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Unusual family characteristics at energies above 10 PeV(*)

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Summary. — In the paper the different characteristics of the usual and unusual gamma families obtained by the Pamir Collaboration are considered. The experimental data are compared with Quark-Gluon String models at primary energies above 10 PeV.

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1. – Introduction

A number of unusual phenomena such as coplanar emission of the most energetic secondary particles and azimuthal peculiarities of gamma families were discovered a few years ago [1, 2, 7]. These phenomena were not observed in experiments with modern accelerators and cannot be described by any theoretical model up to now. The unusual phenomena may be manifestation of unknown features of strong interactions at superhigh energies above 10 PeV.

In this paper the characteristics of nuclear interactions are studied through the observation of families (the groups of γ-rays related by common origin) in X-ray emulsion chambers. These families are the results of a Nuclear-Electromagnetic Cascade (NEC) processes initiated by primary particles in the atmosphere. The γ-quanta family with highest energy bring more direct information from the parent interactions.

For the adequate interpretation of the observed effects the experimental results are compared with the MCO Quark-Gluon String (QGS) Model [3] that gives a good description of many accelerator data as well as cosmic-ray data up to energies $E_0 < 10$ PeV. It takes into account generation of strange and charm particles, hadron resonances both

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in soft (including diffraction) and jet processes with increasing inelasticity coefficient $\overline{K}$ from 0.5 up to 0.7 in the energy region $E_0 = 10^{14}$–10^{17} eV. The computer program of jet process simulation uses results of [4] predicting partially two knees of P_t spectrum of jets and dependence of its form on jet rapidity. Minimal jet $P_t = 1.8$ GeV/c. Energy and momentum of "survival" leading particles are sampled after jet generation. A particle type can exchange charm and strange hadrons, including creation of barion resonances. The diffraction cross-section is determined mainly by three-pomeron exchange. The algorithm reproduces predictions of the QGS-model for hadron interactions with air nuclei [5] without any specific mechanism of coplanar particle emission. It is used for nuclear cascade modelling in atmosphere in order to get a set of simulated events.

In conclusion a new interpretation of the alignment effect based on the conception of heavy leading resonance production is presented.

2. – Experimental results

One analysed $N_0 = 798\,\gamma$-families of Pamir experiment with observed energy $\sum E\gamma =$ 100–2000 TeV, number of particles $n_\gamma \geq 4$ and energies $E_\gamma \geq 4$ TeV selected within a circle of radius $R_0 = 30$ cm.

The electromagnetic cascading process has a great influence on the observed characteristics of γ-families. Therefore the families are subjected to the "decascading" procedure which essentially reduces that influence by re-construction of original γ-quanta at their production point [6]. We use the parameter $\mathcal{Z}_{ik}$ between i-th and k-th γ-quanta in a family defined as

$$\mathcal{Z}_{ik} = \frac{E_i E_k R_{ik}}{(E_i + E_k)}\,,$$

where E_i and E_k are the respective energies and R_{ik} their mutual distance. If $\mathcal{Z}_{ik} < \mathcal{Z}_0 = 10$ TeV·mm, the quantum pair decascades into a single "initial" quantum with energy $E_i + E_k$ at the position of the energy centre of the two. Repeating the process of joining the two over all possible pairs of quanta, we arrive at the "decascaded", initial family.

The families are further subjected to "rejuvenation" procedure [7] that allows us to record the γ-quanta from fragmentation region of the incident particle. Only the quanta satisfied the condition

$$f' = \frac{E_{\rm in}}{\sum E_\gamma} \;\geq\; 0.04\,,$$

where $E_{\rm in}$ the energy of the initial quanta is included in the family. The number of such initial, "rejuvenated" quanta is denoted by $n'_{\rm in}$.

For each initial "rejuvenated" family the azimuthal and alignment parameters are evaluated. The azimuthal parameter

$$\alpha = \frac{\sum \cos 2\varepsilon_{ij}}{n'_{\rm in}(n'_{\rm in} - 1)},$$

(where $n'_{\rm in}$ is the particle number, ε_{ij} is the angle between the lines, connecting the family centre of mass with i-th and j-th particles, $0 < \varepsilon_{ij} < \pi,\ i = 1,\ 2,\ ...,\ n'_{\rm in};\ j =$

1, 2, ..., $n'_{\rm in}$; $i \neq j$) reaches a value of $\alpha_{\max} = 1$ for coplanar events. An alignment parameter is defined by

$$\lambda_N = \frac{\sum \cos 2\phi_{ij}^k}{N(N-1)(N-2)},$$

where ϕ_{ij}^k is the angle between two straight lines connecting the k-th centre with i-th and j-th, N is the number of the most energetic particles in the family, $N = 4$. The parameter λ_N is equal 1 for the case of N centres aligned along the straight line.

