



The chemical composition of primary cosmic rays in the energy range $\sim 10^{15}$ eV from muon energy spectrum with the Okayama muon telescope

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Abstract: The energy spectrum of muons associated with extensive air shower (EAS) is studied by the synchronized observations with the EAS array and the solid iron spectrometer for muons, in the primary energy range of about 50 TeV - 5 PeV. We have determined muons momentum in EAS for 344 events. As the result, the median energy of spectrum lies on about 10 GeV and its FWHM is 2 to 70 GeV. And the obtained muon spectrum is compared with the simulated results. As follows from Aires air shower simulation with SIBYLL/HAS for hadronic interaction models assuming proton dominant model for primary cosmic ray compositions and iron dominant one, the muon energy spectrum below 20 GeV is well explained in case of the proton dominant composition. Above 20 GeV, the obtained spectrum indicates no significant difference between primary compositions.

Introduction

Studying the properties of EAS particles such as the EAS size, the lateral distribution, the compositions of electrons and muons, and the energy spectrum can provide the information on the hadronic interaction model, the primary energy and the mass composition number of a primary cosmic ray. Therefore, measuring the muon energy spectrum in EAS was one of the tools to explore cosmic ray composition.

In order to determine the chemical composition of primaries, we focus on analyzing the coincidence event of EAS and muons in the solid iron spectrometer.

Apparatuses

The EAS array is placed on the roof of the building in Okayama University [3, 7]. It consists of 8 scintillation counters. Each counter is equipped with a scintillator disk, of which size and thickness are

50 cm \times 50 cm \times 5 cm, and a fast photomultiplier. The scintillation counters are set within about 30 m \times 20 m in area (figure 1).

The Okayama muon telescope is installed in the building of the floor just below the EAS array (figure 1). The telescope is a momentum spectrometer and a momentum of incident particle is calculated by the trajectory registered in this detector [6]. It can determine a muon momentum ranging from 0.9 to 150 GeV/c and has 1 mrad angular resolution. The acceptance is 24.4 cm²sr. The detail of the arrangement and properties of the detector are shown in reference [8].

For coincidence observation of muons and EAS, the EAS array provides the telescope with the arrival information of EAS particles by on-line. If there is an event in EAS array within 1 μ sec from the event observed in the telescope, the event is registered as EAS events by the telescope.

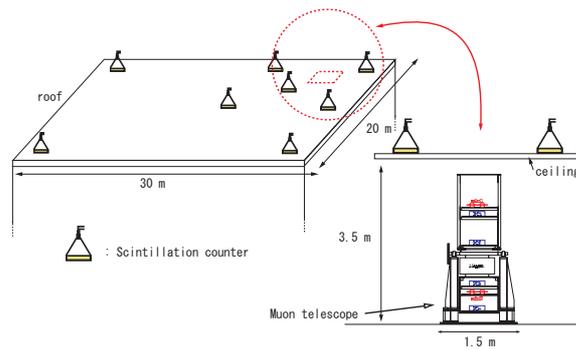


Figure 1: Arrangement of the EAS array and the muon telescope (quarter view).

Data analysis

We used the data from 1/February/2004 to 11/January/2007, the total observational time is 968 days and 7.8×10^5 events are obtained.

To determine each muon momentum, observed events are selected with the following criteria. Figure 2-(a) shows the cross sectional view of X-Z plane of the telescope. Figure 2-(b) shows also the projection of X-Z plane and Y-Z plane of the telescope for an event we determined a muon momentum.

The criteria of events selection are what an incident particle penetrates a magnet, all drift chambers register information and a trajectory is calculated from the relation between trajectories in the chamber above and below the magnet. Even if there are more than two trajectories satisfied above criteria at the same time, there are rejected in this analysis, because such an event cannot be reconstructed the trajectory and determined the momentum.

We have determined each muon momentum for 344 single trajectory events.

