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 31–34

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Revised Energy Spectra for Primary Elements (H – Si) above 50 GeV from the ATIC-2 Science Flight

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Abstract: The Advanced Thin Ionization Calorimeter (ATIC) long duration balloon experiment had a successful science flight (12/02 -1/03) accumulating 18 days of data during a single circumnavigation of Antarctica. ATIC measures the energy spectra of elements from H to Fe in primary cosmic rays using a fully active Bismuth Germanate calorimeter preceded by a carbon target, with embedded scintillator hodoscopes, and a silicon matrix charge detector at the top. Preliminary results from ATIC have been reported in previous conferences. The revised results reported here are derived from a new analysis of the data with improved charge resolution, lower background and revised energy calibration. The raw energy deposit spectra are de-convolved into primary energy spectra and extrapolated to the top of the atmosphere. We compare these revised results to previous data..

Introduction

The Advanced Thin Ionization Calorimeter (ATIC) Experiment was developed to measure the energy spectra of the major primary elements (H–Fe), plus electrons, to as high energy as possible from balloon platforms, to search for signatures of particle acceleration sites. It is believed that particle acceleration associated with supernova remnant (SNR) shocks appears to be the best (but not the only) explanation for how galactic cosmic rays (GCR) below the "knee" achieve their high energies. Evidence that particle acceleration is taking place at SNRs is provided by electron synchrotron and gamma-ray emission measurements. Moreover, the SNR acceleration mechanism is expected to have an upper energy limit imposed by the conditions in the expanding shell following the supernova explosion. Thus, one might well expect to find changes in the cosmic ray spectra of different elements as observations move to higher and higher energy, and ATIC is intended to provide direct particle-by-particle measurements to compare with both the air shower data and previous measurements.

The ATIC instrument and flights

A schematic diagram of the ATIC instrument is shown in Figure 1. The topmost element is a pixilated Silicon matrix detector (4480 pixels) to measure the charge of the incident particle. This is followed by three layers of scintillator hodoscopes (S1, S2, S3) embedded within a graphite target (0.75 proton interaction length). S1-S3 provides the instrument trigger and the x-y measurements from the scintillators are used for trajectory determination, along with shower centroid position provided by the eight layer BGO calorimeter. Each layer contains 40 BGO crystals of

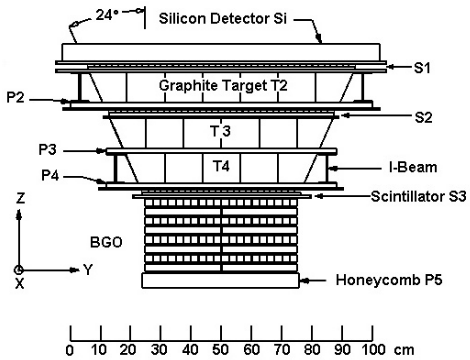

Figure 1: Schematic diagram of the ATIC instrument in flight configuration.

25 mm x 25 mm x 250 mm with alternate layers oriented orthogonally. The total energy deposited in the calorimeter is a measure of the incident particle energy [1].

Preliminary results from the on-going ATIC analysis have been presented previously [2-7]. These results have been based upon the charge resolution provided by the silicon matrix (Si-mat) detector [8]. The top layers of scintillator, S1x and S1y, can also be used to measure the particle charge, thereby providing a second, independent measurement, which improves the overall charge determination [9].

ATIC has been calibrated at the SPS at CERN with proton and electron beams [10]; has had a test flight from McMurdo in 2000-2001 [11]; returned good data from its science flight in 2002-2003 [12]; and had its second science flight terminated just after launch in 2005 due to a balloon failure. ATIC is anticipating completing its second science flight in 2007-2008.

Revised ATIC-2 results

Since our previous report [2], the data from the first science flight have been re-processed/re-analyzed to (a) incorporate better charge determinations, (b) more accurately account for the overlap of the "tails" of the charge distributions, (c) restrict the data to only the central 40 cm x 40 cm of the top detector, (d) apply more detailed corrections for interactions in the material above the Si-matrix plus the overlying atmosphere, (e) re-do the energy calibration including revised corrections for the temperature dependence of the BGO response, and (f) include revised systematic uncertainties in the deconvolved energy spectra.

1. Hydrogen and Helium

The separation between H and He is based upon the Si-matrix detector, corrected for overlap due to the non-Gaussian tails of the charge distributions, for interactions in the material above the Si-mat, for albedo particles produced in the cascade and for instrumental broadening of the response. This involved detailed FLUKA Monte-Carlo runs for the instrument geometry at 0.1, 1 and 10 TeV. Little energy dependence was found [13] so the results were averaged to obtain the corrections.

The reconstruction of the primary spectrum was based upon deconvolution of the energy deposit spectrum using the Tikhonov regularization technique [14, 2]. The set of Fluka simulated data was subjected to the same deconvolution technique from which the deconvolution uncertainties were derived.

