Comparison of Some Parameters of EAS Initiated by Light and Heavy Nuclei in the Region of Energy Spectrum Break

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Abstract

For the first time the comparison of EAS parameters, initiated by light and heavy nuclei was performed at Tien-Shan. The distinction of parameters of EAS, selected by EAS array, and installation recording Vavilov-Cherenkov Radiations (V-ChR), allows (at least on the average) to determine parameters of showers initiated by light and heavy nuclei at identical initial energy.

1. Tien-Shan EAS Complex

Tien-Shan array [1] has 112 scintillators with $S = (0.25-1.0)m^2$ controlled the area inside the circle with radius R=70 meters and 10 detectors of V-ChR located at distances from 0 up to 300 meters from shower array center. Seven nearest detectors ($R < 110m$) consist of single phototube with photocathode diameter d=15 cm looking up. Three distant detectors at distances 111, 241 and 301 m contain 9, 18 and 36 analogous phototubes. Such installation with dense central part have permit to find out the EAS axis position with accuracy not worst than 2 meters and estimate the EAS parameters with small errors [2].

2. EAS Energy Estimation

To find factor of conversion from a flux of V-ChR Q, measured in a ring with radii 50 and 150 meters from an shower axis, to energy of the particle which has initiated EAS, we have carried out comparison of Cherenkov photons lateral distribution (LD), calculated for a primary proton with energy $E_0 = 10^{16}$ eV on QGS model [4], with experimental LD at selection of showers on number of particles. For comparison 68 showers in a narrow interval on $N_e = (5.69-10.1)\cdot 10^6$ particles were selected. It was received [6] the good consent of experimental and calculated LD of V-ChR. The average meaning of V-ChR flux for these showers $< Q >= 1.58 \cdot 10^{11}$ photons. Thus, for an estimation of primary energy of the particle which initiated a shower, on a flux of V-ChR, we used the formula $E = 6.33 \cdot 10^4 Q$ [eV]. The uncertainty of this factor of recalculation at energy 10^{16} eV does not exceed $\pm 10\%$.

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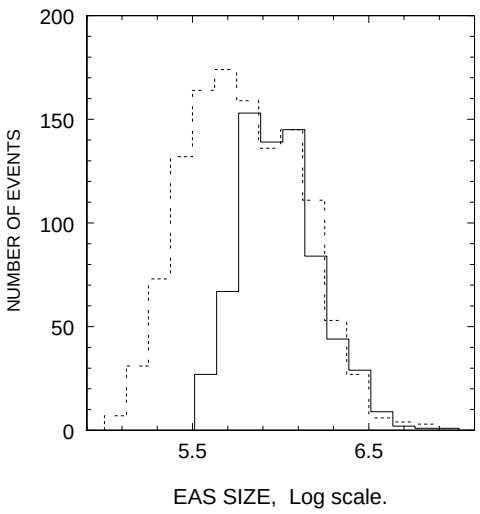

Fig. 1. $W(N)$ at Q_fix(dotted); $W(Q)$ at N_fix (solid); see text.

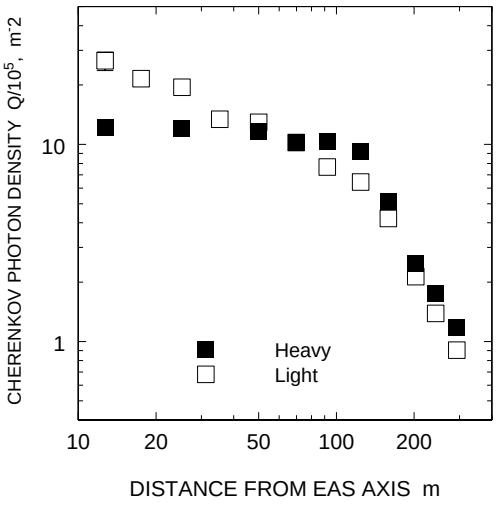

Fig. 2. Cherenkov photon LD: light primaries (squares); heavy primaries (black).

3. Selection of EAS Initiated by Heavy Nuclei

It were compared the distribution of EAS on V-ChR flux $W(Q)$, at the fixed shower size N_{fix}, with distribution of showers on number of particles $W(N_e)$, at the fixed flux of V-ChR Q_{fix}. In Fig. 1 the distribution $W(Q)$ is given at $N_{fix} = (1.00 - 1.33) \cdot 10^6$ at average $< N_{fix} >= 1.16 \cdot 10^6$ and $< Q >= 3.54 \cdot 10^{10}$. The number of events here is 695.

