EAS SPECTRUM IN THE PRIMARY ENERGY REGION ABOVE 10^{15} eV BY THE AKENO AND THE YAKUTSK ARRAY DATA

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ABSTRACT

The EAS spectrum on scintillation density ρ_{600} in primary energy region $E_o \simeq 10^{15}$-10^{20} eV on the Yakutsk array data and recent results of the Akeno is given.

1. Introduction

At present the EAS observations at sea-level take the widest energy range of primaries. The observed EAS spectra on particle number N in a shower at $E \lesssim 10^{18}$ eV and on particle density ρ_{600} at a distance R=600 m from axis at $E_o >$ 3.10^{17} eV are obtained. Either for the recovery of the spectrum on E_o or for the comparison it is reasonable to obtain these results in aform of "corrected" spectra where effects of the development fluctuations (different for N and ρ_{600}) and N and ρ_{600} measurement dispersions (different for various arrays) are taken into account. To consider the EAS spectrum on the whole it is required also to use in the analysis a common basic unit of measurement of the shower particle number (density) and a common parameter of the shower size. Yet it is reasonable and possible only on the basis of ρ_{600} : there is the experimental estimation of ρ_{600} and E_o relationship and only in the Akeno array data there is the possibility of transition from N to ρ_{600} .

2. Results

a) Yakutsk. In the central part of the array [4] the registration of showers was triggered by a small master (SM) and on the whole array - by a big master (BM). For the analysis the shower events were selected with an axis within fixed receiving areas (different for various ranges of ρ_{600}) and for those periods of the array operation T, when ~100 % - efficiency of registration and levels of $\delta\rho_{600}$ summary relative deviations of fluctuations of the shower development and their measurement dispersions obtained from a total measurement simulation [5] and accepted for the analysis [1,2] were provided. Each shower was individually treated as follows: 1) from approximation of measured particle densities by $\rho(R)_i \propto R^{-n_i}$ [5] n_i and $\rho_{600,i}$ were determined; 2) $\rho_{600,i}$ was reduced to the zenith angle $\theta = 0^\circ$, atmospheric temperature 240 K and pressure 1006 mb (ρ_{600} and E_0 relationship at the atmospheric depth X=1025 g.cm^{-2} at these parameters was found) using the absorption length measured in the experiment $\lambda(\rho_{600}) = (218 \pm 15) + (172 \pm 15)\cdot\sec\theta$, g.cm^{-2}, $\theta < 60^\circ$, a barometric coefficient $\alpha_p = -0{,}25 \pm 0.03$ % per mb and temperature coefficient $\alpha_T(\rho_{600}) = 0.30 \pm 0.11$ % per K. For $-0.35 < \lg\rho_{600} < 0.6$ as an intermediate parameter of shower size the $\rho_{300,i}$ having the absorption length $\lambda(\rho_{300}) = 251 \pm 21$ g.cm^{-2}, $\theta < 40^\circ$ and $\rho_{600} = (0.14 \pm 0.01)\cdot\rho_{300}^{0.89\pm0.02}$ were used.

Data used in spectrum construction on the whole have following common characteristics:

	$\lg[\rho_{600}, m^{-2}]$	$\delta\rho_{600}$	$ST\Omega$, $m^2 s\cdot sr$	Number of events
SM	$-0.35 \div 1$	$0.40 \div 0.17$	$(0.16 \div 4.33)\cdot 10^{13}$	534
BM	$1 \div 1.5$	$0.22 \div 0.21$	$(1.88 \div 4.40)\cdot 10^{15}$	109
BM	> 1.5	0.21	$5.69 \cdot 10^{15}$	79

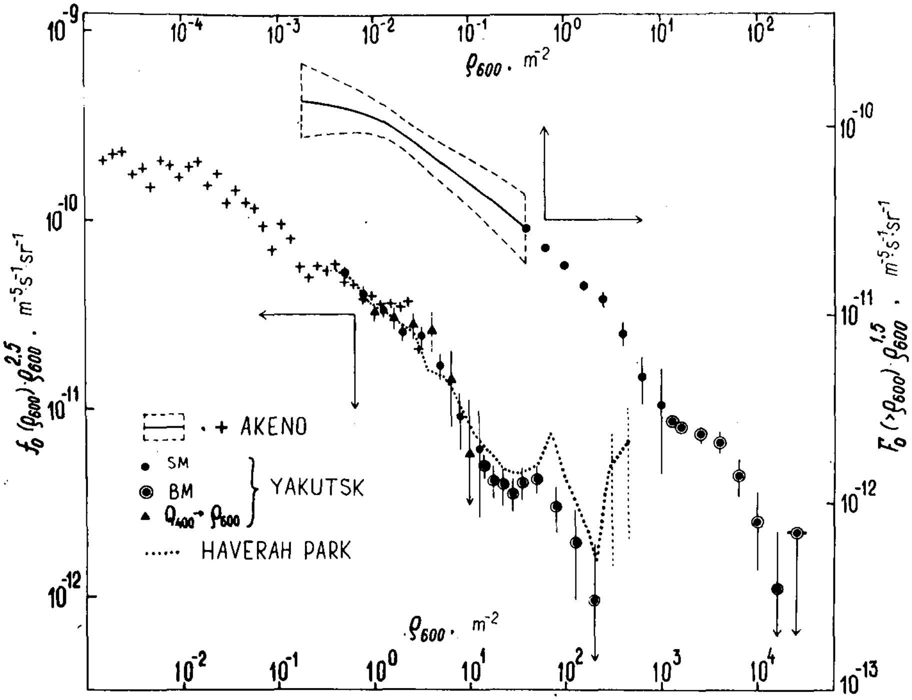
Introducing into the observed intensities the corrections for the summary effect of the development fluctuations and measurement dispersions with the correction factor [2] $K = 0.98\,[1 + \delta\rho_{600}^2]^{-0.5\varkappa(\varkappa-1)}$ the differential $f_0(\rho_{600})$ and the integral $F_0(>\rho_{600})$ corrected EAS spectra (see Figure) were obtained.

