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Large transverse momenta in nuclear interaction at $E_0 > 10^{16}$ eV detected in stratosphere (STRANA superfamily)

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A gamma-hadron superfamily of cosmic rays created by a primary cosmic ray particle with energy $> 10^{16}$ eV was detected at the altitude of 30 km by a stratospheric balloon-born emulsion chamber. Being of superhigh energy this event is the unique example in the world statistics of practically pure nuclear interactions in the energy range unattainable for modern accelerators. The present analysis allowed to estimate the interaction height above the chamber and transverse momenta of the secondaries produced in the interaction. Mean value of transverse momenta appears to be very large (average $\langle p_t \rangle > 2.5$ GeV/c).

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 stratosphere [1]. This event named STRANA is supposed to be the result of a single nuclear interaction undistorted by cascade degradation due to very thin air layer above the chamber (about 10 g/cm^2). Now the superfamily has been reanalysed, using modern model simulations and new measuring technique.

While reconsidering the event a clear evidence of alignment effect (arrangement of particle tracks along a straight line in a film resulting from coplanar scatter of secondaries in the interaction) was found [Hamb, vystr]. It is consistent with the facts of alignment observed in the same energy range $> 10^{16}$ eV in mountain emulsion experiments [2, 3]. Necessity of large transverse momenta for display of alignment phenomenon was already presumed [4, 5]. Therefore the determination of p_t in such event is a rather important aim.

2. Experiment and General characteristics

The flight was carried out from Kamchatka peninsula to Volga river during 160 hours, detection probability for an event with such energy is less than 10^{-4}. The emulsion chamber with area 40x50 cm^2 consisted of 3 blocks (Figure 1): a target, a spacer and a lead calorimeter [1]. The results discussed here are based mainly on calorimeter data. The calorimeter contains 9 layers of 0.5 cm lead plates interlayered with nuclear and X-ray emulsions.

STRANA superfamily consists 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 (or a jet) carrying a large portion of primary particle energy (around 2 PeV). 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 to be ($9.2 \cdot 10^{15}$ eV + leading particle). Independent method of energy estimation for the family is the comparison of experimental and calculated pseudorapidity distributions of secondaries (Figure 2). Such analysis gives total energy estimation around 10^{16} eV and C or Mg group as probable primary type.

3. Estimation of interaction height above the chamber and average p_t

It is possible to estimate the distance H between the interaction point and the chamber assuming that all gamma-quanta in the superfamily are pairs from the decay of neutral pions from a single interaction of the primary paricle producing the family. Such method for superfamilies was elaborated [6] using QGSJET model simulations [7]. The method includes constructing of height distribution for all possible pairs of family gamma-quanta using famous formula $m_{\pi0} = \theta\sqrt{(E_1 \cdot E_2)}$, where $m_{\pi0}$ is π^0 mass, E_1 and E_2 are gamma quanta energy, $\theta \approx \Delta R/H$, ΔR is the distance between 2 cascades in a film. The most probable height of family generation found from such distribution (Figure 3) has to be corrected with some coefficient determined in [6]. For STRANA superfamily the estimation with use of coefficient 1.15 gives H = (1180 ± 340) m. Using the estimated H and coordinates of family hadrons, p_t is determined from relation $p_t \cdot H = ER$, where R is the distance from the family center. Here average $\langle p_t \rangle = (2.5 \pm {}^{1}_{0.6})$ GeV/c, p_t distribution for 30 hadrons is presented in Figure 4.

Another estimation of the height was made on the base of pseudorapidity distributions in the family. Using QGSJET model simulations pseudorapidity distributions were calculated for various interactions heights (from 50 up to 2000 m), various primary types and energy E_0. By χ^2 method the accordance of experimental and calculated distributions was considered in a wide range of parameters. (See Figure 5 for example). It is worth to note, that energy amount per a nucleon must be consistent with estimated energy of the central spot (related to leading particle or jet) origin. The energy balance, primary and central leading jet origin types and H appeared to be consistent, if H = 200–400 m, primary type is of CNO group, central spot origin is a bundle of 2-3 nucleon-spectators. For interaction height H = (300 ± 100) m the average $\langle p_t \rangle = (10 \pm {}^{5}_{2.5})$ GeV/c.

Let us take into account, that π^0 method was based on the simulation model with normal p_t behavior. If a model with rather larger $\langle p_t \rangle$ is used, the method would give less interaction height closer to the second method. In Figure 6 there is presented $p_t - \eta$ correlation for 30 hadrons of STRANA superfamily under assumption of interaction height H = 300 m. One can see a reasonable physical behavior of the dependence.

4. Conclusions

Our cautious conclusion arises to be as following: in the observed interaction of a nucleous of CNO group probably with $E_0 > 10^{16}$ eV average $\langle p_t \rangle$ appeared to be > 2.5 GeV/c. This interpretation has been constructed without coming out too far of traditional physics. One cannot exclude another explanation of unusual features of the family STRANA involving hypotheses of an exotic primary or of essential violation of interaction mechanism at superhigh energy.

