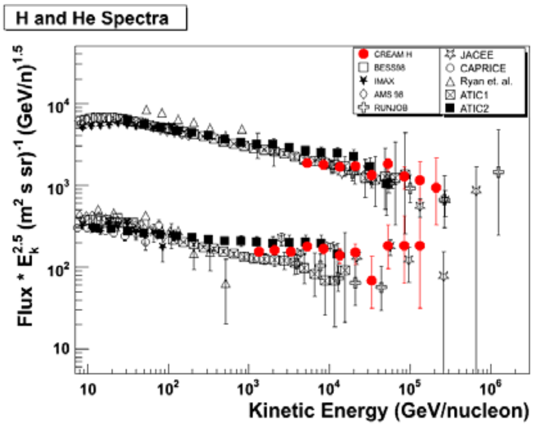

Figure 2: Preliminary CREAM proton and helium spectra (red circles) and previous measurements.

the CREAM result shows agreement with JACEE within the quoted uncertainty.

Further work remains to be done, including using TCD data to remove events with interactions in the instruments above the SCD[23], estimates of systematic uncertainties, and energy dependant correction factors. The charge measurement uncertainty is expected to be reduced by requiring consistency between the SCD and TCD. Currently only statistical uncertainties are displayed.

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