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Momentum Spectrum of Muons Associated with Cosmic-Ray Air Shower at Sea Level

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The compact extensive air shower (EAS) array and the solid iron magnet spectrometer have been used to measure momentum spectrum of muons associated with air showers. The EAS array which is a part of Large Area Air Shower experiment is also operated, and telescope is located almost right under of this array. From January 2004, we started observation between the EAS array and the Okayama telescope. By means of analyzing those data, we attempt to obtain momentum spectrum of muons associated with EAS.

1. Introduction

The atmospheric muons are produced by decay of charged mesons. These muons give us the informations of the atmospheric neutrino flux, the ratio of decaying mesons, i.e. K/π ratio and the primary composition. Muons are also generated by charged mesons in EAS.

The investigation of the muon component in EAS is to study the charged mesons and primary particles generated EAS. The momentum spectrum of the EAS muon was measured by several experiments at sea level and underground. By using both the EAS array and the magnet spectrometer, Bennett and Greisen studied the EAS muon spectra for some core distances, and sought the following equation in the reference [1]:

$$\rho_\mu(N, r, \geq E) = \rho_\mu(N, r) \left[\left(\frac{3}{E+2} \right)^{a(r)} \left(\frac{51}{E+50} \right) \right], \tag{1}$$

with $a(r) = 0.14 r^{0.37}$.
Grishinia et al. also measured the EAS muon spectrum in the similar way.[2]

In Okayama University, both a compact EAS array (the OU array) and a magnet spectrometer (the Okayama telescope) are located. From January 2004, the Okayama telescope was synchronized with the OU array and observing muons associated with EAS was starting. In this paper, we present the results of the momentum spectrum and the positive excess of muons obtained by coincidence observation between the EAS array and the magnet spectrometer.

2. Apparatus

The Okayama telescope was synchronized with the OU array. The OU array is a part of Large Area Air Shower (LAAS) group arrays [5, 6]. The OU array is equipped with 8 detectors, each consist of a plastic scintillator (50 cm×50 cm×5 cm) and a fast PMT. The Okayama telescope [3, 4] is located almost right under of the OU array as sown in figure 1.

The telescope consists of trigger counters (2 scintillation counters), position chambers (3 multi-wire proportional chamber sets used as drift chambers), an iron core magnet (thickness: 32 cm), a theodolite and azimuthal boards. The main characteristics are summarized in the references [3], and detailed arrangement of the detectors are shown in the reference [4]. If an EAS event come in both detectors within $\pm 1\mu$ sec, EAS signal is recorded by the telescope.

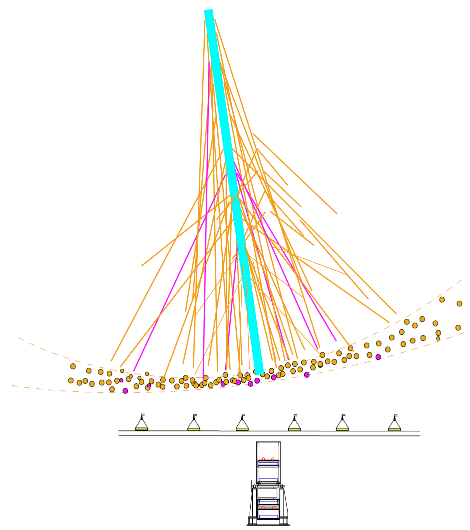

Figure 1. The arrangement of detectors, the OU array and the Okayama telescope. An EAS event come in both detectors within $\pm 1\mu$ sec, EAS signal is recorded by the telescope.

3. Results

3.1 Coincidence events

The coincidence events have been accumulated between the Okayama telescope and the OU array from January 2004. These events are hereafter determined 'coincidence events'. In coincidence events, the events reconstructed single track in the Okayama telescope (see in the reference [4] , figure 4-(c)) are hereafter determined 'single muon events'. Analyzed data are used from 18th January 2004 to 30th April 2005. Total observation time is 380.2 days. The total number of coincidence events and single muon events are 299306 and 195 respectively.

Figure 2 shows the distribution of the number of trigger counters in the OU array. The dashed histogram corresponds to all EAS events and the solid histogram corresponds to coincidence events.

It is clear that 2 trigger counters are dominant among all EAS events, since the trigger signal occurs in case of 2 counter hits or more. On the other hand, the rate of the 8 trigger counters is the most frequent among coincidence events. The primary energies of coincidence events are estimated to be higher than those of EAS events without coincidence events.

