ICRC 2001

The CNO concentration in cosmic ray spectrum as measured from The Advanced Thin Ionization Calorimeter Experiment

A. R. Fazely and R. M. Gunasingha for the ATIC Collaboration

Southern University and A&M College,Baton Rouge,LA 70813,USA

Abstract. We present preliminary results on the spectra of CNO nuclei in the cosmic radiation as measured in the first flight of the Advanced Thin Ionization Calorimeter Balloon Experiment (ATIC) which lasted for 16 days, starting in December, 2000 with a launch from McMurdo, Antarctica. ATIC is a multiple, long duration balloon flight, investigation for the study of cosmic ray spectra from below 50 GeV to near 100 TeV total energy, using a fully active Bismuth Germanate (BGO) calorimeter. It is equipped with the first large area mosaic of small fully depleted silicon detector pads capable of charge identification in cosmic rays from H to Fe. As a redundancy check for the charge identification and a coarse particle tracking system, three projective layers of x-y scintillator hodoscopes were employed, above, in the center and below a Carbon interaction 'target'.

1 Introduction

Cosmic rays are the only sample of matter from distant region of the galaxy, and possibly elsewhere in the universe, that can directly be observed by a space experiment in our solar system. The study of cosmic ray composition and energy spectra can provide clues to the origin of cosmic rays, their acceleration, and how they propagate through the intergalactic and galactic medium. The all-particle energy spectrum of cosmic rays obeys the power law dependence of the observed flux on energy, from about 10 GeV up to the highest energy measured by ground based experiments at over $10^{20} eV$. In the middle of this wide range of energies, however a "knee" is observed near 10^{15} to 10^{16} eV where the spectrum steepens. It is not known whether this steepening is due to:

– A change in the propagation of cosmic rays;

– A change in the composition of the cosmic ray;

Correspondence to: A. R. Fazely
(fazely@feynman.phys.subr.edu)

– A change in the acceleration mechanism of cosmic rays. related to energies from shock acceleration in galactic supernova remnants;

The Advanced Thin Ionization Calorimeter (ATIC) is a balloon-borne experiment designed to investigate the spectral shapes of individual elements from Hydrogen to Iron, from about 10 GeV to 100 TeV with a statistical accuracy of better than 30% for protons (Guzik *et al.*, 1999) at the highest energy. ATIC also measures the spectra of nuclei up to Iron.

During December 2000 - January 2001, ATIC balloon payload was launched to an altitude of 36.6 km above sea level from McMurdo, Antarctica. It traveled around the south pole for 16 days and collected data. After preliminary calibration, we have started analysis of data for various physics goals.

In this paper, we discuss the preliminary results of analysis of Carbon, Nitrogen and Oxygen (CNO). The flight and analysis of other elements from H to Iron will be discussed by other ATIC collaborators in this conference (Wefel *et al.*, Seo *et al.*, Adam *et al.*, and Zatsepin *et al.*).

The study of C,N,and O is important for various reasons. Next to the H and He, CNO are the most abundant in cosmic rays. The study shows that the odd-even effect where more tightly bound even Z, nuclei are more abundant. The main process that separate these two elements are well understood. The Carbon comes from triple-alpha reaction of helium while Nitrogen originates in CNO processing by the conversion of Carbon and Oxygen during Hydrogen burning. There has been very little knowledge of generation sites for these nuclei (Henry *et al.*, 2001). It is not known whether they come from short lived massive stars or from long lived progenitor of asymptotic giant branch stars. The reason is that the threshold temperature for the production of both Carbon and Nitrogen are reached in both stellar types.

In nucleosynthesis, ^{20}Ne, Mg, Al, and Na are all produced by Carbon burning. Oxygen and Si burning produce S, Ar, Si, and Ca. The abundance of the galactic cosmic rays is inconsistent with the value expected from nucleosynthesis and

it suggests a component expected by the presence of helium-burning materials (Silberberg *et al.*, 1990). In massive stars (Wolf-Rayet stars) the CNO cycle convert the initial CNO into $^{14}N, ^{18}O, ^{22}Ne$ and transform ^4He into ^{12}C. The massive stars strong wind strips off the outer layer thereby exposing the star's ^4He-burning core. The wind material then becomes highly enriched with the products of ^4He burning. The spectral index depends on the compression ratio due to the supernova shock waves. The different spectral indices for element (H, He, C, N, O etc) suggest different sources (Biermann *et al.*, 1993).

