

Preliminary Results from the First Flight of ATIC

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Abstract. The Advanced Thin Ionization Calorimeter (ATIC) instrument is designed to measure the composition and energy spectra of $Z = 1$ to 28 cosmic rays over the energy range ~ 10 GeV - 100 TeV. The instrument was calibrated in September 1999 at CERN using accelerated electron, proton and pion beams. ATIC was launched as a long duration balloon test flight on 12/28/00 local time from McMurdo, Antarctica. After flying successfully for about 16 days the payload was recovered in excellent condition. Absolute calibration of the detector response was made using cosmic-ray muons. The data analysis algorithm which was developed with Monte Carlo simulations and validated with the CERN beam test will be used for the flight data analysis. Preliminary results of the protons and helium spectra are reported in this paper.

1. Introduction

Various space-based experiments such as ACE have provided excellent composition measurements at low energies. The low energy cosmic rays contain essentially all of the elements in the periodic table, with a composition similar to that measured in the local Galaxy. Due to their high flux, low-energy cosmic rays have become relatively well understood in the ~ 90 years since the discovery of cosmic rays. It is important to extend this level of detailed understanding of composition higher in energy, especially into the energy region where our present understanding of supernova acceleration of charged particles begins to fail. High energy composition measurements are rather difficult due to conflicting requirements: the numbers of cosmic rays at high energies are quite low, so particle detectors need to have large aperture while staying within the weight limit for space flight. We have developed an approach for making high

quality measurements of cosmic rays above the maximum energy reach of existing magnet spectrometers, where very few data sets are available and uncertainties are great. To address whether there are any spectral differences among different elements and/or whether there are any spectral features that may be due to a supernova acceleration limit, simultaneous measurements of protons and heavier nuclei with a single instrument over a wide energy range are needed.

ATIC is based on ionization calorimetry which is the only practical method for measuring protons above 1 TeV. The ATIC instrument (Wefel et al. 2001) consists of a Si matrix for charge measurements, a carbon target to force nuclear interactions, scintillator strip hodoscopes for triggering and to assist in trajectory measurements, and a BGO calorimeter to measure the energy of incoming particles. The ATIC instrument is designed to measure the composition and energy spectra of $Z = 1$ to 28 cosmic rays over the energy range ~ 10 GeV - 100 TeV. This provides enough overlap with the magnet spectrometer energy range to minimize systematic uncertainties due to different measurement techniques, and it reaches the highest energy possible with the longest-available near-space platform, i.e., long duration balloon flights.

2. Antarctic Balloon Flight

ATIC was launched as a long duration balloon test flight on 12/28/00 from McMurdo, Antarctica. The payload made a full circle around the south pole and landed not very far from the launch site on the Antarctic plateau on 1/13/01. During the flight the payload stayed around 36 km altitude. The temperature for various components during the flight stayed reasonably stable within \pm a few degrees C. Operations preceding and during launch, flight, and recovery went very smoothly. After 16 days of successful operations, the flight was terminated, and the payload landed upright in good shape. Except for a few

SIP (balloon Support Instrument Package) solar panels, the payload was pretty much intact. The first Twin Otter flight to the site recovered high priority items, such as the flight data hard disk, BGO calorimeter and electronics bays. The second flight recovered the remainder of the payload on 1/25/01. ATIC collected a total of about 45 GB data for about 3×10^7 events.

3. Calibrations

In September 1999, ATIC was placed in the H2 beamline at CERN, where it collected data from proton, electron and pion beams at energies ranging from 100 GeV to 375 GeV (Ganel et al. 2000). The instrument was triggered externally using CERN-provided scintillator paddles and trigger electronics. These accelerator calibrations were essential for both functional verification of the ATIC detectors and for verification of the simulation model, which must be relied on to extrapolate the accelerator response to the response for much-higher-energy cosmic rays observed during the balloon-flight exposures.

Cosmic-ray muons were also measured before the flight, and special runs of pedestal, charge-pulsar and LED flasher events were collected during the flight for calibration purposes. For cosmic-ray muons the ATIC pre-trigger was utilized (with requirements only on hodoscope hits). Using our ATIC Data Processing System (ADPS), a ROOT-based custom package, the pedestal values for each electronic channel were extracted. Note that ATIC has a total of 6248 channels including 960 channels for the BGO calorimeter, 808 channels for the scintillator hodoscopes, and 4480-channels for the silicon matrix charge detector. After the pedestal subtraction, cosmic-ray muon distributions were plotted and fitted for each BGO crystal, scintillator strip, and Si pixel to provide a calibration for each detector system's low-range readouts. These provided the inter-crystal calibration for most crystals. By comparing with our muon simulations, 1 minimum ionizing particle (MIP) energy deposition was assigned to the ADC counts where the 1 MIP peak is located. In this way, ADC counts were converted to physical units, i.e., MeV. Events with showers as well as LED data were used to extract the inter-range calibrations for the mid-range and high-range readouts. With the pedestal and gain corrections handled, the calibrated data could be analyzed.

