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The reality of the old - established processes of the hadron production in the system of center mass of the colliding nucleons

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Abstract. The break in the extensive air shower spectrum, the significant fluctuation in the altitudes of the generation showers by primary protons at energies $10^{16} - 10^{17}$ eV, the very brief cascade process in the atmosphere, which is confined by the pion decay – all this peculiarities are connected with the very high multiplicity of the secondary hadrons in the first collision of the primary protons with the air nuclei.

1 Introduction

A knee in the spectrum of the extensive atmosphere showers (EAS) (Fig. 1) had the two explanation: as the knee in the primary cosmic ray energy spectrum and as the result of the essential increase of the hadron multiproduction in the first interaction of the primary cosmic ray protons with the atmosphere nuclei. The first interpretation was fastened after discover of the EASs knee (T.Kameda, 1960; G.V.Kulikov, 1960), my be as the some border between the galactic and metagalactic cosmic rays. However the experimental investigation of the EASs by the different cascade parameter S allowed to obtain the spectra of showers, produced by the primary protons in the depth of atmosphere and the spectrum of the EASs, produced by the primary nuclei. The both spectra have not any knee at the electron number $N_e \simeq 10^6$. The reality of such assortment was conformed by the determination of the absorption lengths of this two spectral groups. The absorption of the EASs with $S \leq 0,75$ fits to the length of the protons in the atmosphere: $\lambda_{abs} \simeq 87$ g/cm^2. The absorption length of the EASs with $S > 1,05$ does not contradict to the absorption of the hadron-electron cascades after the maximum of its development $\lambda_{abs} > 170$ g/cm^2 (S.I.Nikolsky, 2000) (Fig. 1).

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2 Alternative explanations of the knee in the spectrum

All showers, forming the spectrum with a knee, have the maximum of its development near the observation level $(0,75 < S \leq 1,05)$ and intermix by the absorption length after the knee in the EAS spectrum by the number of electrons (S.I.Nikolsky, 2000). If the decrease of the flux of showers

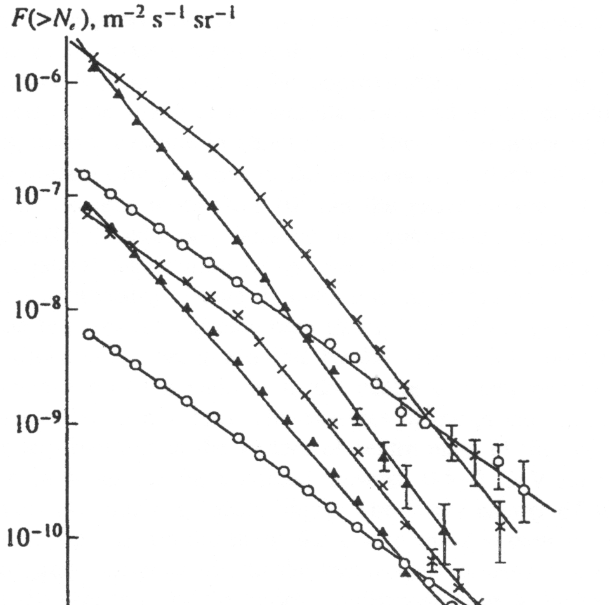

Fig. 1. The components of the total the flux of EASs involving N_e electrons at various values of the parameter S at the observation levels of 720 g/cm^2 ($\Theta < 25°$) and 960 g/cm^2 ($\Theta \geq 25°$): (○) – $S \leq 0.75$, (×) – $0.75 < S \leq 1.05$ and (△) – $S > 1.05$.

with the absorption length of the primary protons can be in an accordance both with the knee in their primary energy spectrum and with the absorption of the shower electrons in the atmosphere above the observation level, that the increase of the flux of showers with the absorption length of the hadron-electron cascade showers can be explained only by a supposition of the significant increase of the hadron multiplicity in the first inelastic collisions of the primary proton with the atmosphere nuclei. Scarcely one can discuss a possibility of the contrary spectral changes in the same energy region for the primary protons and for primary nuclei.

