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Shower age dependence of the muon density in EAS

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Abstract: Measurements have been made on muon and electron distributions in cosmic ray extensive air showers (EAS). The correlation between muon density and shower age parameter has been studied.

1. Introduction:

The study of high-energy muons in EAS along with the other parameters provides information about the primary cosmic rays as well as on the characteristics of particle interactions in the ultra high-energy regime. Measurements with air shower experiments are, however, limited by shower fluctuations and this imposes a major constraint on the possibility of determining the primary mass for an individual EAS. But it should be possible to obtain an average feature of primaries as well as the characteristics of high energy particle interactions from a comprehensive study of all components of the EAS at a given observation level. Study on the correlation among the different components is an important step in this direction.

The correlation between electromagnetic and muon components of EAS is normally studied through examining the relation between muon and electron sizes in EAS. In fact the muon-to-electron size (N_μ/N_e) ratio is regarded as one of the most sensitive parameter of primary mass (e.g. see Wdowczyk, 1994). Simulation results show that the differences of the ratio N_μ/N_e between proton and iron induced showers are larger than the corresponding differences between the interaction models (Knapp *et al*, 1997). Total muon content in a shower is also considered as a best parameter to discriminate gamma ray induced showers from the hadron-initiated showers. Many workers in the field have made extensive study about the variation of N_μ/N_e with shower size. Shower age is another important parameter associated with electromagnetic component of EAS. It represents the slope of the lateral density distribution of electrons. This parameter also describes the longitudinal development of EAS (Bhadra, this conference). The correlation between muon component and shower age is not a very well studied one.

In the present work an analysis has been made using the air shower data of North Bengal University (NBU) EAS array to examine the correlation of the ratio $\rho_\mu(>E_\mu, r)/\rho_e(r)$ (at certain core distances) with shower age. Since good estimation of total muon content in EAS requires large area muon detectors, which the NBU array do not have, in the present analysis we restrict to the more straightforward parameter, muon density at some distance from the shower axis instead of total muon content.

2. Experimental set up:

The NBU EAS array has been developed in stages since 1980. Due to some modification and developmental work the muon spectrograph of the array is not operating now. In the present preliminary analysis the spectrograph data obtained by the array in the period 1994 to 1996 has been used. Briefly, during that period the array contained a particle shower array of 24 plastic scintillation detectors. Eight of the scintillation detectors were also used to measure arrival direction of the shower by fast timing technique. Two shielded muon magnet spectrographs of maximum detectable momentum ~500 GeV/c, each of area 1 m^2, under a concrete shielding observer were also operated in conjunction with the particle shower array. The muon trajectories were determined using four neon flash tube hodoscopes with an accuracy of ± 1.4 mm. A shower is recorded by the detecting system of the array only if the registered density in four central triggering detectors are ≥ 4 particles/m^2 or if the observed particle density in any three of the four central detectors and in any one of the four triggering detectors situated at the four corners of the array are ≥ 4 particles/m^2. A detailed description of the experiment, shower selection, detecting efficiency of the

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array and data analysis is given elsewhere (Basak *et al*., 1984; Bhadra *et al*., 1998).

3. Data analysis:

The measured particle density data were analyzed for shower parameters (core position, shower age and shower size). Artificial shower analysis gives uncertainty in core position, shower age and shower size (N_e) as ±2m, ±0.09 and $\pm 0.14 N_e$ respectively. The arrival direction of individual EAS were obtained from timing data with a zenith angle resolution ~1.1^o. The average muon density in a shower as a function of the radial distance from the shower core was estimated for each of various small size bin and shower age bin using the average density defined as

$$\rho_\mu(\geq E_\mu, N_e, s, r) = \frac{N(\geq E_\mu, N_e, s, r)}{N_t(N_e, s, r)A} \qquad (1)$$

where N is the total number of muons recorded in a particular distance r for a particular shower size N_e and for a particular shower age s in a certain period of time above a threshold energy E_μ, N_t represents the total number of showers of size N_e and of shower age s at the same distance interval recorded by the array during the same time interval and A is the effective area of the muon detectors. In the present analysis muons of minimum threshold energy (2.5 GeV) are only considered. Only showers recorded by the array with detection efficiency >90% were analyzed for all values of shower age in the range $.8 \leq s \leq 1.7$.

4. Results:

The lateral distribution of electrons and muons as observed by the array is presented elsewhere (Bhattacharya *et al*, 1995; Saha *et al*, 1998) and are consistent with the other observations. The detail characteristics of shower age parameter, estimated from the present data set, is also reported earlier (Bhadra, 1999). In the shower size range (1-3) $\times 10^5$ particles, the mean shower age is found 1.28 for zenith angle < 12^o.

