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The muon component and its relation with shower age in the EAS initiated by primaries of knee region

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Abstract: Measurements, obtained by the muon magnet-spectrographs (mdm $\sim$ 500 GeV/c) of NBU air shower array, representing lateral structure of low and high- energy muons in extensive air shower (EAS) with sizes ranging from $10^{4.6}$ to $10^{6.4}$ particles at sea level are studied to investigate its potential significance in understanding the primary composition and the development of EAS in the atmosphere. The relation between the electron cascade age (s), which represents the longitudinal development of EAS in atmosphere, and the muon component, which as the progeny of nucleon cascade, has been studied in detail. Our observations with different muon energy threshold ($E_\mu \geq$ 2.5 GeV) and radial distance from shower core as measured directly by magnet spectrographs are presented. Our measurements of the distribution of muons in young and old showers are seen to be similar to those measured in other experiments and show considerable variation with the shower age. This dependence of muon distribution on shower age are presented in detail and its importance to understand the kinematics of particle production at high energy, their propagation in atmosphere and their implication in the development of EAS have been explored and discussed.

Introduction

The longitudinal development of cosmic ray extensive air shower (EAS) in the atmosphere is the effect of the nucleon cascade and the associated photon-electron cascade, and is conventionally indicated by the age parameter (s) as defined in the cascade theory. Most of the earlier investigators including ourselves have noted that the average age(s) of showers, when divided into groups according to their size(N_e), decrease with increasing size. Studying the dependence of EAS size spectrum with shower age, Danilova [4] observes rapid increase of young showers fraction with shower size increasing up-to $N_e \sim 10^7$. Danilova [4] and Yakovlev [13, 12] have further observed that that at the primary energy $E_0 \sim$ (3-5) $\times 10^{15}$ eV older shower ($<s>$ = 1.17) were initiated mostly by primary nuclei and the younger shower ($<s>$ = 1.01) were initiated by primary proton (and possibly by nuclei of helium). These authors have also suggested appearance of unstable particles with heavy quarks after proton interaction with nuclei of air. And, because of heavy quark presence such particles keep the momentum up-to their disintegration, after which cascade starts to develop. With increasing of unstable particles energy its decay length grows and cascade maximum in air rapidly shifts its position to the deeper layer in the atmosphere. These observations suggest that the values of age (s) are different due to mostly the result of interaction and, possibly, nature of primary nuclei. However, not much study has been done to understand the relation between the photon-electron cascade age and the muon component, which is the progeny of the nucleon cascade. A study of this correlation by measuring both electron and muon components simultaneously in individual air shower has not yet been carried out extensively at different atmospheric depth. Only some experimental observations of the MSU experiment [7, 8] and recent experimental result of the GAMMA [5] have been reported about the relationship between age parameter and lateral distribution of muons. They have studied the muon lateral distribution for different age values and shower size (N_e) up-to 3×10^6 and have reported a noticeable dependence of muon lateral distribution function on age(s). We have also studied the muon distribution, measured at near sea level by NBU air shower array, in EAS of different ages and some preliminary results are reported here.

Experimental setup and data analysis

The NBU EAS array, described in detail in our earlier publications [10, 3, 1, 9, 2], has 35 plastic scintillation counters spread over an area of 3000 m^2 and working in conjunction with two magnet spectrographs. The scintillation counters are used to measure electron density at different points of shower front incident over the array. The two shielded muon magnet spectrographs of maximum detectable momentum $\sim$ 500 GeV/c are used to detect and measure the energy of muons associated with the incident shower. The lower cutoff energy of muons is 2.5 GeV. The basic characteristic parameters of each EAS, viz. core position (X_0 & Y_0), shower size (N_e) and shower age (s), are determined by fitting the measured electron density at different points on shower fronts to NKG function. The uncertainties in determining these parameters, estimated by the method of artificial shower analysis explained in detail in our earlier publication [1, 9, 2], are seen to be $\pm$2m (core position), 9.7% (N_e) and $\pm$0.09 (s) at typical shower size of 5×10^5 particles. For the present analysis, showers registered by array were grouped according to their size in seven different size bins in the range $10^{4.3}$ to $10^{6.3}$ particles. For each shower size bin the average age ($\overline{s}$) was calculated and for the present analysis showers with ages below and above the average value, of that particular size range, are termed respectively as young and old showers.