The comparison of the simulation based on MCO-model taking into account statistical fluctuations in the NEC propagation with experiment showed a considerable excess of the experimental alignment events, mainly for the parameters $\lambda_N \geq 0.8$ and $N = 4$. The probability to observe these experimental values is less than 0.01 according to Poisson distribution [2]. A "normal" composition of primary particles, consisting of 36% protons p and 66% nucleus A at the energies $E_0 = 1$ PeV and enriched by heavy nucleus above 10 PeV, was assumed.

Figure 1 shows the relation between normalised parameters anisotropy and lateral spread

$$\frac{\alpha'_{\rm in}}{\langle \alpha'_{\rm in} \rangle} \quad \text{and} \quad \frac{\overline{R}_{\rm in}}{\langle \overline{R}_{\rm in} \rangle},$$

where

$$\overline{R}_{\rm in} = \frac{\sum R_{\rm in}}{n_{\rm in}}$$

($R_{\rm in}$ is the distance of initial quantum from family centre, $n_{\rm in}$ the number of quanta, $\langle \overline{R}_{\rm in} \rangle$ the average value of lateral spread $\overline{R}_{\rm in}$ obtained for all N_0 families, $\langle \alpha'_{\rm in} \rangle$ the value of $\alpha'_{\rm in}$ is averaged in the region $\overline{R}_{\rm in} = (0\text{–}1.4)\langle \overline{R}_{\rm in} \rangle$). According to fig. 1 the azimuthal correlation increasing effect appears for "wide" families with $\overline{R}_{\rm in} > 1.4 \langle \overline{R}_{\rm in} \rangle$ and one is absent in the MCO-model.

The events with parameters $\alpha'_{\rm in} > \langle \alpha_{\rm in} \rangle$, $\lambda_4 \geq 0.8$ are considered, respectively, as "anisotropic" and "aligned" families. The fraction of the aligned events between N "anisotropic" families

$$P_\lambda = \frac{\triangle N(\lambda_4 > 0.8)}{N(\alpha'_{\rm in} > \langle \alpha'_{\rm in} \rangle)}$$

(where $\Delta N(\lambda_4 \geq 0.8)$ is the number of "aligned" families) essentially grows for the "wide" families: in the region $\overline{R} > 1.4 \langle \overline{R} \rangle$. The experimental value is $P_\lambda^{\rm exp} = 0.20 \pm 0.07$, while the $P_\lambda^{\rm mod}$, obtained from MCO-model, is only 0.04 ± 0.02.

These results are not represented by MCO model.

3. – Interpretation of the results

Some theoretical interpretations of the alignment phenomena were already suggested [8, 9]. The most elaborated explanation supposes the production of aligned energy distinguished particles by semihard double diffraction dissociation. However, such model

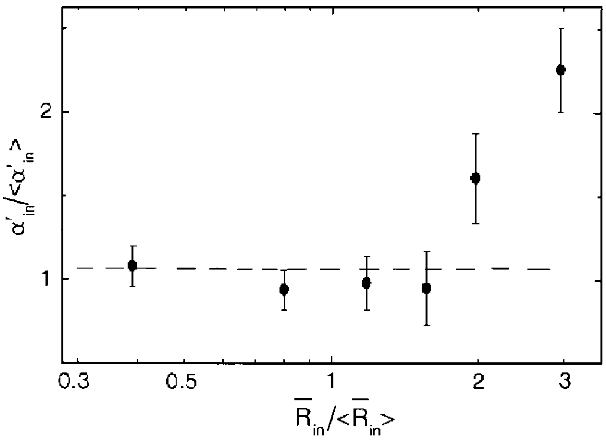

Fig. 1. – Correlation relation between normalized values of anisotropy parameter $a'_{\rm in}$ and family lateral spread $\bar{R}_{\rm in}$: • experiment, − − − MCO-model.

is not be able to describe the number of alignment characteristics. In this work a new alternative interpretation of that unusual phenomena is proposed.

