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Indication of change in primary at knee region from the study of EAS muons at sea level

R. K. Chhetri[b], S. K. Sarkar[a] and K. Ghosh[a]
(a) High Energy and &Cosmic Ray Research Centre, North Bengal University, Darjeeling 734430, India
(b) Sikkim Govt. College, Gangtok 737102, India
Presenter: R. K. Chhetri (rkchhetri@rediffmail.com), ind-chhetri-RK-abs1-he12-oral

Density of Muons with different energy (≥2.5GeV) associated with EAS of sizes $10^{4.3}$ to $10^{6.3}$ particles are measured by NBU air shower array situated at near sea level, which consists of 35 scintillation counters and two muon magnet-spectrographs. The variations of muon density with different shower parameters are studied. The variation of muon density with shower size shows a change in slope around knee position indicating increase in muon content of EAS. Similar features are also seen in the measured muon to electron density ratio at particular distance from shower core and the muon number estimated from the lateral distribution. The increase in muon content could be taken as indication of primary changing from lighter to heavey beyond the knee region.

1. Introduction

Since long time, it has been realized that a comprehensive study of different components of EAS at a given observation level bear the possibility of giving information about the characteristic properties of primary cosmic rays. In spite of severe constraints posed by the observational uncertainties and developmental fluctuation of EAS, in determining the characteristic properties of primary cosmic ray initiating individual EAS, studies of the average characteristics of EAS has been used by many investigators to gain knowledge concerning the primary-mass spectrum and its change, if any, with the primary energy.

Many simulations of cosmic ray EAS have shown that a number of measurable properties of muons in EAS could be used as a possible mass-sensitive parameters. Different studies of correlation between electromagnetic and muon components of EAS have shown that muon to electron size (N_μ / N_e) ratio as one of the most sensitive parameter of primary mass [see for example. 1,2 & 3] . They have shown that the muon content of EAS could be one of the important differentiating factors to identify the EAS initiated by lighter (proton dominated) or heavy (iron dominated) primary. Total muon content in a shower is also considered as a best parameter to discriminate gamma ray induced showers from the hadron-initiated showers. Earlier model predictions of Gaisser et al [4] had shown that on average a ∼60% increase in the relative muon content of an iron nucleus induced EAS relative to a proton initiated shower at ground level, for fixed primary energy.

Our measurements of radial distribution of muons in EAS of sizes 10^4 to 10^6 particles, reported earlier [5] and in this conference [ind-ghosh-Kasturi-abs1-he12-oral], obtained by NBU EAS array have shown some notable changes in the such distribution , which could be an indication of primary change in the neighborhood of ”knee” in the primary spectrum. But, considering the fact that radial distribution depends upon several other factors like the fluctuation in depth of shower maximum, the stage of longitudinal development, the propagation of secondaries etc., cannot alone be taken as indicator of primary change. Apart from mean muon lateral density distribution of muons in EAS the variation of muon content in EAS of different sizes showing its relative abundance with electromagnetic component could be a better parameter sensitive to primary mass. The measurements of Haverah Park EAS array, as reported by Blake and Nash[6], have observed significant difference in muon content of EAS initiated by primaries with energy above and below the knee region of primary spectrum and has been taken as an indication of primary composition becoming lighter towards knee approaching from below and remaining unchanged above the knee. While studying the muon content of EAS in shower size range $10^{4.3}$ to $10^{6.3}$ from the measurements of NBU EAS array, a similar change has been observed and the results are reported in this paper.

2. Experimental setup & Data analysis

The NBU EAS array was set up in the year 1980 and has undergone some changes which is described in detail in our earlier publications [7]. In the year 1998, with addition of few more detectors a major change in data recording system was made. At the time of experiment whose results are being reported in this paper the array consisted of 35 plastic scintillation counters spread over an area of ∼3000 m^2 and working in conjunction with two magnet spectrographs. The scintillation counters, each of area 0.25 cm^2, were 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 ∼500 GeV/c were used to detect and measure the energy of muons associated with the incident shower. The lower cutoff energy of muons, provided by the lead and concrete absorbers placed above the magnet spectrographs 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 [6], are seen to be ±2m (core position), 9.7%(N_e) and ±0.09 (s) at typical shower size of 5×10^5 particles.