Simulation

For EAS simulation, AIRES [4] program is used with SIBYLL2.1 and the Hillas Splitting Algorithm. The dependence on the hadronic interaction model for the muon spectrum in EAS have been reported to be weak in reference [2].

The energy of primary particles is sampled from

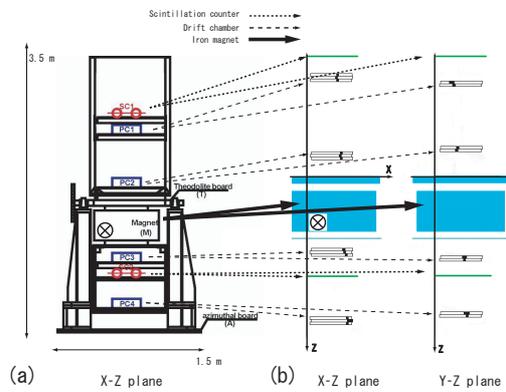


Figure 2: (a): The section of X-Z plane of the telescope. (b): Imaging of a typical event in the projection of X-Z and Y-Z plane of the telescope. Block points in drift chambers indicate registered events.

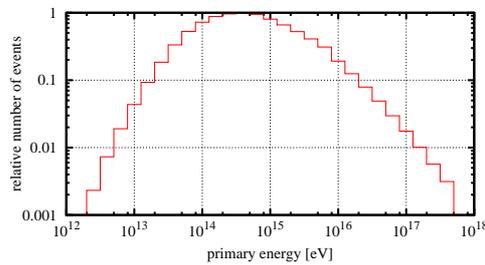


Figure 3: Relative primary energy distribution.

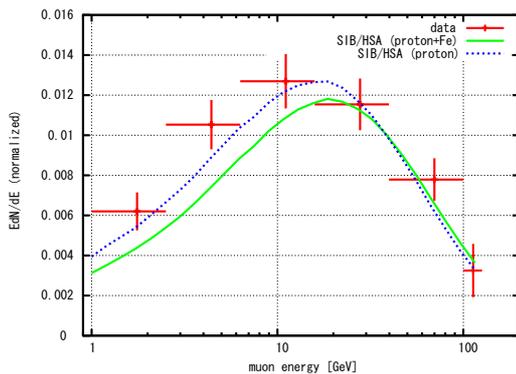


Figure 4: The comparison between the muon energy spectrum obtained by the experiment and simulations. The cross indicates experimental data. (a): Solid line indicates simulation result (proton+Fe). (b): Dash line indicates simulation result (proton).

figure 3 and the effective primary energy range is from about 10^{13} to 10^{16} eV [5]. The sensitive area in which EAS particles can be detected, is about 1200 m^2 from core position.

The zenith angle of primaries is not necessary to be considered because the telescope narrows the acceptance and limits the zenith angle within about 10 degree. The proportion of thinning energy to primary energy is set on 10^{-5} . We assume two cases for the primary composition. One of the case is proton only and another case is the ratio of proton and Fe is about 5:1 [1].

Results and conclusions

In figure 4, the cross shows the experimental data and the error bar shows statistic error. Those distributions are normalized by are which is calculated by integrating each distribution.

For the experiment data, the mean and the median energy of spectrum lie on about 27 GeV and 10 GeV, and its FWHM is 2 to 80 GeV. Figure 4-(a) shows the simulation results using proton and Fe for primaries. In figure 4-(a), the mean and the median lie on about 38 GeV and 10 GeV, and its FWHM is 2 to 78 GeV. Figure 4-(b) represents the simulation results using proton primary. In figure 4-(b), the mean and the median lie on about 38 GeV and 10 GeV, and its FWHM is 2 to 68 GeV.

For FWHM, the mixed primary is better agreement with the experimental data than the proton primary. The muon energy spectrum below 20 GeV tend to be consistent with the case of the proton dominant composition. Above 20 GeV, the obtained spectrum indicates no significant difference between primary composition.

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