29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

Measurement of electron size spectra and absorption length of EAS below and above the knee of primary

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The electron size spectra of EAS initiated by primaries below and above the knee region are measured for different atmospheric depths by NBU air shower array located at sea level. Similar to the observation of other investigators, the present measurements also show a change in knee position with atmospheric depth. Furthermore, using the angular method of constant intensity of primary the absorption lengths of EAS is estimated and its variation with shower size is studied. The absorption length is observed to decrease significantly with increase of shower size up to knee but remains constant above knee indicating a gradual change in primary composition towards knee, which tend to remain same beyond knee.

1. Introduction

The longitudinal development of EAS in the atmosphere can be studied by the measurement of flux density at the observation level. After shower maximum the intensity of EAS with fixed shower size (N_e) decreases exponentially with atmospheric depth. The dependence of N_e on the atmospheric depth determined by measuring the zenith angle (θ) of shower incidence, can be defined as

$$N_e(\theta) = N_e(\theta = 0^0) Exp[-X_0(sec\theta - 1)/\lambda] \quad (1)$$

where, $N_e(\theta = 0^0)$ is the shower size at the vertical atmospheric depth of observation level and $N_e(\theta)$ is the number of particles at zenith angle (θ) and λ is the attenuation length. In addition to the basic assumption of exponential attenuation of N_e, a power law dependence of the size spectrum can be written as $I(N_e, \theta) \propto N_e{}^{-\gamma}$ with the spectral index γ. Again from the integral size spectrum

$$I(> N_e, \theta) = I(> N_e, \theta = 0^0) Exp[-X_0(sec\theta - 1)/\Lambda] \quad (2)$$

it is seen that the decrease of integral flux $I(>N_e)$ of showers with size ($>N_e$) at a given depth of the atmosphere is depends upon the absorption length (Λ) of showers with size N_e, considering X_0 is the vertical atmospheric depth.

Since the attenuation length depends on the inelastic cross section of the collision between primary and atmospheric nuclei, thus it may be expected to be a mass sensitive parameter. So the study of variation of attenuation length with shower size is of importance to understand the primary composition. Different experimental groups (like KASCADE [1], EAS TOP [2], MAKET ANI [3]) have tried to analyse the knee feature of the primary by measuring the variation of attenuation/ absorption length with primary energy. In the present work we have estimated the absorption length for different size bins in the knee region ($10^{4.6}<N_e<10^{6.4}$) from the zenith angle distribution ($0^0< \theta <46^0$). In addition to that we have also studied the variation of the knee position with shower size from the integral size spectrum.

2. Experimental setup & Data analysis

The North Bengal University (NBU) air shower array situated at 130 m a s l (Latitude $26^0 42'$ N, Longitude $88^0 21'$ E) was setup in the year 1980 and has undergone few changes from time to time reported in our earlier publications [4]. At the time of experiment, during 1998 to 2002, whose results are being reported in this paper, the array consisted of 35 plastic scintillations counters spread over an area of $\sim$3000 m^2. Among these 35 counters, each of area 0.25 m^2 and 5 cm thick, 8 are fast timing detectors. These fast timing detectors were used to determine the arrival direction of shower front. The triggering system of the array, described in [4], facilitates it to detect EAS of size $\sim 10^4$ to 10^6 particles at near sea level. The errors in estimating the shower parameters were determined by the method of artificial shower and NKG distribution function. The typical values of uncertainties were estimated to be $\pm$2m (core position), 9.7%(N_e) and $\pm$0.09(s) at shower size 5×10^5. The resolution in the arrival angle determination was measured by the partial array method, as described in our earlier paper [4]. The resolution of the present setup are estimated to be 1.6^0 in 60^0 zenith and 1.9^0 in azimuth for vertical showers.