4. Event Reconstruction

During the first ~20 hr while the instrument remained within line-of-sight (LOS), a full system check was conducted, the experiment was operated in several test configurations, and all major instrument tuning was completed. With our fully functioning analysis software we were able to monitor the data in nearly real time. Each event was reconstructed event-by-event to confirm the detector performance (Wang et al. 1997). An example of

a high energy event with a reconstructed trajectory in the ATIC detector system is shown in Fig. 1. The top layer represents Si pixel hits, the middle three x-y layer pairs (S1, S2, and S3) represent the scintillator strips with signals, and the bottom four x-y layer pairs represent the BGO crystals with signals. The box size is scaled for the signal size.

The cross-stacked BGO layers give measurements of the x and y cascade axis coordinates. The entrance particle position was calculated by extrapolating a linear fit of the cascade axis coordinates to Si and S1. See Seo et al. (1996) for details. From the energy deposit distribution pattern in BGO as well as in scintillator hodoscopes, the shower axis was reconstructed and projected backward to locate the incident particle as shown with the line. In this example the incident particle obviously entered near the center of the Si matrix, hit the S1 pair near the center, interacted in Carbon, and started a shower in the lower carbon section, i.e., between S2 and S3. Based on the total energy deposit, the incident energy for this particular event is estimated to be about 5 TeV.

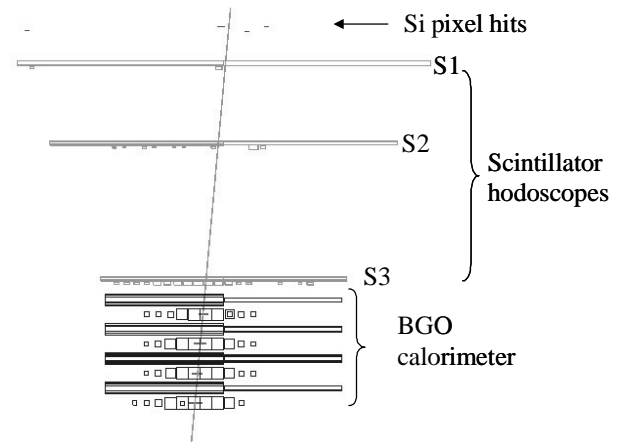


Fig. 1. ATIC detector response to a high energy event (~ 5 TeV incident energy) and the reconstructed incident particle trajectory (nearly vertical line) in the ATIC detector system.

5. Data Analysis and Results

It is characteristic of a calorimeter that backscattered particles can reach the charge detector and confuse the charge measurement. The number of backscattered particles increases with the incident energy, so the probability for protons to mimic helium or higher charge particles increases. This could cause some steepening of the measured spectra of lighter elements relative to heavier ones. In ATIC the incident particle charge is measured with a finely segmented Si matrix (1.5 cm x 2 cm pixels) in order to minimize the backscatter effect. Based on our simulations, the impact of residual errors from backscatter (protons being misidentified as heavies) on the measured

energy spectra should be small enough not to steepen the spectral index by more than 0.01.

All Si pixels within the circle of confusion of the reconstructed track were examined, and the one containing the largest signal was assumed to contain the incident particle's trajectory. Currently, for simulated 100 GeV protons, an 8.4 cm radius circle of confusion centered at the reconstructed trajectory is used as the search area for all energies. Since the trajectory resolution is better at higher energies, due to the greater shower collimation, we should be able to use smaller circles of confusion for higher energies. The top scintillators also provide supplementary charge measurements. Even with our preliminary calibrations, charges measured with S1 and Si show a good correlation. The raw charges measured with the Si detector are shown in Fig. 2. These measurements show clear separation of p and He. Note that these plots use very preliminary calibrations, and no data quality cuts or corrections have been made. The resolution will be improved as our analysis progresses.

