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TO THE PROBLEM OF NOVEL MECHANISM OF NUCLEAR CASCADES GENERATION AT HIGH ENERGIES

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TO THE PROBLEM OF NOVEL MECHANISM OF NUCLEAR CASCADES GENERATION AT HIGH ENERGIES

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I. Some features of a cascade shower development in an ionization calorimeter

The Refs 1–9 report about the irregularities connected with the dynamics of a nuclear cascade process in a dense substance (the absorber of an ionization calorimeter) observed at energies above 200 GeV by means of the setup "Pion" [9,10].

The calorimetric data were analyzed by studying the fluctuations of the forms of cascade showers in the calorimeter. To specify each cascade the following set of parameters was used: the depth x_i of the i-th interaction (the generation point of the i-th ionization maximum of a cascade shower) ; the distance between the i-th and the k-th interactions, ℓ_{ik} ; the share of the primary energy E_0 taken by the secondary particle generating the i-th maximum, $U_i = \frac{E_i}{E_0}$.

Using the parameter x_i one can determine, whether the i-th ionization maximum in the given cascade unit is due to the primary or the secondary interaction. The x -distribution for primary maxima is described by the exponent

$$w_1 \sim exp\left(-x/\lambda\right) \qquad (1)$$

while for secondary ones by the dependence having

$$w_2 \sim x \cdot \exp(-x/L) \qquad (2)$$

type maximum, where L is a complex function of the relation between the nuclear length and the ones up to the i-th interaction.

The distribution function of the parameter ℓ_{12} also has the exponential form $w_{12} \sim \exp(-\ell_{12}/\langle \ell \rangle)$ and is determined by the interaction lengths and the mean number $\langle n \rangle$ of secondary hadrons contributing to the second maximum of the cascade curve. If all the secondaries are nucleons and π -mesons, then $\langle \ell \rangle = \frac{\lambda}{\langle n \rangle}$. When $\langle n \rangle \approx 1$, then the energy spectrum of secondary maxima $u = \frac{E_2}{E_0}$ is, presumably, the spectrum of leading hadrons in the laboratory reference frame.

We had also made use of the ratio E_2/γ_c characterizing in the ultrarelativistic limit the cms momentum of the secondary particle (γ_c is the cms Lorentz-factor) and in the nonrelativistic limit the mass of the secondary.

The irregularities observed in these works consist in the fact that at $E_0 \geqslant 200$ GeV among the cascades with $u \geqslant 0.5$ there appear an admixture of events, the first and the second ionization maxima of which are distributed over the calorimeter depth according to (2) type rule, where the parameter L corresponds to the interaction length $\sim 2\lambda$. In the vicinity of 200 GeV the distribution $w(\ell_{12})$ also changes due to the rise of a "long path" component with $\langle \ell \rangle \sim 2\lambda$ (20% of events in the 200 - 400 GeV range and $\sim$ 50% for energies in excess of 400 GeV).

The regularity of the E_2/γ_c distribution is simultaneously violated. For $E_0 < 200$ GeV this distribution coincides with the expected one obtained from the measured $N(E_0)$ and $N(u)$

spectra; however, for energies in excess of 200 GeV there arise an additional maximum on the part of higher E_2/γ_c values.

As the above anomalies are correlated, it proves possible to evolve the events accountable for them . The procedure is based on the assumption that the unknown process is a binary reaction in which all the energy is transmitted to two secondary particles (T-particles),the interactions of which with a matter are relatively weak in nature.

In the framework of such a model one can obtain the characteristics of this phenomenon in more detail. The T-particles were found to have $m_T \sim 10$ GeV/c^2 mass, the mean lifetime $\tau_0^T \gtrsim 10^{-11}$ sec and the preferred forward and backward cms directions of flight near the reaction threshold (200 - 400) GeV. With the increase of E_0 the angular distribution approaches the isotropic one.

II. The behaviour of calorimetric cascades at energies higher than 1 TeV

The utilization of data obtained with the large ionization calorimeter[11], consisting of 10 arrays of ionization chambers interleaved with 10 cm thick iron filters and having the effective solid angle of 1.54 m^2 sterad, allows one to proceed to energies up to 10 TeV. From the viewpoint of the hypothesis of the generation of observed "anomalous" cascades, the energies above 1000 GeV are of interest already because the information at these energies could reveal the presence or absence of the energy dependence of the process in question and will help to choose between two T-reaction versions:

i. The long-lived T-particles ($\tau_0^T \gtrsim 10^{-9}$ sec) having the interaction length in iron $\lambda_T \sim 2\lambda$.

ii. The relatively short-lived T-particles weakly interacting with matter ($\tau_0^T \lesssim 10^{-10}$ sec, $\lambda_T \gg \lambda$).