3. Experimental results

3.1 Integral Size Spectrum

For the measurement of shower size spectrum, the showers whose cores hit within the area of observation with the detection efficiency not less than 95% were considered. The integral size spectrum for the shower size range $10^{4.6} - 10^{6.4}$ particles in the zenith angle $\theta \leq 46^0$ is presented in fig. 1. The figure shows that the knee position is towards the lower value of N_e with the increase of θ. The figure shows that the knee position shift towards lower N_e with increase of θ. The variation of the measured knee position with the relative atmospheric depth is presented in fig. 2 along with the the experimental results of ANI [5] and KASCADE [6]. Within statistical error, present result is seen to be consistent with the result of other observations. The integral size spectrum is approximated with the equation of the form I ($\geq N_e$) $\propto$ $(N_e/10^5)^{-\gamma}$. The value of power exponent (γ) estimated in the present measurement (-1.38 $\pm$ 0.125) is close to the values estimated by other experiments: KASCADE 1.4, GAMMA 1.6. The spectral indices for the electron size spectra as a function of zenith angle for below (γ_1) and above the knee (γ_2) are presented in fig.3. The weighted average values are γ_1 = -1.55 $\pm$ 0.012 below and γ_2 = -2.056 0.042 above the knee. Furthermore it appears that the variation of γ with θ become steeper with increasing depth (below knee: slope = 0.0006$\pm$ 0.0001 and above knee: slope = 0.0036$\pm$ 0.0006) for the showers above the knee as an indication of change of primary mass[7].

3.2 Absorption length of EAS

The absorption length (Λ) have been estimated from the zenith angle distribution using angular distribution method based on the constant intensity of primary [8, 9]. The basic idea of this procedure is to compare the average size of showers which have the same rate[showers per (m^2 sec. Sr.)] in different bins of the zenith angle of shower incident and different slant depth respectively. If I(N_e,θ) be the rate of showers at zenith angle θ and I(N_e, θ_0) be the rate of vertical showers at the observation level, the zenith angle distribution can be written as

$$I(N_e, \theta) = I(N_e, \theta_0) cos^n \theta \quad (3)$$

The zenith angle distribution for seven different shower size bins and for $\theta \leq 42^0$ are presented in fig.4. Again we can write an approximated but a simplified form of absorption length $\Lambda = X_0 / n$, comparing the expanded value of $Cos^n\theta$ and $Sec\theta$ up to 2^{nd} order, when incident angles are not very high. The present measurement of absorption lengths Λ as a function of shower size is shown in fig. 5 along with the result of the KASCADE experiment [6]. The present measurement is consistent with the result of KASCADE [6] and earlier result of the Kobe University [10]. The differential electron size spectra as a function of zenith angle can be written as

$$I(N_e, \theta)dN_e \propto N_e^{-\gamma} exp[-(\gamma - 1)X_0(sec\theta - 1)/\lambda]dN_e \quad (4)$$

where I(Ne, θ) dN_e is the number of EAS of size between N_e and N_e +dN_e at angle θ. Thus we can write an equation of absorption length $\Lambda = \lambda / (\gamma\text{-}1)$. Therefore, in case of integral size spectrum we have $\Lambda = \lambda / \gamma_{int}$. The measured value of the absorption length at the knee for different atmospheric depth, considering average value of γ (single slope), is presented in table 1.

Table 1. The fitted values of Λ

Atmospheric depth(gm cm^{-2})	1034	1080	1139	1219	1300
Absorption length at knee	144.4±10.1	132.5±10.9	136.7±11.8	135.0±14.1	150.2±16.7

4. Discussion

The experimental measurements of present experiment is seen to be fairly consistent with measurements of other groups [5, 6, 7, 10]. The measurements of integral size spectrum of electrons show smooth variation of knee position with atmospheric depth (fig. 1 & 2). Similar observations were reported by other groups [5, 6]. The exponential variation of the knee with slant depth is consistent with the general assumption of longitudinal development of EAS in atmosphere. The study of variation of spectral indices (γ) of size spectrum with atmospheric depth (fig. 3) shows that the change in spectral indices is significantly different above and below knee. The steeper variation of spectral indices with relative atmospheric depth for the showers above the knee in comparison to the showers below the knee, also reported by KASCADE group [7], could be an indication of change of composition above the knee. The observation of decrease of absorption length with shower size (fig. 5) towards knee and remaining constant thereafter in the present measurement is also consistent with the observations of KASCADE [6] and the ANI [5] experiment. However, with atmospheric depth no such change of absorption length is observed at the knee (table 1).