Experimental results

The radial distribution of muon and its dependence on s

The measured radial densities of muons with the energy threshold $\geq$ 2.5 GeV were fitted to the equation of the form

$$\rho_\mu(\geq E_\mu, N_e, r, s) = A \times r^{-\alpha(s)} \times Exp(-\frac{r}{r_0}) \tag{1}$$

The variation of α (s) for different muon energy threshold ($\geq E_\mu$) for young and old showers and for below and above knee of the primary are presented in table 1 & 2.

Table 1: Values of α (s) for different E_μ and s at $N_e = 2.5\times10^5$

E_μ	s < 1.246	s $\geq$ 1.246
$\geq$ 2.5	0.433$\pm$0.005	0.302$\pm$0.004
$\geq$ 5.0	0.732$\pm$0.019	0.425$\pm$0.011
$\geq$ 25.5	0.805$\pm$0.051	0.589$\pm$0.032

Table 2: Values of α (s) for different E_μ and s at $N_e = 1.2\times10^6$

E_μ	s < 1.246	s $\geq$ 1.246
$\geq$ 2.5	0.567$\pm$0.024	0.309$\pm$0.014
$\geq$ 5.0	0.876$\pm$0.021	0.563$\pm$0.011
$\geq$ 25.5	1.053$\pm$0.064	0.648$\pm$0.033

The lateral distribution of young and old showers for different muon energy thresholds ($\geq E_\mu$) are shown in fig. 1 & 2 along with the results of MSU [6, 11].

The relative muon density distribution

Further analysis have been made by defining the following ratio

$$\eta = \frac{\rho_\mu(\geq E_\mu, N_e, r, s \geq \overline{s})}{\rho_\mu(\geq E_\mu, N_e, r, s < \overline{s})} \tag{2}$$

which represents the ratio of muon densities in older showers of s $\geq \overline{s}$ and young showers of s $< \overline{s}$. The variations of η as a function of muon energy and core distances for one range of shower size with average value $N_e = 2.5 \times 10^5$ are presented in Fig 3. The measurements of the MSU experiment [6] are also shown in fig 3 along with their calculated result, based on scaling model.

The age dependence of muon size (N_μ) $-$ ($\geq E_\mu$)

The total number of muons (N_μ) in showers for different muon energy threshold ($\geq E_\mu$) are obtained

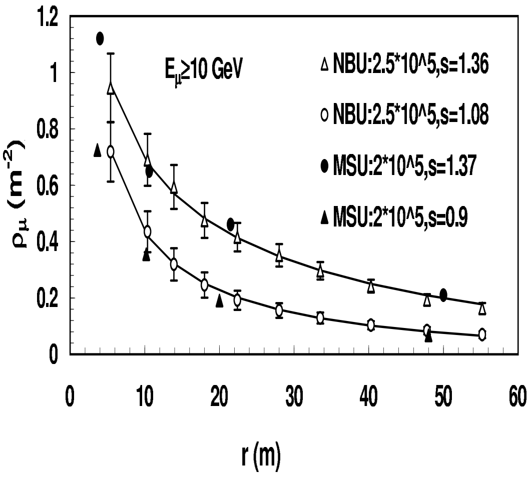

Figure 1: Lateral distribution of muon ($\geq$ 10 Gev) in comparison with MSU result [6] $N_e = 2 \times 10^5$; NBU: $N_e = 2.5 \times 10^5$

