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Azimuthal correlation peculiarities in gamma families with energies $\Sigma E\gamma$=100-2000 TeV.

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Abstract

In the paper presents data concerning to azimuthal correlations in gamma-families registered in "Pamir" experiment. The dependence of azimuthal parameter on different gamma-family characteristics and primary energy (E_0=3-30 PeV) of protons and nucleus are considered. It is discussed the relation between azimuthal and alignment parameters. Obtained results are not represented in frame of the Quark-Gluon String models at the energies above 10 PeV.

1 Introduction:

Characteristics of hadron-nucleus (hA) interactions at the energies of E=1-100 PeV are studied through the observation of cosmic-ray families recorded in large-scale X-ray emulsion chambers at high mountain altitudes. The experiments carried out by Pamir and Chacaltaya collaborations give an evidence for an appearance at the energies E>10 PeV number of unusual phenomena such as binocular and alignment events, azimuthal peculiarities of families (groups of gamma-rays and hadron related by common origin) arising from nuclear-electromagnetic cascades (NEC) in atmosphere initiated by primary interactions.

These phenomena were not observed in experiments with modern accelerators and cannot be described by any theoretical model up to now. Such exotic events may be manifestation of unknown features of strong interaction at superhigh energies as well as off characteristics of primary cosmic radiation at energies of 10-100 PeV. There are some speculations on existence of new primary particles like stranglets producing unusual events. That is why primary mass determination is of great interest for solving exotic phenomena problems.

2 Method:

In /1/ it was proposed a new azimuthal parameter:

$$\alpha = \frac{\sum_{i\neq j}^{n_\gamma} \cos 2\varepsilon_{ij}}{n_\gamma(n_\gamma-1)},$$

(where n_γ is the particle number in gamma-families, ε_{ij} is the angle between projections of i-th and j-th particles in azimuthal plane, $0<\varepsilon_{ij}<\pi$, i=1, 2,..., n_γ; j=1, 2,..., n_γ; $i\neq j$) which reaches a value of $\alpha_{max}\sim 1$ for coplanar events and equals $\alpha_{min}\sim 0$ for the isotropic distribution of azimuthal angles. It was shown that a fast rise of azimuthal correlations as with the average transverse momentum of family particles increases observed in cosmic rays cannot be described by models based on the smooth extrapolation of interaction characteristics obtained in the accelerator experiments /2/.

Another interesting problem, that has not been explained yet, is the phenomenon of alignment of the most energetic particles /3/. An alignment parameter is defined by

$$\lambda_n = \frac{\sum\limits_{i\neq j\neq k}^{n} \cos\varphi^k_{ij}}{n(n-1)(n-2)},$$

where φ_{ij} stands for the angle between two straight lines connecting the k-th center with i-th and j-th centers, n is the number of centers, n >3. Parameter λ_n =1 for the case of n centers aligned exactly along the straight line, while $\lambda_n \sim -1/(n-1)$ corresponds to the isotropic distribution of the centers.

For the adequate interpretation of observed effects it is necessary to compare the experimental data with simulation of nuclear-electromagnetic cascades propagation through atmosphere. The experiment results are compared with Quark-Gluon Strings MCO-model /4/. In that model "normal" composition of primary particles consisting of 36% protons p and 66% nucleus A at the energies Eo=1 PeV and enriched by heavy nucleus above 10 PeV is assumed.

3 Experimental results:

In the paper the correlation relations of anizotropy and alignment parameters with spatial family characteristics that are more sensitive to strong interaction mechanism are considered. It is analysed N=798 γ-families registered by Pamir Collaboration with observed energy ΣE_γ= 100-2000 TeV, number of particles $n_\gamma \geq 4$ and $E_\gamma^{min} \geq 4$ TeV selected within a circle of radius R_0=30 cm. The families were subjected to the electromagnetic "decascading" procedure. All family particles satisfied the condition $Z_{ik}<Z_0$=10 TeV·mm, (where $Z_{ik} = R_{ik} \cdot (1/E_i + 1/E_k)^{-1}$, R_{ik} is a distance in mm between the particles, E_i , E_k - their energies), were united into initial quantum. Thus the observable γ-families are transformed in the initial γ_{in} -families.

After that initial families were further subjected to "rejuvenation" procedure: the quanta satisfied the condition $f' = E_{\gamma i} / \sum E_{\gamma i} \geq f'_{min} = 0.04$, i.e. particles with energy $E_\gamma^{min} \geq 0.04 \cdot \sum E_\gamma$, were included in the family. The anisotropy parameter α'_{in} for all n'_{in} initial, rejuvenated particles and the alignment parameter $\lambda'_{4in} \geq 0.8$ for the most energetic four particles of family are calculated.

Estimation of primary energy E_{est} was founded on using correlation relation with n_{in} initial particles:

$$\lg E_{est} = A + B \lg n_{in},$$

where the coefficients A and B were derived from comparison with simulation data of the MCO model.

Fig.1 presents correlation relations between anizotropy parameter α'_{in} and family leteral spread $\bar{R}_{in} = \sum R_{in} / n_{in}$ normalized on their average values $<\alpha'_{in}>$,$<\bar{R}_{in}>$. According to Fig.1 a) azimuthal correlation increasing observed for "wide" families (i.e. events with value $\bar{R}_{in} > 1.6 <\bar{R}_{in}>$) in experiment at the energies E_{est} =3-100 PeV are not represented by the model .