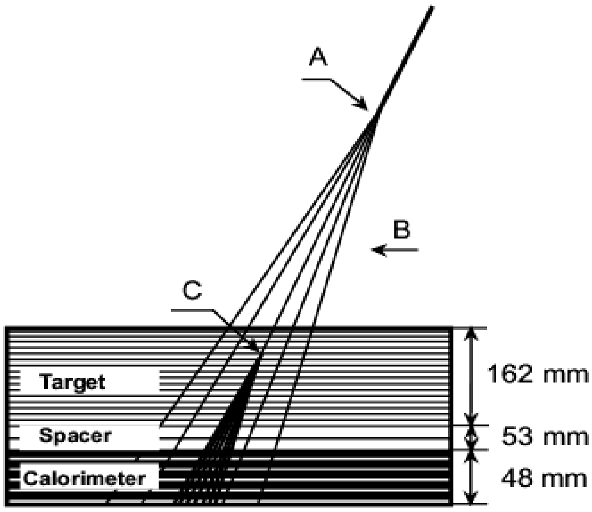

Figure 1. The emulsion chamber and detection scheme. A - primary interaction point, B - secondaries, C - leading particle (or jet) interaction point.

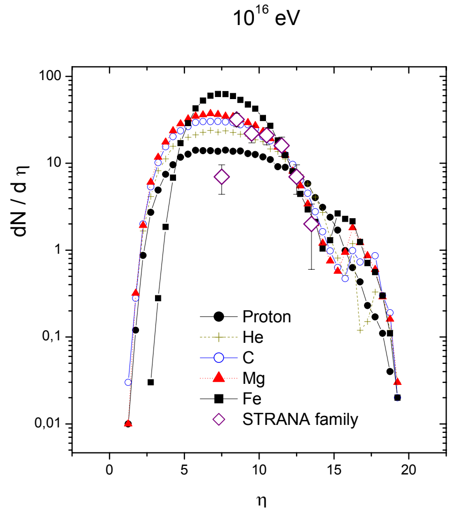

Figure 2. Comparison of experimental and calculated pseudorapidity distributions in the family. Simulations were made with QGSJET model for various primary types and $E_0=10^{16}$ eV.

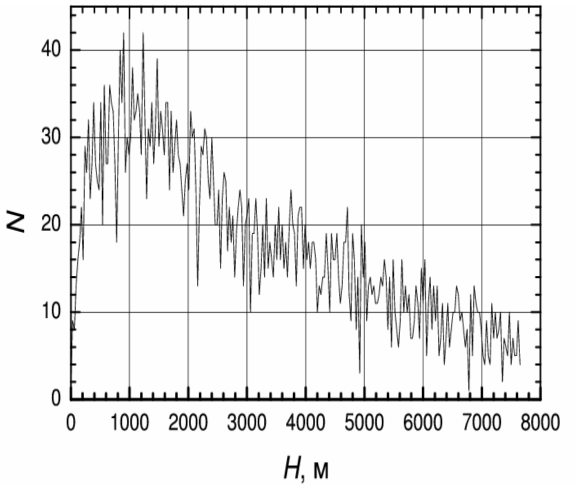

Figure 3. Distribution of heights of various assumed pairs of gamma-quanta from π^0-mesons decay in STRANA superfamily.

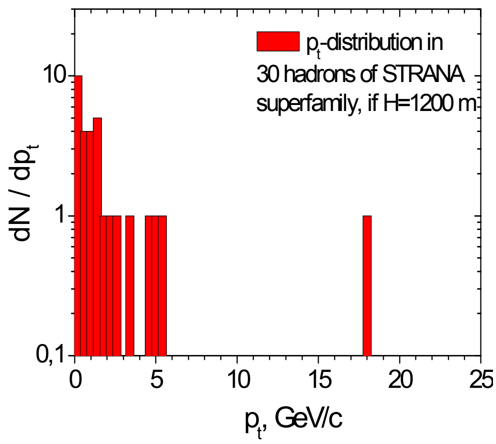

Figure 4. Distribution of p_t for all 30 hadrons in STRANA superfamily under assumption of interaction height H=1200 m.

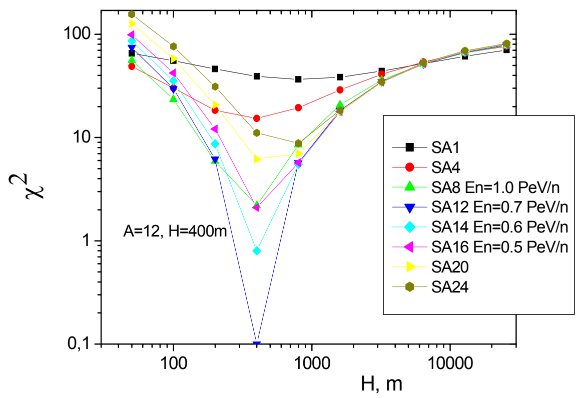

Figure 5. Estimation of interaction height by pseudorapidity distribution analysis for various primary types and energy (an example of χ^2 minimization).

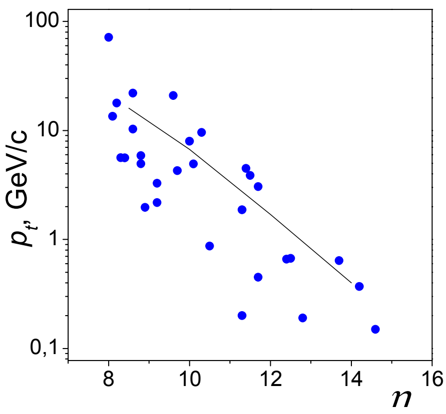

Figure 6. P_t - η correlation for 30 hadrons in STRANA superfamily under assumption of interaction height H= 300 m.

5. Acknowledgements

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