Measurement of Low Energy Muons in EAS at Energy Region Larger than 10^{17} eV.

Y.Matsubara*, T.Hara, N.Hayashida, K.Kamata, M.Nagano,
H.Ohoka, G.Tanahashi and T.Teshima*

Institute for Cosmic Ray Research, University of Tokyo,
Tanashi, Tokyo, 188 Japan
* Department of Physics, Kyoto University,
Sakyo-ku, Kyoto, 606 Japan

Abstract

A measurement of low energy muons in EAS (threshold energies are 0.25, 0.5, 0.75 and 1.38 GeV) was carried out. The density under the concrete shielding equivalent to 0.25 GeV at core distance less than 500 m and 0.5 GeV less than 150 m suffers contaminations of electromagnetic components. Therefore the thickness of concrete shielding for muon detectors for the giant air shower array is determined to be 0.5 GeV equivalence. Effects of photoproduced muons are found to be negligible in the examined ranges of shower sizes and core distances. The fluctuation of the muon density in 90 m^2 is at most 25 % between 200 m and 600 m from the core around 10^{17} eV.

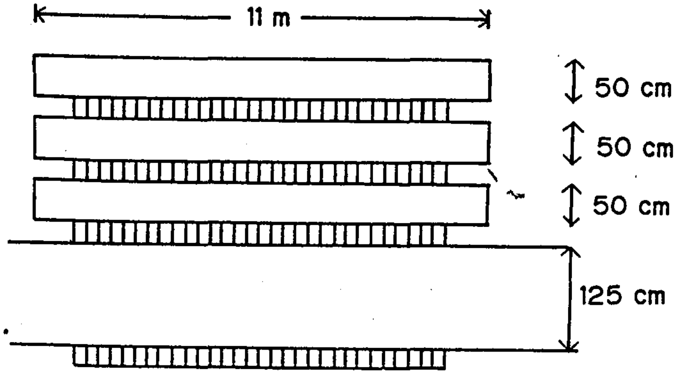
1. Introduction

Constrution of muon detectors for the giant air shower array starts from 1984 at Akeno. One of the purposes of this experiment is to determine the appropriate absorber thickness. Muons in EAS must be measured under the shielding in order to eliminate electromagnetic components. On the other hand, the thickness of shielding is desired to be as thin as possible from the economical point of view. Another purpose is to examine whether effects of photoproduced muons appear appreciably in giant air showers when we measure such low energy muons.

2. Experiments and Data Analysis

The measurement was done by using a large calorimeter of 100 m^2 area (effective area 90 m^2) at the center of Akeno EAS Array (Hara et al. 1979), which consists of four layers of proportional counters under the concrete shielding as is shown in Fig.1. The threshold energies for muons at each layer correspond to 0.25, 0.5, 0.75 and 1.38 GeV respectively. Counters are made of iron square pipes of size 10 cm x 10 cm x 500 cm filled with P10 gas (Hayashida and Kifune 1980). The trigger condition is 7-fold coincidence with more than 4 particles out of 38 scintillation counters in Akeno EAS Array, which are arranged in lattice shape with mutual spacing of 120 m. 18000 showers are analyzed and the conditions for data

Fig.1 The structure of the calorimeter



selection are as follows; shower size lager than 10^7, core distance larger than 50 m from the calorimeter and chi square for the fitting of shower sizes and directions reasonably small. Only vertical showers are examined in this paper except those shown in Fig.4. Present data are compared with those by other nine muon stations of 25 m^2 each, where the thickness of the concrete shielding corresponds to threshold energy 1 GeV .

3. Results and Discussions

The lateral distribution of muons of energy more than 1 GeV is given by Greisen's formula (Greisen 1960)

$$\rho_\mu(R) = C(R/R_0)^{-0.75}(1+R/R_0)^{-2.5} \quad \ldots \text{(A)}$$

from the data of muon stations in Akeno EAS Array, where R is a core distance, C is a normlization factor depending on sizes and zenith angles, and R_0 is a characteristic distance which varies with zenith angles (Hara et al. 1983). Greisen presents also the lateral distribution as a function of muon energy $E\mu$ as follows (Greisen 1960)

$$\rho_\mu(>E_\mu,R) = (A) \times (51/(50+E_\mu)) \times (3/(2+E_\mu))^{f(R)} \quad \ldots \text{(B)}$$

where $f(R) = 0.14 \times R^{0.37}$. We use this function as a reference, though the Greisen's formula were derived from the data of lower sizes and larger energy regions of muons than are considered now.