Distribution of showers $W(N_e)$ here is shown at $Q_{fix} = (3.16 - 4.22) \cdot 10^{10}$ photons; here $< Q_{fix} >= 3.6 \cdot 10^{10}$ that corresponds $< E_0 >= 2.3 \cdot 10^{15}$ eV, and $< N_e >= 8.42 \cdot 10^5$. The number of events here is 1221. The position on an abscissa axis in this figure (number of particles in a shower) for distribution $W(Q, N_{fix})$ is chosen as follows: the average $< Q >$ is placed at meaning $< N_{fix} >$. We call attention to the equality of average values $< Q >$ and $< Q_{fix} >$ in these distributions. It is seen that the right parts of its coincide near completely. However, the distribution $W(N_e)$ at Q_{fix} is much wider than distribution on $W(Q)$ at N_{fix}. More than 40% of showers with Q_{fix} there has a much smaller size. Average age for the right and left part of this distribution differ: at N_e, greater, than $< N_e >$, showers are younger: their age $< S >= 0.85 \pm 0,010$, and at N_e, smaller than $< N_e >$, showers older: their age $< S >= 0.92 \pm 0,022$. Such distinction in EAS size and in the age of showers allows to assume, that the showers from the left part of distribution $W(N_e, Q_{fix})$ are initiated, basically, by primary heavy nuclei. The showers from nuclei faster develop, reach the maximum and are absorbed, in comparison with showers initiated by primary

protons. Therefore at a level of mountains they have smaller number of particles and greater age. From the given comparison it is possible to conclude, that the EAS arrays in the given energy interval select mainly showers initiated by protons and, probably, nuclei of helium. The installations recording V-ChR select all showers with identical energy realized in an atmosphere. Using this circumstance, we have carried out comparison of some parameters of EAS, initiated (on the average) by light and heavy nuclei.

4. Comparison of EAS Parameters

It were compared [3] lateral distributions of V-Ch photons and electrons for these groups of showers. For this purpose 1105 showers with $N_e = (1.00-1.78)\cdot 10^6$ particles (selected by shower array) were used, at a flux of V-ChR, registered in a ring with radiuses 50 and 150 meters from shower axis $< Q >= 3.74 \cdot 10^{10}$, and also 1925 showers with $Q = (3.16 - 5.62) \cdot 10^{10}$ at $< N_e >= 9.11 \cdot 10^6$ for showers selected by installation, recording V-ChR. An average V-Ch photon flux in these 2 groups of showers and, hence, energy of the particles which have formed these showers, practically are identical. Average energy of these showers $< E >= 2.57 \cdot 10^{15}$ eV. Lateral distribution (LD) for heavy nuclei were defined as a difference between LD for all showers minus LD for light nuclei, taking into account the statistics of events. In a fig. 2 LD of V-ChR are shown. It is seen, that for heavy nuclei down to distances ~ 100 meters from an axis of a shower LD practically do not change. LD for showers initiated by light nuclei, is quite a different: it smoothly falls down, since small distances from an axis, and is crossed with LD from heavy nuclei in area of 60 meters from an axis of a shower. Only behind 100 meters its slope approximately coincides with an LD slope for heavy nuclei. Electron LD for heavy nuclei up to the distances ~ 3 meters from an axis of a shower practically do not change. All electron LD in showers from heavy nuclei lays below, than LD for light nuclei, and a little more flat.

We have compared also [3] some parameters of EAS, initiated by light and heavy nuclei. For this purpose we have selected 695 showers in a narrow interval on $N_e = (1.00 - 1.33) \cdot 10^6$ particles at $< N_e >= 1.15 \cdot 10^6$ particles and $< Q >= 3.54 \cdot 10^{10}$ photons. Also was selected 1221 showers in a narrow interval on $Q = (3.16 - 4.21) \cdot 10^{10}$ photons of V-ChR at $< Q >= 3.6 \cdot 10^{10}$ photons and $< Ne >= 8.12 \cdot 10^5$ particles. The parameters of showers initiated by heavy nuclei, were determined, as a difference of parameters for all showers and showers initiated by light nuclei, taking into account the statistics of events. It were compared the following parameters: number of events; an average flow of V-ChR $< Q >$; an average number of particles in showers $< N_e >$; average age of showers $< S >$; the ratio of density of V-ChR flow on distance of 50 meters from an axis of a shower to similar density on distance of 150 meters $a = \rho_{50}/\rho_{150}$. According to paper [5] this ratio characterizes distance from a level

Table 1. EAS Parameters

Type	Events	$\langle Q\rangle/10^{10}$	$\langle N_e\rangle/10^5$	$\langle S\rangle$	$\langle\rho_{50}/\rho_{150}\rangle$	$\langle Q\rangle/\langle N_e\rangle$
All	1221	3.60	8.12 ± 0.20	0.88 ± 0.01	5.68 ± 0.18	44434 ± 1092
Light	695	3.54 ± 0.09	11.5	0.85 ± 0.01	7.67 ± 0.26	30782 ± 783
Heavy	526	3.62	3.65 ± 0.09	0.92 ± 0.02	3.05 ± 0.20	99178 ± 4965

of observation to a maximum of a shower. The ratio of an average flux of V-ChR to an average number of particles in a shower $< Q > / < N_e >$ also was analyzed. The results of comparison are shown in the table 1. Average energy of analyzed events $< E >= 2.3 \cdot 10^{15}$ eV. From the table it is seen: the fraction of light nuclei, at the break of a spectrum, makes $(57 \pm 4)\%$. Showers initiated by light nuclei are younger. They have the greater number of particles, more steep photon LD and much smaller photon number per one shower particle.

5. Conclusion

The researches carried out allow to hope that use of complex installation for EAS research, including array for registration of V-ChR, will permit us to determine the nature of the particle initiated individual EAS. It, in turn, will allow to establish a nature of observable features of EAS parameters at $E > 10^{16}$ eV, i.e. to understand, whether they are connected to change of character of interactions or with change of composition of primary cosmic radiation.

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