If the latter version took place and the estimates of the mass and the lifetime were correct, then at energies above 1000 GeV one couldn't anticipate exactly such effects which were observed in the calorimeter "Pion".

Indeed, although the cross section of this reaction is rather large (according to Refs 3,6,9, the estimate of lower bound on the cross section makes ~ 40 mbn for $E_0 \sim$ 1000 GeV), in the vicinity of 1000 GeV it is likely to reach plateau. At the same time, with the increase of energy all the more T-particles will leave the calorimeter and decay outside of it. Hence, the probability to observe the characteristic cascades produced by the T-particles must quickly reduce. The T-events detected by the calorimeter are either of the form of one-maximum cascades (when only one of the T-particles decays within the absorber) or two-maxima ones with near energies E_1 and E_2 as at largy E_0 mainly the events with T-particles ejected at $\pi/2$ in the cms are selected.

Presumably, one can gain the information on the T-events from the analysis of one-maximum cascades only on the grounds of the x_1-distribution and only with sufficiently large statistics. Two-maxima T-cascades would have the u-values close to 0.5. It is easy to see that in such a case the analysis of the E_2/γ_c -distribution is of no use; in the $f(u) = 0.5 =$ const limit the distribution

$$dN(m) = \int f[u(E_0)]\cdot N(E_0)\,dE_0 = N(E_0)\,\mathrm{const}\cdot dm$$

will simply follow the primary $N(E_0)$ spectrum. On the other hand, the loss of a part of the most energetic events connected with the production of T-particles should lead to the distortion of the measured E_0 spectrum chiefly for $u \geq 0.5$ cascades (for energies $E_0 \leq 1000$ GeV approximately a half of these cascades are the T-events). For these reasons let us turn to the experiment.

In Fig.1 the spectra of E_0 energies as measured for all the 1055 cascades with $E_0 > 700$ GeV irrespective of their configuration and for 244 cascades with $u \geq 0.5$ are shown . The spectra have different slopes: the spectrum index determined by means of the method of least squares by $E_0 > 1000$ Gev events is $\gamma_{u \geq 0.5} = -3.57 \pm 0.12$ and $\gamma_{\mathrm{all}} = -3.27 \pm 0.07$. The E_2/γ_c -distribution calculated from the measured $N(E_0)$ spectrum and the $f(u)$ spectrum is shown in Fig.2 together with the experimental E_2/γ_c -distribution for cascades with $u \geq 0.5$. The agreement between the measured and the expected distributions is satisfactory- no irregularities are seen.

No any inconsistency is seen either in the distribution of $N(x_1)$, $N(x_2)$ and $N(\ell)$ lengths(Figs 3,4).

Thus, the only experimental fact that could be related to the T-effect is the excessive steepness of the primary spectrum. If we discard the cascades with $u \geq 0.5$, then the remaining 811 events will be distributed over the spectrum having the index γ without $_{u<0.5} = -3.2 \pm 0.08$ (Fig.2). Such a large γ -value could be explained by the increase with energy of the relative number of hadrons coming in groups or as a part of showers. The rejection of tracking events leads to a seeming steepening of the spectrum [12].

However, the fact is essential that the E_o spectrum differs appreciably for $u \geqslant 0.5$ events from the spectrum of all the other events . The analogous spectra obtained with the "Pion" calorimeter practically coincide in the range of $E_o > 150$ GeV :

$\gamma_{all} = -2.79 \pm 0.03$ and $\gamma_{u \geqslant 0.5} = -2.71 \pm 0.08$.

It was shown in Refs 3,6,9 that T-particles with the mass $m_T \sim 10$ GeV/c^2 and the lifetime $\tau_o^T \sim 0.8 \cdot 10^{-10}$ sec begin to leave in appreciable number the calorimeter at energies about 1000GeV when their decay length becomes comparable with the thickness of the calorimeter x_o . At $E_o \sim 1000$ GeV the decay path λ_d turns to be $\gtrsim 10x_o$, i.e. about 90% of all the T-events are lost. Therefore, if in the vicinity of 1000 GeV the T-events make up $\sim \frac{1}{2}$ of all the cascades with $u \geqslant 0.5$, and subsequently the cross section stays more or less constant, then at 10000GeV the observed number of cascades with $u \geqslant 0.5$ should reduce half as much because of the loss of all the T-particles . Assuming the slope of the spectrum of primary particles generating the cascades of arbitrary configurations (including the T-cascades) to be $\gamma^* = -3.2$, it is easy to establish that the loss of all the T-events at 10000 GeV gives approximately the same change of the spectrum index γ as that observed in the experiment.

