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Experimental evidences of two component model for CR composition around the "knee".

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Abstract. The N_e spectra for EAS and EAS with γ-families, received in experiment "Hadron" (Tien-Shan, 685 g/cm^2), are compared. A fenomenological model gives a good fit for both N_e spectra around the knee, is consistent with direct measurements of the nuclei energy spectra and supposes them break for magnetic rigidity $R \simeq 0.13$ PeV. Besides an analysis of E_γ spectra in different N_e intervals shows that such simple model must be added by the additional, consisting mainly from the light nuclei, CR component which arises at energies $E_0 \simeq 5 - 6$ PeV, i.e. beyond the EAS spectra break .

1 Introduction

The recent results of the experiment "Hadron" (Shaulov, 1986, @; Shaulov, 1987, @), which were received by the new method of EC (X-ray emulsion chamber) exposition in association with EAS array, change experimental situation in the investigation of CR composition, because this method has a number of advantages as compared with muon (underground installations) and hadron (ionization calorimeters) one's traditionally used.

Replacing the ionization calorimeter by EC enhances the spatial resolution in $\sim 10^3$ times, resulting in possibility to measure spectra of the individual high energy γ and hadrons instead them showers.

In principle, an information, which comes from muons and γ data, is similar, but an energy thresholds are differ in thousands times. Muon energies are as usual of order few GeV, rare tens or hundreds GeV and γ energies in EC are 1-100 TeV.

An unique spatial-energy resolution in EC, a knowledge of the primary energies for $\gamma-$families in EC from EAS data and relatively high EAS detecting level (685 g/cm^2) permit to enhance the sensitivity to CR composition and to receive a number of the new results.

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2 Experimental results.

A large statistic of EAS+γ data (1665 ev.) permits to analyze the differential N_e spectrum for them. It is shown at Fig. 1 in comparison with experimental EAS spectrum and a theoretician EAS+γ spectrum, calculated by means of MQn model (Dunaevsky et al., 1991, @).

For a long time MQn was a base model for EC data interpretation in "Pamir" collaboration. As usually it uses a "normal" CR composition with a large part of the protons ($30 - 40\%$) before break and supposes a maximal value of the scaling violation in the fragmentation area of the nuclear interaction, a large increase of the total inelasticity coefficient K_{in} in forward area from $K_{in} \simeq 0.55$ up to 0.84 for $E_0 = 10$ PeV and probability of the pion inelastic exchange $P_{ex} = 0.3 - 0.5$ to receive a good fit of the total $\gamma-$family intensity (Dunaevsky, 1993, @).

A model gives a true value of the total intensity, but essentially different shape of the N_e spectrum. An agreement probability by χ^2 criterion for the experimental and model spectra in Fig. 1 is very small $P < 10^{-8}$. A model gives more large intensity in range $N_e < 10^5$ and too small in range $N_e = 3 \cdot 10^5 - 5 \cdot 10^6$. Another reason is that the local irregularities (maximums) are present in the experimental spectrum, which existence are unfeasible if proton part in CR is dominant.

A probability of agreement between experimental points and them polynomial approximation is $P < 10^{-3}$, what corresponds to 3σ deviation. So it is possible argue that dispersion of the experimental points isn't described by Poisson low (Shaulov, 1998, @).

As it shown in Fig. 2, six local maximums may be separated in the total spectrum ($\Sigma E_\gamma \geq 10$ TeV, $E_\gamma \geq 2$ TeV, $n_\gamma \geq 1$), $\theta = 0 - 90°$) with confidence 2.6σ, 1.7σ, 2.9σ, 2.6σ, 3.1σ, 3.3σ by means of χ^2 criterion from left to right consequently. The confidences were determined relative to smooth background curve, passing through the lower experimental points (Eadie et al., 1971, @).