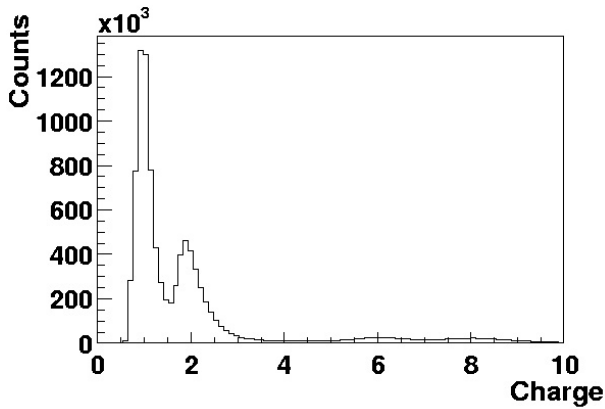


Fig. 2. Uncorrected charge measurements with Si matrix.

We also checked the calorimeter response. Figure 3 shows the mean energy deposit in each layer as a function of the calorimeter depth. The longitudinal shower profiles for simulated protons with incident energy about 100 GeV, 1 TeV, and 10 TeV are compared with the flight data corresponding to similar incident energies. Our preliminary data show reasonably good agreement with the simulations. Both data and simulations show that the shower starts at the top layer, reaches its maximum in the middle layers, and then dies down. The higher the energy, the deeper the shower maximum is located in the calorimeter. Even the highest energy shower maxima are well contained.

Our analysis is still in progress, but the preliminary “all-particle” spectrum, shown with the proton and helium spectra in Fig. 4, exhibits a nice power law over a wide energy range, from several 10^2 's of GeV to about 100 TeV. The roll off below 10 GeV is due to the trigger. Note that the horizontal axis in Fig. 4 is not the incident energy but

the energy deposit in the calorimeter. Based on simulations, the mean energy deposit is estimated to be about 35% of the incident energy. The preliminary proton and helium spectra also show a power law. These spectra need to be deconvolved by taking into account the energy resolution and response of the calorimeter. Corrections for the path length, background contamination, trigger efficiency, particle detection efficiency, interactions in the residual atmosphere etc. will also be taken into account to obtain the final spectra.

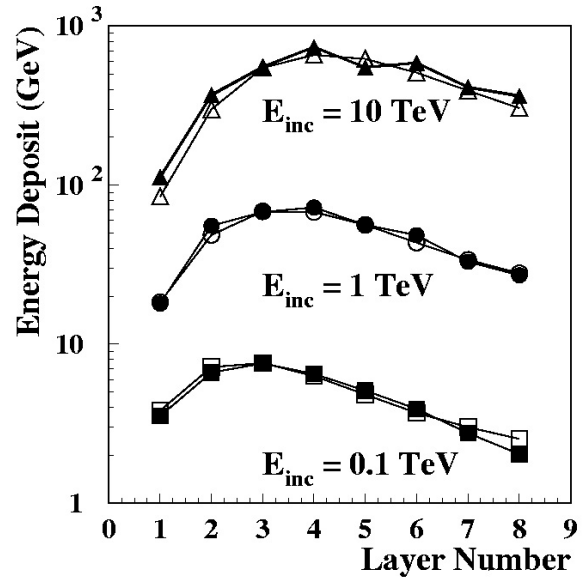


Fig. 3. Longitudinal shower profile of 0.1, 1, and 10 TeV protons: Monte Carlo simulations, open symbols; flight data, filled symbols.

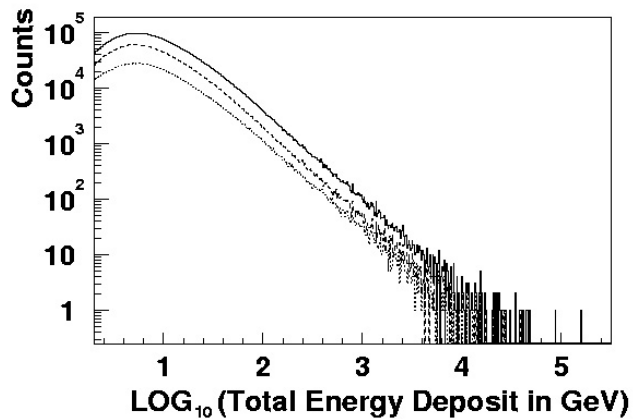


Fig. 4. Particle counts as a function of energy: All particles (solid curve), proton candidates (dashed curve), and helium candidates (dotted curve). No unfolding procedures have been applied.

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