Observed showers were grouped according to their size in seven different size bins in the range $10^{4.3}$ to $10^{6.3}$ particles. And, the average muon density in a shower as a function of the radial distance from the shower core was estimated for each of various size bins using the average density defined as, $\rho_\mu(\geq E_\mu, N_e, r) = N(\geq E_\mu, N_e, r)/(N_t(N_e, r)* A$, where N is the total number of muons recorded in a particular distance bin with average value r for a particular size bin with average size N_e and having energy $\geq E_\mu$, N_t is the total number of the showers having size in the same bin and recorded during the same time interval. A is the effective area of the muon detectors.

3. Experimental results

3.1 Variation of muon density with shower size

Some representative measurements of muon density (ρ_μ) in EAS of different average sizes at two distance bins with average value of 18m and 48m from the shower core are shown in fig. 1. From this figure, it is apparent that the mean density of muons increases smoothly with shower size up to a range of average value 5.5 x 10^5, beyond which there is an enhanced increment in muon density. As a result the variation of muon density with average shower size in the whole range of shower sizes studied cannot be represented by a power function of the type $\rho_\mu \sim N_e^\gamma$ with single exponent. Taking two different shower size range, above and below the range with average value 5.5×10^5 particles, and representing the variation by power function, the value of exponent shows a significant increase in the higher shower size range. The values of two exponents γ_1 and γ_2 are shown in table 1.

Table 1. The fitted values of γ_1 & γ_2 for $E_\mu \geq$ 2.5 GeV at different distances

r (m)	12-16	20-25	30-36	44-52
γ_1	0.68±0.01	0.68±0.01	0.66±0.02	0.67±0.02
γ_2	0.79±0.04	0.84±0.05	0.82±0.07	0.78±0.10

3.2 The ratio of muon to electron density

To study the abundance of muons relative to electromagnetic component, ratio of muon to electron density (ρ_μ($\geq$E$_\mu$, r) / ρ_e(r)) with different muon energy threshold measured at the same distance from shower core were calculated and its variation with shower size was studied. Fig. 2 shows such variation of muon to electron density measured at two distance bins of r = 16-20m and 44-52m from shower core for muon threshold energy E$_\mu$ $\geq$2.5 GeV. The figure clearly shows that the ratio (ρ_μ($\geq$E$_\mu$, r) / ρ_e(r)) decreases steadily upto the average shower size range of 5.5x10^5 but beyond which it does not decrease as fast as it does in the lower size region indicating there is a notable increase in muon content in EAS of size larger than 5.5x10^5.

3.3 The total muon number in EAS

As explained in our earlier presentation in this conference, the measured lateral distribution of muons were fitted to an equation of the form

$$\rho_\mu(\geq E_\mu, N_e, r) = A * r^{-\alpha(\geq E_\mu, N_e)} * Exp(-r/r_0) \quad (1)$$

and using the values of fitted parameters, equ. (1) was integrated for a distance of 4 to 55 metres to estimate the so called truncated muon number N$_\mu^{tr}$. And, to study further the muon abundance in the shower, the ratio of truncated muon numbers with shower size N$_\mu^{tr}$ ($\geq$E$_\mu$) / N$_e$ was calculated. Fig. 3 shows variation of this ratio with shower size. The figure shows that, the ratio decreases smoothly upto the shower size range of average value 5.5x10^5 and beyond that the ratio decreases much more slowly with shower size reflecting the increase in muon content in EAS of sizes beyond 5.5x10^5. Similar observation was also reported by investigators of GAMMA experiment [8] and their measurements(not corrected for altitude difference) are also shown in the fig. 3.

