H and He spectra from the 2004/05 CREAM-I flight

Y. S. YOON[1,2], H. S. AHN[2], P. ALLISON[3], M. G. BAGLIESI[4], J. J. BEATTY[3], G. BIGONGIARI[4], P. BOYLE[5], J. T. CHILDERS[6], N. B. CONKLIN[7], S. COUTU[7], M. A. DUVERNOIS[6], O. GANEL[2], J. H. HAN[8], J. A. JEON[8], K. C. KIM[2], J. K. LEE[8], M. H. LEE[2], L. LUTZ[2], P. MAESTRO[4], A. MALININE[2], P. S. MARROCCHESI[4], S. MINNICK[9], S. I. MOGNET[7], S. W. NAM[8], S. NUTTER[10], I. H. PARK[8], N. H. PARK[8], E. S. SEO[1,2], R. SINA[2], S. SWORDY[5], S. WAKELY[5], J. WU[2], J. YANG[8], R. ZEI[4], S.-Y. ZINN[2]
[1]*Dept. of Physics, University of Maryland, College Park, MD 20742 USA*
[2]*Inst. for Phys. Sci. and Tech., University of Maryland, College Park, MD 20742 USA*
[3]*Dept. of Physics, Ohio State University, Columbus, Ohio 43210, USA*
[4]*Dept. of Physics, University of Siena and INFN, Via Roma 56, 53100 Siena, Italy*
[5]*Enrico Fermi Institute and Dept. of Physics, University of Chicago, Chicago, IL 60637, USA*
[6]*School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA*
[7]*Dept. of Physics, Penn State University, University Park, PA 16802, USA*
[8]*Dept. of Physics, Ewha Womans University, Seoul, 120-750, Republic of Korea*
[9]*Dept. of Physics, Kent State University Tuscarawas, New Philadelphia, OH 44663, USA*
[10]*Dept. of Physics and Geology, Northern Kentucky University, Highland Heights, KY 41099, USA*
ysy@physics.umd.edu

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 nuclei. A finely segmented Silicon Charge detector (SCD) located above the targets is used for charge measurements. The position of the primary particle in the SCD is determined by 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.

I. 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 CREAM payload had its first Long Duration Balloon (LDB) flight from McMurdo Station, Antarctica from 12/16/2004 for a record-breaking 42 days, until 01/27/2005, 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 measured by the CREAM calorimeter during this flight. We also discuss the current status of the ongoing analysis.

II. CREAM-I Calorimeter Module

II.1 Instrument Description

The CREAM-I instrument has several detectors for redundant charge identification, namely a Timing Charge Detector (TCD), a Cherenkov Detector (CD), and the SCD. CREAM-I also had redundant energy measurement 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 and 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 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 the 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.

II.2 Calorimeter Calibration and Flight Performance

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 during the flight.

III. Analysis

III.1 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. Calorimeter energy was reconstructed from the ribbon with the highest energy deposit and its neighbors [8]. Extrapolated position resolution at the SCD is 1.0 cm in the flight data.

III.2 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, at 95 ADC units, 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 95 ADC units are counted as protons, and those with SCD signal above 95 ADC units are counted as helium nuclei.

Further work is in progress intended to improve the accuracy of charge assignment. This includes e.g. adding the selected SCD pixel to the tracking algorithm and using the more accurate angles for better angle corrections to the SCD signal.

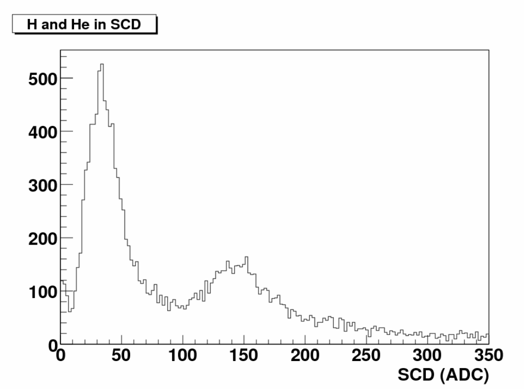

Figure 1: SCD signal distribution, ~Z^2, (in ADC units) after event selection. The proton peak is centered at ~38 ADC units and the helium peak is centered at ~140 ADC units. Charge resolution is about 0.3e.

III.3 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 an 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[9,10]-based Monte Carlo 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 0.148% 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 energy-dependent leakage at very high energies.

III.4 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 correction factor for atmospheric attenuation. The raw GF value was calculated requiring 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 based on MC simulations. For protons, trigger efficiency was calculated from fits to the MC distributions. Above 10 TeV, the proton trigger efficiency is about 70.5%. For helium nuclei, the trigger efficiency is calculated based on proton simulations correcting for the higher interaction probability for helium nuclei. At 10 TeV, the helium trigger efficiency is about 83.8%. The reconstruction efficiencies are about 96.7% for both protons and helium nuclei. Simulations show no significant energy dependence for these efficiencies. The background (δ) was also calculated from MC simulations. At 10 TeV, the background for protons is 3.22% and for helium nuclei is 3.23%, with no significant energy dependence. Live-time (T) is calculated from the length of the selected data range (~618 hours) using the live-time fraction, 80%. Further work on the live-time fraction estimate for the first flight is expected to reduce uncertainties. The correction factor for atmospheric attenuation loss (η) is calculated for protons and helium nuclei considering the atmosphere above the instruments, reported as $3.92 g/cm^2$ on average [1] and the effects of instrument material above the calorimeter module. The correction factor used is 82.1% for protons and 87.6% for helium nuclei.

