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# Air showers in the size range $10^{4.25} - 10^{6.45}$ at different atmospheric depths

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## ABSTRACT

The differential size spectra in the size range $10^{4.25} – 10^{6.45}$ for different atmospheric depths obtained by the North Bengal University (NBU) extensive air shower (EAS) experiment shows a systematic shift of the 'knee' towards smaller size with the increase in zenith angle. A comparative study of the characteristics of the air showers in the said size region observed by the present experiment and similar such experiments and simulations has also been made.

## Introduction:

The study of the origin and propagation of cosmic rays need a detailed knowledge about the primary energy spectrum. Direct measurements of the energy spectrum have been carried out up to ~$10^{14}$ eV by balloon and satellite borne detectors (Balasubrahmanyan & Ormes , 1973; Lezniak & Webber , 1978; Akimov et al, 1971) flown to the top of the atmosphere. At energies higher than $10^{14}$ eV the extensive air shower (EAS) technique is the only feasible method by which the energy spectrum can be deduced from different EAS observables. From various measurements it is established that the primary energy spectrum can be well represented as a power law. The steepening of the spectrum at primary energy ~$3x10^{15}$ eV (the so called 'knee') was first detected from the study of EAS size spectra at sea level (Khristiansen & Kulikov , 1958). The existence of the knee was confirmed from the measurements of different components in the EAS at different atmospheric depths . In this paper a study of the characteristics of the air showers at the knee region of the spectrum observed by the present experiment and similar such experiments has been made.

## Experiment:

The EAS array is located at the North Bengal University (NBU) Campus, Darjeeling, India (latitude $26^0 42^/$ N, $88^0 21^/$ E, atmospheric depth 1000 gm.cm. $^{-2}$). The array covers an area of ~2000 $m^2$ consisting of twenty one electron density sampling plastic scintillation detectors, eight fast timing scintillation detectors and two muon magnet spectrographs. Each scintillation detector has been built up with a 50cm. X 50cm. X 5cm. plastic scintillator (NE102A) block fixed at the upper end of an inverted pyramidal shaped light tight box made of galvanized iron sheet which is viewed by a photomultiplier (PM) tube from the lower end. For the electron density measuring detectors any one of Dumont 6364 / RCA 5819 / Philips XP2050 PM tubes are used while Philips XP2020 fast PM tubes (rise time ~2nS) are used for the fast timing detectors. The array has a circular symmetry with ~8m spacing between the detectors.

The detectors are operated under an EAS trigger generated by four- fold coincidence of the fast timing detectors located around the center of the array. This fast coincidence generates the reference time for the time delay measurements by the fast timing detectors. To digitize the relative arrival time delay between the timing detectors the LeCroy 2228A time-to-digital converter (TDC) module is used. The analog pulses from the electron density measuring detectors are digitized using the 8-bit analog-to-digital converters (ADC 0809). The digitized information from the entire ADC and the TDC channels along with the event time are sent to the memory units (62256) for subsequent transfer to the interfaced Computer for permanent storage.

**Data analysis and results:**

The recorded electron densities are corrected for transition effect in plastic scintillator (Asakimori et al, 1981). The estimation of the EAS parameters are performed by means of a chi-square minimization routine using gradient search technique in which the recorded electron densities are compared with the theoretical NKG lateral distribution function (Greisen , 1960).

The arrival direction of the shower front is estimated by minimizing the quantity $\chi^2$ defined as,

$$\chi^2 = w_i \, [\, lx_i + my_i + nz_i + c(t_o - t_i) \,]^2,$$

where $(x_i, y_i, z_i)$ are the coordinates of the $i^{th}$ timing detector, (l, m, n) are the direction cosines of arrival, $t_i$ is the actual arrival time measured at that detector, $t_o$ is the time at which the shower front passes through the origin of the coordinate system, c is the velocity of the shower front and $w_i$ is the statistical weight factor defined as,

$$w_i = (\sigma_{inst}^2 + \sigma_{dsk}^2)^{-1},$$

where $\sigma_{inst}$ is the instrumental uncertainty and $\sigma_{dsk}$ is the uncertainty due to finite thickness of the EAS disk (Linsley, 1985) which is dependent on shower parameters. The instrumental uncertainty measured in the present experiment, $\sigma_{inst}$ = 1.5 nS.