Another data part deals with measurements of the energy
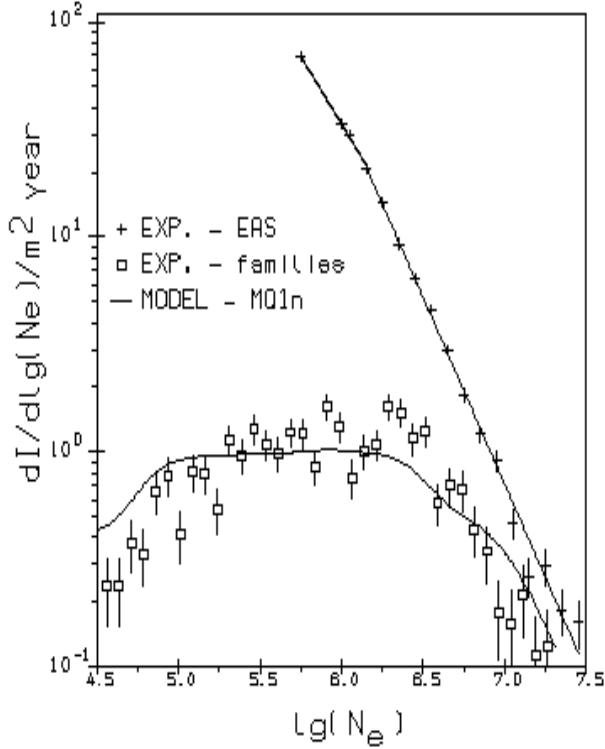
Fig. 1. N_e spectra for EAS and EAS with $\gamma - families$, selected by the criteria $\Sigma E_\gamma \geq 16$ TeV, $E_\gamma \geq 4$ TeV, $n_\gamma \geq 1$), $\theta \leq 30°$. A smooth curve is a simulation calculation for EAS+γ spectrum by MQn model.

spectra for γ in different N_e intervals. N_e dependence of the slope for the integral energy spectra is shown in Fig. 3 (Janceitova et al., 1998, @; Cherdyntceva et al., 1999, @).

The experimental spectra become more rigid for $N_e \geq 3 \cdot 10^6$, i. e. in range above the EAS spectrum break at $N_e^{br} = 1.5 \cdot 10^6$. This scaling violation is anomalous because nuclear effects and QCD one's have make spectra more soft with energy increase. The essentially different models, but with "normal" CR composition, give close and about constant slopes of γ spectra $\kappa \simeq 1.9 - 2$ over all N_e interval in Fig. 3 (Dunaevsky and Krutikova, 1993, @; Tamada, 1992, @). The only a change of the CR composition from mix one up to mainly protons can explain an index decrease in Fig. 3 (Aguiree et al., 1996, @).

It is possible that scaling violation is limited by range $N_e = 3 \cdot 10^6 - 10^7$, but the event statistic is small for last point at Fig. 3 and this conclusion has be verified.

3 Discussion.

The maximums may be interpreted by only one way as a manifestation of the different nuclear energy spectra, i.e. the multicomponent CR composition, and it permits to make a number of conclusions, which are independent from model of the interaction.
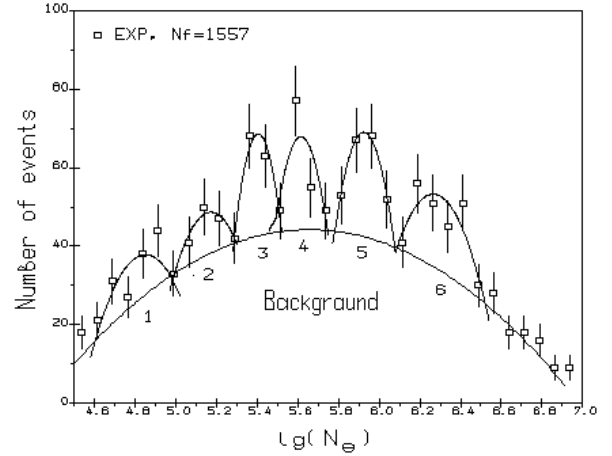
Fig. 2. N_e spectrum for EAS with $\gamma - families$, selected by the criteria $\Sigma E_\gamma \geq 10$ TeV, $n_\gamma \geq 1$.

1) The γ-families generation efficiency is maximal for protons and quick decreases with atomic number. This reason an existence of the maximums means that a part of protons is small enough in range before EAS spectrum break ($\sim 10 - 20\%$ near the break) and a break in CR nuclear spectra is ruled by magnetic rigidity $R = E_0/Z$, where Z is averege electric charge for a given group of the nuclei.

2) The maximums positioning at energy scale permits to estimate a magnetic rigidity value of break in nuclear energy spectra $R = \simeq 0.1$ PV. It is just follow from this value that break in EAS spectrum is connected with one in spectrum of the Fe group nuclei instead of the protons as in "normal" composition.

3) A simple calculation shows that maximums in the spectrum may be fitted only in assumption that nuclear energy spectra have a bump near the break, i.e. them slopes are changed from $\kappa \simeq -2.5$ up to $\kappa \simeq -1.0$ before break (Shaulov, 1999, @).

4) The maximums are merge together in the spectrum for all EAS. It follows that N_e fluctuations are decrease when EAS+γ are selected.

5) A promise about the large scaling violation in the fragmentation area prove to be surplus (quasi-scaling model) if CR composition becomes more heavier in comparison with "normal" one.

A model, which is regarded only nuclear spectra break for $R \simeq 0.1$ PV, is incomplete, as don't takes properly into account of the additional maximum in the EAS+γ spectrum beyond the break for $N_e > 10^6$ (Fig. 1) and the scaling violation in the same N_e range (Fig. 3).

