A Simulation of the Silicon Charge Detector on ISS

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Abstract:: In 2007, ACCESS (Advanced Cosmic ray Composition Experiment for the Space Station) on the International Space Station (ISS) detectors will measure the individual elemental composition of cosmic rays at energies a thousand times higher than any previous measurement of similar resolution - reaching to 10^{15} eV for understanding of the origin, source and acceleration mechanism of cosmic rays. We can determine the charge of cosmic rays using the silicon detector, one of the detectors in ACCESS.

We simulate the reaction of very high energy heavy ions in silicon detector by Geant4 simulation tool. The simulation is carried out for one layer Si-detector and full ACCESS structure. The heavy ions (Z up to 28) with high energies from 10 GeV to 10 TeV penetrate one silicon layer with various thickness and the ions from 1 to 100 TeV penetrate the full detector.

The results show that energy loss is linearly proportional to Z^2 and thickness. In full ACCESS simulation we can distinguish the backscattered particles originated in calorimeter from primaries. In order to determine the contamination of the backscattered particles in the primaries in each pixel, the average distance distribution of the primary particles and the backscattered particles are calculated. Results show that the secondary particles do not affect so much for the identification of each element.

1. Introduction

The Advanced Cosmic-ray Composition Experiment for the Space Station is an instrument designed to measure the energy spectra of individual elements in the cosmic rays at energies up to about 10^{15} eV. The observed overall energy spectrum of cosmic rays is shown in Figure 1, covering the range from around 10^9 eV (1 GeV) up to at least 10^{20}eV[Take98, Grei66]. This overall energy spectrum is remarkably featureless, but a unified scheme for the origin for all these particles remains elusive. The physical characteristics (magnetic field and size) required to obtain the highest energy particles in the acceleration region are not yet certain in known astrophysical objects [Long94].

Above about 10^{14}eV, the measurements are almost useless for determination of the origin of cosmic rays because they lack the key ingredient which is analogous to spectroscopy in optical radiation: the ability to reliably determine the properties of each arriving nucleus[Acce00]. The most popular paradigm of cosmic ray origin is that of diffusive shock acceleration in supernovae remnants (SNR) [Long94]. The most convincing argument for identifying supernova explosions as the source of the bulk of the cosmic rays arises from the staggering power required.

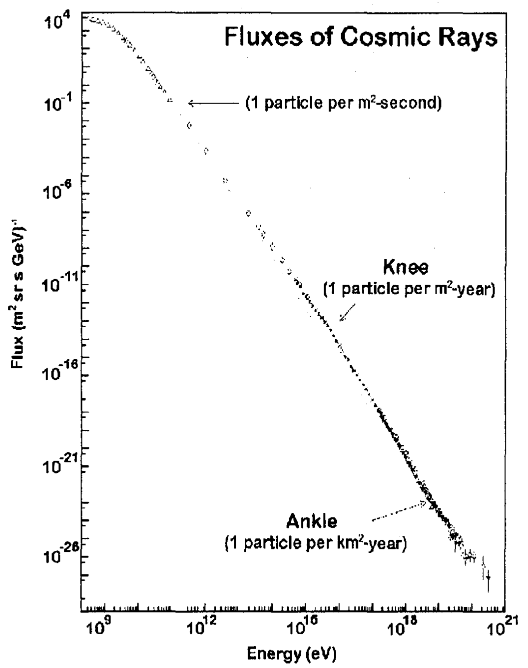

Fig. 1. Flux of Cosmic Ray vs. Total Energy[Acce00]

This investigation has four purposes[Swod90]. First is to probe the limits of supernova (SN) acceleration, reaching energies where SN models predict changes in the elemental composition of cosmic rays. Second is to test models of cosmic-ray confinement and propagation in the galaxy, thereby permitting extrapolation from observed energy spectra to the energy spectra produced at the cosmic-ray source and thus testing SN models that predict the source spectra. Third is to examine cosmic-ray composition at energies where there are fewer secondary cosmic rays produced by fragmentation of primaries, and so derive a clearer picture of the abundances of rare elements at the comic-ray source. At last, the forth is to observe the energy spectrum of cosmic-ray at energies where theories have predicted that we will observe structure in the spectrum due to contributions from individual discrete sources. The ACCESS scientific objectives require an experiment with large collecting area and the ability to measure the charge and energy of individual nuclei over a wide range of atomic number and of energy, as well as the ability to distinguish electrons from protons.

2. Detectors in ACCESS

ACCESS is composed of three detectors[Acce00]. They are TRD(Transition radiation Detector, SCD(Silicon Charge Detector), and Imaging Calorimeter. TRD Detects the X-ray occurred when the particle traverses the boundary between two different materials. It is composed with multiple radiator/detector combinations. It can determine energy of heavy elements. Imaging calorimeter determines the energy of elements. It is composed of high-density materials such as carbon, tungsten, scintillator and silicon. The SCD distinguishes the elements.

When the charged particles penetrate the Si detector, the particles lose their energy in Si. This is described by the Bethe-Bloch formula[Long94]:

$$\frac{dE}{dx} = 4\pi\, e^4 \frac{z^2}{m_{e0}\, v^2} NZ \left[\ln\frac{2\, m_{e0}\, v^2}{I} - \ln\left(1-\frac{v^2}{c^2}\right) - \frac{v^2}{c^2}\right]$$

v : velocity of the primary particle, ze: charge of primary particle, m_{e0}: electron rest mass, N: density number of absorber, Z: atomic number of absorber, I: ionization potential of absorber

This equation shows that the ionization loss energy is proportional to Z^2. which allows us to identify the particles in SCD.