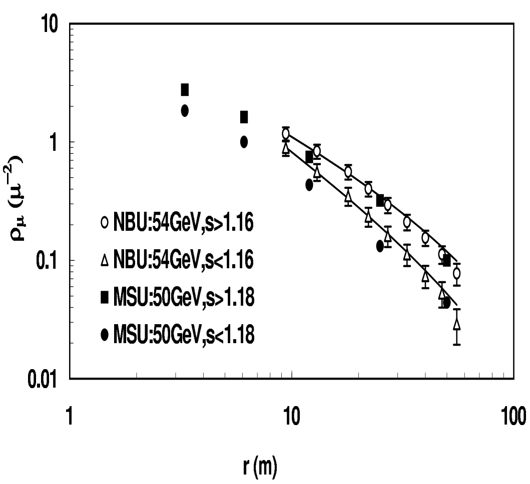

Figure 2: Lateral distribution of muon; NBU: $E_\mu \geq 54$ GeV, N_e 1.2×10^6. MSU: $E_\mu \geq 50$ GeV, N_e 1×10^6 [11]

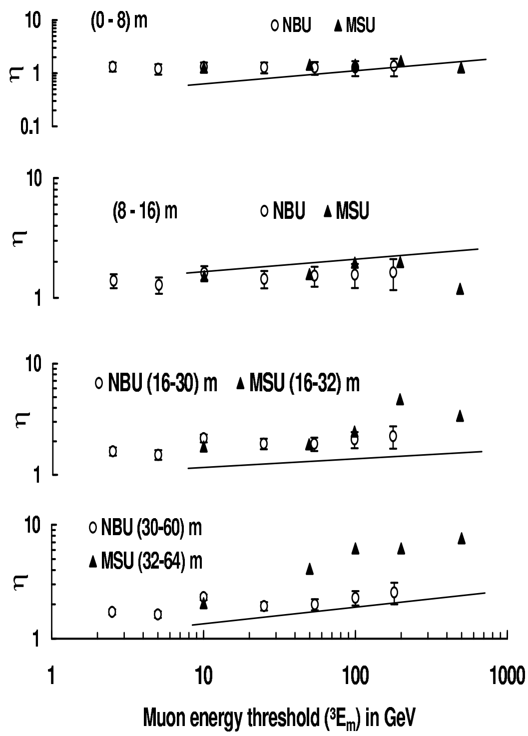

Figure 3: Variation $\eta = \frac{\rho_\mu(\geq \bar{s})}{\rho_\mu(<\bar{s})}$ with muon energy($\geq E_\mu$). NBU: $N_e = 2.5 \times 10^5$, MSU: $N_e = 2 \times 10^5$

by the equation

$$N_\mu(\geq E_\mu, N_e, s) = \int \rho_\mu\left(\geq E_\mu, N_e, r, s\right) 2\pi r dr \qquad (3)$$

The variation of N_μ with E_μ is shown in fig 4 for young and old showers at $\langle N_e \rangle = 2.5 \times 10^5$ (NBU) along with the result of the MSU experiment ($N_e = 2 \times 10^5$) [6]. The present measurements are fitted to the equation of the form

$$N_\mu(\geq E_\mu, N_e, s) = K \times \left(\frac{E_\mu + 2}{4.5}\right)^{-\lambda} \times Exp(-E_\mu \times \delta) \qquad (4)$$

This result again shows that the muon content increases with s and the trend of the variation is in agreement with the experimental results of Moscow group.