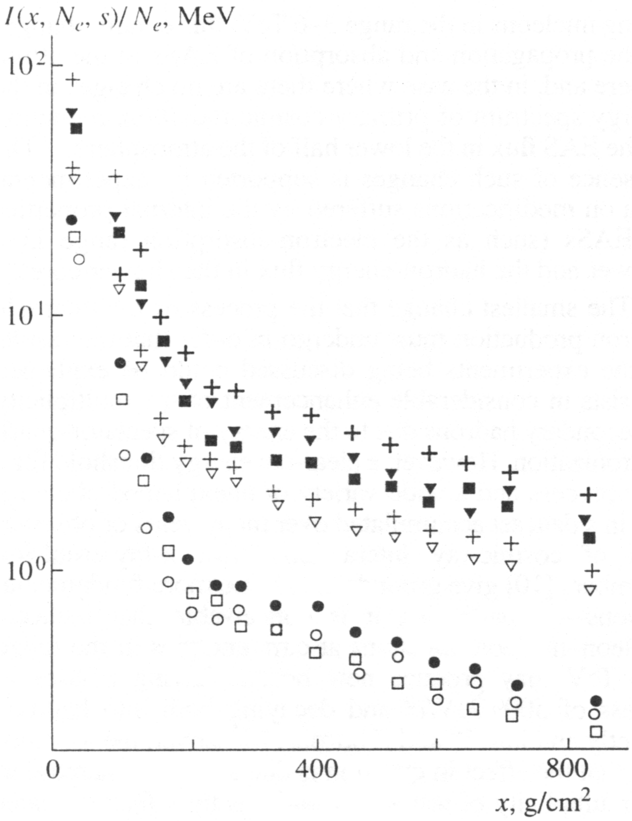

Fig. 2. Absorption of the electron-photon and hadronic components of the EASs cores in the lead of ionization calorimeter. The data presented for $S > \bar{S}$ (blacken symbols) and $S < \bar{S}$ (open symbols) at various numbers of electrons in shower: $(1-3)10^5$; $(3-10)10^5$; $(1-3)10^6$ and $(3-10)10^6$.

The fivefold distinction in the number of electrons in the EASs, by which one observes the essential decrease of the relative energy flux in the its cores (Fig. 2), from the number of electrons by which one observes knee in the EASs spectrum (Fig. 1), one can understanding only by the supposition of the change in the processes of the EASs generation. The essential increase of the hadron multiplicity accelerates a development of the showers in the upper atmosphere and following absorption of the EASs above the observation level. This EASs replenish the shower flow at the number of electrons $N \simeq 10^6$, that imitates a knee in the spectrum of the EASs. The hard indication upon the wrong of an application of the model extrapolation of the hadron multiproduction up to energies more 10^{17} eV was obtained at a discover of the relic GZK limit of the primary cosmic ray nuclei in

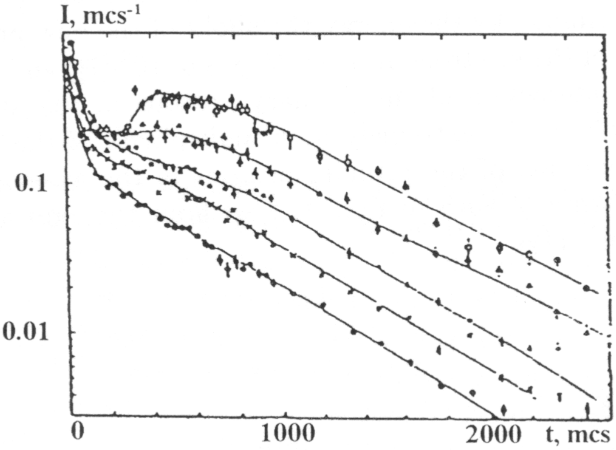

Fig. 3. Temporal distributions of the number of neutrons I for the different total multiplisity of detected in monitor neutrons: 316–400, 500–630, 794–1000, 1258–1584, 1995–2511 (from below upwards).

the energy region $(3-5)10^{18}$ eV instead $(3-5)10^{19}$ eV (M.N.Dyakonov, 1990; D.J.Bird, 1993).