The differential spectrum for $-0.3 < \lg\rho_{600} < 1.7$ displays significant irregularities and at the description by $f_0(\rho_{600}) = A(\rho_{600}/10)^{-\varkappa-1}$ has the following parameters:

$\lg\rho_{600}$	$-0.3 \div 0.5$	$0.5 \div 1.2$	$1.2 \div 1.7$	$1.7 \div 2.3$
lg A	$-13.37 \div 0.04$	$-13.63 \div 0.02$	$-13.92 \div 0.05$	$-13.20 \div 0.09$
$\varkappa+1$	$2.95 \div 0.04$	$3.58 \div 0.05$	$2.45 \div 0.10$	$3.43 \div 0.11$

The spectrum on ρ_{600} obtained by the relationship $\rho_{600} = (2.05 \pm 0.11)\cdot(Q_{400}/10^7)^{0.99\pm0.02}$ from the transformation of the density spectrum of the shower atmospheric Cerenkov light Q_{400} [1] and having the form of the spectrum of loss in atmosphere confirms the change for $-0.3 < \lg\rho_{600} < 1$.

In the Figure a dashed line corresponds to the observed spectrum on Haverah Park data [6] reduced by us to the scintillation density ρ_{600} due to [7]. In this case according to [8] the effect of $\delta\rho_{600}$ at $\lg\rho_{600} \lesssim 1$ is small ($\lesssim 10\%$ on intensities) and at $\lg\rho_{600} \gtrsim 1$ somewhat increases. Taking into account this fact we find a satisfactory agreement of the results of both arrays. It is remarkable that the Haverah Park spectrum reveals also the steepening tendency for $1.8 \lesssim \lg\rho_{600} \lesssim 2.3$.



b) Akeno. The observed EAS spectrum at sec $\theta = 1.1$ (at the depth 1011 $g.cm^{-2}$) is given by $f(N_e)dN_e = A(N_e/10^6)^{-\varkappa_N} N^{-1}$ with $A = (1.2 \pm 0.2)\cdot 10^{-13} m^{-2} s^{-1} sr^{-1} part.^{-1}$, $\varkappa_N = 1.49 \pm 0.17$ for $5 < \lg N_e < 6$ and $\varkappa_N = 1.80 \pm 0.12$ for $6 < \lg N_e < 8$. Some corrections were made: the spectrum is reduced to the Yakutsk level 1025 $g.cm^{-2}$ with absorption length $\lambda(N_e) =$ 235 $g.cm^{-2}$; the effect of the shower development fluctuations was taken into account on [9] with average correction factor $\overline{K}_\delta = 0.89\cdot[1 + \delta N_e^2]^{-0.5\varkappa_N(\varkappa_N - 1)} = 0.77$ where the deviations were taken according to [10] to be 0.7 for $5 < \lg N_e < 6$ and 0.44 for $6 < \lg N_e < 8$.

From [11,12] we find $\lg\rho^*_{600} = \lg[\rho^*_{600,e} + \rho^*_{600,\mu}] =$ $= 0.961 \lg N_e - 7.46$ at the depth 966 $g.cm^{-2}$ at $T = 279$ K.

Recounting ρ_{600} to depth 1025 $g.cm^{-2}$ with $\lambda(\rho_{600}) = 390$ $g.cm^{-2}$ at $T = 240$ K with $\alpha_T = 0.3$ % per K and to the Yakutsk basic unit of muon equivalent having the relationship $u_\mu/u_e = 1.15$ with the electron equivalent unit [3] the relationship $\lg\rho_{600} = 0.96\cdot\lg N_e - 7.534$ is obtained.

In the Figure the differential and integral corrected EAS spectra on ρ_{600} from the Akeno data are given. For $\lg\rho_{600} < 0.12$ we obtain: $f_o(\rho_{600})d\rho_{600} = A_o(\rho_{600}/10^{-1.80})^{-æ-1}d\rho_{600}$ with $A_o = (1.2 \pm 0.2)\cdot 10^{-5.297} m^{-2}\cdot s^{-1}\cdot sr^{-1}(part./m^2)^{-1}$, $æ = 1.55 \pm 0.18$ for $-2.76 < \lg\rho_{600} < -1.80$ and $æ = 1.88 \pm 0.13$ for $\lg\rho_{600} > -1.80$.

3. Conclusion

In the considered 5-decade energy range the EAS spectrum on ρ_{600} reveals significant irregularities. For $\lg\rho_{600} < 1.2$ the steepening(rather consecutive) of inclination of $f_o(\rho_{600})$ with increase of ρ_{600} occurs: $-æ-1 = -2.55 \pm 0.18$; -2.88 ± 0.12; -2.95 ± 0.04 and -3.58 ± 0.05 for $\Delta\lg\rho_{600} = -2.76 \div -1.8$; $-1.8 \div -0.3$; $-0.3 \div 0.5$ and $0.5 \div 1.2$, respectively. At $\lg\rho_{600} > 1.2$ the irregularity is observed: $-æ-1 = -2.45 \pm 0.1$ at $1.2 < \lg\rho_{600} < 1.7$ and $-æ-1 \lesssim -3$ at $1.7 < \lg\rho_{600} < 2.3$. We assume that four shower events with $\lg\rho_{600} > 2.3$ from the spectrum of [6] if to eliminate the effects of methodical character could indicate the possible existence of the other irregularity in the range out of the control of the Yakutsk array.

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