29th International Cosmic Ray Conference Pune (2005) **6**, 353-356

Dependence of EAS size spectrum on a form of charged particle lateral distribution function.

Yu.A.Fomin[a], N.N.Kalmykov[a], J.Kempa[b], G.V.Kulikov[a] and V.P.Sulakov[a]
(a) D.V.Skobeltsyn Institute of Nuclear Physics of M.V.Lomonosov Moscow State University, Moscow 119992, Russia
(b) Politechnika Warszawska, Szkola Nauk Technicznych I Spolecznych w Plocku, Plock 09-400, Polska
Presenter: J.Kempa(kempa@pw.plock.pl), pol-kempa-J-abs1-he13-oral

One of the important problems of extensive air shower (EAS) studies is the investigation of charged particle lateral distribution function (LDF). It is necessary for determination of total number of particles at observation level and this parameter is often used as a measure of shower primary energy. Although the nuclear-cascade process plays the main role in shower development, the Nishimura-Kamata-Greisen (NKG) function of lateral distribution obtained in electron-photon cascade theory is used up to now in the most of experimental works. In this connection we investigated the form of EAS size spectra applying NKG-function and so called "scaling" LDF introduced in [5] which was obtained with taking into account nuclea-cascade process.

1. Introduction

The knowledge of EAS charged particle LDF enables one to determine the total number of particles. In turn, this value can be used (to some extent) as a measure of primary energy or, at least, as a suitable classification parameter.

We used experimental data obtained with the MSU EAS array to study how the EAS size spectrum depends on form of charged particle LDF.

The description of the EAS MSU array is given in [1]. The array covers an area of approximately 0.5 km^2 and includes 77 detectors of charged particle density ρ. Each detector consists of 3 groups of different Geyger counters to measure an interval of densities from 0.5 up to ~ 1500 particles/m^2.

Our previous analysis showed that experimental LDF's are described rather well by the function proposed by Greisen [2]

$$\rho \sim x^{s-2} \cdot (1+x)^{s-4.5} \cdot (1+\beta x) \, ,$$

where s is the age parameter, $x = r / r_0$, $r_0 = 80$ m at sea level and $\beta \sim 0.2 \div 0.4$. However the best agreement can be achieved for the empirical LDF having more complicated form

$$\rho \sim x^{s-2} \cdot (1+x)^{s-4.5} \cdot \left[x \cdot (1+x) \right]^{\alpha} \, ,$$

where parameter α depends on distance from shower axis [3].

Nevertheless in most cases the Nishimura-Kamata-Greisen (NKG) function of the lateral distribution obtained in electron-photon cascade theory [4]

$$\rho \sim x^{s-2} \cdot (1+x)^{s-4.5}$$

is used up to now although the nuclear-cascade process plays the main role in EAS development.

2. Discussion

In present work we used for experimental data analysis the electron LDF [5] calculated on the basis of so called scaling formalism [6] taking into account the nuclear-cascade process in shower. This function has the following form

$$\rho = N_e \cdot 0.28 \cdot R_{m.s.}^{-2} \cdot (r / R_{m.s.})^{-1.2} \cdot (1 + r / R_{m.s.})^{-3.33} \cdot \left[1 + (r / R_{m.s.})^2\right]^{-0.6}$$

where the single parameter $R_{m.s.}$ is the mean square radius. It follows from the calculations [7] that this mean square radius depends on average cascade curve maximum position and consequently on particle primary energy.

Normalized electron LDF's for proton showers are given in Fig.1 for primary energy range 10^{15} – 10^{17} eV which is investigated with the MSU EAS array. Fig.1 shows that the LDF form depends on primary energy rather weak. In particular, in essential for our array interval of distances from shower axis $3-300$ m differences in LDF does not exceed 20%. For example we plot in Fig. 1 also the NKG-function for $s = 1.2$.

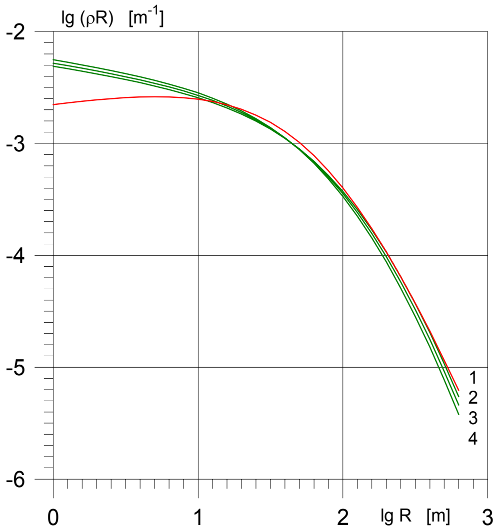

Figure 1. Normalized LDF's

LDF NKG,	$s = 1.2$		(1)
LDF [5]	E_0, eV	$R_{m.s.}, m$	
	10^{15}	153	(2)
	10^{16}	141	(3)
	10^{17}	129	(4)

Then we compared theoretical LDF's with experimental charged particle LDF's for wide range of sizes $N_e = 10^5 \div 3 \cdot 10^7$. Showers in this range were partitioned into narrow size intervals $\Delta \lg N_e = 0.2$. The size N_e in every shower was determined by maximum likelyhood method for NKG-function as a priori LDF function.

In Fig.2 the experimental and calculated LDF's are compared for some intervals $\Delta \lg N_e$. On comparison the value of $R_{m.s.}$ in each interval was determined in the following manner. Knowing the average N_e for NKG- function in each interval we obtained primary energy E_0 using QGSJET-model [8] and then obtained $R_{m.s.}$ according to [5]. Theoretical N_e for each interval were found by the least-squares method. The results of comparison show that calculated functions agree with experimental data rather poorly, especially for small distances from the shower axis. It is clear from Fig. 2 that the NKG-functions agree with experimental LDF much better.