(1) Lateral distribution

Fig.2 shows the lateral distribution of the density at each layer for vertical showers. Curves are those given by the formula (B) with R_0=280 m. Densities under shieldings equivalent to 0.5, 0.75 and 1.38 GeV at more than 150 m from the core can be fit well to this formula, but those under the shielding equivalent to 0.25 GeV show larger values than this curve. The lateral distribution of the density ratio of each layer to the fourth layer in three shower sizes is shown in Fig.3, where the density of the lowest layer is taken as a reference value. Curves are given by the formula (B). It is suggested from both figures that the concrete shielding equivalent to 0.25 GeV can not prevent the leakage of electromagnetic components at the core distance less than 500 m , and 0.5 GeV less than 150 m also. Fig.4 is the zenith angle dependence of this ratio for the concrete shielding equivalent to 0.25 GeV x secθ at equal size. The higher the threshold energy becomes, the less the leakage of electromagnetic components is observed. We decide the thickness of concrete shielding for the observation of muons in giant air showers to be 0.5 GeV equivalence for safety, though the minimum absorber thickness is found to be 0.34 GeV (this is the case for secθ = 1.3-1.4) from Fig.4.

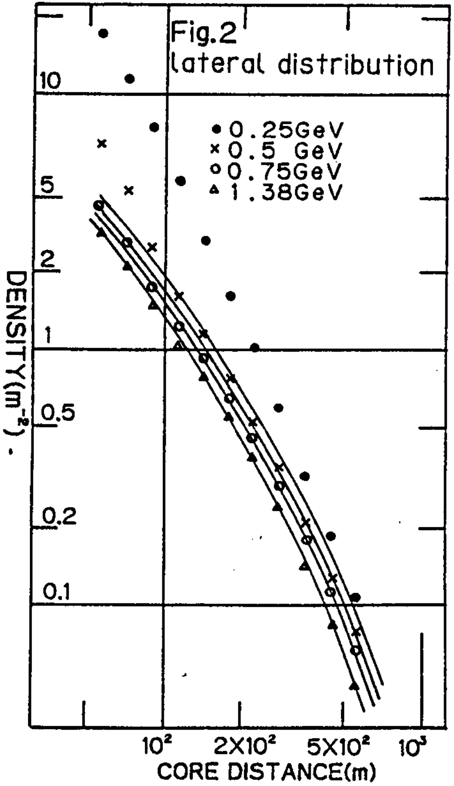


Fig.2 lateral distribution

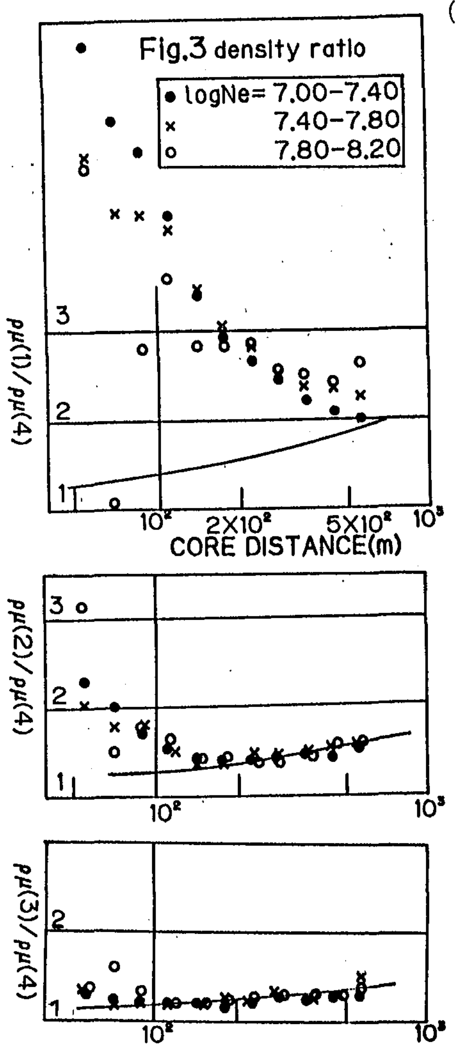


Fig.3 density ratio

(2) Effects of photoproduced muons

The number of photoproduced muons in EAS is proportional to the primary energy E_0, while the number of muons in nuclear cascades to $E_0^a (a<1)$. Therefore, the contribution of photoproduced muons to total muons becomes significant in larger shower sizes. According to the simulation (McComb et al. 1979), if the density of photoproduced muons takes over that from pionization, 'α' in $\rho_\mu \propto Ne^\alpha$ becomes 1. Fig.5 shows the relation between the muon density and the shower size, and between the muon size and the shower size. There exists no significant tendency that the power 'α' becomes larger as the shower size becomes larger. Effects of photoproduced muons may be negligible in the examined ranges of shower sizes and core distances.

