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COSMIC RAY SHOWER SIMULATION AND RECONSTRUCTION FOR THE ATIC EXPERIMENT

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ABSTRACT

The Advanced Thin Ionization Calorimeter (ATIC) experiment is designed to study cosmic ray composition and energy spectra at energies up to $10^{14} eV$. In the absence of ultra-high energy beam tests, Monte Carlo simulations are critical in the ATIC design and data analysis. The charge measurement and background suppression are strongly dependent on cosmic ray shower reconstruction. This paper presents results from simulations of isotropically incident particles and explores the algorithm of shower reconstruction.

INTRODUCTION

High energy particles play an important role in both the galactic and extragalactic energy source. Current data reveal the tendency for different energy spectral shapes between cosmic ray protons and heavier nuclei at energies above 1 $TeV/nucleon$, which may indicate the existence of two different mechanisms in the source/acceleration of cosmic rays (Swordy, 1993). High precision direct observations over a wide range with a single instrument is critical for verifying this fundamental characteristic. The ATIC experiment is designed to study cosmic rays spectra at energy from $10^{10} eV$ up to $10^{14} eV$. Its advanced design employs a fully active BGO calorimeter to measure the energy of cosmic ray showers and a silicon matrix detector for high resolution charge measurements. The balloon-borne experiment will take advantage of NASA's long duration balloon flight capability to measure proton and heavier nuclei spectra with statistical accuracy better than 30% at the highest energy.

For a detailed description of the ATIC instrument and its expected performance, refer to Guzik et al. (1996) and Seo et al. (1996). In this paper, we discuss the simulation and shower reconstruction for isotropically incident particles.

MONTE-CARLO SIMULATION

ATIC Configuration

The ATIC instrument contains three main parts: charge module, carbon target and BGO calorimeter (Figure 1). A typical event passes first through the charge module, then interacts in the carbon target, and finally develops a shower in the BGO calorimeter. The simulation model based on GEANT 3.21 and FLUKA has been extensively studied (Seo et al. 1996).

Isotropic Simulation

An isotropic event generator was developed for the ATIC geometry with particles incident from the upper hemisphere. Following the incident trajectories, all events can be categorized into three groups: (1) Good events — the trajectories pass through the charge module and 10 BGO layers; (2) Analyzable events — the trajectories pass through the charge module and 6~9 BGO layers; (3) Background — all other events, including those whose trajectories do not pass through the charge module and those whose trajectories pass through less than 6 BGO layers. Figure 2(a) shows the relative fraction of events in the three categories. We have explored algorithm for shower reconstruction with the objective of being able to remove most of the background and save most of the good events. In this study, we simulated 50,000 incident protons with energy of 100 *GeV*, 1 *TeV* and 10 *TeV*, respectively.

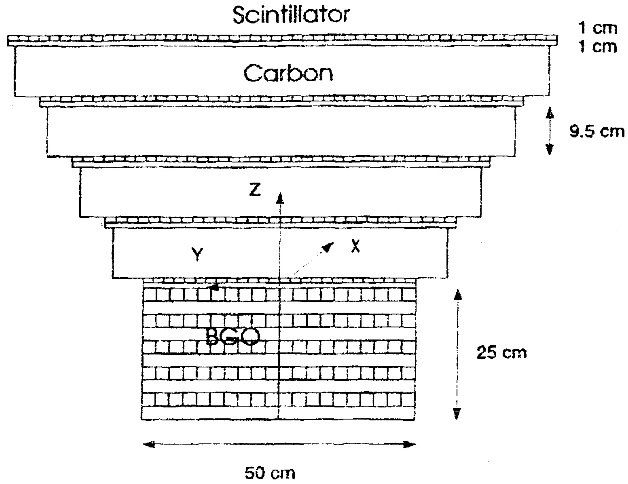

Fig. 1: Schematic diagram of the ATIC configuration used in the cascade simulation

ANALYSIS

Trigger

Using the simulated data, we applied a two-level trigger requirement: in geometry (INGEO) trigger and master trigger. The INGEO trigger requires at least 1 *MeV* energy deposit in each layer of the top and bottom scintillator pairs: SCN1x, SCN1y, SCN5x and SCN5y. In the master trigger, a total of at least 4 *GeV* energy is required to be deposited in the BGO calorimeter. Figure 2(b) shows the fraction of events passing these trigger requirements. Due to the backscattering of secondaries, a large fraction of the background events trigger the system. To remove these background events, we have to reconstruct the incident particle trajectory.

Algorithm of Shower-axis Reconstruction

In order to obtain information about the shower profile, the BGO calorimeter is segmented into 10 layers of BGO strips, which are alternatively arranged in the X, Y directions. Based on the distribution of energy deposited in the BGO strips, an algorithm to determine the incident trajectory was developed (Seo et al. 1996). The center of mass concept was used to determine the X, Y coordinates of the shower core in each BGO layer, and a linear χ^2 fitting of these X, Y coordinates was used to reconstruct the shower axis.

In order to reduce fluctuations, two requirements were applied: (1) each BGO layer used in the fitting is required to have an energy deposit greater than 3% of the total energy deposit in the entire BGO calorimeter; (2) an event is accepted if it has at least 3 BGO layers that satisfied the above condition in both X, Y directions; otherwise, it is rejected. In Figure 2(c), we show the distribution of reconstructed events. The background for 10 *TeV* events is about two thirds of the total reconstructed events: even after charge requirement in SCN1 (see below), the background is still 40%.

