CORRELATION OF HIGH ENERGY MUONS WITH

PRIMARY COMPOSITION IN EXTENSIVE AIR SHOWER

C.Cho, S.Higashi, N.Hiraoka, S.Ozaki, T.Sato,
T.Suwada, T.Takahashi and H.Umeda

Depertment of Physics, Osaka City University

Osaka, Japan

Abstract

An experimental investigation of high-energy muons above 200 GeV in extensive air showers has been made for studying high-energy interaction and primary composition of cosmic-rays of energies in the range $10^{14} \sim 10^{15}$ eV.

The muon energies are estimated from the burst sizes initiated by the muons in the rock, which are measured by four layers of proportional counters, each of area 5 x 2.6 m^2, placed at 30 m.w.e. deep, Funasaka tunnel vertically below the air shower array. The air shower array, area of about 30 x 40 m^2 contains 21 plastic scintillation counters, of which five are for fast timing and all used for density determination.

The lateral distributions of high-energy muons above 200 GeV has been determined in the size range $10^4 \sim 10^6$ particles and in the lateral range $0 \sim 20$ m. These results are compared with Monte Carlo simulations based on the scaling model and the fireball model for two primary compositions, all proton and Mixed.

1. Introduction

High-energy muons in cosmic-rays keep information with characteristics of nucleus interaction and composition of primary cosmic-rays. An experimental investigation of high-energy muons in EAS with other components of the shower has been performed to take accurate information on both aspects. In this experiment the energies of muons are determined from the burst sizes initiated by them in the rock above the

detector and incoming directions are also determined by the use of the center of gravity of burst. By the use of this direction and the data from the shower array, we can determined the shower size N_e, age parameter S and distance between shower core and muon. Here we present results from an investigation of muon component (≥ 200 Gev) of EAS in size range $4 \times 10^4 \sim 10^6$ particles.

2. Experimental Arrangement and Method of Analysis

The apparatus consists of a scintillation counter array for the detection of air showers and four layers of proportional counters at the underground to observe bursts initiated by muons. Sixteen scintillation counters, 1 x 1 m^2 and 10 cm thick, are used to record the densities correspond to 1 to 2000 particles. Five, 50 x 50 cm^2 and 10 cm thick, counters are used for fast timing. These counters are distributed as shown in Fig. 1. Four layers of proportional counters are used to measure the size and the two dimensions lateral spread of the shower particles which are produced in the rock by high-energy muons. The area of each layer is 2.6 m x 4.5 m, the spatial resolution, i.e., distance of adjacent two wires, are 5 cm along 2.6 m and 10 cm along 4.5 m, and the distance between the top and
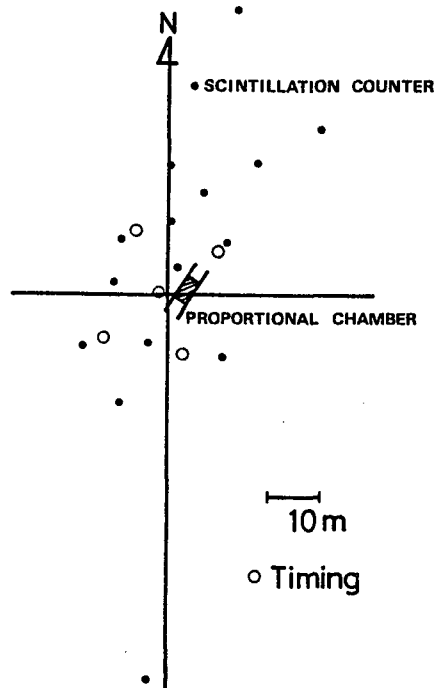
Fig.1 Plan of extended particle array. O, timing and particle density; ●, particle density.

the bottom layer is 94 cm. The burst detector is located inside the Funasaka Tunnel whose depth is 30 m.w.e. (1) and which is 18 m below the air shower array. Data are taken when each layer of the burst detector has more than 10 particles and any one of 16 scintillation counters has more than 6 particles. Lateral distribution of particles in observed burst is flat which is produced by multi-muon, or convex by a muon. Then convex bursts are selected by the following conditions which are determined on the basis of the analysis of bursts without air shower.