3. Simulation

Si detector has carbon absorbers. When particles pass through the ACCESS, the carbon absorbers make the backscattered particles. The backscattered particles make the information of original particles.

SCD in ACCESS is pixel type. The simulation was done for determine pixel size of SCD with Geant4. The Geant4 is simulation tool for particle detector. Two simulations were done. One is one layer structure of Si detector and another is whole structure of ACCESS. In one layer structure simulation, the incident particles are heavy ions with Z=1 to Z=28. Incident particle number is 10,000 events, incident energy is 10 GeV to 10 TeV. The thickness is varied over 100 □, 300 □, 380 □, and 600 □. In whole detector structure, we select backscattered particles. The incident particles are proton, helium, carbon, and iron. Its energies are 1, 10, and 100 TeV. The thickness of two layer is 380 □.

4. Result and conclusion

The results of one layer structure of SCD are given in Fig. 2, Fig. 3, and Fig. 4. Fig. 2 shows the energy loss distribution of various Z numbers of 1 to 28. We can distinguish the element one by one. Fig. 3 shows the energy loss vs. Z number for three different thicknesses, 100, 300, 600 □. This result shows us the ionization loss energy is proportional to the thickness. Fig. 4 shows the energy loss with respect to the incident energy up to 10 TeV. The energy loss is independent of the incident energy for the range investigated. Even if the very high-energy cosmic rays pass through the ACCESS, we may be able to identify the particles.

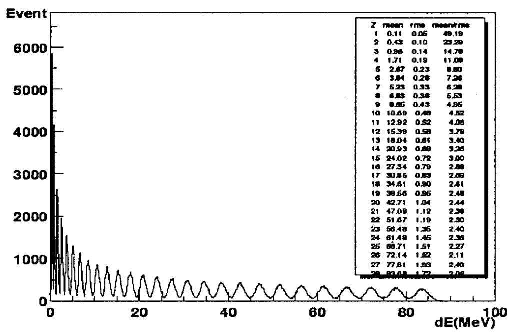

Fig. 2. Energy Loss Distribution of Z

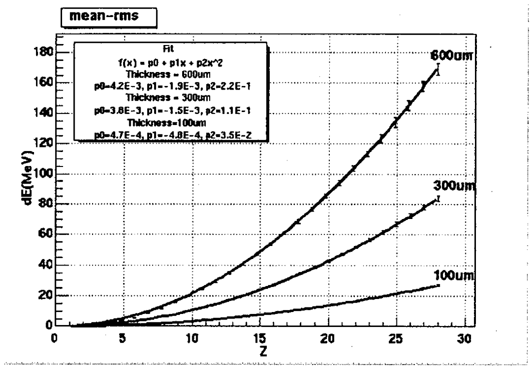

Fig. 3. Energy Loss vs. Z Number for Three Thickness

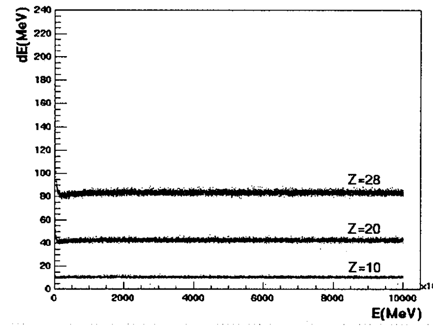

Fig. 4. Energy Loss with Respect to the Incident Energy

The results of whole structure of ACCESS are given in Fig. 5 and Fig. 6. In this analysis, we select events that first interaction arises in only carbon-absorber below silicon detector. For the analysis of contaminated fraction between proton and helium, we choose the cut value which does not contain helium event.

Fig. 5 shows the misidentified fraction of proton in helium windows vs. each diameter up to 200 mm for 1 TeV, 10 TeV, and 100 TeV. Fig. 6 shows the data of smaller diameters. From the result of deposited total energy in each pixel, we conclude that the pixel size of 1cm or 2cm is adequate for the identification of the elements.

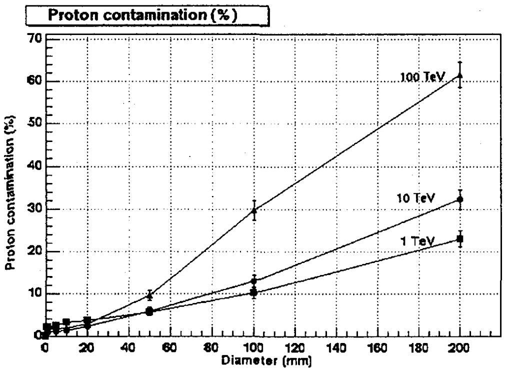

Fig. 5. Proton Contamination in He Window

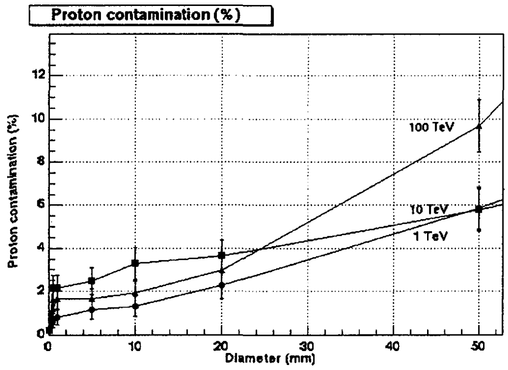

Fig. 6. Proton Contamination in He Window; Diameter less than 5cm

Acknowledgement

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