These surviving background events are mainly side-exit events. To reject them, an edge

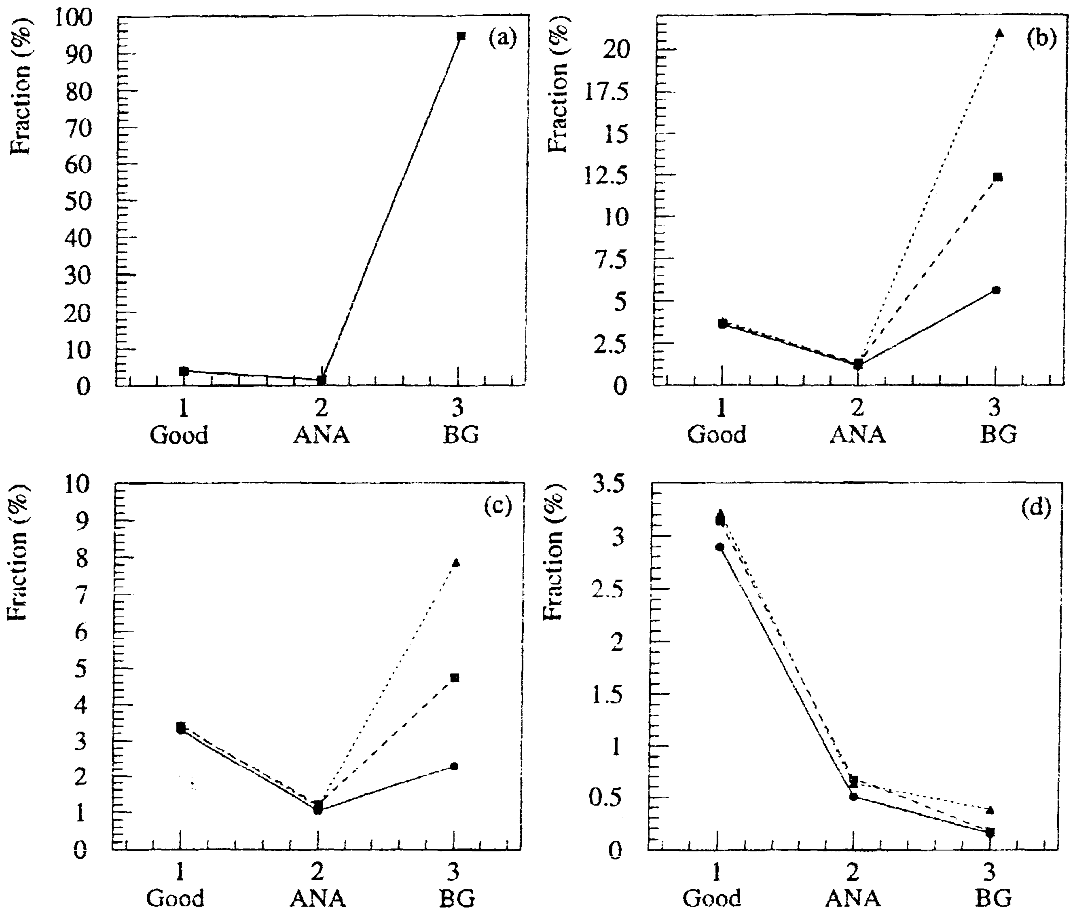

Fig. 2: Fraction of events in three categories. (a) Incident Events; (b) triggered events; (c) reconstructed events; (d) surviving events. Circles, incident energy 100 GeV; squares, 1 TeV; triangles, 10 TeV. The unit of Y-axis is the percentage to total incident events

cut is applied, i.e., for each BGO layer, if the strip with maximum energy deposit is at the edge of the calorimeter, this layer will not be included in the linear fitting. This cut works effectively in removing the side-exit events.

Charge Requirement in SCN1

After the shower reconstruction, we project the shower axis backward to the charge module and look for events within a 3σ confusion circle. If no particle is found, the event is said not to satisfy the charge requirement and is rejected.

Table 1: Fraction of Surviving Events

Energy (GeV)	Good Events	Analyzable Events	Background events
100	82%	14%	4.3%
1000	79%	17%	4.3%
10000	76%	15%	9.0%

RESULTS

Surviving Events and the Composition

The composition of the final, surviving events are shown in Figure 2(d) and Table 1. More than 91% of the surviving events are either good events or analyzable events in the energy range up to 10 *TeV*. Compared with Figure 2(a), one can see more than 99.6% of the background events are rejected, while most of good events, about 80%, are saved (See Figure 3). The removed 20% of good events are mostly those either with no interaction in the instrument, or the first interaction position is deep in the BGO layers, where there is not enough material for shower development.

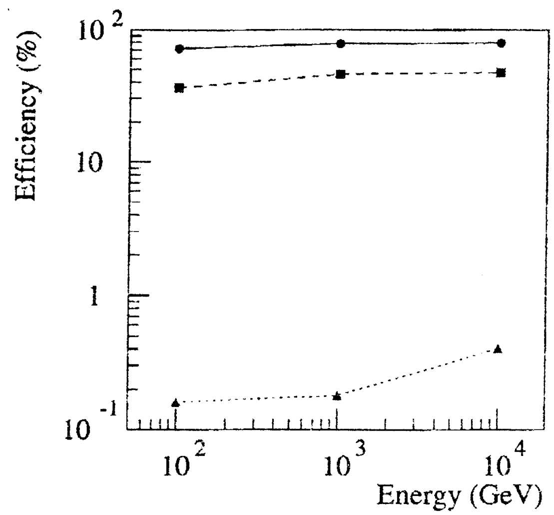

Fig. 3: Measurement efficiency of protons in ATIC. Circles, good events; squares, analyzable events; triangles, background events.

Measurement Efficiency

Figure 3 shows the measurement efficiencies for good events, analyzable events and background events. These results indicate that, the ATIC instrument can achieve a very good measurement efficiency with high background rejection.

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