COMMENTS ON THE MEASUREMENTS OF MULTIPLE MUON PHENOMENA

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Abstract

According to the Kiel group (1), the extensive air showers in the energy around 10^{15} eV include those initiated by astrophysical primary gamma-rays. In such observations, we need to have a precise measurement on the directions of primary particles. It is one of the methods to measure the directions of high-energy muons in air showers. We have investigated the accuracy in measuring the direction, by caluculating the cosmic-ray phenomena in the atomosphere at very high energy. The results caluculated by Monte Calro method suggest that one may determine the direction of primary cosmic-rays within errors of 10^{-3} rad in observing muons of above 100 GeV at sea level.

1. Introduction

On the observation of high-energy gamma-ray ($\sim 10^{15}$ eV) from point source such as Cyg-X3, it is very important to have a precise measurement on the direction of primary particles. When we observe the extensive air showers by using scintillation counters, the arrival direction of showers may be determined by measuring differences on the arrival time of incident particles into scintillation counters. However, the shower front having thickness of a few meters, it is difficult to make the errors in the detection of arrival direction less than 10^{-2} rad for the zenith angle.

On the other hand, high-energy muons in air showers are produced at the first stage of development of air showers, and the deviation of these direction from one of primary particles depend on the transverse momentum (∿ 400 MeV/c) of hadrons, which are parent of the muons in the first interaction. So, it is expected that these high-energy muons (above 100 GeV) may have much the same direction as primary particles have.

In this paper, the accuracy of the primary direction obtained by measuring the direction of muons at sea level have been investigated by Monte Calro method.

2. Method of simulation

Here the protons have been used as primary particles and energy region of primary particles are 10 ∿ 30 TeV. We have used the energy spectrum of primary cosmic-rays by Grigorov et al. , which have been measured as total particle spectrum (2). Our simulation have been made using the scaling model standing for the Feynman scaling in hadronic interaction (3). The interaction cross section of a hadron is assumed to increase as increasing of energy (4). The multiplicity distribution is assumed to obey the Koba-Nielsen-Olsen scaling low (5) (6). The transverse momentum of each secondary particle, p_t is sampled using the distribution of linear exponential form and the average value $\langle p_t \rangle$ set to 440 MeV/c. The effect of energy losses and of geomagnetic field have been taken into account.

3. Results of simulation and Discussion

The present simulation has been carried out on the high-energy muons initiated by primary cosmic-rays with vertical direction. The energy, the zenith angle, the position and the other properties of muons for each shower at sea level have been simulated (7). Fig. 1 shows the distribution of difference between the average arrival direction of muons and the direction of primary particle, Δθ. In Fig. 1, a solid line , a dashed line and a dotted line shows the distribution taking 100 GeV, 200 GeV and 500 GeV as threshold energy of muons, respectively. The deviation of these

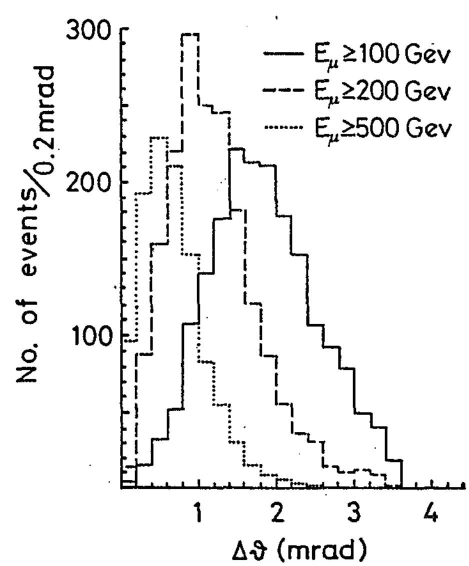

Fig.1 Δθ-distribution.

distribution gives a accuracy of the measurement on the arrival direction, and the deviation for each threshold energy is decreasing as increasing of energy. Namely higher energy muons is detected, more precise observation on the arrival direction of primary particles is obtained, though number of muons detected is a few in higher threshold energy. In Fig. 2 the number of muons detected per shower for each threshold energy is shown. Though Kiel group had reported that the air shower started from gamma-ray primary is muon-rich, generally, such showers have a few muons. This method which use a few muons is very useful to determine the arrival direction of the showers started from gamma-rays.

