Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 2 (OG part 1), pages 23–26

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

Preliminary measurements of carbon and oxygen energy spectra from the second flight of CREAM

R. ZEI[6], H.S. AHN[1], P.S. ALLISON[4], M.G. BAGLIESI[6], L. BARBIER[10], J.J. BEATTY [4], G. BIGONGIARI[6], T.J. BRANDT[4], J.T. CHILDERS[5], N.B. CONKLIN[3], S. COUTU[3], M.A. DUVERNOIS[5], O. GANEL[1], J.H. HAN[1], J.A. JEON[7], K.C. KIM[1], M.H. LEE[1], P. MAESTRO[6], A. MALININE[1], P.S. MARROCCHESI[6], S. MINNICK[8], S.I. MOGNET[3], S. NAM[7], S. NUTTER[9], I.H. PARK[7], N.H. PARK[7], E.S. SEO[1,2], R. SINA[1], P. WALPOLE[1], J. WU[1], J. YANG[7], Y.S. YOON[1,2], S.Y. ZINN[1].
[1]*Inst. for Phys. Sci. and Tech., University of Maryland, College Park, MD 20742 USA*
[2]*Dept. of Physics, University of Maryland, College Park, MD 20742 USA*
[3]*Dept. of Physics, Penn State University, University Park, PA 16802, USA*
[4]*Dept. of Physics, Ohio State University, Columbus, Ohio 43210, USA*
[5]*School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455, USA*
[6]*Dept. of Physics, University of Siena and INFN, Via Roma 56, 53100 Siena, Italy*
[7]*Dept. of Physics, Ewha Womans University, Seoul, 120–750, Republic of Korea*
[8]*Dept. of Physics, Kent State University Tuscarawas, New Philadelphia, OH 44663, USA*
[9]*Dept. of Physics and Geology, Northern Kentucky University, Highland Heights, KY 41099, USA*
[10]*Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771, USA*
riccardo.zei@pi.infn.it

Abstract: The Cosmic Ray Energetics And Mass (CREAM) experiment was successfully flown twice on long–duration balloons from McMurdo, Antarctica, in 2004/05 and 2005/06. During the second flight, the redundant charge identification system of the instrument (based on scintillators and silicon detectors) was upgraded with the addition of a second layer of pixelated silicon sensors. A measurement of the particle energy was provided by an ionization calorimeter. From the on–going analysis of the data of the second flight, preliminary results on carbon and oxygen spectra up to a few TeV/n are presented.

Introduction

A multi–mission balloon experiment, CREAM [1] is designed to provide direct measurements of the individual energy spectra and elemental composition of cosmic–ray nuclei at energies approaching 10^{15} eV. In a period of 13 months, from December 2004 to January 2006, two successful flights were completed from McMurdo, Antarctica lasting a total of 70 days.

During the second flight (CREAM–II), redundant charge identification was performed by means of different sub–detectors: (from top to bottom of the instrument) a timing–based charge detector (TCD), a Cherenkov detector (CD) and a pixelated double–layer silicon charge detector (SCD). The measurement of the energy of the incoming particle was performed by a thin sampling tungsten/scintillating fiber calorimeter, preceded by a graphite target. A more detailed description of the CREAM–II instrument can be found elsewhere [2], together with a summary of its flight performance.
Carbon and oxygen energy spectra from a preliminary analysis of the data of the second flight are presented here.

Data analysis

Only a subset of the data, taken in the period from December $19^{\rm th}$ to January $12^{\rm th}$, is used in the present analysis. The effective total time for the selected period amounts to 32226.2 minutes. The live–time T, during which the read–out electronics was available for event triggers, was measured by on–board scalers (about 24267.7 minutes), providing an average of $\sim 75\%$ for the ratio of live–time to total time.

The preliminary analysis presented in this paper is made using only the information provided by two sub–systems, the SCD and the calorimeter. Events are selected within an entrance window of 78×78 cm^2 on the upper SCD plane and 50×50 cm^2 on the first calorimeter layer. The corresponding geometry factor $G_{\rm F}$ is 0.46 ± 0.01 m^{2}sr.