2 ATIC Detector

ATIC detector (see Fig. 1) is comprised of a fully active 50 cm wide BGO calorimeter, preceded by a graphite target having an outwardly projective angle of 24 degrees. The BGO crystals of $2.5 \times 2.5 \times 25.0 \ cm^3$ arranged horizontally in 8 layers, with long axes aligned alternatively along the X and Y axes, and the vertical direction is along the Z axes. Each layer consist of 40 BGO crystals, totaling 320 BGO's in the calorimeter. The construction and commissioning of the detector, the data acquisition system and the software development for detector calibration are discussed in other papers at this conference.
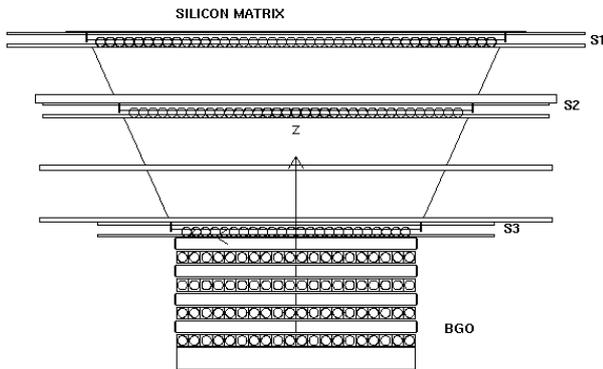

Fig. 1. McMurdo configuration of ATIC

3 Data readout and Calibration

ATIC detector hardware and software was validated by exposing the detector to the high energy proton beam line at CERN Super Proton Synchrotron (SPS). Just after completion of the detector in September 1999, data was collected from proton, electron, and pions beams at energies from 100 GeV to 375 GeV as well as cosmic ray muons. This data was used to test the response of BGO crystals as well as scintillator hodoscopes. The detailed description of the beam test

and the comparison of data with an ATIC Monte Carlo was reported previously (Ganel *et al.*, 2000). The measured and the calculated results were in good agreement.

In December 2000, ATIC performed its first Long Duration Balloon (LDB) Flight at McMurdo, Antarctica. Duration of the flight was 16 days and it collected about 3×10^7 data events and cosmic ray muon samples. The ATIC data acquisition system recorded events in a raw data format. This data includes a series of events with various types (science, calibration, environment) each with its own header, size and addresses.

In the first phase of the data analysis, muon data was used to determine the 1 MIP peak for each silicon pixel. The mean value of the muon peak corresponds to single charge response and it was used to develop the particle identification parameter or charge number and the energy deposition of each Si pixel. Figure 2 shows the charge number obtained using silicon data for a sample of data. The domination of the proton and helium in the data has suppressed the higher charge elements.
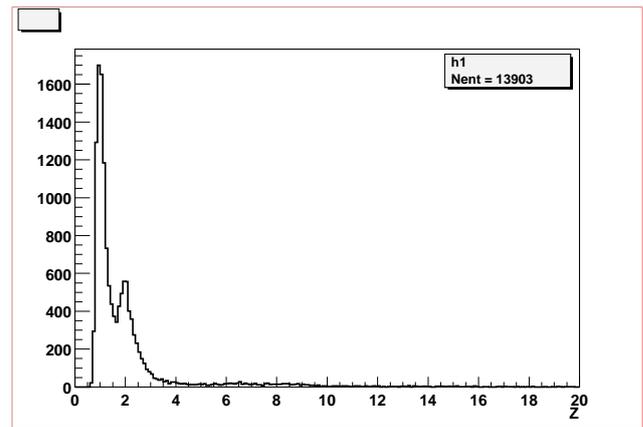

Fig. 2. Particle Identification or Charge Number as from Si matrix data

The particle identification can be performed, as well, using data for S1 scintillator hodoscope. The S1 hodoscope contains 42 strips of scintillators in each X and Y direction. X and y positions for each scintillator with respect to the coordinates of the detector are known. Using the pulse height information for X and Y PMT's of S1, x, and y positions for an event can be calculated. Therefore the distance from a particular PMT to the position of a muon hit on S1 can be calculated. Plotting the distance and pulse height information we have obtained the attenuation length for each scintillator strip. Figure 3 shows the distance vs pulse height for a particular S1 strip. Using this plot, we obtain attenuation length and Z_0 pulse height for muon at zero distance for each scintillatori strip. In the data, we know the position for every event from pulse height information for S1. The corresponding muon peak Z for a given position (l) can be calculated using $Z = Z_0 exp(-l/L)$ where L is the attenuation length. This is a powerful technique for position determination when

