Rigidity Spectra of Protons and Helium as Measured in the First Flight of the ATIC Experiment

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Abstract

ATIC (Advanced Thin Ionization Calorimeter) is a balloon borne experiment designed to measure cosmic ray composition for elements from hydrogen to iron and their energy spectra from 30 GeV to near 100 TeV. It is comprised of a fully active BGO calorimeter, a carbon interaction target, scintillator hodoscopes, and a silicon matrix that is used as a charge detector in the experiment. ATIC had two successful balloon flights in Antarctica: from 28 Dec 2000 to 13 Jan 2001 (ATIC-1) and from 29 Dec 2002 to 18 Jan 2003 (ATIC-2). Preliminary rigidity spectra of protons and helium nuclei and their ratio are presented for the test flight (ATIC-1). Particular attention is given to problems associated with measuring energy.

1. Introduction

The most popular acceleration model - acceleration in supernova remnant shells - predicts the same rigidity source spectra for different components of primary cosmic rays. This prediction is tested by analyzing proton and helium rigidity spectra in the present paper.

2. ATIC instrument

ATIC consists of three main parts: charge module, carbon target and calorimeter. The ATIC configuration and operation are described in more detail in [3]. Silicon matrix applied for charge determination in the ATIC experiment is

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described in [1]. The algorithm of charge determination and influence of backscattering from the calorimeter are presented in accompanied paper at this conference [5]. The calorimeter module consists of a "package" of 320 BGO crystals. Each crystal is viewed by a photomultiplier tube (PMT). The readout has to cover energy deposits from 5 MeV to over 10 TeV in each individual crystal. This forces the readout of the PMT to be split into three gain ranges. The absolute energy calibration of the calorimeter is done by utilizing cosmic ray muons. First the energy deposit per ADC count is determined for the low energy range of every BGO crystal. Then the higher energy ranges are calibrated using the overlap between ranges. The design and calibration of the calorimeter is described in [4].

3. Problems in energy determination

In the first flight of ATIC, we found two problems in the operation of the calorimeter electronics: "jumping pedestals" and "oversaturation". As a criterion of correct operation of the electronics, we used correlation between summary energy deposits measured in odd and even layers of the calorimeter.

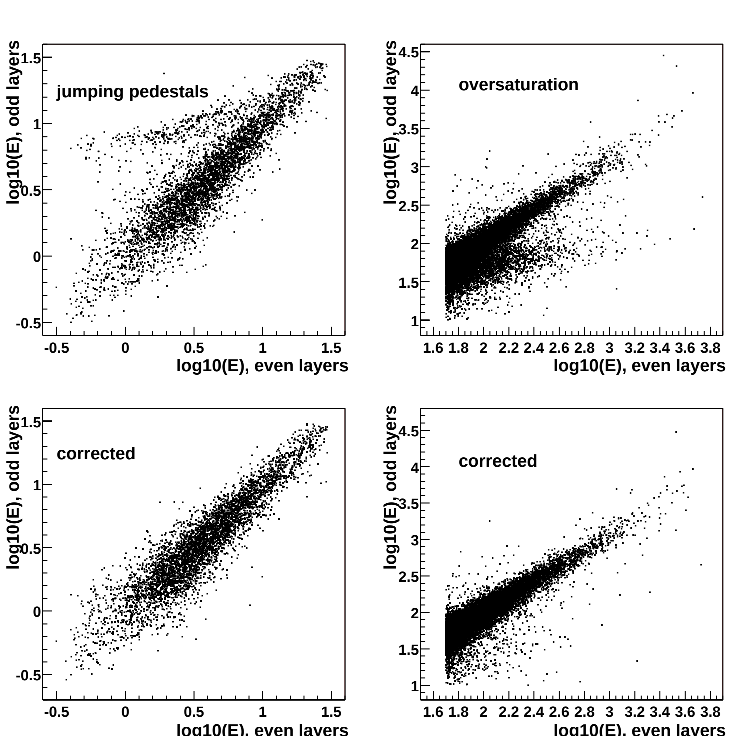

Fig. 1. Jumping pedestals and oversaturation

Fig.1 (top, left panel) shows the first problem. One can see that in some events E_{odd} strongly exceeds E_{even}. The analysis shows that E_{odd} is measured incorrectly in these events. The reason is random jumping of pedestal values in the ADC of odd calorimeter layers in a small fraction of the events. These unstable pedestals were corrected in the following way: In the calorimeter, 16-channel ACE chips were used, but only 10 channels were connected to PMT outputs, while the other 6 were not connected at all. We have found that if there are jumps in all 6 unconnected channels, all connected channels had the same jump. During processing, the values in unconnected channels were checked, and if pedestals jumped, the values of pedestals of connected channels were corrected with accounting for the magnitude of jumps in the unconnected channels. Fig.1 (bottom, left) shows the situation after the correction of this unstability. This problem appears to be significant at $E_d < 50$ GeV only.

