EAS size spectra and its relation with shower age and zenith angle

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Abstract: The measurements of electron density at different locations of shower front incident with different zenith angle (θ) from 0^0 to 60^0, obtained by NBU Air Shower array (Latitude: 26^0 $42^{'}$ North and Longitude: 88^0 $21^{'}$ East and $\sim$130 m a s l), are studied to investigate correlation between lateral shower age (s) with atmospheric depth and electron size spectra of EAS in the size range $10^{4.6}$ to $10^{6.4}$ particles. It is observed that the variation of shower age with zenith angle (θ) is linear with increasing slope at higher shower sizes. Our estimated values of $\frac{ds(\Theta)}{dx}$ is similar to that of other experiments. EAS size spectra for young (s $<$ 1.2) and old showers (s $\geq$ 1.2) as well as for low ($0^0 < \theta \leq 30^0$) and high zenith angles ($30^{\,0} < \theta \leq 60^0$) are also studied. Our measurements show that young showers exhibit the knee feature while it is not evident for old showers. It is also observed that the knee position changes towards the lower value of N_e for higher atmospheric depth. The absence of knee for older showers may possibly indicate their origin from heavier primary with different knee position.

Introduction

The lateral distribution of charged particles of extensive air shower (EAS) at different altitude carries information about the longitudinal development of shower in the atmosphere. Thus the study of longitudinal development is of great importance to estimate the primary composition as well as the high-energy particle interaction in the atmosphere. In NKG type lateral distribution function of charged particles the stage of development of EAS is parameterized with the so-called age parameter (s). The lateral shower age s was originally introduced in the analytical description of electromagnetic cascade to define the actual stage of EAS development. For same primary energy it is considered that those showers are developed early in the atmosphere have larger age. In EAS experiment the lateral shower age s is usually estimated by fitting the distribution of observed values (like densities) at the observation level, assuming that the s parameter reflects the actual longitudinal EAS stage. Different experimental groups have studied the variation of s with particle numbers at different altitude with the aim to gain information about the longitudinal development and thereby understanding the interaction mechanism and the composition of primary cosmic rays [11, 8, 7, 2]. Most of these investigators have pointed out that either the primary mass composition gets heavier for energies $> 10^{15}$ eV or the multiplicity of secondary particle production in hadronic interaction is increases unexpectedly. This conclusion was further strengthened from the study of the size spectrum dependence of shower age [2, 3] where it was observed that the size spectrum for older showers has practically no knee and is steeper than the size spectrum for all showers where as the evidence of knee is clear for young showers. It may due to the change of mass composition to heavier for older shower. The knee position also changes with slant depth as well as shower age due to the change of attenuation length with shower size [2]. In the present work we have studied the lateral age parameter distribution and its dependence on atmospheric depth for EAS of size range $10^{4.6}$ to $10^{6.4}$ particles. The integral size spectra for young and old showers have also been studied in the said size range for zenith angle 0-60^0.

Experiment

The experiment whose results are being reported in this paper has performed at the North Bengal University campus (Latitude: 26^0 $42^{'}$ N and Longitude: 88^0 $21^{'}$ E) by using 35 plastic scintillation counters spread over an area of $\sim$ 3000 m^2 at 130 m a s l. The set-up has been designed to detect the showers in the knee energy region with the scintillation detectors of size 50 cm $\times$ 50 cm $\times$ 5 cm to measure the electron density at different points of the incident EAS front. The condition for triggering and hence subsequent recording of the shower incident on the array is such that, a shower is recorded only if the registered density in four central triggering detectors are $\geq$ 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 $\geq$ 4 particles/ m^2.

Data analysis

The basic parameters of each of the incident showers, viz. core position (X_0, Y_0), shower age (s) and shower size (N_e) are determined by fitting the measured electron density at different points of shower front to NKG function. The uncertainties in determining these parameters, estimated by the method of artificial shower analysis, is seen to be $\pm$ 2m (core position), $\pm$ 0.09 (s) and 9.7 % (N_e) at typical shower size of 5 $\times$ 10^5 particles. The uncertainty in estimating the arrival direction is estimated to be 1.2^0 at 60^0 zenith.

Result

Variation of shower age with atmospheric depth

The variation of the average shower age s(θ) on the average zenith angle (θ) for three different EAS size range are presented in fig 1. The error bars represent the statistical error.