one the two phototubes in a scintillator strip malfunctions. The charge numbers for a data sample calculated in this way are shown in Fig. 4.
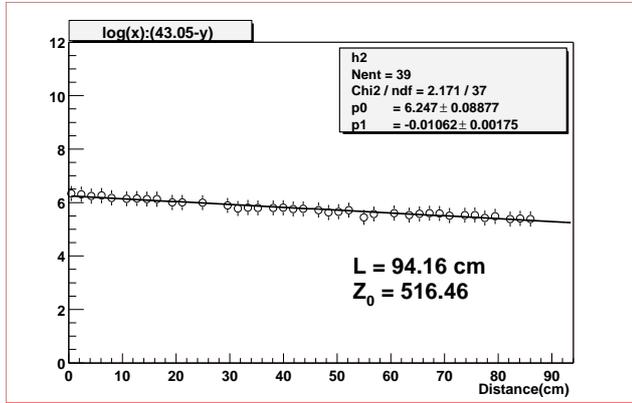

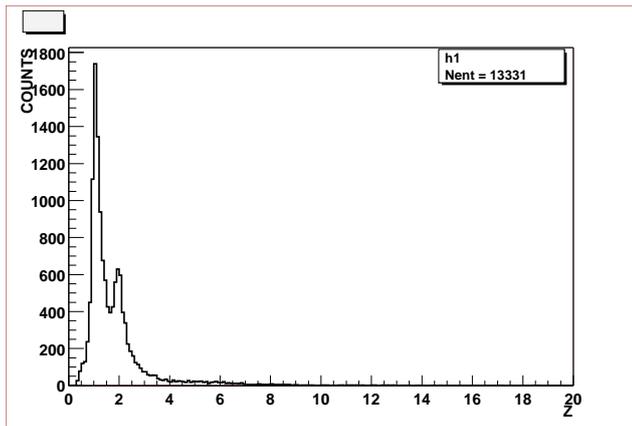**Fig. 3.** Attenuation length for a typical scintillator strip

Fig. 4. Particle Identification or Charge Number measured from S1 data

4 Data Analysis

In the first phase of the analysis the ROOT tree files were created with variables for particle identification, energy deposition in each Si, BGO, scintillator strip, and direction cosine and particle identification parameters for each event. In the conference we will present the preliminary results using these data files. In the second phase of the data analysis we will improve all of our calibrations in order to obtain better particle and charge identification.

As shown in Figs. 2 and 4, Proton and Helium are well separated and dominate the data as expected. For CNO, we have employed a software cut for charge number Z greater than 4.0 and less than 12. A preliminary plot of the zenith angle for a CNO event shows that majority of these events triggering the detector have an angle less than 60° (see Fig. 5). Events outside of the 60° cone travel a long path in

the scintillator and give rise to a tail in the energy deposit for an event. We have therefore applied a software cut for zenith angle, keeping events with cosine of the zenith angle $cosinez > 0.5$.
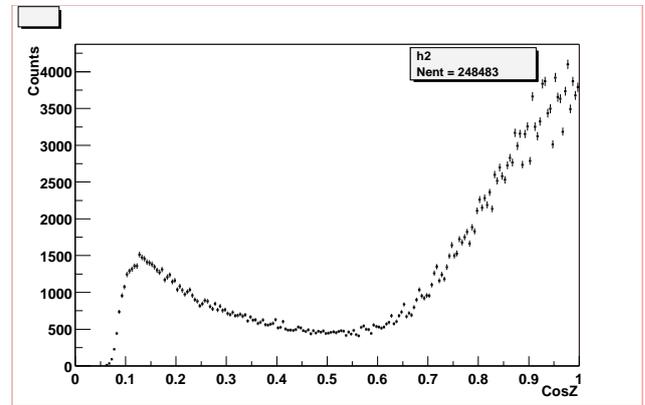

Fig. 5. Preliminary cosine of the zenith angle of the incident CNO
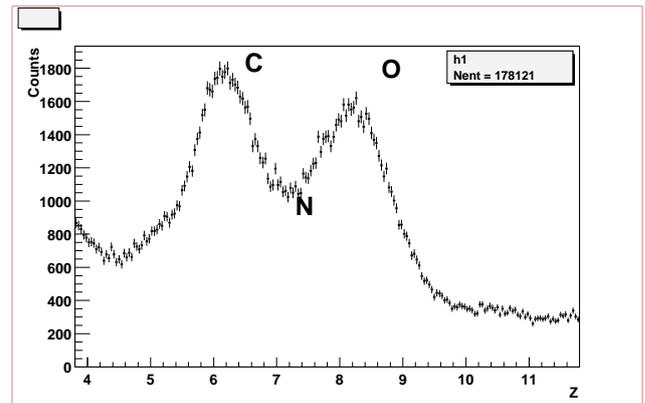

