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 $\rho_{600}$ in primary energy region $E_0 \approx 10^{15}-10^{20}$ 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 $E \leq 10^{18}$eV and on particle density $\rho_{600}$ at a distance $R=600$ m from axis at $E_0 > 3 \times 10^{17}$eV are obtained. Either for the recovery of the spectrum on $E$ or for the comparison it is reasonable to obtain these results in a form of "corrected" spectra where effects of the development fluctuations (different for $N$ and $\rho_{600}$) and $N$ and $\rho_{600}$ 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 $\rho_{600}$: there is the experimental estimation of $\rho_{600}$ and $E$ relationship and only in the Akeno array data there is the possibility of transition from $N$ to $\rho_{600}$.

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 $\rho_{600}$) and for those periods of the array operation $T$, when $\sim 100\%$ - 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 $\rho(R) \propto R^{-n}$ [5] $n$ and $\rho_{600}$ were determined; 2) $\rho_{600}$ was reduced to the zenith angle $\theta = 0^\circ$, atmospheric temperature $240$ K and pressure $1005$ mb ($\rho_{600}$ and $F_0$ 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 $-0.35 < \log \rho_{600} < 0.6$ as an intermediate parameter of shower size the $\rho_{300}$ having the absorption length $\lambda(\rho_{300}) = 251 \pm 21$ g.cm$^{-2}$, $\theta < 40^\circ$ and $\rho_{600} = (0.14 \pm 0.01) \cdot 0.89 \pm 0.02$ were used.

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

<table>
<thead>
<tr>
<th>$\log[\rho_{600}, \text{m}^{-2}]$</th>
<th>$\delta \rho_{600}$</th>
<th>$\text{STO, m}^2 \cdot \text{s} \cdot \text{sr}$</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM $\log 0.35$ + 1</td>
<td>0.40 + 0.17</td>
<td>(0.16 + 0.33) $\cdot 10^{13}$</td>
<td>534</td>
</tr>
<tr>
<td>BM $1 + 1.5$</td>
<td>0.22 + 0.21</td>
<td>(1.88 + 4.40) $\cdot 10^{15}$</td>
<td>109</td>
</tr>
<tr>
<td>BM $&gt; 1.5$</td>
<td>0.21</td>
<td>5.69 $\cdot 10^{45}$</td>
<td>79</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>$\log \rho_{600}$</th>
<th>$0.3 + 0.5$</th>
<th>$0.5 + 1.2$</th>
<th>$1.2 + 1.7$</th>
<th>$1.7 + 2.3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\log A$</td>
<td>$-13.37 + 0.04$</td>
<td>$-13.63 + 0.02$</td>
<td>$-13.92 + 0.05$</td>
<td>$-13.20 + 0.09$</td>
</tr>
<tr>
<td>$\chi + 1$</td>
<td>$2.95 + 0.04$</td>
<td>$3.58 + 0.05$</td>
<td>$2.45 + 0.10$</td>
<td>$3.43 + 0.11$</td>
</tr>
</tbody>
</table>

The spectrum on $\rho_{600}$ obtained by the relationship $\rho_{600} = (2.05 \pm 0.11) \cdot (Q_{400}/10^7)^{0.99 \pm 0.02}$ 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 $-0.3 < \log \rho_{600} < 1$.

In the Figure a dashed line corresponds to the observed spectrum on Hanawah Park data [6] reduced by us to the scintillation density $\rho_{600}$ due to [7]. In this case according
to [8] the effect of $\delta_6^{600}$ at $\log \rho^{600} \leq 1$ is small ($\approx 10\%$ on intensities) and at $\log \rho^{600} \geq 1$ 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 $1.8 \leq \log \rho^{600} \leq 2.3$.

b) Akeno. The observed EAS spectrum at sec $\theta = 1.1$ (at the depth 1011 g.cm$^{-2}$) is given by $f(N_e) dN_e = A(N_e / 10^6)^-\varepsilon_N^{-1}$ with $A = (1.2 \pm 0.2) \times 10^{-13}$ m$^{-2}$ s$^{-1}$ sr$^{-1}$ part.$^{-1}$, $\varepsilon_N = 1.49 \pm 0.17$ for $5 < \log N_e < 6$ and $\varepsilon_N = 1.80 \pm 0.12$ for $6 < \log N_e < 8$.

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 $K_\delta = 0.89 \times [1 + \delta N_e^2]^{-0.5} \varepsilon_N (\varepsilon_N^{-1}) = 0.77$ where the deviations were taken according to [10] to be 0.7 for $5 < \log N_e < 6$ and 0.44 for $6 < \log N_e < 8$.

From [11,12] we find $\log \rho^{*}_{600} = \log [ \rho^{*}_{600, e} + \rho^{*}_{600, \mu} ] = 0.961 \log N_e - 7.46$ at the depth 966 g.cm$^{-2}$ at $T = 279$ K.
Recounting \( \rho_{600} \) 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 \( \log \rho_{600} = 0.96 \cdot \log \bar{N}_e - 7.534 \) is obtained.

In the Figure the differential and integral corrected EAS spectra on \( \rho_{600} \) from the Akeno data are given. For \( \log \rho_{600} < 0.12 \) we obtain: \( f_0 (\rho_{600}) d\rho_{600} = A_0 (\rho_{600} / 10^{-1.80})^{2.95} d\rho_{600} \)

with \( A_0 = (1.2 \pm 0.2) \cdot 10^{-5.297 m^{-2} s^{-1} sr^{-1} \text{(part.}/m^2)^{-1} \}

\( \se = 1.55 \pm 0.18 \) for \(-2.76 < \log \rho_{600} < -1.80 \) and \( \se = 1.88 \pm 0.13 \) for \( \log \rho_{600} > -1.80 \).

3. Conclusion

In the considered 5-decade energy range the EAS spectrum on \( \rho_{600} \) reveals significant irregularities. For \( \log \rho_{600} < 1.2 \), the steepening (rather consecutive) of inclination of \( f_0 (\rho_{600}) \) with increase of \( \rho_{600} \) occurs: \( -\se = -2.55 \pm 0.18; -2.88 \pm 0.12; -2.95 \pm 0.04 \) and \( -3.58 \pm 0.05 \) for \( \Delta \log \rho_{600} = -2.76 \pm 1.8; -1.8 \pm 0.3; -0.3 \pm 0.5 \) and \( 0.5 \pm 1.2 \), respectively. At \( \log \rho_{600} > 1.2 \) the irregularity is observed: \( -\se = -2.45 \pm 0.1 \) at \( 1.2 < \log \rho_{600} < 1.7 \) and \( -\se = -3 \) at \( 1.7 < \log \rho_{600} < 2.3 \). We assume that four shower events with \( \log \rho_{600} > 2.3 \) 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.

References

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ver, 4, 2507.