These effects can be understood if proton component arises beyond a break of the Fe group energy spectrum. It means that for $N_e > 10^6$ we deals with additional CR component which has another generation or acceleration mechanism.

Two interpretations for this component are possible: i) it may consists mainly from protons and arises in area of mag-
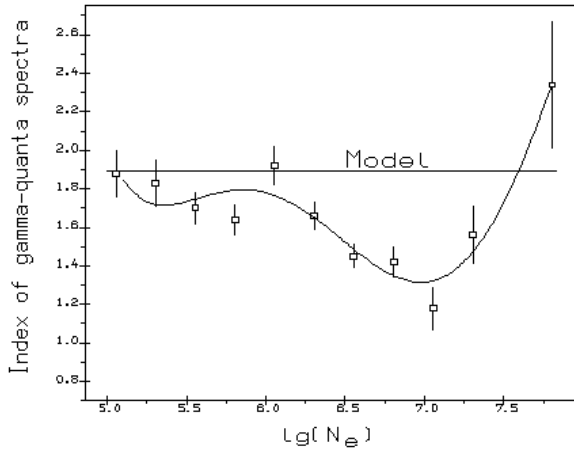
Fig. 3. N_e dependence of the slope index for γ-quanta energy spectra $N(> E_\gamma)$ in EAS with $\gamma - families$.

netic rigidity $R \sim 5 - 6$ PV, ii) it may be sixth component with electric charge $Z \geq 50$ in the radiation of the same single, close CR source, which generates the bumps in the nuclei spectra for $R \simeq 0.1$ PV. In particular, the hypothetical particles of the strange quark matter (Bjorken and McLerran, 1979, @; Witten, 1984, @) may discussed in last case (Shaulov, 1996, @).

A model, which includes a break and bumps in the nuclear spectra for one the same magnetic rigidity $R \simeq 0.1$ PV, CR composition which conforms with direct measurements data, only bumps of the same shape for additional component ($R \simeq 5.6$ PV) and light composition (95% p+α) for it and a decrease of the N_e fluctuations for EAS+γ gives a good fit as for EAS spectra (break), so for EAS+γ one (maximums) in the wide N_e range with accuracy $10 - 20\%$ (Shaulov, 1999, @). These fits are shown in Fig. 4.

The bumps in the nuclear spectra may be connected with a contribution of the single, close CR source in the total radiation (Berezgko et al., 1996, @; Erlykin and Wolfendale, 1997, @). Additional component totally is generated by the same source or may be another (Shaulov, 1999, @).

4 Conclusions.

The method of EAS+γ association, which was realized in experiment "Hadron", prove to be extremely effective for CR composition investigation in the area of the spectrum break. This way is likely permits to resolve the break (knee) problem in CR spectrum. It is now planned a check of received data and a further development of these investigations at the installation "Hadron-M" (Slavatinsky, 2001, @).
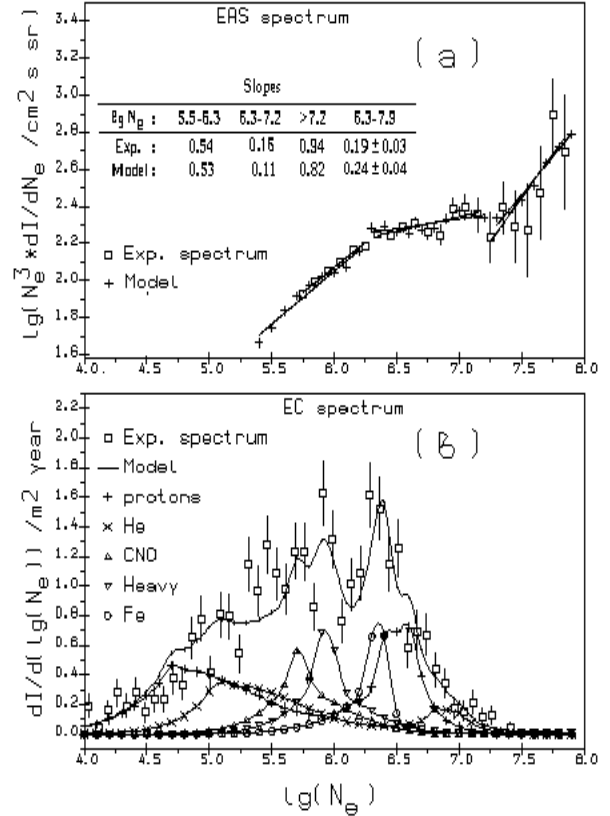
Fig. 4. The model fits of N_e spectra for EAS (a) and EAS+γ (b).

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