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A superfamily with $\Sigma E_\gamma > 10^{15}$ eV observed in stratosphere

V. I. Osedlo[1], **I. V. Rakobolskaya**[1], **V. I. Galkin**[2], **A. K. Managadze**[2], **L. G. Sveshnikova**[2], **L. A. Goncharova**[3], **K. A. Kotelnikov**[3], **A. G. Martynov**[3], **and N. G. Polukhina**[3]

[1]Physical Department of Moscow State University, Moscow, Russia
[2]D.V Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia.
[3]P.N. Lebedev Physical Institute, Academy of Science of Russia, Moscow, Russia.

Abstract
A gamma-hadron family with energy $> 10^{16}$ TeV detected in 1975 with an emulsion chamber in stratosphere at 30 km altitude is under analysis. Only two such events are known to be detected in stratosphere. They have high probability to be the "pure" result of a single nuclear interaction. It is of great interest that both events show azimuthal asymmetry and alignment of secondary particles. Besides that, in the presented event here is a halo.

1 Introduction

In 1975 the unique gamma-hadron family with energy above 10^{16} eV was detected by balloon borne emulsion chamber at 30 km altitude in atmosphere (Apanasenko et al., 1977). This event is the result of practically pure interaction undistorted by cascade degradation. By energy it is comparable with the most energetic events detected by large scale X-ray emulsion chambers with long exposure in mountain experiments (Pamir Collaboration, 1985). At almost the same energy in Concord experiment at observation level 17 km there was registered a gamma family with alignment of g-quanta (Capdevielle, 1997). Specific feature of the family presented hear is that in his periphery concentric ring structures have been recognized (Apanasenko et al, 1981). At very high energy in gamma-hadron families of mountain experiments there were found such new physical phenomena, as halo and alignment of most energetic objects in a family. The purpose of this study is an analysis of the unique stratospheric event, taking into account new model simulations and Pamir experiment experience accumulated in the field of superfamily investigation.

2 Experiment

As a detector in the experiment there was used an emulsion chamber exposed in stratosphere at the altitude about 30 km by ballooning with rout Kamchatka—Volga. Exposure duration was around 160 hours. The chamber consists of 2 blocks: a target and a calorimeter (Apanasenko et al., 1977). The target consists of 100 nuclear emulsion layers. The calorimeter contains 9 layers of 0.5 cm lead plates interlayered with nuclear and X-ray emulsion.

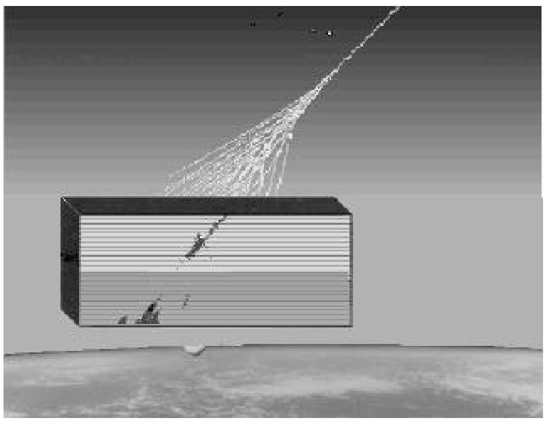

Fig. 1. Chamber and registration scheme.

The family with appearance presented in Fig. 2 was detected by such chamber.

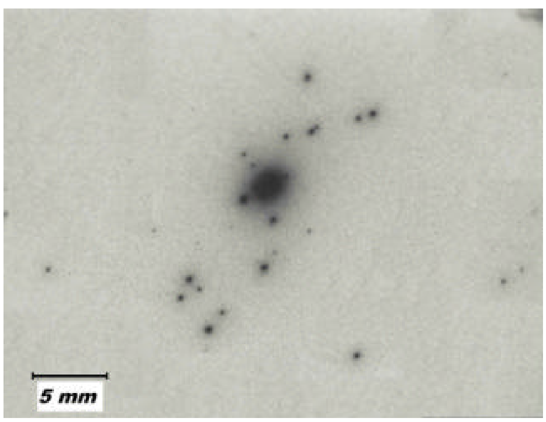

Fig. 2. Photo of the family in X-ray film in the calorimeter under 7 c. u. of lead.

