WHAT HAPPENS IN EAS AT $N > 10^6$ PARTICLES ?

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Abstract

There are steps in at least 5 EAS parameters in dependence on EAS size N in narrow interval of $N = (3 - 6).10^6$ particles. All these data indicate on the possible average atomic weight of cosmic rays increasing.

From another side comparison of EAS size spectra of all showers and young showers (S = 0,20-0,60) demonstrates rapid increasing of young showers fraction (in 10 times) in the interval of $N = 10^5 - 10^7$ particles. It indicates on increasing fraction of protons, by this their spectrum is very hard: differential slope γ = - 2,2.

Totality of data can be coordinated in the assumption on the big role of unstable particles, produced in fragmentational region at the proton's interactions. This leads to hardening of young EAS size spectrum, because of unstable particles decay length increases rapidly with energy. At some treshold (which ruled by life time and unstable particles energy) high energy hadrons and γ-quanta escape from the registration, that seems as the increasing (by step !) of atomic weight of primary cosmic ray flux. Escaped protons produce then excess of showers at big zenith angles.

1 Introduction

The attention to region of EAS size spectrum in vicinity of $N{\sim}10^6$ particles is paid starting from the discovery of the break here [1]. It is connected in particularly with those the fact that in accordance with the diffusion model of cosmic ray propagation in the Universe the change of the energy spectrum of primary cosmic rays (PCR) has to be very smooth. From another hand the position of EAS size spectrum break has to shift rather fast to the smaller size with decreasing of the observation level in the atmosphere because of particles attenuation. M.Hillas was the first who paid attention [2] that this shift was too small to connect it with the break in the energy spectrum of PCR. In fact, according to paper [3] particle attenuation length in EAS with fixed primary energy (it was measured by using of Cherenkov light) $\lambda = 146 g/cm^2$. That means that between Chakaltaya ($x = 550 g/cm^2$) and sea level ($x = 1020 g/cm^2$) number of particles has to be attenuated in $exp((1020-550)/(\lambda\cdot(<cos\theta>)) \approx 30$ times, or taking into account the fluctuations not less than 15 times. However totality of experiments give value of 6 for the first Chakaltaya result [4] and only 2 (but not 15 !) for more recent data [5].Thus it seems the connection between the break in EAS size spectrum and the assumed break in energy spectrum of PRC is not synonymous.

The question arises what happens in EAS at $N > 10^6$ particles ?

2 The data on EAS properties at $N > 10^6$ particles

The big complex arrays such as Tien-Shan EAS array [6] and Tien-Shan HADRON array [7] have permitted to investigate the properties of different components of EAS. The main advantage of these installations was the presence of dense central part. HADRON array had 112 scintillators with area S=(0,25-1,0) m^2 distributed in the circle with R=70 m, big hodoscopical array, installation for registration of muons with energy E_μ>5 GeV, the array with S=160 m^2 for registration of high energy hadrons and gamma quanta families. 10 detectors were intended for registration of Vavilov-Cherenkov photon's flux which is the most adequately connected with primary energy of particle initiated the shower. The usage of such perfect arrays permitted to establish a number of sharp irregularities (like steps) in dependencies of different EAS parameters in narrow shower size interval $3.10^6 - 8.10^6$ particles,from which it is possible to conclude that PCR composition suddenly became havier. Here are the data.
a) In experiment HADRON it was investigated [8] relative energy of high energy (E_γ> 4 TeV) γ-quanta: $\Sigma E_\gamma / E_0$ (where E_0 is the energy of particle started shower) in dependence on EAS size N. This dependence is shown in fig.1. It demonstrates sudden decreasing of fraction of energy transferred into high energy γ-quanta. This result was conformed by data received at Chakaltaya [9]. Sudden escaping of protons can lead to such effect.
b) The energy of hadronic component per one shower particle was investigated [10] by using of the big ionization calorimeter. Fig.2 presents this result. Here the step also exists, indicating possibly on the sudden increasing of heavy nuclei fraction.
c) Dependence of total number of muons with energy E_μ> 5 GeV on EAS size [11] demonstrates its increasing at the same interval of shower size as it is possible to see from fig.3.
d) The number of shower particles in dependence on primary energy (measured by using of Vavilov-Cherenkov photon's flux Q) decreases by step [12] (fig.4) that could be accounted for by sudden increasing of heavy nuclei fraction, because showers initiated by nuclei develop, reach their maximum and attenuate faster than those initiated by protons.
e) The position of EAS maximum suddenly shifts up in the atmosphere [12] as it is possible to see from fig.5. Here the ratio ρ_{50}/ρ_{150} in dependence on Q is shown, where ρ_{50} and ρ_{150} are the densities of Cherenkov photons at distancies 50 and 150 meters from shower axis. According to [13] this ratio reflects the distance between shower maximum and observation level: the greater this ratio - the closer the maximum. It is clear that maximum of shower initiated by heavy nuclei has to be more distant from observation level in comparison with those initiated by proton. Thus all data presented could be accounted for by sudden escaping of protons from PCR flux or sudden increasing of heavy nuclei fraction in PCR.