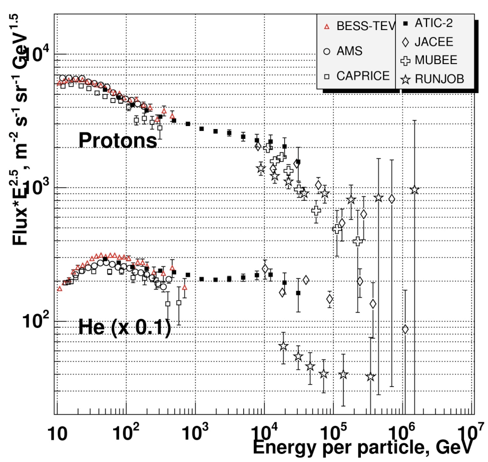

Figure 2. H and He spectra at the top of the atmosphere compared to previous results.

Each of the corrections was at the <10% level, but together improved the absolute normalization of the data. In addition the shape of the energy spectra were modified. Figure 2 shows the revised p and He spectra compared to previous work at lower energy and to emulsion chamber results at higher energy [15-21]. ATIC-2 data are in good agreement with BESS and AMS results in the 100 GeV region and demonstrate spectra that flatten as energy increases. The He spectrum differs significantly from H, which is in basic agreement, at high energies, with previous emulsion chamber

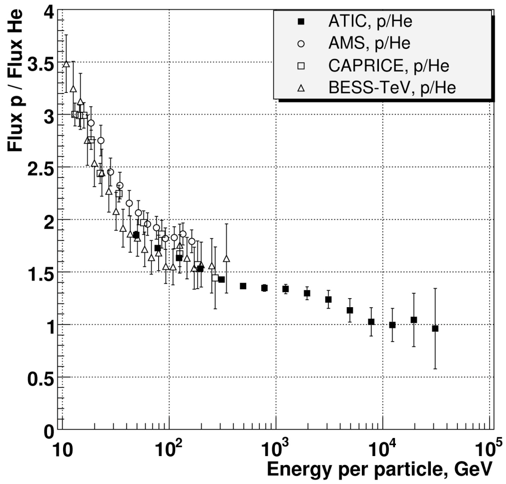

Figure 3. Ratio of protons to helium compared to the data of magnetic spectrometers.

results. The He spectrum, however, is consistent with JACEE data, but is inconsistent with RUNJOB results.

Since the H and He spectra are different, the H/He ratio is energy dependent, and this is shown in Figure 3, compared to low energy results. The ratio continues to decrease with energy, becoming unity above 10 TeV.

2. Heavy Nuclei

The spectra for the abundant heavy nuclei were reconstructed in a similar fashion except for the charge determination for which both Si-mat and the S1 scintillators were employed giving a two-detector charge measurement [9]. The charge determined by the scintillators and the Si-mat were required to agree within 0.65 charge units. The improved charge resolution is shown in Figure 4 for three energy deposit bins; 50-100 GeV, 100-200 GeV and 200-400 GeV. The charge resolution varies slightly with energy deposit, and the peak locations shift a small amount with increasing energy. These have been incorporated into the analysis. In addition, accurate background estimates for fragmentation/interactions in the material above the Si-mat have been included. Finally, we have updated the extrapolation of the fluxes to the top of the atmosphere. [More details can be found in [22] at this conference.]

Figure 5 shows the ATIC-2 results for C, O, Ne, Mg and Si compared to previous data from HEAO-3-C2 [23] and CRN on Spacelab-2 [24] and to preliminary results from the TRACER

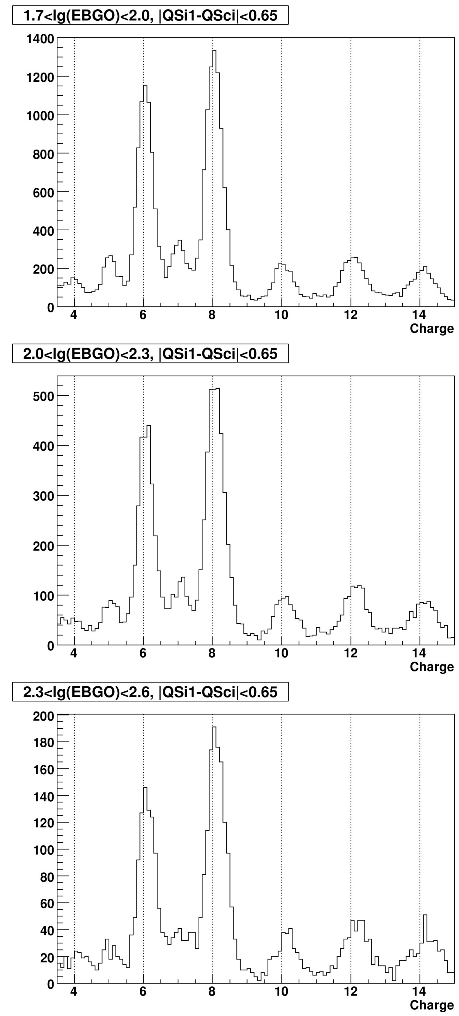

Fig. 4. Charge spectra in these energy intervals used in the data processing to obtain the spectra of even nuclei.