Correspondence to: Osedlo V. (vlad@dec1.npi.msu.su)

3 Results

3.1 General characteristics

This gamma-hadron family consist of 107 particles: 76 gamma quanta with total energy $\Sigma E_\gamma \approx 1400$ TeV and 30 hadron with total energy $\Sigma E_h^0 \approx 2500$ TeV (except a leading particle). In the center there is a leading particle carrying a large portion of energy comparable with the primary particle energy. Taking into account chamber efficiency 40% of hadron detection and the loss of 30% of family particles due to cut by chamber edge, the total energy of primary particle is estimated as $2 \cdot 10^{16}$ eV.

3.2 Halo

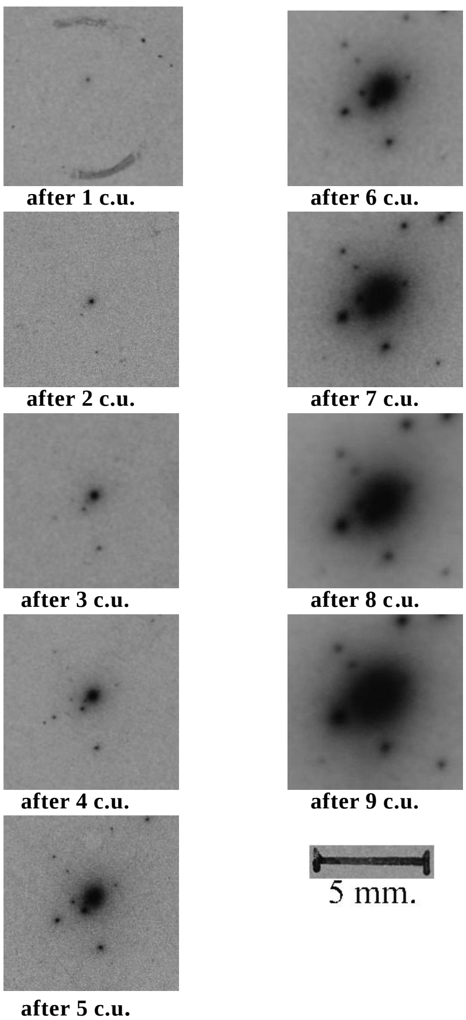

Fig. 3. Halo images in various layers X-ray film in the calorimeter from 1 c.u to 9 c.u.

Second nuclear interaction of the leading particle was registered in this family in 12-th emulsion layer of the target. The narrow bundle of secondaries, originated in this interaction, rapidly develops in the carbon target, and then produces the central area of halo in X-ray films of lead calorimeter. Halo phenomenon observed early only in mountain experiments is detected for the first time in a pure event and at stratosphere altitude. The halo development in the lead calorimeter is presented in Fig. 3.
In deeper layers this halo involves besides the central super high energy particle some neighboring hadrons and gamma quanta that is seen in Fig.4.

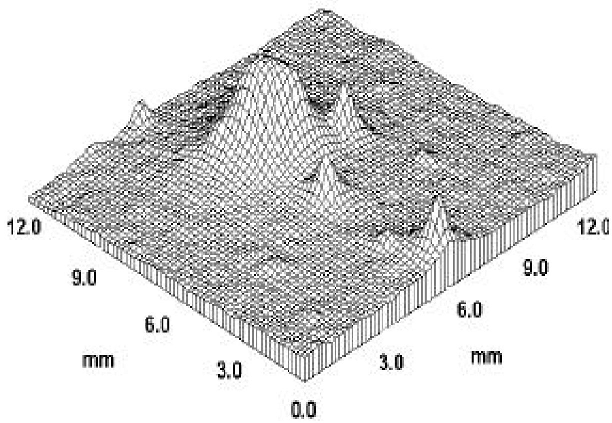

Fig. 4. Lateral distribution of density in the central area with halo.

3.3 Interaction height above the installation.

The height of primary interaction above the chamber was determined by triangulation method based on particle spot x, y-coordinates shifts in various detection layers. This method allows restoring an interaction vertex only in the case of small heights. The magnitude of shifts here appeared to be 30–100 mkm while measurement accuracy of spot centers being better than 10 mkm. Having been applied to 7 hadrons this method gave the height estimation H= 120±40 above the chamber. Altitude of π^0-meson creation was estimated also by neighboring pairs of gamma quanta assumed to be produced by π^0-meson, estimation of such π^0 production appeared to be from 80 m up to 150 m being consistent with the triangulation result. Further the height 120 m will be used.