1) $\beta_2 \geqq 3$, $\geqq 30$ particles for each layer, where

$$\beta_2 = \mu_4/(\mu_2)^2, \quad \mu_k = \Sigma f_i(r_i - \langle r \rangle)^k/n, \quad n = \Sigma f_i, \quad \langle r \rangle = \Sigma f_i r_i/n,$$
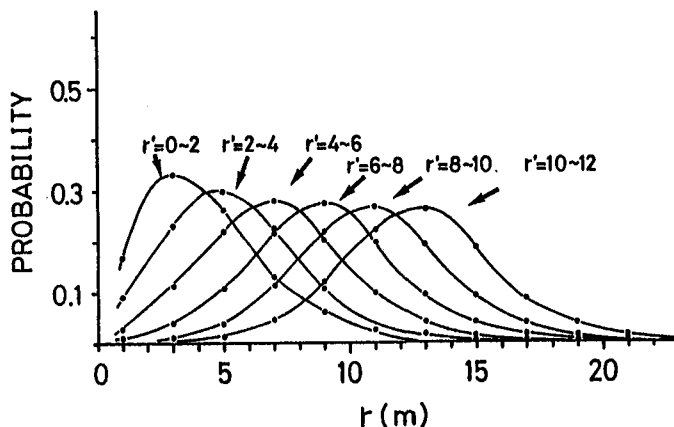
f_i, r_i : particle number and position of i-th wire,
Σ : sum of wires within a burst for each layer.

2) ratio of numbers of particles in a layer is
between 0.5 and 2.0.

For the selected data, center of gravity of burst size is calculated for each layer. Incoming direction of muon, namely, of air shower is determined from these 4 points. The energy of muon is determined from the burst size (N_b) using the next equation:

$$E \, (\, GeV \,) = 0.67 N_b^{-1.03}.$$

Size (N_b) is obtained from the average of four layers and zenith angle correction is applied. This equation is obtained from the conversion of burst size spectrum to energy spectrum. The air shower parameters, size (N_e), core location (X,Y) and age parameter (S), are determined by a least square fit of observed densities to NKG

Fig.2 Probability distribution of finding muon within interval r' for muon core distance r.

lateral distribution (2). We estimate the errors of these parameters, $\sigma(X,Y) = \pm 2$ m and $\sigma(\theta,\psi) = \pm 6^0$ from analysis of artificial showers. The probability of finding muon within interval r' for muon of core distance r is calculated by Monte Carlo method using the $\sigma(X,Y)$ and $\sigma(\theta,\psi)$, and the result is presented in Fig. 2.

3. Results and Conclusion

During the 13666 hours, 2776 events have been obtained which are satisfied with burst conditions and air shower conditions. Only 103 events in which muon energy is $\geqq 200$

GeV are survived after next five conditions are applied.
1) air shower sizes N_e are in the range $4 \times 10^4 \sim 10^6$ particles,
2) zenith angles θ are in the range $0 \sim 35^0$,
3) modified χ^2 values for lateral fit are in the range $0 \sim 5$,
4) core distance are in the range $0 \sim 20$ m.

Four conditions are on the basis of analysis of artificial showers. Under these conditions, correction factor of the acceptance-area is estimated to be 1. Relative densities of muon are obtained from 103 events by acceptance-area and finding probabilities. The density in the range 0 to 2 m becomes low because of flat lateral distribution of burst. Fig. 3 shows the lateral distribution of muons with energies more than 200 GeV in the associated shower size $4 \times 10^4 \sim 10^6$ particles. Comparing the data curve with the predictions of Monte Carlo simulation (3), the data are normalized at the range $2 \sim 4$ m. The figure shows that the primary composition of cosmic-rays in the energy interval $10^{14} \sim 10^{14.5}$ eV is proton dominant. Data have errors due to energy estimation of air shower, short range of core distance and poor statistics, but the conclusion that the primary composition of cosmic-rays in the energy range till $10^{14.5}$ eV are proton dominant, as other experiments suggest (4), may be correct. It is necessary to increase the range of shower size and core distance.
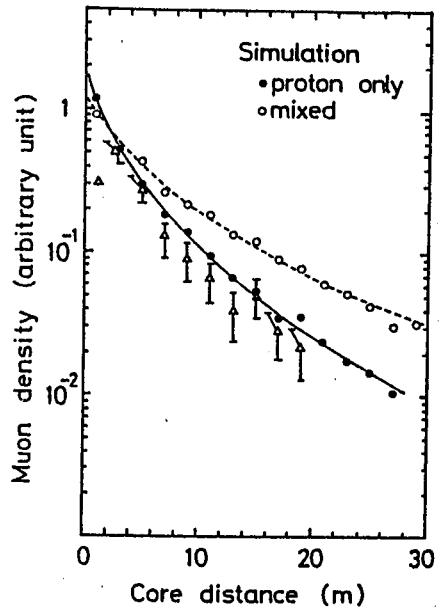

Fig.3
Density distribution of muon above 200 GeV against core distance.

References

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(3) Mizutani, K. et al. , this Conference Paper, OG 5.2-9.
(4) See, for example, Acharya, B.S. et al, 16th ICRC, Kyoto, 8, 304, (1979). ; Burnett, T. H. et al. , Phys. Rev. Lett., 51, 1010, (1983).