The variations of the ratio $\rho_\mu(>E_\mu,r)/\rho_e(r)$ with shower age in the shower size range (1-3) $\times 10^5$ particles at muon threshold energy 2.5 GeV are shown in figures 1 and 2 for two different core distances (12 m and 20 m). To construct the ratio $\rho_\mu(>E_\mu,r)/\rho_e(r)$ the whole radial range is divided into small distance bins but at the same time the radial bins are made wide enough (width 4 m) to accommodate the error in r_μ (~2m). Then the average value of the $\rho_\mu(>E_\mu,r)/\rho_e(r)$ is estimated for the radial bins of mean core distance r~12 m and 20 m. The quoted errors represent the statistical uncertainties. The errors are large as the statistics of the muon data set is low. It is clear from the figures that the ratio increases with shower age. The dependence of the $\rho_\mu(>E_\mu,r)/\rho_e(r)$ on shower age can be approximated by the quadratic relation

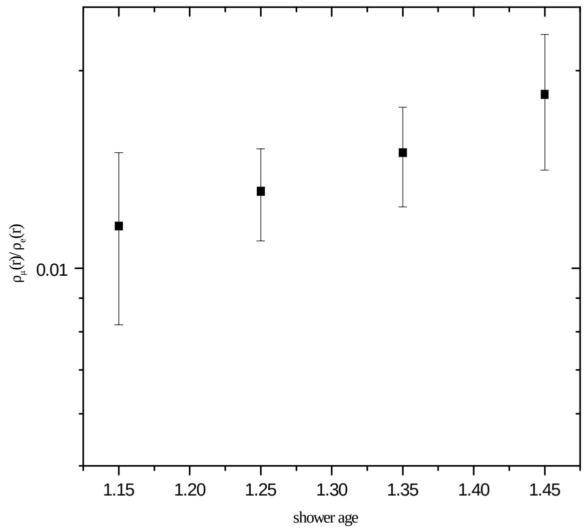

Fig 1. Variation of the ratio of muon-to-electron density with shower age at core distance 12 m in the shower size range (1-3) $\times 10^5$ particles for muon threshold energy 2.5 GeV.

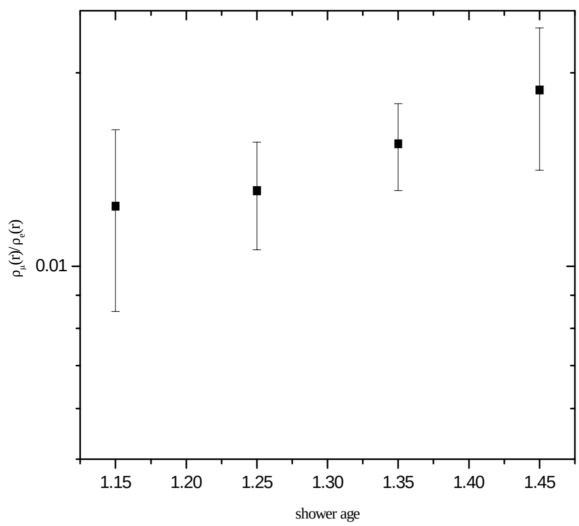

Fig 2. Variation of the ratio of muon-to-electron density with shower age at core distance 20 m in the shower size range (1-3) $\times 10^5$ particles for muon threshold energy 2.5 GeV.

$$\ln[\rho_\mu(r)/\rho_e(r)] = a\,(s-c)^2 + b \qquad (2)$$

with a=2.0±.6, b=4.55±.08 and c=0.9±.1 when r =12 m and a=3.4±.9, b=4.40±.04 and c=1.09±.04 when r =20 m.

5. Discussion:

The present observation shows that the ratio $\rho_\mu(r)/\rho_e(r)$ has a strong dependence on shower age parameter and it increases with shower age. This is probably due to the fact that at a fixed shower size, to have a higher shower age value (i.e. in the case of early development of shower in the atmosphere), the primary energy needs to be higher and for higher primary energy, muon density will be obviously higher.

In the Moscow State University experiment (Vashkevich *et al*, 1988) muon lateral distribution was studied for two groups of showers, one for old showers ($s > s'$, s' is the mean age) and other for younger showers (at $s < s'$). They found that the muon content is higher in old showers than in younger showers. Thus the present result is consistent with MSU observation. In the Akeno observation (Hara *et al*, 1983), N_μ/N_e ratio was found to increase with shower age in accordance with the present result. In another analysis, Akeno group studied muon size alone as a function of shower age and it was observed that with age muon size decreases slowly (Nagano et al, 1984).

The observed variation of $\rho_\mu(r)/\rho_e(r)$ on shower age can be approximated by the relation given in eq. (2). Using dual parton model (HDPM) (Capdevielle, 1989) of high-energy interactions, Capdevielle and Gabinski (1990) obtained similar dependence of the ratio $N_\mu(>5\text{GeV})/N_e$ ratio on s from Monte Carlo simulation result.

6. Conclusion.

The correlation between muon-to-electron density and shower age of electromagnetic component of EAS has been studied. Though the statistics of the analyzed events is small but the observed trend of the variation suggest that the ratio $\rho_\mu(r)/\rho_e(r)$ increases sharply with shower age parameter for fixed shower size. The present result indicates that shower age is a sensitive parameter of shower development. This follows from the fact that since shower size is kept constant in the present analysis, high shower age implies early-developed showers with higher primary energy, which obviously produces high muon density and hence is the observed increase of the muon-to-electron density ratio with shower age. Thus it appears shower age can indicate early or late development of showers. Another important point is that variation of the ratio N_μ/N_e with shower size can be largely affected by fluctuations of shower age. Since the dependence of $\ln[\rho_\mu(r)/\rho_e(r)]$ on s is quadratic, the effect of fluctuation of shower age around its mean value will be cumulative in the estimation of N_μ/N_e. As a consequence proton initiated showers, for which shower fluctuation is high, might appear to have more muons than what it should contain without any fluctuation.

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