3.4 Pseudorapidity analysis

Pseodorapidity analysis of both whole family (air particles) and inside the narrow jet from leading particle (tracks in emulsion) was carried out (Fig. 5).
Comparison of the distributions for both interactions with artificial events obtained from VENUS and QGS model simulations for pC interaction shows that both experimental distributions are closed to each other, far beyond energy 500 TeV and come to extrapolated curve for 10^{16} eV. Such estimation is consistent with total energy estimation mentioned above (3.1) Thus, the leading particle and total energy of other family particles have comparable energies.

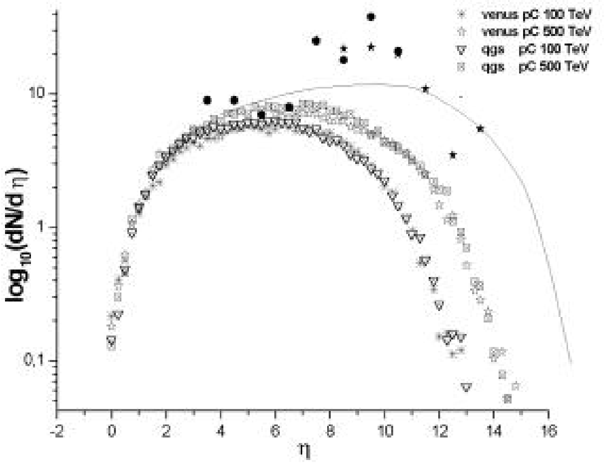

Fig. 5. Pseudorapidity distributions for experimental and simulated events: ● - primary interaction in air, * – central jet from the leading particle (inside the chamber), — extrapolation to 10000 TeV from simulations.

3.5 Transverse momenta.

Basing on the determined value of interaction height H above the chamber and on determined energy of hadrons in the family the estimation of average transverse momentum in air interaction gives

$$\langle P_t \rangle = \langle ER \rangle_h / H = 23 \pm 7 \text{ GeV}$$

This is tremendous momentum exceeding the assumed theoretic value for p-air interaction. The jet spatial development shows increased transverse momenta in the interaction inside the chamber too.

3.6. Alignment

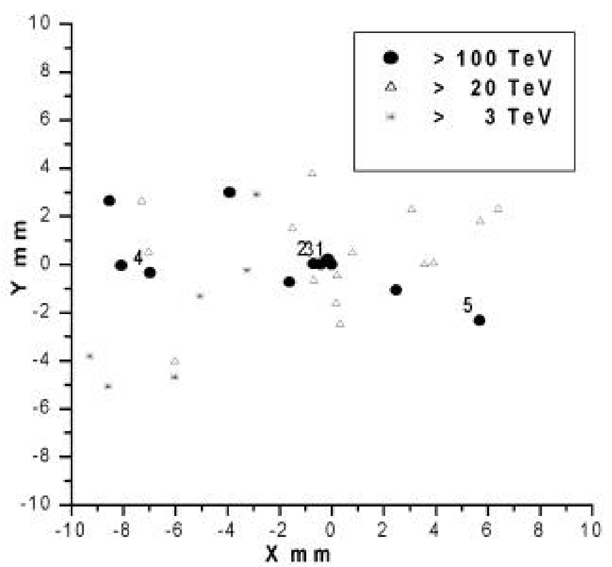

Fig.6. Target diagram of EDC in the family Numbers stand for most energetic objects in decreasing order.

One of the most interesting features of this family is its evident asymmetry and alignment of energy distinguished centers (EDC) (Kopenkin et al., 1995). As EDC here are considered gamma quanta and hadrons with their complete energy. For identification of alignment a parameter l was used (Pamir Collaboration, 1988). When all points are disposed exactly in a line, l =1. An event is regarded as aligned one, if l >0.8. Target diagram for EDC in the family one can see in Fig.6.

l values for first 3, 4 and 5 EDC are in Table 1. The family is a bright example of alignment phenomenon. It is worth to note, that on the whole all particles in the central area of the event are extended along to the direction of alignment. Among 107 particles of the family 15 ones are located close to the alignment line. These 15 particles carry out more than half of primary energy.

Number of EDC	l
1	0.9849
4	0.9878
5	0.8966

Table. 1. Alignment parameter l for various numbers of EDC under consideration.

4 Conclusion

Unusual interaction characteristics unobserved at lower energy are revealed at primary energy >10^{16} eV. Those are family anisotropy and EDC alignment, fast development of hadron halo, large transverse momenta in nuclear interaction. It would be very interesting to fit some new model to such features. Further experimental analysis for more precise study is necessary.

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