For example, the extensive air showers around 10^{15} eV have ∿ 0.5 muons/m^2, which had energy above 100 GeV, in the core. Therefore, using the muon detector with the area of 100 m^2, we could observe ∿ 50 muons. Though the number of muons in the air shower started from gamma-rays are 1/20 of one in air shower started from proton, we can observe at least a few muons. Therefore, the arrival direction of the extensive air showers may be determined better than 2.0 mrad.

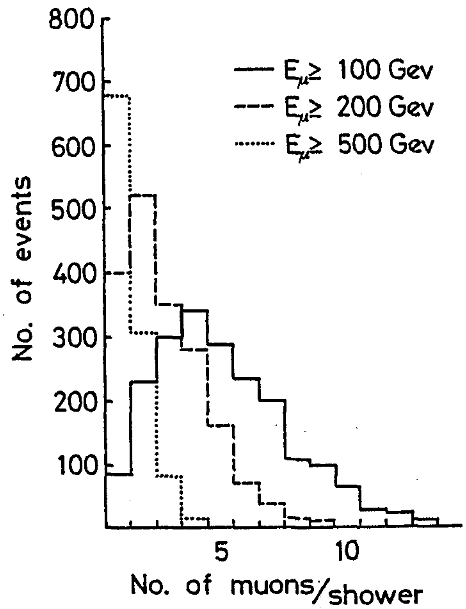

Fig.2 Number spectrum of muons.

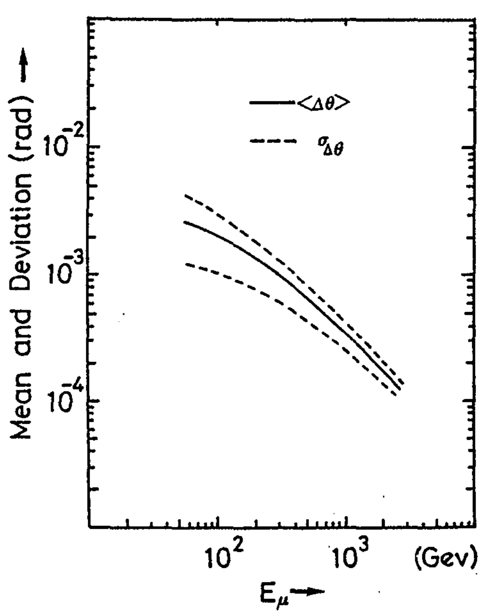

Fig.3 $\langle\Delta\theta\rangle$ and $\sigma_{\Delta\theta}$ against threshold energies of muons.

4. Conclusion

The accuarcy in determining the arrival direction of extensive air showers by high-energy muons have been estimated by Monte Carlo simulation.

Fig. 3 shows the result of the simulation, where a solid line shows the means of difference between the direction determined by high-energy muons and the arrival direction of air showers against threshold energies of muons and a dashed line shows the dispersion of the differences. This simulation has not included the multiple Coulomb scatterring of charged particles in passing through the matter, which depend on total amount of matter above a muon detector. But the result in this paper may be help to attempt the experiments.

References

(1) Samorski, M. et al. , 18th ICRC, Bangalore, 1, 135, (1983).
(2) Grigorov, N. L. et al. , 12th ICRC, Hobart, 1971, 5, 1746, (1971).
(3) Feynman, R. P. , Phys. Rev. Lett. 23, 1451 (1969).
(4) Giacomelli, G. et al. , Phys. Rep. , 55, 1 (1980).
(5) Koba, Z. et al. , Nucl. Phys. , B40, 317 (1972).
(6) Slattery, P. , Phys. Rev. Lett. , 29, 1624 (1972).
(7) Mizutani, K. et al. , this Conference Paper, OG 5.2-9.

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