Since the observed family fraction originating in primary AA interactions grows with increasing energy E_0 all events with E_{est} >10 PeV was devided on two groups according to criterion $d = n_\gamma/n_{in}$. The criterion d>0.7 <d> selects mainly P-families originated from PA-interactions, the condition d < 0.7<d> selects A-families. With the result that, the composition of devided families consist of 73%P and 27% A-families for d>0.7<d> and 46% P and 54% A-families for d<0.7<d>. The composition of families at the energies E_{est}<10 PeV consists of 75%P and 25% A-families. As can see from 1 b) the azimuthal parameter α'_{in} increases at the energies E_{est} >10 PeV (crosses) while at the E_{est}<10 PeV (triangles) such dependence is expressed very little. According to this fig. azimuthal correlation increasing effect appears for "wide" families (cross) at the ultra high energies E_{est}>10 PeV in the PA-interactions and is absent for AA-interactions (squares).

Fig.2 presents family lateral spread $\bar{R}_{in}$ distribution normalized on average value $<\bar{R}_{in}>$ for the different energy regions. It is observed the considerable excess of the number of "wide" families (15 ±2%) is not described by MCO-model at the energies above 10 PeV. (Fig. 2a).

According to table 1 fraction of "anizotropic" families (i.e.events with azimuthal parameter $\alpha'_{in} > 0,26$) $P_\alpha = \Delta N (\alpha'_{in}>0,26) / N$ and aligned events $P_\lambda = \Delta N (\lambda_4>\underline{0}.8) / N (\underline{\alpha}'_{in} > 0,26)$ between "anizotropic" families essentially grows for the "wide" families region $R_{in} >1.6<R_{in}>$ at the energies E_{est}=4-50 PeV.

Table 2 presents the dependence of fractions of aligned between anizotropic events P_λ and "wide" families $P_R= \Delta N (\bar{R}_{in} > 1.6 <\bar{R}_{in}>) / N$ on the energy E_{est} . As can see from the table 2, at the energies E_{est} >10 PeV it is observed the considerable increasing of fraction aligned and "wide" families.

These results are not represented by MCO-model. Thus, "Pamir" experimental data point to changing of strong interaction, that leads to the appearance of the "wide", coplanar and alignmented events at the superhigh energies above 10 PeV.

Table 1

$\bar{R}/<R>$	0 ÷ 0,6		0,6 ÷ 1,4		1,4 ÷ 3,0	
	P_λ	P_α	P_λ	P_α	P_λ	P_α
Experiment	0,09 ± 0,04	0,28 ± 0,04	0,08 ± 0,03	0,27 ± 0,03	0,20 ± 0,07	0,36 ± 0,06
MCO model	0,08 ± 0,05	0,20 ± 0,03	0,09 ± 0,03	0,21 ± 0,02	0,04 ± 0,02	0,25 ± 0,04

Table 2

$<E_{est}>$	5 PeV		10 PeV		30 PeV	
	P_λ	P_R	P_λ	P_R	P_λ	P_R
Experiment	0,10 ± 0,04	0,11 ± 0,03	0,07 ± 0,03	0,16 ± 0,03	0,18 ± 0,06	0,25 ± 0,04
MCO model	0,04 ± 0,02	0,10 ± 0,03	0,06 ± 0,03	0,06 ± 0,01	0,03 ± 0,02	0,10 ± 0,02

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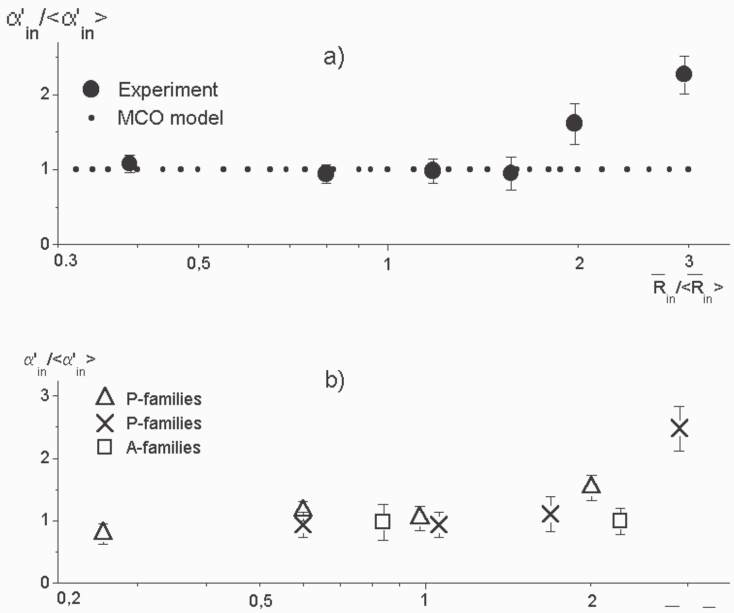
a)
Experiment
MCO model
b)
P-families
P-families
A-families

Fig. 1

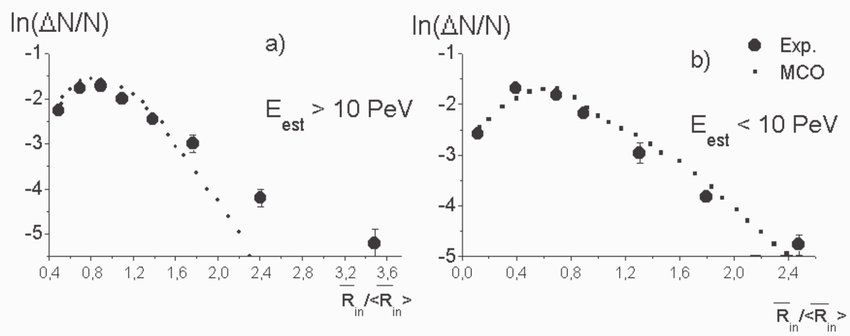
ln(ΔN/N)
a)
E est > 10 PeV
b)
Exp.
MCO
E est < 10 PeV

Fig. 2