balloon experiment [25]. The agreement is, in general, good. ATIC data in the region between ~0.2-20 TeV per particle confirm previous results. The one exception is Carbon (not measured by TRACER) for which ATIC-2 shows a turn-up beyond 10 TeV, which was not seen by CRN, and this needs further investigation.

Summary

The revised ATIC-2 results complete a picture of the energy spectra of major components in the region ~0.1 to 20 TeV. The p and He spectra do

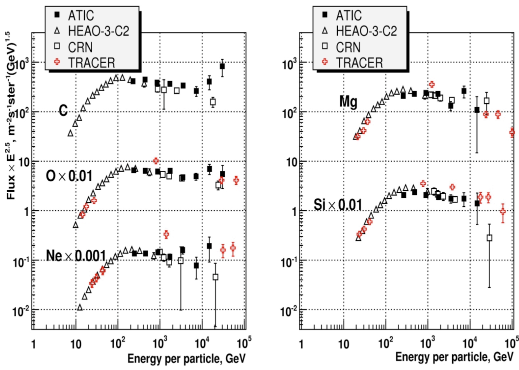

Figure 5. Spectra of even abundant nuclei compared to the results of other experiments.

not show the same slope, as was pointed out by JACEE [19]. The heavy nuclei follow more closely the Helium spectrum, and agreement among the experiments measuring the abundant heavy nuclei is good.

Acknowledgements

This work was supported in the US by NASA (NNG04WC12G at LSU), in Russia by the Russian Foundation for Basic Research and in China by the Ministry of Science and Technology.

References

[1] Guzik, T.G.. et al., Advances in Space Res., 33, 1763 (2004).
[2] Panov, A.D. et al., Bull. Russian Acad. Sci.; Physics, 71, 494 (2007).
[3] Wefel, J.P. et al., Proc. 29th Intl Cosmic Ray Conf (Pune), 3, 105, (2005).
[4] Panov, A.D. et al., Advances in Space Res., 37, 1944 (2006).
[5] Chang, J. et al., Proc. 29th Intl Cosmic Ray Conf (Pune), 3, 1, (2005).
[6] Ahn, H.S. et al., Advances in Space Res., 37, 1950 (2006).
[7] Zatsepin, V.I. et al., Bull. Russian Acad. Sci.; Physics, 68, 1780 (2004).
[8] Zatsepin, V.I. et al., Nucl. Instr. Meth. A., 524, 195 (2004).
[9] Guzik, T.G., et al., Advances in Space Res., in press (2007)
[10] Ganel, O. et al., Nucl. Instr. Meth. A., 552, 409 (2005).
[11] Wefel, J.P. et al., Proc. 27th Intl Cosmic Ray Conf (Hamburg), 6, 2111, (2001).
[12] Wefel, J.P. et al., Proc. 28th Intl Cosmic Ray Conf (Tsukuba), 4, 1849, (2003).
[13] Watts, J. et al., Proc. 29th Intl. Cosmic Ray Conf (Pune), 6, 89 (2005).
[14] Batkov, K.E. et al., Proc. 29th Intl. Cosmic Ray Conf (Pune), 3, 353 (2005).
[15] Alcaraz, J. et al., Phys. Lett. B, 490, 27, (2000).
]16] Alcaraz, J. et al., Phys. Lett. B, 193, 27, (2000).
[17] Boezio, M. et al., Astroparticle Physics, 19, 583, (2003).
[18] Haino, S. et al. Phys. Lett. B, 594, 35, (2004).
[19] Asakamori, K. et al., Ap. J., 502, 278, (1998).
[20] Zatsepin, V.I. et al., Phys. At. Nucl., 57, 645, (1994).
[21] Apanasenko, A.V. et al., Astropart. Phys., 16, 13 (2001).
[22] Panov, A.D. et al., (ATIC Collaboration), "Relative abundances of cosmic ray nuclei B-C-N-O in the energy region from 10 GeV/n to 300 GeV/n. Results from the science flight of ATIC" (this conference).
[23] Engelmann, J.J. et al., Astron. Astrophys., 233, 96, (1990).
[24] Müller, D. et al., Astroph. Journal, 374, 356, (1991).
[25] Müller, D. et al., Proc. 29th Intl. Cosmic Ray Conf (Pune), 3, 89 (2005).