3 Hadron generation with the extreme high multiplicity

An unexpected experimental indication about an extreme high multiplicity of the hadrons, generated in the nucleon-nuclear collisions, was exposed at the investigations of flux of the non-relativistic neutrons in the EASs (V.Aushev et al., 1997). The analysis of 850 EASs with the number of electrons more than 10^6 revealed 25 showers with the total multiplicity of more than 1260 neutrons in the neutron monitor during the time interval 3,6 msec after the electron front of the EASs (Fig.3). The peculiar double-peaked shape of the neutron arrival time distribution exposes the production such non-relativistic neutrons in the inelastic collisions of the EAS hadrons with the nuclei of the air atoms above the observation level ($< 10^3$ m), which is impossible to realize without the utmost high multiplicity of the secondary hadrons in the ‘first inelastic collision of the primary proton with the air nucleon. It means that such hadron multiproduction process takes place in the first interaction of the primary proton in the atmosphere and the secondary hadrons are generated in the centre mass system of the colliding particles. The secondary hadrons have to be approximately equally on its energy, that involves the simultaneous end of the developing hadron cascade in atmosphere. The total number of the non-relativistic neutrons in the showers with $(3-6)10^6$ electrons exceeds more than 10^5 but the exact number of the neutrons is unknown, because the experimental data about the lateral distribution of this neutrons in the showers are absent in reality. However even this approximated estimation requires the extreme high multiplicity of the generated hadrons only, that is possible by the supposition about the generation of the hadrons in the centre of mass system of two colliding particles. The energies of the producted secondary hadrons in the system of centre mass of the colliding particles can be confined between 0,5–5 GeV for the pions and nucleons accordingly. The lower energy of secondary pions, produced in the centre mass system of the colliding nucleons, fits to the transverse moments of pions in the processes of the hadron multiproduction at the energies of the colliding nucleons $\leq 6 \cdot 10^3$ GeV in the centre mass system. The number of secondary pions with the energy in the system of centre mass of colliding nucleons can surpass 10^4 and such process of the pion multiproduction can be assimilated to a form and the following hadronization of the quark-gluon plasma. The further development of the hadron cascade has be limited by the pion decays after one-two generations.

The energy of the secondary particles in the centre mass system ~ 5 GeV conforms to a decay of the excited hadron system into nucleons. This two outermost evens enclose between themselves the all other variants of the hadron multiproduction in the centre mass system of the colliding nucleons. Now the both variants are indistinguishable for the cosmic ray experiments: the transverse momentum is to small, the lesser multiplicity of the secondary nucleons and accordingly the greater energies after their generation can be compensated by the one additional generation in the following cascade development.

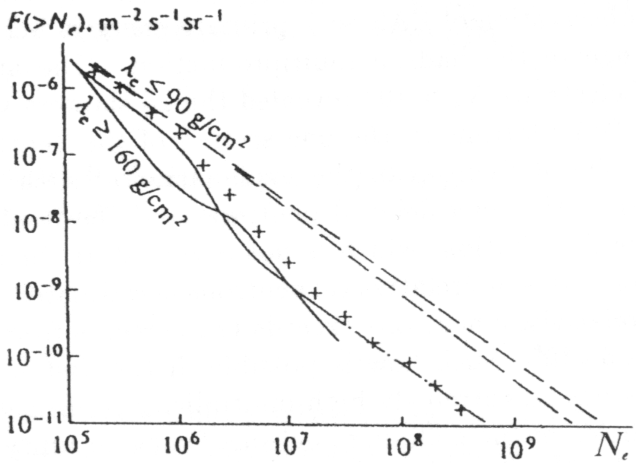

Fig. 4. Integrated electron number spectrum of EASs at an atmosphere depth of 760 g/cm^2 (+) and its two components with the different values of the absorption (λ_a) of the electron number. Stroke straight lines conform to the expected spectrum of EASs in the case of the standard model of the hadron multiproduction.