IV. Results

Preliminary CREAM-I proton and helium spectra were obtained as described above. Several improvements are currently in progress. Further corrections to the energy deconvolution will be implemented (e.g. extending the spectra below a few TeV by applying corrections in the range where trigger efficiency is energy-dependent, energy-dependent shower leakage corrections at very high energies, etc.).

Figure 2 shows the CREAM-I proton and helium spectra (red circles) superposed on spectra from previous experiments (AMS [11, 12], BESS [13], RUNJOB [14], JACEE [15], IMAX [16], CAPRICE [17], Ryan et al. [18], ATIC-1 [19] and ATIC-2 [20]). Although some corrections are not included yet, the proton spectrum follows a power law without significant feature up to ~100 TeV and shows good agreement with those of ATIC-1, RUNJOB and JACEE. The CREAM-I proton spectrum shows a flatter power law than those of previous measurements at lower energies. The CREAM-I 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 and no clear statement can be made at this time.

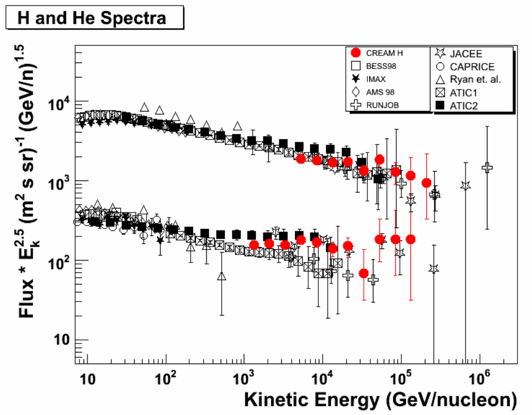

Figure 2: Preliminary CREAM-I proton and helium spectra (red circles) and previous measurements.

The preliminary CREAM-I ratio of protons to helium nuclei is about 12.2 ± 2.6 at 13 TeV. JACEE reported 12.1 ± 3.6 at 10 TeV [15]. The earlier measurements in about two decade lower energy ranges are almost twice higher values. (ig. Ryan's ratio of protons to helium nuclei is 26 ± 3 at 40 – 100 GeV [18] and LEAP[21] and CAPRICE[17]'s results are about 20 at 100 GeV.) Although it is the preliminary result of CREAM-I, the ratio of protons to helium nuclei shows good agreement with JACEE within uncertainty. Reducing the uncertainty in charge determination by requiring consistency between SCD and TCD, it will improve the ratio of protons to helium nuclei.

Further work remains to be done, including using TCD data to remove events with interactions in the instruments above the SCD, estimates of systematic uncertainties, and energy-dependant correction factors. Currently only statistical uncertainties are displayed.

V. Acknowledgement

We thank NASA, the Columbia Scientific Balloon Facility, the National Science Foundation Office of Polar Programs, and the Raytheon Polar Service Company for the successful balloon launch, Antarctic operations and recovery.

References

[1] E.S. Seo et al., Adv. Sp. Res., 33, 1777-1785, 2004
[2] S.Y. Zinn et al., Proc. 29th Int. Cosmic Ray Conf., Pune, 3, 437-440, 2005
[3] H.S. Ahn et al., Nucl. Instr. Meth. A, in press, 2007
[4] Y.S. Yoon et al., Proc. 29th Int. Cosmic Ray Conf., Pune, 8, 371-374, 2005
[5] H.S. Ahn et al., Nucl. Phys. B (Proc. Suppl.), 150, 272-275, 2006
[6] I.H. Park et al., Nucl. Instr. Meth. A, 535, 158-161, 2004
[7] M.H. Lee et al., Proc. 29th Int. Cosmic Ray Conf., Pune, 3, 417-420, 2005
[8] H.S. Ahn et al., Proc. 30th Int. Cosmic Ray Conf., 2007
[9] R.F. Brun et al., GEANT User Guide, CERN DD/EE/84-1, Geneva, 1984
[10] A. Fasso et at., Proc. IV Int. Conf. on Calorimetry in High Energy Physics, La Biodola, Italy, 21-26 Sept. 1993, Ed. A. Menzione and A. Scribano, World Scientific, p. 493
[11] J. Alcaraz et al., Phys. Lett. B, 490, 27-35, 2000
[12] J. Alcaraz et al., Phys. Lett. B, 494, 193-202, 2000
[13] T. Sanuki et al., Ap. J., 545, 1135-1142, 2000
[14] A. V. Apanasenko et al., Astropart. Phys., 16, 13, 2001
[15] K. Asakimori et al., Ap. J., 502, 278, 1998
[16] W. Menn et al., Ap. J., 533, 281-297, 2000
[17] W. Boezio et al., Ap. J., 518, 457-472, 1999
[18] M.J. Ryan et al., Phys. Rev. Lett., 28, 985, 1972
[19] H.S. Ahn et al., Adv. Sp. Res., 37, 1950-1954, 2006
[20] J.P. Wefel et al., Proc. 29th Int. Cosmic Ray Conf., Pune, 3, 105-108, 2005
[21] E.S. Seo et al., Ap. J., 378, 763-772, 1991