The first step in the analysis of the data is the reconstruction of the trajectory of CR nuclei traversing the instrument. The 3D–imaging calorimeter, with its fine granularity, provides the direction of the incident particle via the reconstruction of the shower axis. In each calorimeter layer, first the ribbon with maximum signal is found, and a cluster of hits around it is defined. Then the position of a candidate track–point is computed as the center–of–gravity of the cluster. If the number of fired layers is greater than 3 in both views, the candidate track is built by matching candidate track–points. The shower axis parameters are calculated by a χ^2 fit. The reconstructed shower axis is back–projected to the SCD. On each SCD plane, the pixels within a search area, defined around the impact point of the extrapolated track, are scanned. The pixel with the maximum pulse height is selected and included as a new track–point. The shower axis parameters are updated accordingly. The resolution on the impact point on the SCD is about 1 cm [2].

Identification of the charge Z of the incoming particle in the SCD relies on two independent samples of the energy deposit per unit pathlength (dE/dx). These can be obtained by correcting the signals of the matched pixels in each SCD plane for the estimated pathlength in the SCD, as calculated from the track parameters. The absolute charge scale is inferred from flight data by fitting the charge distributions of the C, O, Ne, Mg, Si and Fe nuclei. An excellent separation of the charge peaks for the CNO group can be seen in the correlation plot between the measurements of the two SCD planes (Figure 1(a)). Consistency of the two ionization signals within 30% is required. The average value of the two signals is used as an estimator of the charge (squared) of the primary particle. With this procedure, a resolution of $\sim 0.2e$ is achieved both for carbon and oxygen nuclei (Figure 1(b)). With a 2σ cut, 583 and 728 events for carbon and oxygen are selected, respectively.

For each reconstructed shower associated with a charge measurement Z, the raw energy deposit of each cell is equalized and converted to physical units (MeV), after appropriate selection of the readout scale [2]. The total energy deposit E_d is determined by summing up the calibrated energy deposits of all the cells of the calorimeter. The result is scaled according to the actual value of the high voltage during the flight.

Energy deconvolution

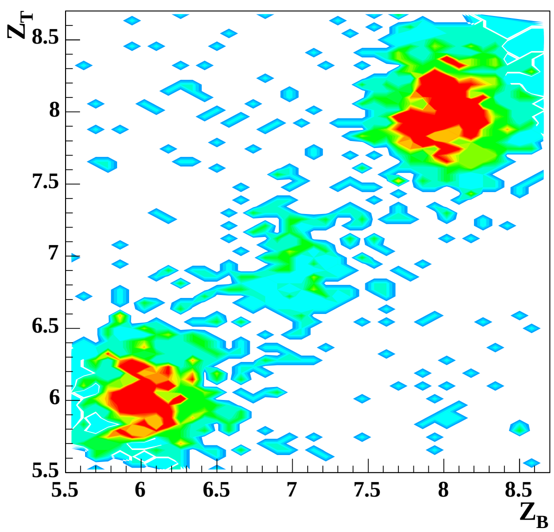
To convert the energy deposit spectra into the primary energy spectra, it is necessary to unfold the instrument response. Due to the finite energy resolution of the instrument, the observed energy deposit distribution $\varphi(E_d)$ is related to the primary spectrum $\phi(E)$ by a convolution–type integral, the so–called "Fredholm integral" equation of the first kind:

$$\varphi(E_d) = \int_{E_{min}}^{E_{max}} A(E_d, E)\phi(E)dE \qquad (1)$$

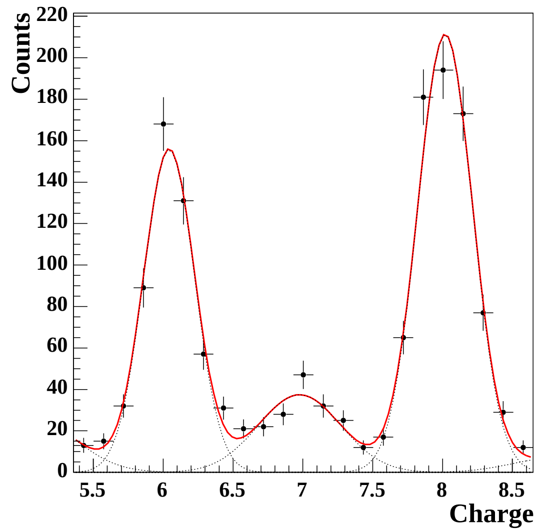
where $A(E_d, E)$ is the response function of the energy meter to incident cosmic–ray particles with primary energy $E \in [E_{min}, E_{max}]$ and E_d is the deposited energy in the calorimeter. It includes the effects of the instrumental resolution and efficiency. Breaking the integral in eq. (1) into a sum over j bins, the unfolding problem reduces to a matrix equation:

$$M_i = \sum_{j=1}^{n} a_{ij} N_j, \quad \text{with} \quad A(E_d, E) \Leftrightarrow a_{ij},$$
$$\phi(E) \Leftrightarrow N_j, \qquad \varphi(E_d) \Leftrightarrow M_i$$

where M_i indicates the measured counts in the deposited energy bin i while N_j are the true counts in the incident energy bin j. Each matrix element a_{ij} represents the probability that the events in the deposited energy bin i come from the incident energy bin j. Particular care must be taken when reconstructing primary energy spectra from measurements using detectors with finite energy resolution. In fact, because of the steeply falling spectrum, signal fluctuations make it more likely to assign a low–energy event incorrectly to a higher en-



(a)



(b)

Figure 1: (a) Correlation between the reconstructed charge by the top (Z_T) and the bottom (Z_B) SCD planes. (b) Preliminary charge distribution of the CNO group with a superimposed multi–Gaussian function fit. The RMS values for C and O peaks from the fit are about $0.2e$.

ergy bin than vice versa. In this way, the reconstructed energy spectrum can be significantly distorted. In order to understand this effect and correct for it, a detailed simulation of the CREAM–II instrument based on FLUKA [3] is used, where the known properties of the detectors and electronics are accounted for. The Monte Carlo code generates a simulated cosmic–ray data set of carbon and oxygen nuclei, which is then subjected to the same analysis procedures as the real flight data. Each matrix element a_{ij} is then estimated from the correlation of the generated primary spectrum E with respect to the energy deposit E_d in the calorimeter. In order to reduce the smearing between nearby bins, the bin width has been chosen to be significantly wider than the rms resolution of the calorimeter. The distribution of energy deposit as well as the primary spectrum have been divided into ~ 4 bins per decade. This results in a 9×9 deconvolution matrix.

Absolute flux normalization

The absolute differential flux ϕ at the top of the atmosphere is determined by normalizing the unfolded counts N, in each incident energy bin of size ΔE, through the relation

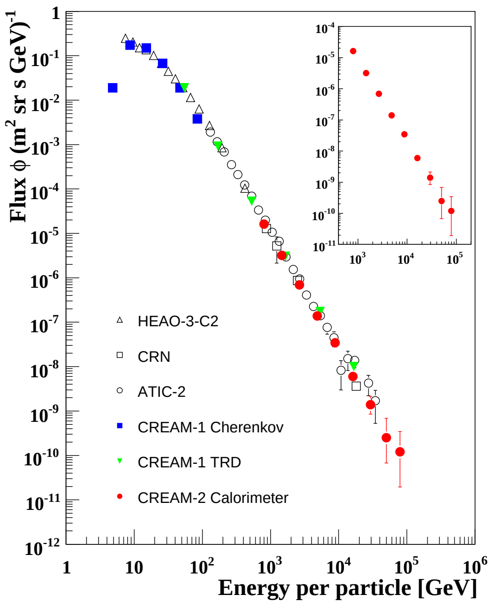
$$\phi = \frac{N}{\Delta E} \cdot \frac{1}{G_{\rm F} \cdot T \cdot \epsilon \cdot \eta}$$

where ϵ takes into account the event reconstruction efficiency (as a function of the primary energy E) and the correction for interactions in the material up to the top of the instrument. The normalization parameters $G_{\rm F}$ and T were defined in the second paragraph and η is the correction factor for the attenuation in the residual atmosphere. The mean atmospheric overburden, as measured during the flight, was $\sim$ 3.9 g/cm^2. The average correction factor η is estimated around 85.5% for carbon and 83.1% for oxygen nuclei, respectively.

