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Some remarks about lateral distribution function of charged particles at energy above 10^{17} eV

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Abstract: The lateral distribution function (LDF) of charged particles is a basic characteristics of extensive air showers (EAS). It is necessary for determination of the classification parameters which are a measure of shower primary energy: total number of particles at observation level or ρ_{600} - the density of charged particles at 600 m from the shower core.

Introduction

Here we present experimental data of the EAS MSU, Yakutsk and AGASA arrays on LDF of charged particles of superhigh energy EAS. Detailed investigation of EAS LDF is necessary because LDF is a basic shower characteristics for evaluation of primary particle energy of a given EAS.

The EAS MSU array is attributed to the type of "compact" arrays with effective registration area about 0.5 km^2 . Classification parameter of the EAS MSU array which used for evaluation of primary energy is a total number of charged particles at observation level. Charged particle detectors are placed at the central part of the array and at its periphery . The distances between detectors at the periphery are about $100 - 150$ m. [1]. The distinguishing feature of the EAS MSU array is the using of Geiger-Muller counters which have no transition effect.

Scintillator detectors with area of 2 x 2 m^2 are used at Yakutsk [2] and 2.2 m^2 at AGASA [3] arrays. Scintillator detectors have large transition effect. Thus it is necessary to correct their signals for evaluation of charged particle density [4,5].

The Yakutsk and AGASA arrays are attributed to the type of "extended" arrays where the distances between detectors are hundred of meters (500 and 1000 m at Yakutsk and 1000 m at AGASA. The classification parameter for these arrays is ρ_{600} - the density of charged particles at 600 m from the shower core. For determination of ρ_{600} the experimental densities are fitted by empirical LDF. Then the densities for showers with zenith angle θ are transformed using absorption curve for ρ_{600} to the equivalent values for vertical showers ρ_{600} (0) which are converted to the shower primary energy.

As empirical LDF was used the LDF proposed by Linsley [6]. This function was modified by introduction of additional factor which provided more steep behaviour of experimental LDF at distances greater that 1 km from shower core.

In this paper we consider LDF only for showers with primary energies less than $(2\text{-}3)\cdot10^{18}$ eV so far as for greater energies according to [2] the form of LDF changes strongly.

Experimental data

Figure 1 shows the experimental LDF obtained with the EAS MSU array. The showers were selected for zenith angles less 30^0 and for interval of the total number of charged particles $\lg N = 8.0 - 8.2$ ($\bar{N} = 1.2\cdot10^8$, $E_0 \simeq 5\cdot10^{17}$) . The empirical LDF [7] giving the best fit of our

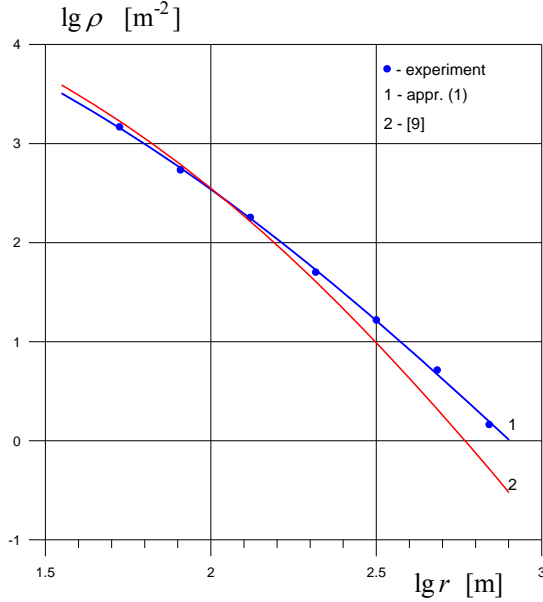experimental data for the less shower size was used for shower selection on number of particles.

Figure 1

We compared our experimental data with LDF (1) suggested by Linsley [6]:

$$\rho(r) = (N/R_m^2) \cdot C(\alpha,\eta) \cdot (r/R_m)^{-\alpha} \cdot (1 + r/R_m)^{-(\eta-\alpha)},$$

$$C = \Gamma(\eta - \alpha)\left[2\pi \cdot \Gamma(2 - \alpha) \cdot \Gamma(\eta - 2)\right]^{-1} \qquad (1)$$

At comparison the value of the Moliere radius R_m was taken equal to 80 m. Figure 1 shows that our experimental data are good fitted by Linsley LDF with values of parameters $\alpha = 1.3$ and $\eta = 3.$ 27. (Note that value of α is near to the value of α used at Yakutsk and AGASA).