The resolutions in arrival angle determination have been measured by divided array method (Sinha et al, 1990; Acharya et al, 1993) which are $1.2^o$ in zenith and $1.8^o$ in azimuth.

For the construction of the differential size spectrum the showers whose cores hit within the area of >95% detection efficiency are selected. The variation of >95% efficient area in terms of radial distance from the center of the array ($R_{95}$) is shown in fig.1 as a function of $N_e$ for different zenith angles. In the present study the shower size spectra are constructed for different angular bins in such a way that the atmospheric thickness increases by a constant amount (~100 gm.cm.$^{-2}$). The showers are classified into different size bins for a particular zenith angle bin in the whole detection range ($10^{4.25}$ – $10^{6.45}$). Size bins are formed by successive multiplication by √2 starting from the initial size of $10^{4.3}$. The $R_{95}$ is determined for the lower size limit of each bin. The differential shower size spectra for five different atmospheric depths are shown in fig.2. To emphasize the change in slope in the size region $10^5$ – $10^6$ particles, the experimentally measured fluxes are multiplied by $N_e^{2.5}$. The vertical bars represent statistical errors only. The fitted knee positions are plotted as a function

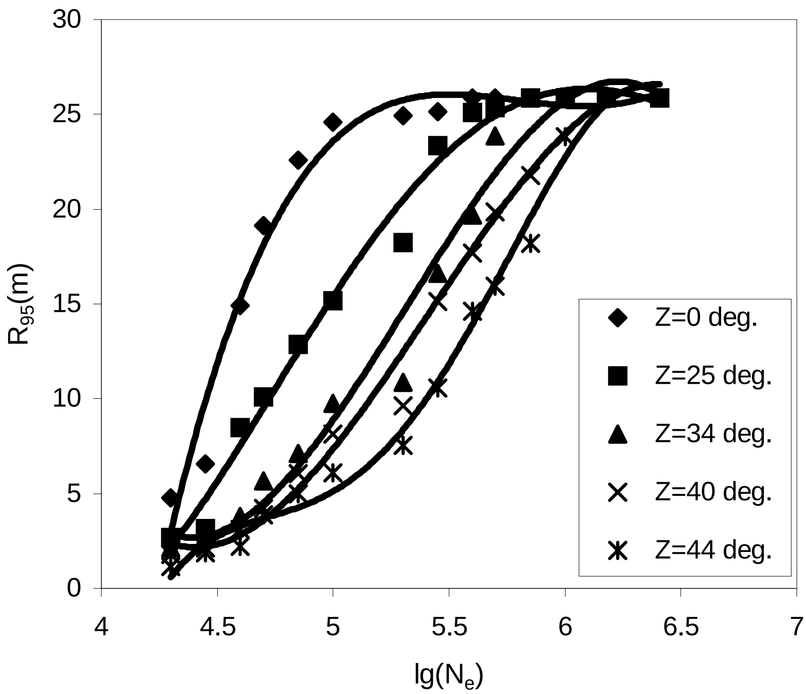


**Fig. 1.**

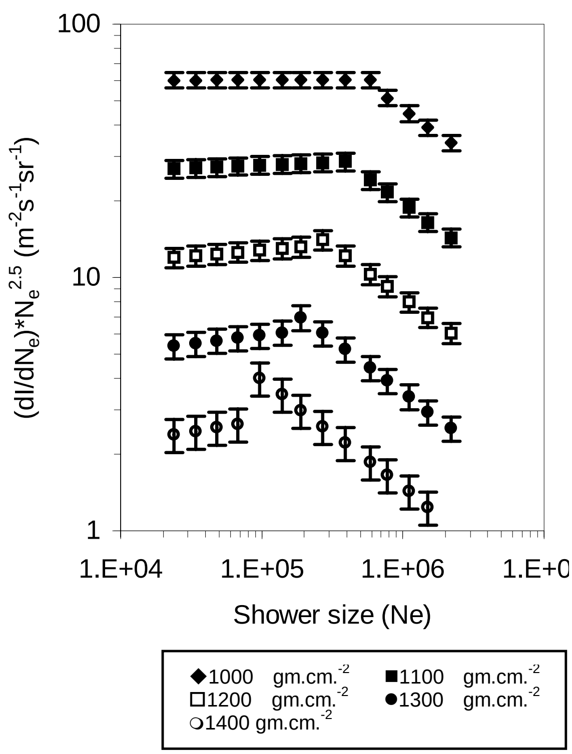


**Fig. 2.**

atmospheric depth in fig.3. The figure also includes the KASCADE data (Chilingarian et al, 1999) and EAS-TOP data (Aglietta et al, 1999).