According to the usual multiparticle production models colourless strings are stretched by (anti)quarks and (anti)diquarks, that are in (anti)triplet states of colour SU_3 group.

It is possible to consider also other strings stretched by exotic partons as it is shown in fig. 2.

At the high energies $\sqrt{s} = 1$ TeV the jet cross-section of the semihard parton scattering consists is $\sigma_{\rm jet}$ ($P_{\rm t} > 3$ GeV) = 20 mb in NN-collisions [8] and the probability of the minijet production by gluon grows with increasing of energies $\sqrt{s}$. If gluons of primary nucleon scatter on partons of target-nucleus, one loses supplementarely quasi-free current quark or antiquark and turn into diquark or exotic parton accordingly.

Exotic parton consists of four valence quarks and it is in triplet colour state. Two quarks in antitriplet colour state are attracted to each other and form a diquark. Two diquarks in triplet state produces an exotic parton. Exotic parton and an antiquark produce hadron beam jets, that differ from minijets generated by scattered gluons. With

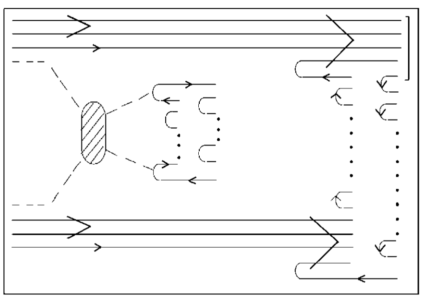

Fig. 2. – Semihard gluon scattering and two beam exotic strings production in NN-interactions: — quark, − − − gluon, ≣] heavy leading resonance.

increasing of primary energy $\sqrt{s}$ the average number of sea quasi-free quarks and antiquarks in nucleon grows infinitely. Therefore, at the high energies incident nucleon lose the sea quark or antiquark and turn into exotic parton with probability about 0.5.

At the cascade breaking of string into two strings [10] the exotic parton is conserved, but after all is converted into heavy leading resonance together with vacuum antiquark. In [11] the theoretical and indirect experimental arguments are given in favour of existence of heavy (with mass > 3 GeV) resonances and their coplanar decays in the rest C-frame. According to [11] angular-momentum conservation law suppresses noncoplanar decays of the heavy resonances placed on the linear Regge trajectory. At small emitted angles of the heavy leading resonance its laboratory helicity gets a small value and decay products will have quasi-coplanar momenta in the laboratory as well as in the C-system.

Absence of the alignment effects in the πA-interactions at the energies 250 GeV (experiment NA22 at CERN-πAu interaction) [12] is explained by the small value of semihard scattering probability of the partons. On the other hand, cosmic-ray experiments are performing at the superhigh energies. According to [12], four particles of highest energies in families are produced in one interaction not far above chamber in atmosphere with an average transverse momentum ~ 1 GeV. Four hadrons originating in the decay of heavy leading resonance will have the highest energies and may be aligned along a straight line.

The minijets production processes at parton semihard scattering create the azimuthal anisotropic families and increase average transverse momentum of secondary particles. In the soft interactions with low transverse momenta the azimuthal anisotropy is absent. If the multiplicity in such interactions is lower than in the minijets production processes, it would be able to explain the increase of the average transverse momentum with the multiplicity observed in $p\overline{p}$ collider experiments at the energies $\sqrt{s} \sim 1$ TeV. In the families originating from minijet processes the secondary particles will have both higher multiplicity and transverse momentum. Therefore, a rise of the azimuthal anisotropy parameter α'_{in} with the family lateral spread $\overline{R}_{\text{in}}$ (see fig. 1) is explained by increasing of the minijet events fraction.

For the family selection criteria: $\overline{R}_{\text{in}} > 1.4 \langle\overline{R}_{\text{in}}\rangle$ and $\alpha'_{\text{in}} > \langle\alpha'_{\text{in}}\rangle$ the probability of minijets production far above chamber is ~ 1.0. However, the heavy-leading-resonance generation probability after semihard parton scattering does not exceed the value of ~ 0.5 and the fraction of aligned events with $\lambda_4 \geq 0.8$ between "wide", "anisotropic" families may consist of $P_\lambda \sim 0.20$.

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