Figure 2 shows experimental LDF of charged particles obtained with Yakutsk array for $E_0 = 2 \cdot 10^{18}$ [2]. These data are described by empirical LDF:

$$\rho(r) = C \cdot (r/R_m)^{-\alpha} \cdot (1 + r/R_m)^{-(\eta-\alpha)} \cdot$$
$$(1 + r/2000m)^{-g} \qquad (2)$$

where $\alpha = 1.3$, $g = 1.0$. and η depends on primary energy and zenith angle [8] (for near vertical showers $\eta = 3.18$ for primary energy 3.10^{17} eV and $\eta = 3.50$ for 2.10^{18} eV). Average value of Moliere radius was taken equal to 70 m for Yakutsk conditions. Figure 2 shows good agreement between experimental data and approximation.
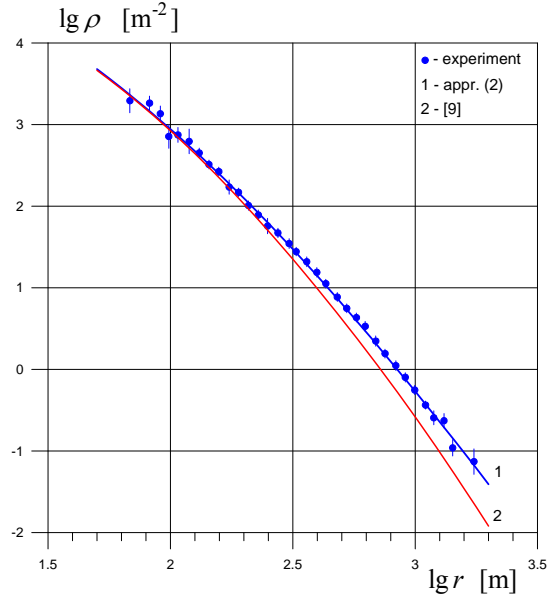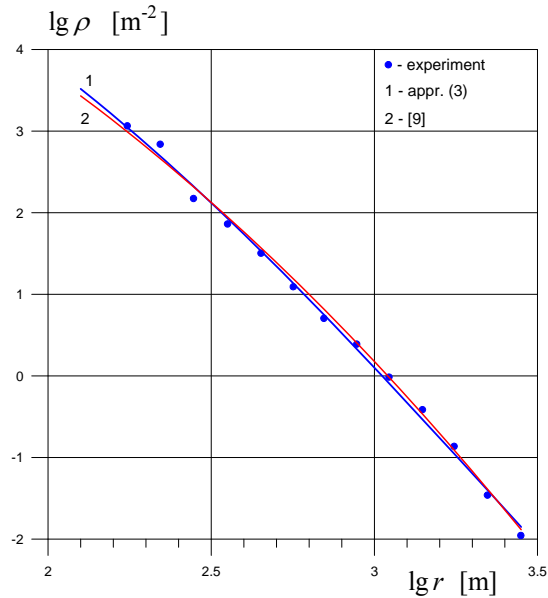

Figure 2

Figure 3

Figure 3 presents the AGASA experimental data for . Empirical LDF (3) was used for their approximation [3]:

$$\rho(r) = C \cdot (r/R_m)^{-\alpha} \cdot (1 + r/R_m)^{-(\eta-\alpha)} \cdot$$
$$(1 + (r/1000m)^2)^{-\delta} \qquad (3)$$

where α = 1.2, δ = 0.6, R_m = 91.6 m, parameter η does not depend on primary energy within experimental errors and strongly depends on zenith angle.

Further we compared experimental LDFs with theoretical predictions [9] for LDF of electrons in EAS based on scaling formalism.

$$\rho_e(r) = N_e \cdot (0.28/R_{ms}^2) \cdot (r/R_{ms})^{-1.2} \cdot$$
$$(1+r/R_{ms})^{-3.33} \cdot \left[1+(r/10\cdot R_{ms})^2\right]^{-0.6} \quad (4)$$

This function was calculated with taking into account the nuclear-cascade process of shower development in the framework of the QGSJET model [10]. The expression (4) is characterized by only parameter R_{ms} - root mean square radius. Calculations [11] showed that R_{ms} depends on the depth of the maximum of the average cascade curve and thus on the primary energy.

To compare the calculations with experimental data the contribution of muons is necessary to take into account [9].
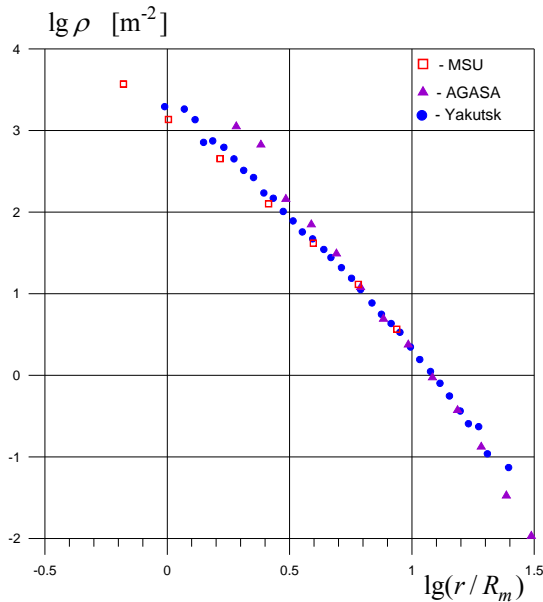

Figure 4

The comparison shows that the best accordance is achieved for the AGASA data (Figure 3) and the least accordance is observed for the MSU data.

It is interesting to compare the data obtained in different experiments. At comparison it is necessary to take into account the difference of Moliere radii in each individual experiment as far as their conditions are different. Results of comparison are shown on Figure 4.

There is a divergence at $(r/R_m) \leq 0.5$. Probably it is related to the overestimate of charged particle density in scintillators because of the transition effect that does the LDFs of more steep.

Acknowledgement

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