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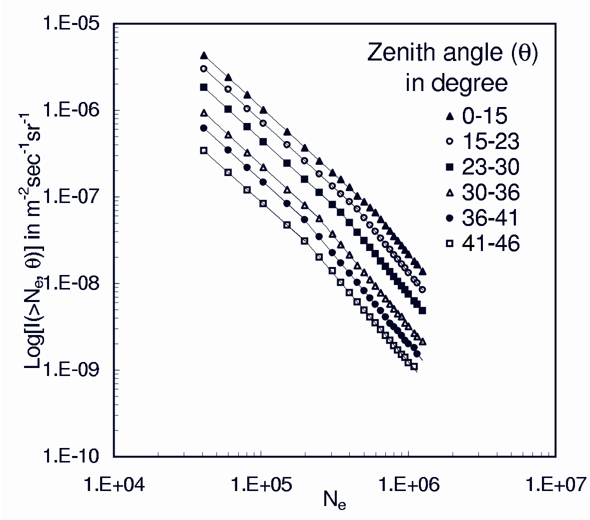

Fig.1: Integral intensity spectrum for different zenith angle

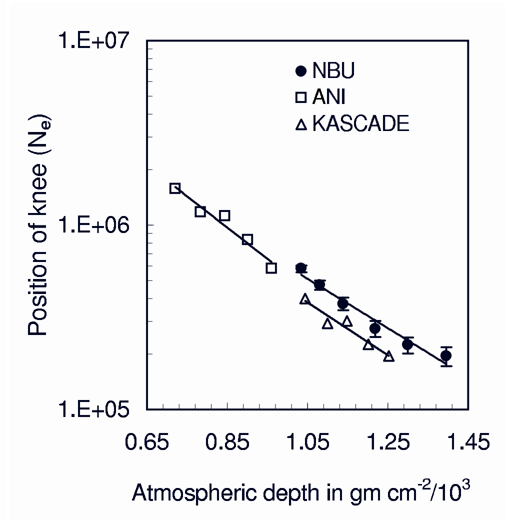

Fig.2: Variation of knee position with slant depth

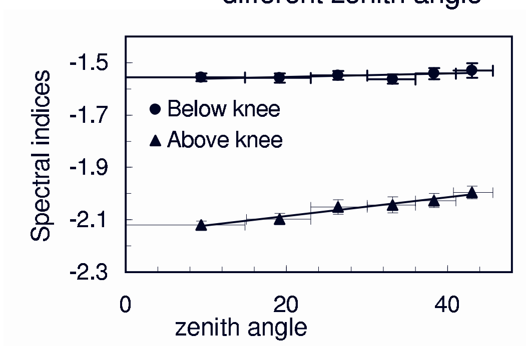

Fig.3: Spectral indeces as a function of atmospheric depth for below and above knee

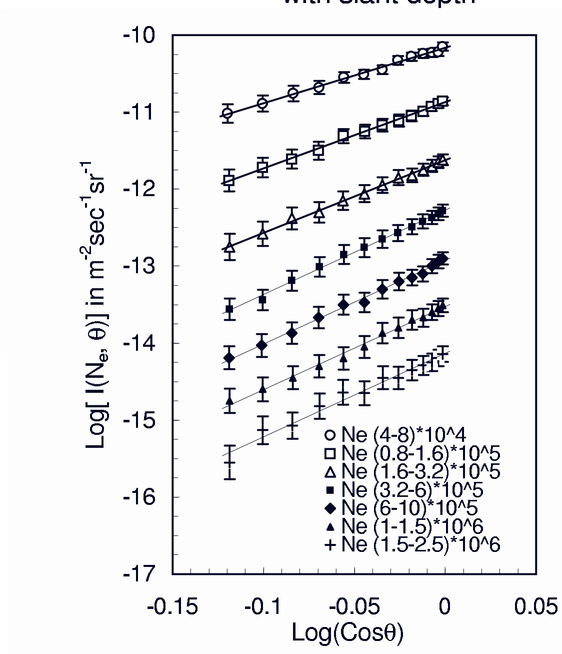

Fig. 4: Intensity distribution of zenith angle for different shower size

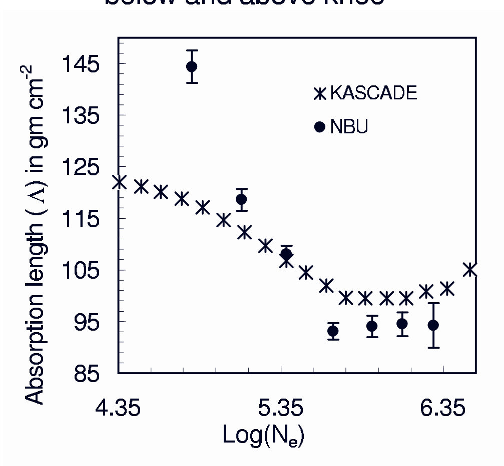

Fig.5 Shower size dependence of absorption length