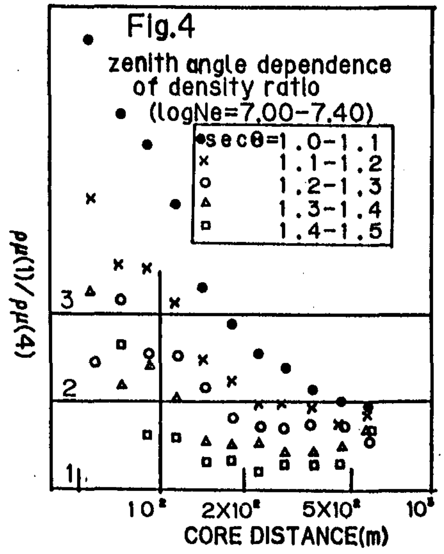
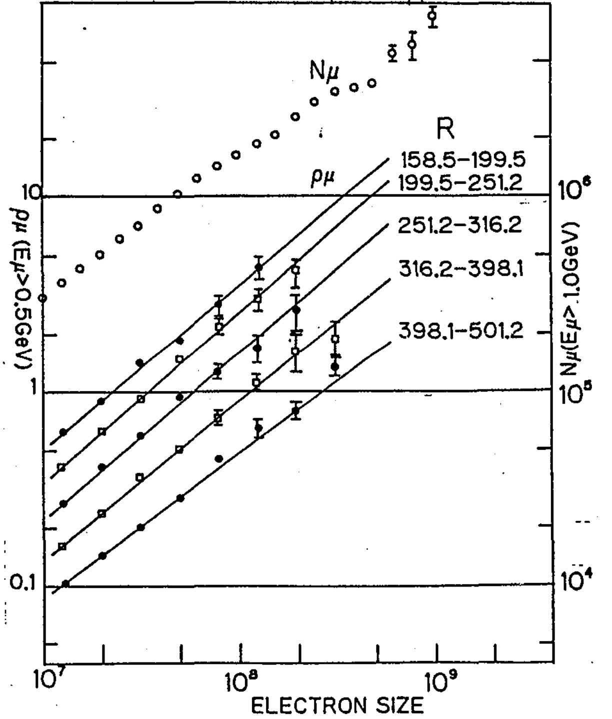


Fig.4 zenith angle dependence of density ratio (logNe=7.00-7.40)

Fig.5 size dependence of Nμ and ρμ



(3) Fluctuation of muons

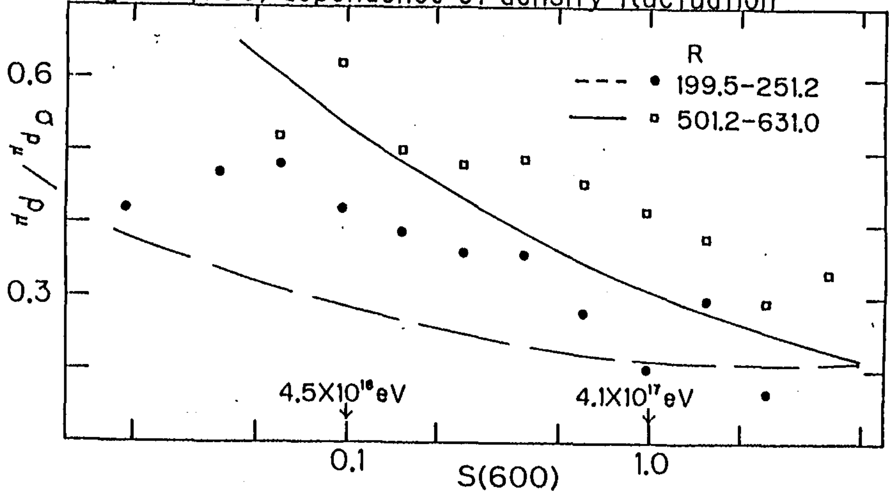


Fig.6 S(600) dependence of density fluctuation

It is important to know the fluctuation of the muon density in EAS. This value is related to not only the accuracy of muon size determination, but also to the primary mass composition. In Fig.6 are plotted the S(600) dependence of σ/ρ_μ for two core distance ranges, where ρ_μ is the density of 0.5 GeV muons in 90 m^2, σ is its fluctuation and S(600) is the electron density at 600 m from the core. S(600) is considered to have a good relation to the primary energy E_0 as (Glushkov et al. 1979)

$$E_0 = 4.1 \times 10^{17} (S(600))^{0.96}$$

Curves in Fig.6 are the experimental errors which are derived from the data of Akeno EAS Array (Hara et al. 1981),

$$\sigma/\rho_\mu = (0.668/\rho_\mu^2 + 1.42/\rho_\mu + 0.04)^{1/2}$$

by using the average density in the corresponding S(600) and two core distance bins. Subtracting these experimental errors quadratically and considering the fluctuation of S(600) for the same primary energy, the fluctuation of the muon density is found to be at most 25 % irrespective of the core distance examined for the primary energy around 10^{17} eV.

Acknowledgements

The authors are indebted to the other members of Akeno group for obtaining and analyzing the data. The data analysis is done by FACOM M380 at the Computer Room, Institute for Nuclear Study, University of Tokyo.

References

Glushkov A.V. et al. 1979, Proc. 16th ICRC(kyoto), 8, 158
Greisen K. 1960, Ann.Rev.Nucl.Sci., 10, 63
Hara T. et al. 1979, Proc. 16th ICRC(Kyoto), 8, 135
Hara T. et al. 1981, Proc. 17th ICRC(Paris), 11, 231
Hara T. et al. 1983, Proc. 18th ICRC(Bangalore), 6, 122
Hayashida N. and Kifune T. 1980, NIM, 173, 431
McComb T.J.L. et al. 1979, Proc. 16th ICRC(kyoto), 9, 126