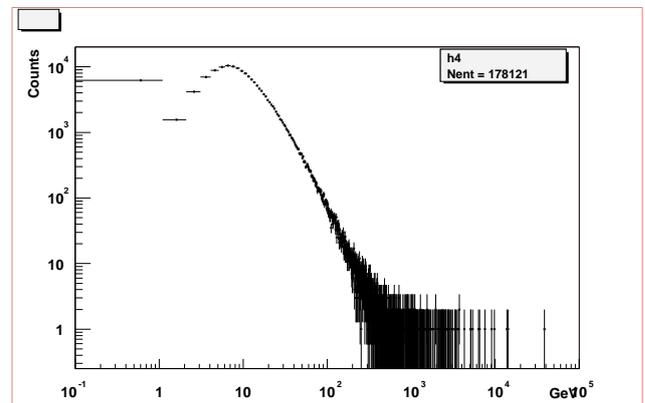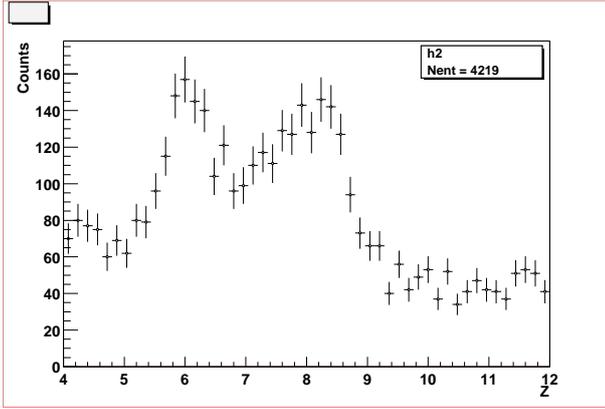**Fig. 6.** CNO peaks after applying cut above $Z > 4.0$.

Fig. 7. Total energy deposition for CNO

As shown in Fig. 6 the data for C and O show distinct peaks. The total energy deposition in the calorimeter for a

Fig. 8. CNO peaks at energy greater than 100 GeV

sample of CNO is shown in Fig. 7.At this stage we have analyzed only 178121 events. Our data analysis is still in progress and we hope to analyze more CNO data in near future. As expected the plot obeys a power law dependence $\frac{dN}{dE} = CE^{-(1+\gamma)}$ at high energy.

In the next step, we looked at the energy spectra of CNO in low energy (less than 100 GeV) and in high energy region (greater than 100 GeV). For energies greater than 100 GeV the nitrogen shoulder begins to appear. See Fig. 8.

The Spectral Analysis and Manipulation program (SAM code) is being used to analyze the total charge spectrum and to estimate the number of events in each specie of C, N, O. The SAM code provides a non-linear search method for fitting the spectra. Peak and background intensities (areas) are determined in a weighted linear least-square fit, while peak position, width (FWHM in channels), and asymmetry parameters (possible tails) are determined by a non-linear least square search.

5 Conclusion

In this paper, we have discussed the preliminary analysis of CNO. The total energy spectrum is consistent with a power law. The data analysis is still in progress. With the improved statistics and refined calibration, coupled with spectral decomposition, we will be able to address models of supernova acceleration and leaky box propagation.

References

1. Guzik T. G.*et al.*, The Advanced Thin Ionization Calorimeter(ATIC) for studies of High Energy Cosmic Rays, in proceedings of the 26th ICRC, eds. D.Kieda, M. Salamon and B. Dingus, 5,pp 9-12, Salt Lake City, 1999.
2. Wefel J.P. *et al.*, Seo E.S. *et al.*, Adam J. *et al.*, and Zatsepin V. *et al.* in this conference
3. Ganel O. *et al.*, First Results from ATIC beam-test at CERN, Advances in Space Research, in press, 2000.
4. Silberberg R. *et al.*, Ap.J. 363,265(1990)
5. Biermann P. L. *et al.*, Astron. Ap. 271,649(1993).
6. "Holifield Heavy Ion Research Facility(HHIRF)" computer hand book, Oak Ridge National Lab,Tennessee, USA.
7 Henry R. B. C. *et al.*, On the Cosmic Origins of Carbon and Nitrogen, preprint from http://xxx.lanl.gov, astro-ph/0101070 (2001).