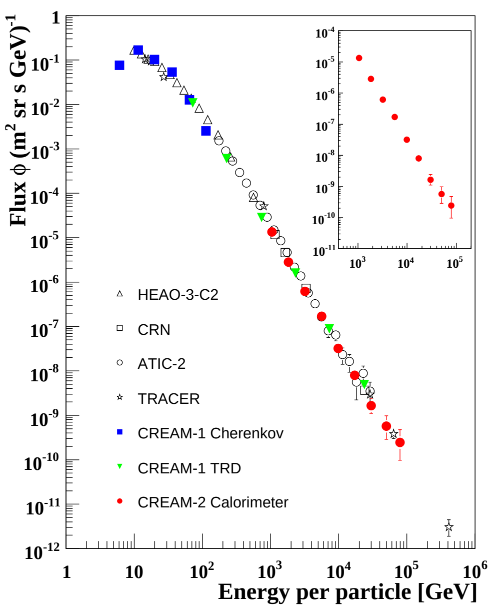
The acceptance cuts were varied to restrict the analysis to a fiducial area of 40×40 cm^2 on the CAL window entrance and 64×64 cm^2 on the upper SCD plane. Also, the $\log_{10}$ bin size used in the deconvolution procedure was varied between ~ 0.2 and ~ 0.4 to check the stability of the result.

Conclusions

The preliminary energy spectra for carbon and oxygen nuclei, as measured by the CREAM in-



(a)



(b)

Figure 2: Cosmic–ray energy spectra for carbon (a) and oxygen (b) nuclei from HEAO [4], CRN [5], ATIC–2 [6] and TRACER [7] with preliminary results from the first [8] and second (red filled circles) flight of CREAM. The latter are also plotted separately in the inserts.

strument during its second flight, are shown in Figure 2(a) and 2(b), respectively, and compared with previous results of other experiments [4, 7, 6, 5]. The preliminary measurements [8] of the first flight (CREAM–I) are shown, where the instrument configuration also included a transition radiation detector (TRD). The proportional tubes of the TRD, filled with a Xe gas mixture, measured the ionization in the region of the relativistic rise, thereby allowing a determination of the Lorentz factor γ up to about 500 GeV/n. An acrylic Cherenkov detector provided a measurement of the particle velocity up to $\sim$ 10 GeV/n, where the light signal reached saturation. By combining these two complementary techniques, the CREAM–I measurements cover almost 4 orders of magnitude in terms of particle energy. The CREAM–II results presented here are based on the analysis of calorimeter data and span over 2 decades in energy. While the preliminary CREAM–I results [8] were arbitrarily normalized to match the HEAO flux at ~ 4 GeV/n, CREAM–II carbon and oxygen differential energy spectra are given as absolute intensities with no arbitrary normalization and are found to be consistent with previous measurements. The CREAM–II results are still preliminary and further analysis is under way.

Acknowledgments

This work is supported by NASA, NSF, INFN, PNRA, KRF, KICOS, and CSBF.

References

[1] Seo E.S. et al., *Adv. Sp. Res.* 33 (2004) 1777

[2] Marrocchesi P.S. et al., *Adv. Sp. Res.* (2007) doi:10.1016/j.asr.2007.02.052, in press

[3] Fassò A. et al., CERN–2005–10 (2005); CHEP2003 eConf C0303241 (2003)

[4] Engelmann J.J. et al., *Astron. & Astrophys.* 233 (1990) 96

[5] Swordy S.P. et al., *Ap. J.* 403 (1993) 658

[6] Panov A.D. et al., *Adv. Sp. Res.* 37 (2006) 1944

[7] Muller D. et al., *Proc.* 29th *ICRC* 3 (2005) 89

[8] Wakely S.P. et al., *Adv. Sp. Res.* (2007) doi:10.1016/j.asr.2007.03.080, in press