The additional loss of the energy above the observation level, connected with the essential increase of the hadron multiplicity in the first interaction of primary protons at the energies more than 10^7 GeV, can see in the difference between an observation number of the electrons and expected one by the extrapolation of the electron number spectrum from the region before the knee at the number of electrons $\sim 10^6$ in the region after second inverse knee (L.I.Vildanova, 1994) the electron number spectrum of the EASs (Fig. 4).

The formation of the short hadron cascades with the total energy $\sim 10^7 - 10^8$ GeV at the inelastic collisions of the primary protons with the air nuclei was confirmed by means analysis of the probability to observe the different energy streams in the cores of the EASs with the different electron number (Fig. 5). One can see the full resemblance of the relations of the hadron energies in the cores to the primary energies for the EASs with the electron number $1,33 \cdot 10^5 - 3,2 \cdot 10^6$. This invariable similarity is violated in the next energy interval of the EASs with the electron number on the observation level $3,2 \cdot 10^6 < N_e < 10^7$. The summary energy in the EASs cores decreases in more than four times (Fig. 2). One can see in Fig. 5, that the energy of the hadrons in the EASs cores at the electron number $3,2 \cdot 10^6 < N_e < 10^7$ are compared with energies, observed at $N_e < 3,2 \cdot 10^6$, less than in 7 percent of the showers. It conforms to the generation of such EASs in the interaction with the very high multiplicity of the secondary hadrons in the system of centre mass of the colliding nucleons on the depth of the atmosphere more than 250 g/cm^2.

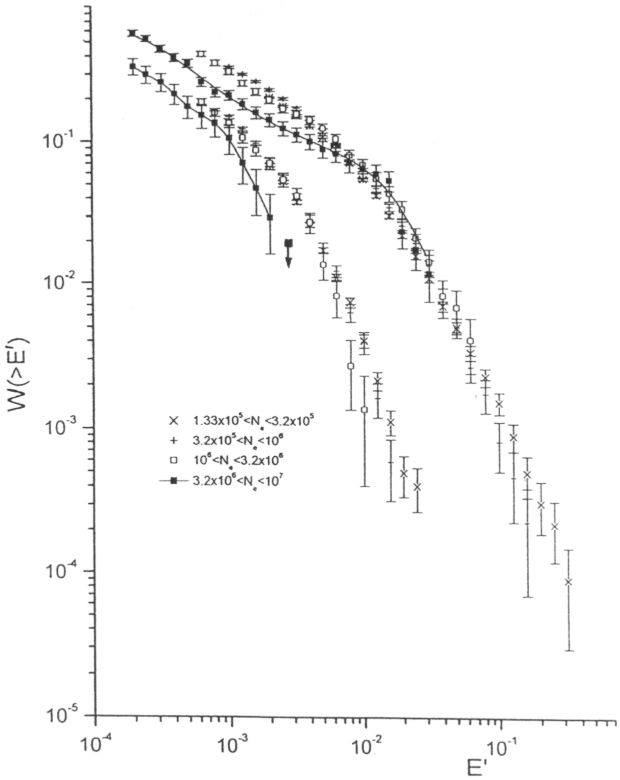

Fig. 5. The energy of hadron in the EAS cores E_h relatively to the energy of the primary cosmic particle E_0 ($E' = E_h/E_0$). The left curves are the neighboring jets (O.E.Krasnova et al., 2001).

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