Fig.1 (top, right) shows the second problem. Energy deposits in even and odd layers are different in some events at $E_d > 50$ GeV. This is associated with conflicting information from BGO crystal obtained from middle and high energy ranges of ADC. Basically, the middle range saturates, but in a small number of cases the ADC "rolls over" and gives low channel numbers in the middle range (mimicking small E_d) while the actual signal is in the high energy range. We call such fenomenon "oversaturation". This problem was resolved in the following manner: for each event we found a ratio η of energy deposits, obtained in the high E and middle E ranges, if they both exist. If the value of η exceeded a certain value η_{th} the energy deposit in this crystal was determined by high E range. The value of η_{th} was selected so that the total distribution of E_{odd}/E_{even} was near Gaussian. Fig.1(bottom, right) shows the situation after the correction.

4. Results

Using the corrected energy deposits in the calorimeter, Fig.2 shows preliminary spectra of protons and helium nuclei by rigidity: $R = 1/Z \times \sqrt{((E_d/k)^2 + 2 \times M \times E_d/k)}$, where E_d is total energy, deposited in all crystals of the calorimeter, and $k = \langle E_d/E_{kin} \rangle$. The values of k for different nuclei were found by simulation with GEANT-3.21 codes, using the QGSM event generator for nucleus-nucleus interactions (for $E_{kin} = 100$ GeV, $k = 0.45 \pm 0.01$ for H and $k = 0.36 \pm 0.01$ for He). In fact, there is little energy dependence in the values of k ($k \sim E_{kin}^{-0.02}$). The flux was determined for 312 hours of ATIC-1 data using the instrument geometry factor of 0.23 m^2ster, and taking into account probability of interaction and the efficiency of event selection. A correction for atmospheric attenuation was also included. An inferred live time of 96 % brings the intensities of protons and helium into agreement with the AMS-1 data [2] in the several hundred GV range. (Below E_d of 100 GeV, there is an energy dependent trigger efficiency in ATIC for which no correction has yet been made.) The high energy proton spectrum appears to be consistent with an $R^{-2.75}$ form with a hint of something changing above 10^4 GV. This may be lack of statistics or might indicate a problem with the energy assignments. The latter is under investigation.

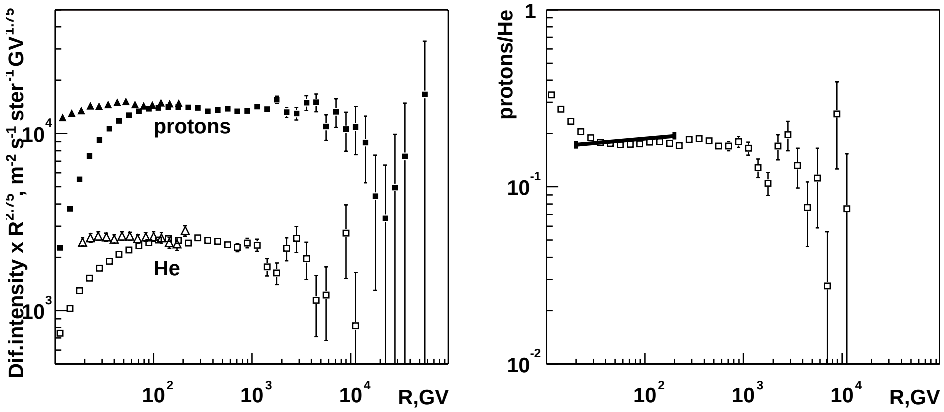

Fig. 2. Rigidity spectra of protons and helium nuclei (flux multiplied by $R^{2.75}$) and their ratio; triangles and solid line: AMS-1; squares: ATIC-1

5. Conclusions

The preliminary rigidity spectra of protons and He-nuclei appear to be very similar. So, the ATIC-1 results, at this stage in the analysis, seem to fall closer to anticipated prediction from SNR acceleration theory. Verifying such a result requires greater statistics at high energy ($> 10^4$ GV). The analysis of ATIC-2 will more than double the number of events at high energy.

6. Acknowledgements

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7. References

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