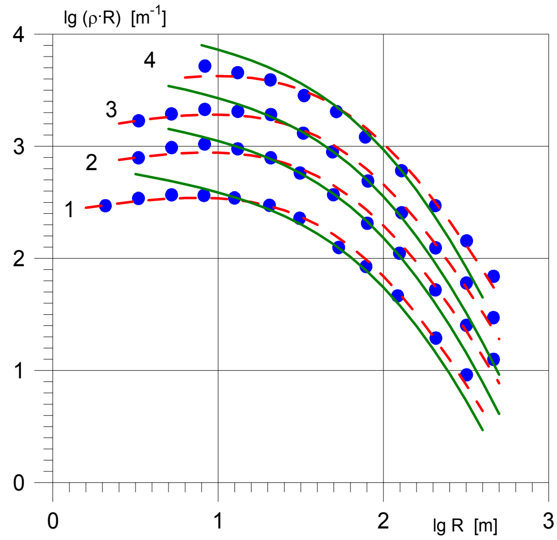

Figure 2. LDF's for different N_e. LDF [5] – solid line; LDF NKG – dashed line.
$1 - \lg N_e = 5.2 - 5.4$, $2 - \lg N_e = 5.6 - 5.8$,
$3 - \lg N_e = 6.0 - 6.2$, $4 - \lg N_e = 6.4 - 6.6$

To obtain the size spectrum using proposed in [5] LDF it is desirable to determine $R_{m.s.}$ and N_e in each shower. However, there exists a large spread of $R_{m.s.}$ values if we determine of $R_{m.s.}$ by maximum likelyhood method, and this spread is considerably greater than theoretical predictions. For many showers it was impossible to determine $R_{m.s.}$. By the way, in [7] the authors direct reader's attention to difficulties of $R_{m.s.}$ determination. On the other hand parameter s in individual showers is defined with a good accuracy if one uses NKG-function. That is why we obtained the size spectrum for LDF with fixed value of $R_{m.s.}$ (the values of $R_{m.s.}$ corresponding to the interval of primary energy of $10^{15} \div 10^{17}$ eV were taken).
The size spectra for nearly vertical showers with zenith angles less 18^o are presented in Fig.3. The indices of power differential spectra before and after knee are shown in table below.

LDF	Before the knee	After the knee
[5]	-2.12	-2.81
NKG	-2.37	-2.87

It is evident that the spectrum obtained for the scaling LDF essentially differs from other available data, especially for energy range before the knee. The spectrum obtained for NKG-functions has the knee at $N_e \sim 4 \cdot 10^5$, and the value of spectral index change is 0.50 ± 0.02 in agreement with our previous results [9].

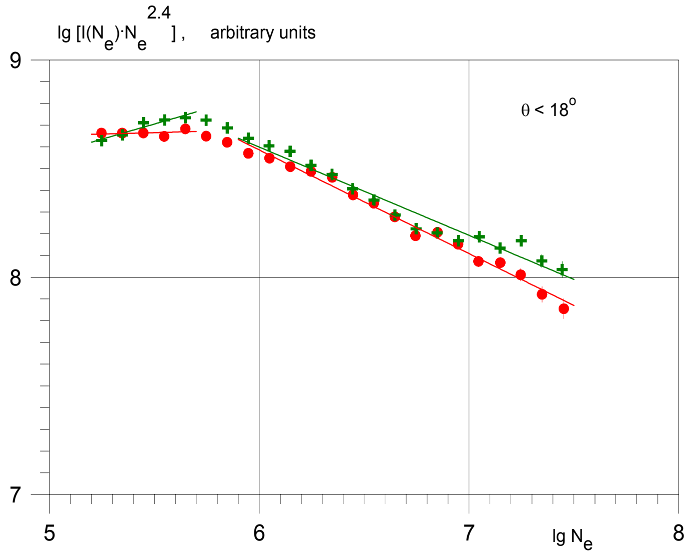

Figure 3. EAS size spectra. Crosses – LDF [5], circles – LDF NKG.

3. Conclusion

So, we conclude that LDF's calculated in [5] and aimed at LDF description at large distances from shower axis (AGASA experiment) agree very poorly with experimental data for smaller distances from shower axis. It is due to the steeper rise of the scaling LDF near the axis as compared with the traditional NKG-function.

4. Acknowledgement

YuF, NK,GK and VS acknowledge the financial support RFBR (grant 05-02-16401).

References

[1] S.N. Vernov et al., Proc.16th ICRC, Kyoto (1979) 8, 129.
[2] K. Greisen K., Ann. Rev.Nucl.Sci. (1966) 10, 63.
[3] Yu.A. Fomin et al., Proc. 28th ICRC, Tsukuba (2003) 1, 119.
[4] K. Kamata and J.Nishimura, Progr.Theor.Phys.Suppl. (1958) 6, 93.
[5] R.I. Raikin et al., Proc 27th ICRC, Hamburg (2001) 1, 290.
[6] A.A. Lagutin et al., Nucl.Phys B (Proc.Suppl.) (1999) 75A, 290.
[7] R.I. Raikin et al., Proc 27th ICRC, Hamburg (2001) 1, 294.
[8] N.N. Kalmykov and S.S. Ostapchenko, Yadernaya Fiz. (1993) 56, 105.
[9] Yu.A. Fomin et al., Proc.22nd ICRC, Dublin (1991) 2, 85.