4. Discussion and conclusion

Our measurements of density of muons ρ_μ ($\geq$E$_\mu$, N$_e$, r) with different energies from E$_\mu$ $\geq$2.5 GeV measured at distances upto 60m from core of EAS of sizes(N$_e$)=$10^{4.3}$ to $10^{6.3}$, show that the relative muon content decrease smoothly up to a size range with average value $10^{5.7}$ particles but beyond that size range the decrease is seen to be much slower. The exponents γ_1 and γ_2 of power function used to represent the variation above and below the average N$_e$=$10^{5.7}$ show significant changes (table 1). Similar observations were reported by other investigators of Haverah Park and GAMMA experiments [6 & 8]. Our observation has shown the change becoming more enhanced with increase in muon threshold energies. This result would be discussed in detail in another report The same feature of increasing muon content in EAS of sizes more than $10^{5.7}$ is also reflected in measured muon-to-electron density ratio at particular distance from shower core and the muon number estimated from the lateral distribution of muons. Considering the simulation results [3], which show significant increase in muon content of EAS with heavy primary, this observation of change in muon content above and below average Ne=$10^{5.7}$ could be taken as an indication of primary change. The present observations, seen to be similar to those of Haverah Park and GAMMA experiments, seem to suggest that the composition of primary initiating EAS of sizes $10^{4.3}$ to $10^{5.7}$ are lighter than the primary initiating EAS of sizes larger than that.

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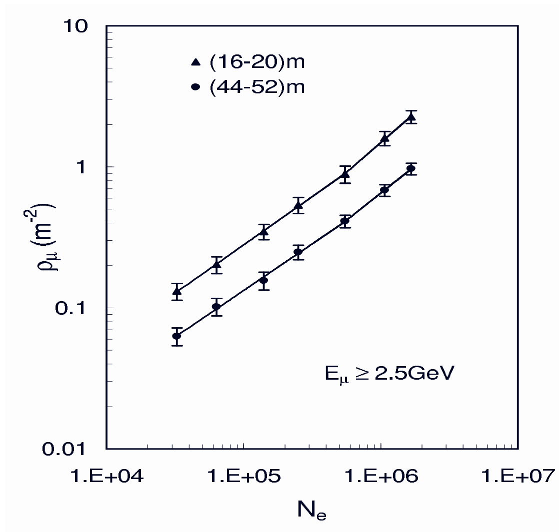

Fif. 1 Variation of muon density as a function of shower size for two distances

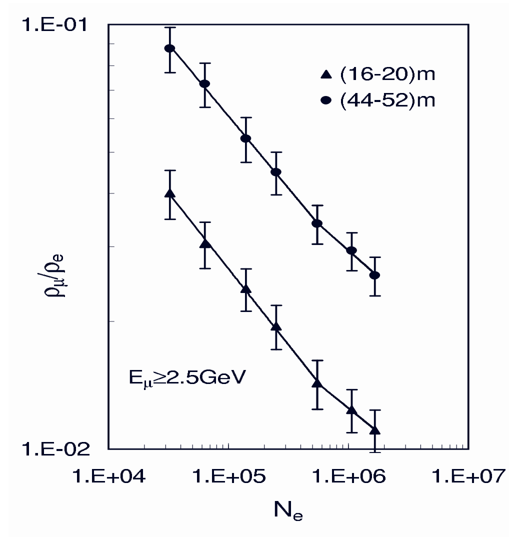

Fig. 2 Dependence of muon to electron density on shower size for two distance bins

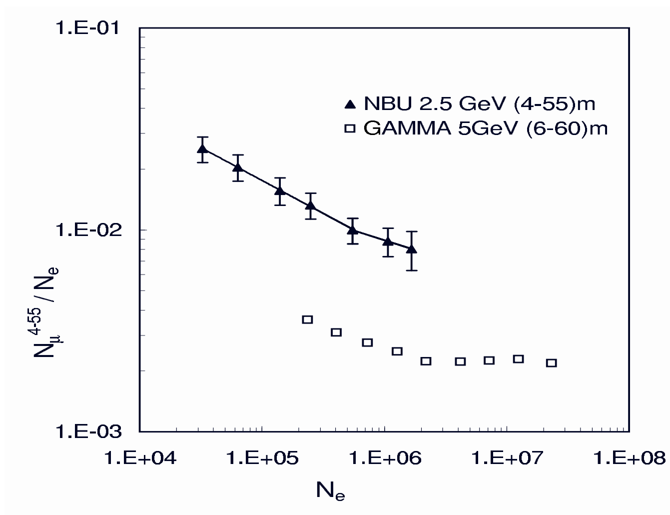

Fig. 3 Variation of muon to electron abundance as a function of shower size

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