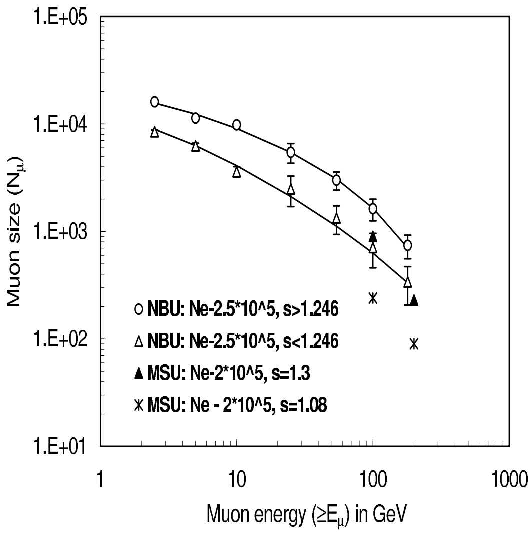

Figure 4: Variation of muon size (N_μ) with muon energy ($\geq E_\mu$). NBU: N_e = 2.5 $\times$ 10^5; MSU: N_e = 2 $\times$ 10^5

Discussion of Results

The present measurements are seen to be fairly consistent with the measurement of other similar experiments. It is evident from the fig 1 & 2 that the radial distribution of muons in young and old showers are significantly different and table 1 shows that in older showers the muon radial distributions are flatter than the young showers. Similar observation of dependence of radial muon distribution on the age of the shower were reported by investigators of MSU [7, 8] and GAMMA [5]. From these observations the shape of the muon distribution for the showers below and above the knee are seen to be similar i.e. the variation α (s) with muon energy ($\geq E_\mu$) is nearly same. The results of this analysis further show (fig 3) that the muon density and hence the muon content of older showers increases with distances in comparison to that of young showers, which is in agreement with what was observed by Miyake et al [8]. From fig 4 it is also evident that the muon energy spectrum for older shower (λ = 0.503 $\pm$ 0.091, δ = 0.007) is flatter than younger showers (λ = 0.774 $\pm$ 0.104, δ = 0.0024). From our preliminary study it is evident that distribution of muon in EAS is noticeably different for showers of different age. As pointed out by different authors [4, 13, 12] the difference in age could be due to different modes of interaction of primary. And, hence an extensive study of distribution of muons in EAS of different age groups could be helpful to understand the interaction of primary and possibly to understand its nature. We will be investigating it further.

References

[1] D. K. Basak et al. *Nucl. Inst. & Meth.*, 227:167, 1984.

[2] A. Bhadra et al. *Nucl. Inst. & Meth.*, A414:233, 1998.

[3] R. K. Chhetri et al. In *International Cosmic Ray Conference, 29th, Pune, India, 2005, Conference Papers. Volume 6.*, page 141, 2005.

[4] E. V. Danilova et al. *Izv, RAN. Ser. Fiz.*, 61:61, 1997.

[5] V. S. Eganov et al. In *International Cosmic Ray Conference, 27th, Hamburg, Germany, 2001, Conference Papers. Volume 1.*, page 948, 2001.

[6] N. N. Grishina et al. In *International Cosmic Ray Conference, 17th, Paris, 1981, Conference Papers. Volume 6.*, page 3, 1981.

[7] G. B. Khrisenten et al. In *International Cosmic Ray Conference, 16th, Kyoto, 1979, Conference Papers. Volume 14.*, page 360, 1979.

[8] S. Miyake et al. In *International Cosmic Ray Conference, 17th, Paris, 1981, Conference Papers. Volume 6.*, page 161, 1981.

[9] G. Saha et al. *Il. Nuovo Cimento*, 21C:215, 1998.

[10] S. K. Sarkar et al. In *International Cosmic Ray Conference, 29th, Pune, India, 2005, Conference Papers. Volume 6.*, page 145, 2005.

[11] V. V. Vashkevich et al. *Sov. J. Nucl. Phys.*, 47(4):672, 1988.

[12] V. I. Yakovlev. In *International Cosmic Ray Conference, 26th, Salt Lake City, 1999, Conference Papers. Volume 1.*, page 256, 1999.

[13] V. I. Yakovlev et al. In *International Cosmic Ray Conference, 25th, Durban, 1997, Conference Papers. Volume 6.*, page 209, 1997.