3.2 EAS muon momentum spectrum

Figure 3 shows the integral momentum spectra of the muons. The solid circles corresponds to the muon flux associated with EAS analyzing single muon events. The open circles corresponds to the atmospheric muon flux. The dashed curve indicate the calculated flux using Greisen's equation (1). In the calculation, equation (1) is convolved with the core distance distribution (Figure.3) and the Okayama telescope's response function in which effects of multiple coulomb scattering and the telescope's angular resolution are taken account of [7]. The three spectra are normalized at 10 GeV/c to be compared with each other. The result spectrum associated

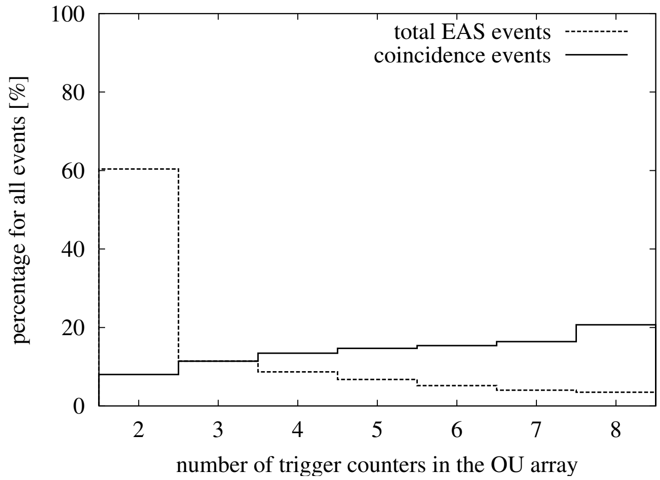

Figure 2. The distributions of the number of trigger counters in the OU array. The dashed histogram: for all EAS events in the OU array. The solid histogram: for coincidence events between the OU array and the Okayama telescope.

with EAS show the good agreement with the calculation flux (1) and the spectrum shows harder than the atmospheric muon's. The integral momentum spectrum of muons associated with EAS is different from the atmospheric muon one.

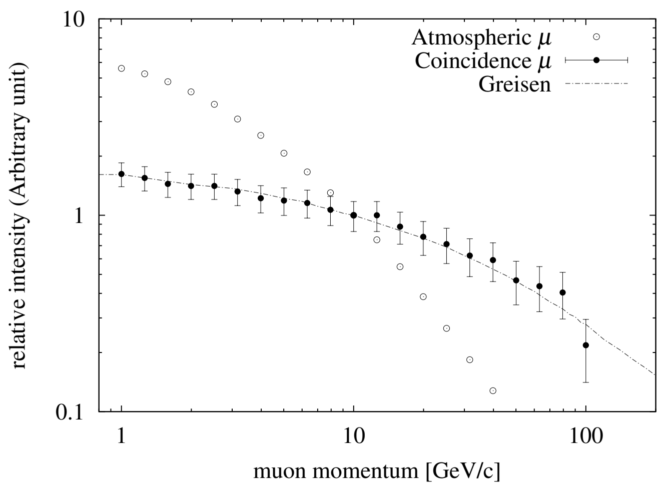

Figure 3. EAS muon momentum spectrum. The solid circles: the muon flux associated with EAS. The open circles: the atmospheric muon flux. The dashed curve indicate the calculated flux using Greisen's equation (1).

3.3 EAS muon positive excess

The Okayama telescope can measure the charge sign from the curvature of incident single muons. Using the positive muon flux f^+ and the negative muon flux f^-, the positive excess η is defined as a following equation.

$$\eta = (f^+ - f^-)/(f^+ + f^-) \tag{2}$$

Here the error bar δ shows

$$\delta = 2\sqrt{(f^- \cdot \delta^+)^2 + (f^+ \cdot \delta^-)^2}/(f^+ + f^-)^2$$

where δ^+ shows positive muon flux error and δ^- shows negative muon flux error.

The positive excess of the atmospheric muons with the momentum more than 1 GeV/c is 0.0909 ± 0.0007. On the other hand, the positive excess analyzing coincidence events is -0.005 ± 0.170 in spite of large error bars. The result is not conflict with Greisen's result [1], since the multiplicity of EAS generating muons is larger than that of the atmospheric muons.

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