**Conclusion:**

The observed systematic shift of the knee towards smaller shower size is in agreement with expectation for its appearance at fixed primary energy. The present experimental result follows the same trend observed by KASCADE. The almost constant exponent in the power law energy spectrum of the primary cosmic rays up to the knee energy level may indicate that there is a single cosmic ray source in the galaxy. The same may also be found if the sources that contribute galactic cosmic rays have identical energy spectra.

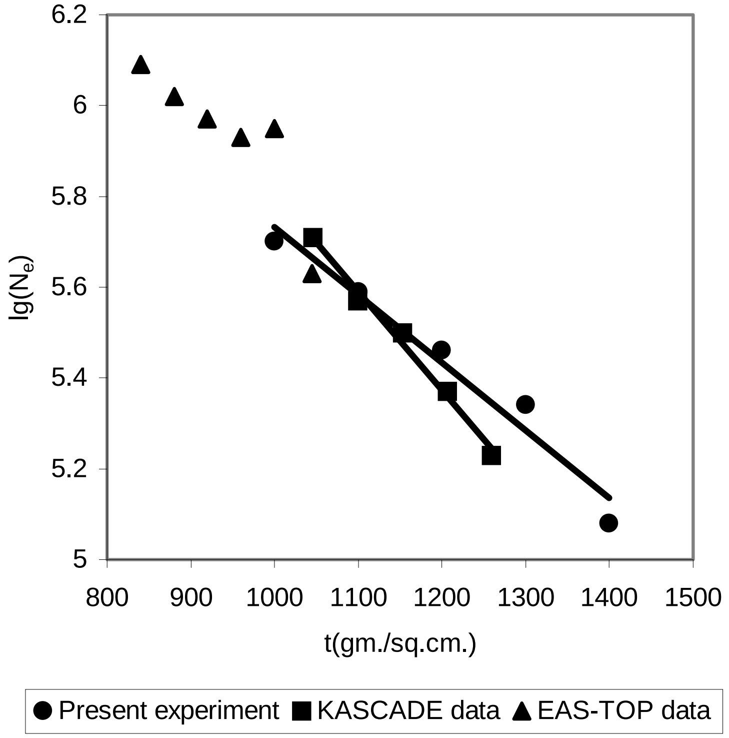


**Fig. 3.**

**References:**

Acharya B.S. et al (1993), Proc.23rd Int. Conf. On Cosmic Rays, Calgary, 1, 212, 388.
Aglietta M. et al (1999), EAS-TOP collaboration, Proc.26rd Int. Conf. On Cosmic Rays, Salt Lake City, 1, 230.
Akimov V.V. et al (1971), Geomagn. & Aeron, 11, 327.
Asakimori K. et al (1981), Proc. 17th Int. Conf. On Cosmic Rays, Paris, 11, 301.
Balasubrahmanyan V.K. & Ormes J.F. (1973), Ap. J., 186, 109.
Chilingarian A. et al (1999), KASCADE collaboration, Proc.26rd Int. Conf. On Cosmic Rays, Salt Lake City, 1, 240.
Greisen K. (1960), Annu. Rev. Nucl. Sci., 10, 63.
Khristiansen G.B. & Kulikov G.V. (1958), Nuov. Cim. Suppl., 8, 742.
Lezniak J.A. & Webber W.R. (1978), Ap. J., 223, 676.
Linsley J. (1985), Proc. 19th Int. Conf. On Cosmic Rays, La Jolla, 3, 461.
Sinha S. et al (1990), Proc. 21st Int. Conf. On Cosmic Rays, 2, 51, 126.