The measured values are fitted to the equation

$$s(\theta) = s(0) + A \times (sec\theta - 1) \qquad (1)$$

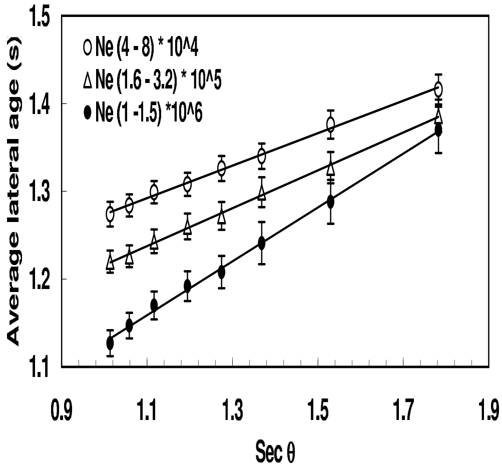

Figure 1: The dependence of meam lateral age (s) on the zenith angle of EAS for different shower size

and the fitted parameters s(0), A in table 1. Again, writing sec θ = $\frac{X}{X_0}$, where X_0 is the vertical atmospheric depth and X the slant depth of the observation level, A can be related to the change $\frac{ds(\theta)}{dx}$ of the average age with X as

$$\frac{ds(\theta)}{dx} = \frac{A}{X_0} \qquad (2)$$

and considering s = 1 at the depth of the shower maximum X_m we can estimate X_m. The calculated values of $\frac{ds(\theta)}{dx}$ are also shown in table 1. It shows that the slope A is increasing with N_e while s(0) is decreasing with N_e which is in good agreement with the other experimental observation [11, 2, 3]. The present measurement of $\frac{ds(\theta)}{dx}$ (table 1) is in good agreement with the experimental result of Mt. Norikura [11] where they have found its value = 0.034 per 100 gm cm^{-2}. The evaluations of N_e dependence of X_m for all s are presented in table 2 which caries some information about the elongation rate indicated by Linsly [10]. The value of X_m for vertical shower is evaluated from the linear fitting of s with slant depth. Furthermore we have evaluated X_m for different zenith angle (θ) from X_m at θ = 0 by considering its linear dependency on θ. The variation of s with X_m for the size range

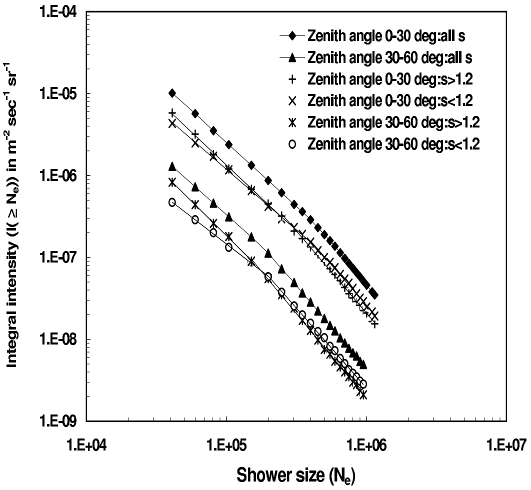

Figure 2: Integral EAS size spectra for young, old and all showers at two different zenith angle

$10^{5.5}$ to $10^{6.2}$ is shown in fig 2. The values of $\frac{ds(\theta)}{dx}$ for the showers below and above the size 3.2×10^5 are (1.841 $\pm$ 0.037) $\times$ 10^{-4} and (2.525 $\pm$ 0.074) $\times$ 10^{-4} respectively shows a major change due to the change of high energy interaction of primaries.

