HADRON INTENSITY AND ENERGY SPECTRUM
AT 4380 m ABOVE LEVEL

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The flux value of hadrons with $E_k^{(n)} \geq 5$ TeV, where $E_k^{(n)}$ is the energy transferred into electromagnetic component is presented. It is shown that the energy spectrum slope $\beta$ of hadrons with $E_k \geq 20$ TeV is equal to 1.9.

The present work is based on the experimental data obtained by means of "Pamir" carbon X-ray chamber. [1] contains the detailed description of detectors's arrangement.

Two sets of experimental data are used.

The first of them represents the result of exposure of "Pamir 77-78" chamber $ST = 60$ m$^2 \times 11$ months. The lead thickness $t$ in hadron block is equal to 10 c.u. For each spot coordinates, zenith and azimuthal angles and darkness have been measured. Hadrons with zenith angle $\theta < 20^\circ$ have been used only.

The second set of the experimental data is composed by selection of spots with darkness $D_\infty \geq 0.6$, measured by aperture of the radius $r = 140 \mu m$, that approximately corresponds to $E_k^{(n)} > 25$ TeV. On the total area $S = 471$ m$^2$ hadrons with zenith angles $\theta < 20^\circ$ have been selected in the chambers with lead thickness in hadron $t = 8$.

In all used chambers carbon layer was 60 cm thick.

Connection between $E^+ - E_k^{(n)}$ spectra is given in the [2] (here $E^+$ is an energy estimated by means of the dependence $E(D)$ for $e^+e^-$-pair, the so-called "$e^+e^-$-pair curves", and $E_k^{(n)}$ is an energy in fact transferred into
electromagnetic component):

\[ I(\geq E_k^{(\nu)}) = C 10^{B(E_k^+ - E^-_k)} \]  

According to [2], in the case of \( r = 140 \mu m \), if \( E_k^+ \) will be estimated by "\( e^+e^-\) pair curves" for \( t_0 + \Delta t \), where \( t_0 \) is the lead thickness in chamber and \( \Delta t \) is equal to 2 c.u., the parameters will take the following values: \( B = 0, \Delta = 0. \)

Hence, to obtain the correct estimate of \( E_k^{(\nu)} \) one can use curves for lead thickness \( t = 12 \) c.u. in the first set of experimental data and \( t = 10 \) c.u. in the second one.

Both sets of data are presented in Table 1.

<table>
<thead>
<tr>
<th>No of set</th>
<th>Area (m²)</th>
<th>( N(E_k^{(\nu)} \geq 7 \text{ TeV}) )</th>
<th>( N(E_k^{(\nu)} \geq 30 \text{ TeV}) )</th>
<th>( N(E_k^{(\nu)} \geq 100 \text{ TeV}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>422</td>
<td>24</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>471</td>
<td>-</td>
<td>197</td>
<td>29</td>
</tr>
</tbody>
</table>

The value of vertical intensity of hadron flux is calculated by well-known formula:

\[ I_o (\geq E_k^{(\nu)}) = \frac{N}{S T \omega} \left( \frac{1}{\rho(\theta_o)} \right) \frac{m+2}{2 \pi} \]  

where \( N \) is number of hadrons with \( E_k^{(\nu)} \) greater than the threshold; \( S \) is chamber area; \( T = 2.7 \times 10^7 \) s exposure time; \( \omega = 0.55 \) is the probability of hadron interaction in chamber; \( \rho(\theta) = 1 - \cos^m \theta \) is the angular factor, which converts hadrons intensity for \( \theta < \theta_o \) to the global one with \( \theta_o = 90^\circ \) (\( m \) is the exponent of angular distribution of hadrons, registered in hadron block); \( (m + 2)/2 \pi \) is converting factor from global intensity to the vertical one. Here \( m \) is the exponent of angular distribution for hadrons falling on the chamber. According to [1], \( m = H/\lambda + 2 = 8 \pm 1 \). Here \( H = 600 \text{ g/cm}^2 \) is atmospheric depth, \( \lambda = 90 + 100 \text{ g/cm}^2 \) is the attenuation length for protons.
The experimental value of $m'$, obtained by formula

$\frac{(m'+2)}{(m'+3)} = \langle \cos \theta \rangle$

where $\langle \cos \theta \rangle = 0.92 \pm 0.01$ is the average cosinus of zenith angle is equal to $m = 9.5 \pm 1.5$, that is in a satisfactory agreement with results of Monte-Carlo simulations for $m = 8$.

Thus, vertical intensity values obtained from experimental sets turned out to be in a good agreement with each other

$I_o(E^{(\gamma)} > 5 \text{ TeV}) = (2.7 \pm 0.1) \cdot 10^{-10} \text{ cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ \hspace{1cm} (4)

$I_o(E^{(\gamma)} > 30 \text{ TeV}) = (0.7 \pm 0.1) \cdot 10^{-11} \text{ cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ \hspace{1cm} (5)

The slopes of energy spectra are in a good agreement also. In Fig. 1 the concluding $E^{(\gamma)}$ spectrum with the slope $1.9 \pm 0.1$ is presented (here after the statistical errors are only given).

For chambers under investigation the value of effective coefficient $K_{\text{eff}} = E^+/E_k$ (here $E_k$ is the energy of incident hadron) is given in [3]. At $E^+ = 5 \text{ TeV}$ $K_{\text{eff}}$ it is equal to 0.25. As energy $E^+ = 5 \text{ TeV}$ turns into $E = 20 \text{ TeV}$, and since the value $E^+ = 5 \text{ TeV}$ corresponds to $E = 7 \text{ TeV}$:

$I_o(E^{(\gamma)} > 5 \text{ TeV}) = I_o(E_k > 20 \text{ TeV})$

\[ [E_k^{(\gamma)}]^{-0.9} I_o(E^{(\gamma)}) \]

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\[ x \text{ set one} \]
\[ \cdot \text{ set two} \]
Thus, we can obtain energy spectrum of hadrons in the interval $20 + 300$ TeV:

$$I_0(>E_h) = (1.4 \pm 0.1) \cdot 10^{-10} \left( \frac{E_h}{20 \text{ TeV}} \right)^{-1.9 \pm 0.1} \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1} \quad (6)$$

In Table 2 the comparison with data from different installations is given. Each value of hadron flux intensity is calculated for Pamir altitude ($H_0 = 600 \text{ g/cm}^2$) and energy $E_h^{(\gamma)} \geq 5$ TeV.

Table 2.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$I_0(E_h^{(\gamma)} \geq 5 \text{ TeV})(\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1})$</th>
<th>The slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fudji [4]</td>
<td>$(3.2 \pm 0.2) \cdot 10^{-10}$</td>
<td>$2.0 \pm 0.1$</td>
</tr>
<tr>
<td>Canbala [5]</td>
<td>$(2.9 \pm 0.1) \cdot 10^{-10}$</td>
<td>$1.85 \pm 0.1$</td>
</tr>
<tr>
<td>&quot;Pamir&quot; Pb chamber [1]</td>
<td>$(1.9 \pm 0.4) \cdot 10^{-10}$</td>
<td>$1.96 \pm 0.1$</td>
</tr>
<tr>
<td>This work</td>
<td>$(2.7 \pm 0.1) \cdot 10^{-10}$</td>
<td>$1.9 \pm 0.1$</td>
</tr>
</tbody>
</table>

REFERENCES

1. Trudy FIAN, v.154, p.39 (in Russian)
2. Wlodorzcik et al. (in press)
3. Pamir collaboration, 18th ICRC v.11, p.122, 1983