However, there are another experimental data which contradict to this assumption.
1) It were investigated distributions of Vavilov-Cherenkov light flux $W(Q)$ at fixed EAS sizes $N_1 = 1,52.10^6$ and $N_2 = 8,31.10^6$ particles [12]. Approximately 50% of events in the second distribution has relatively much less value of Q (in comparison with the first distribution) and in 2,44 times less value of $< Q >$ in comparison with $< Q >$ for the whole distribution. This result justify on the rapid shifting of EAS maximum deep into atmosphere, because the main Cherenkov light flux is irradiated from the region of its maximum: the less particles path in the atmosphere - the less Cherenkov light they irradiate. 2) In paper [14] it were investigated the EAS size spectra for all showers and young showers ($S = 0,20 - 0,60$). These spectra are

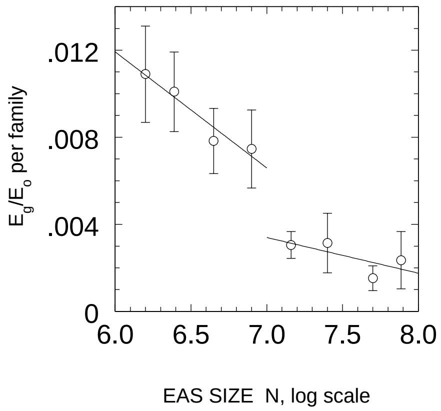

Figure 1: $\Sigma E_\gamma / E_0$ *per family*

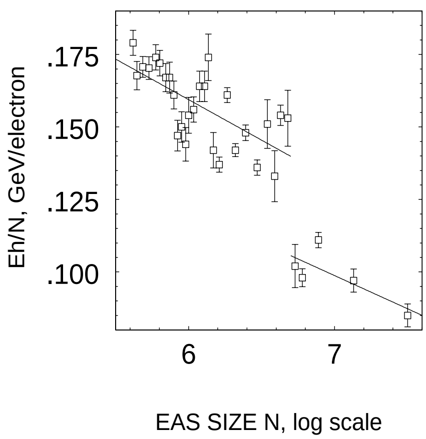

Figure 2: *Energy of hadrons in dependence on EAS size*

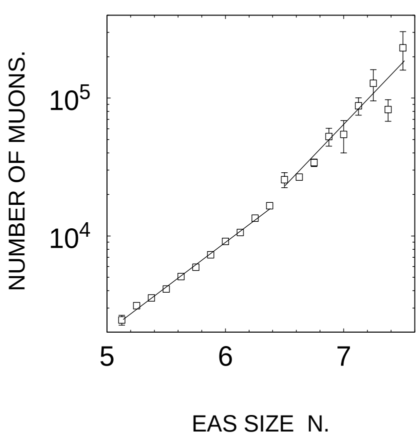

Figure 3: *Dependence of muon number* N_μ *on EAS size Ne.*

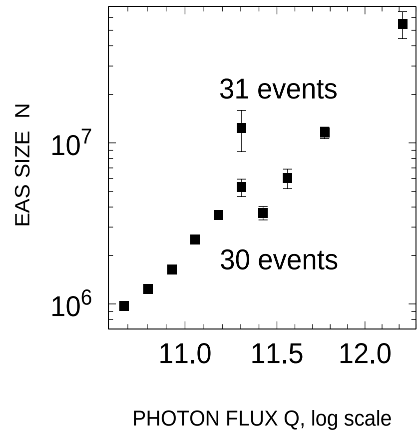

Figure 4: *EAS size at fixed flux of light.*

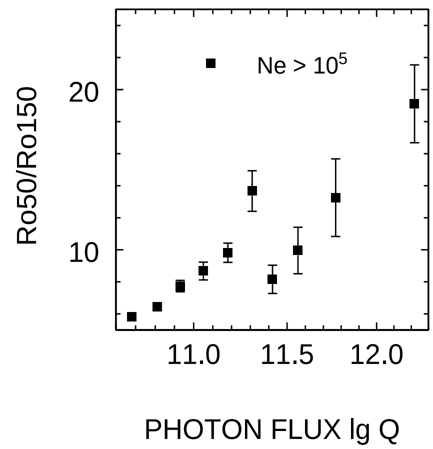

Figure 5: *Dependence* ρ_{50}/ρ_{150} *on Cherenkov light flux Q.*

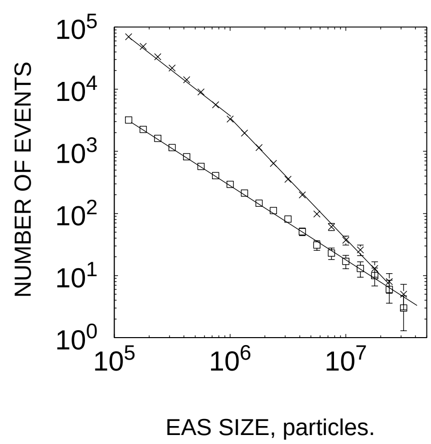

Figure 6: *Differential EAS size spectra: upper-all showers, lower - young showers.*

shown in fig.6. It is seen, that fraction of young showers increases rapidly: in 10 times when EAS size changes from 10^5 to 10^7 particles and differential spectrum of young showers is very hard: $\gamma = -2,20$. The fast increasing of young EAS fractiom coordinates with fast sfifting of shower maximum deep into atmospere and decreasing of EAS age.

3 Conclusion

Totality of data can be coordinated in the assumption on the big role of unstable particles with heavy quarks in high energy EAS development. Because of heavy quark presence such particle keeps the momentum up to decay and thus carries the energy deep into cascade. The decay length of unstable particles rapidly increases with energy. In addition production of unstable particles in the consequent interactions is possible. In the case the fraction of young EAS has to increase rapidly with energy and shower maximum has to shift fast deep into atmosphere. At some threshold (which is ruled by life time and energy of unstable particle) maximum of shower (in which leading unstable particles were produced) crosses the observation level, thus high energy hadrons and γ-quanta have to escape from the registration demonstrating the seemed escaping of protons (as the step!) and increasing of atomic weight of PCR. Escaped particles produce then excess of showers at big zenith angles [15].

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