Table 2: Values of X_m for different N_e

N_e	X_m
(3.2-6)$\times 10^5$	179 $\pm$ 30
(6-10)$\times 10^5$	405 $\pm$ 20
(1-1.5)$\times 10^6$	596 $\pm$ 16
(1.5-2.5)$\times 10^6$	543 $\pm$ 38

Dependence of EAS size spectra on shower age

All the observed showers are divided into two zenith angle bins 0-30^0 and 30^0-60^0 and subdivided into two groups as young (s $<$ 1.2) and old (s $\geq$ 1.2). Fig 3 shows the integral size spectra for all, young and old showers of two different angular ranges of shower incidence. The spectral indices γ of equation I($>N_e$, θ, s) $\propto$ $(\frac{N_e}{10^5})^{-\gamma(\theta,s)}$ for different s and θ are presented in table 3 & 4. The spectra for young showers exhibit the knee feature while the knee is not evident for old showers. It also shows that the knee position is changing towards the lower value of N_e for higher atmospheric

Table 3: Observed values of spectral indices γ for $0^0 < \theta < 30^0$

	Below knee	Above knee
All s	1.55$\pm$0.006	1.95$\pm$0.020
s $<$ 1.2	1.43$\pm$0.020	1.90$\pm$0.033
s $>$ 1.2	1.66$\pm$0.030	1.88$\pm$0.036

Table 4: Observed values of spectral indices γ for $30^0 < \theta < 60^0$

	Below knee	Above knee
All s	1.52$\pm$0.001	1.99$\pm$0.008
s $<$ 1.2	1.31$\pm$0.028	1.92$\pm$0.015
s $>$ 1.2	1.57$\pm$0.106	2.21$\pm$0.078

depth. These are in good agreement with the result of KASCADE, GAMMA and ANI [5, 3, 2]. This feature may be an indication of heavier primaries for older showers as they have pointed.

Discussion

The present measurement shows that the average s value decreases with N_e up-to 10^6 particles and the measured mean shower age increases slowly with zenith angle for all shower sizes, which is in good agreement with the other experimental observations as well as the theoretical predictions [11, 2, 5]. The slope of linear variation of s with zenith angle increases with shower size but in case of higher shower sizes the change is faster may an indication of mass change or interaction mechanism for high-energy primaries. The change of the lateral age parameter with the atmospheric depth of EAS incidence can be related to the change of the EAS maximum (X_m) with N_e. The gradual increase of X_m with shower size is consistent with other experimental result [6, 4, 9]. The increase of average shower age with shower maxima (fig 2) is consistent with the theoretical consideration. The size spectra for different zenith angles and for different ages show different attenuation. The change of slope as well as the position of the knee may be due to the change of composition and / or interaction mechanism [3]. The knee of the size spectra for young showers is sharper than the knee for all showers spectra may due to the effect of the radial

Table 1: Values of s(0), A and $\frac{ds(\theta)}{dx}$ for different N_e

$N_e \times 10^5$	0.4-0.8	8-1.6	1.6-3.2	3.2-6.0	6-10	10-15	15-25
s(0)	1.274 $\pm$0.003	1.246 $\pm$0.003	1.216 $\pm$0.003	1.192 $\pm$0.003	1.159 $\pm$0.003	1.128 $\pm$0.003	1.152 $\pm$0.003
A	0.185 $\pm$0.007	0.191 $\pm$0.007	0.216 $\pm$0.008	0.232 $\pm$0.008	0.262 $\pm$0.008	0.307 $\pm$0.008	0.318 $\pm$0.008
$\frac{ds(\theta)}{dx} \times 10^4$	1.812 $\pm$0.007	1.877 $\pm$0.007	2.116 $\pm$0.008	2.277 $\pm$0.008	2.573 $\pm$0.008	3.010 $\pm$0.009	3.122 $\pm$0.008

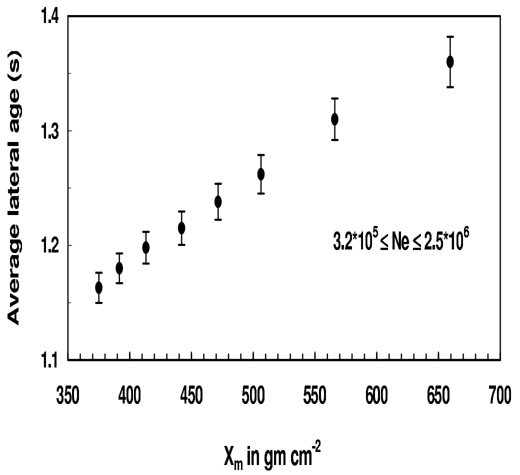

Figure 3: The dependence of shower age (s) on the atmospheric depth of shower maximum (X_m)for $10^{5.5} \leq N_e \leq 10^{6.4}$

variation of shower age and the finite area of the array as mentioned by Capdevielle et al [1].

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