If at $E_o = 1000$ GeV the measured number of N_o events with $u \geqslant 0.5$ coincides with their real number N_o^*, and at N_1^*

E_1 =10000 GeV N_1 is twice as little, i.e.

$$\frac{N_1^*}{N_1} = \left(\frac{E_1}{E_0}\right)^{-\gamma^*} \Big/ \left(\frac{E_1}{E_0}\right)^{-\gamma} = 2$$

then the visible change of the index γ makes $\Delta\gamma = (\gamma - \gamma^*) =$ $= \lg 2 = 0.3$, i.e. we shall have $\gamma^* = 3,2$ instead of $\gamma^* =- 3,5$

Short conclusions

Thus, by reasons of both the methodical and physical nature, the above results don't give the unambiguous answer to the problem under consideration. One can say, however, that our observations made with the large calorimeter for energies above 1000 GeV as a whole don't contradict the hypothesis of short-lived T-particles. The hypothesis of long-lived T-particles failes to explain the disappearance with energy of correlated anomalies in the E_2/γ_c spectrum and in the distributions of x and ℓ lengths.

FIGURE CAPTIONS

Fig. 1 The E_0 spectrum for all the 1055 cascades and for 244 cascades with $u \geq 0.5$.

× and the solid line - all the cascades

o and the solid line - the cascades with $u \geq 0.5$

and the dashed line (all the cascades without the cascades with $u \geq 0.5$)

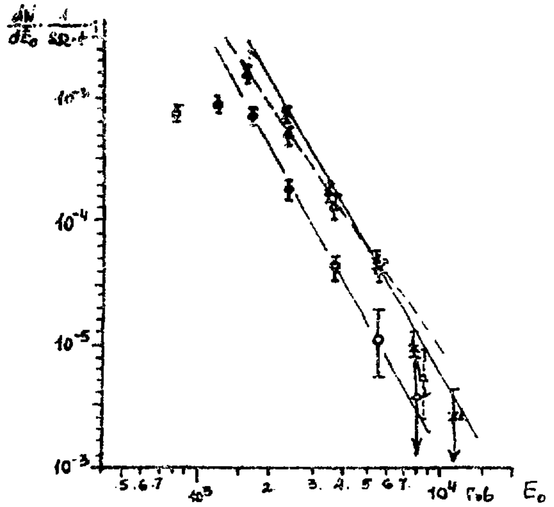
Fig. 2 The E_2/γ spectrum - the experimental and the anticipated ones for the cascades with $u \geq 0.5$. The curve is the anticipated distribution.

Fig. 3 The distribution of X_1 - and X_2 -lengths. The curves are the anticipated distributions for the model of succeeding interactions.

Fig. 4 The distribution of ℓ_{12}-lengths. The lines are the approximations to the experimental data by the method of least squares.

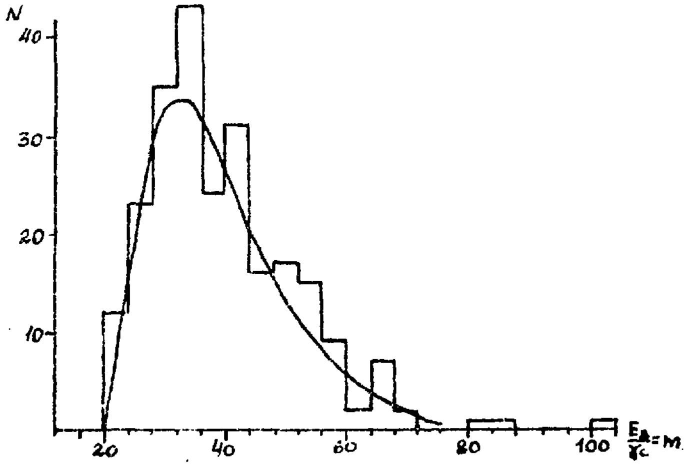
X - the cascades with $u \geq 0.5$.

o - the cascades with $u < 0.5$.



$\frac{dN}{dE_0}\cdot\frac{1}{S\Omega\cdot t}$
10^{-3}
10^{-4}
10^{-5}
10^{-3}
5 6 7
10^3
2
3
4
5
6
7
10^4 Гэв
E_0

Fig.1



N
40
30
20
10
20
40
60
80
100
$\frac{E_\Delta}{\gamma_c}=M$

Fig.2

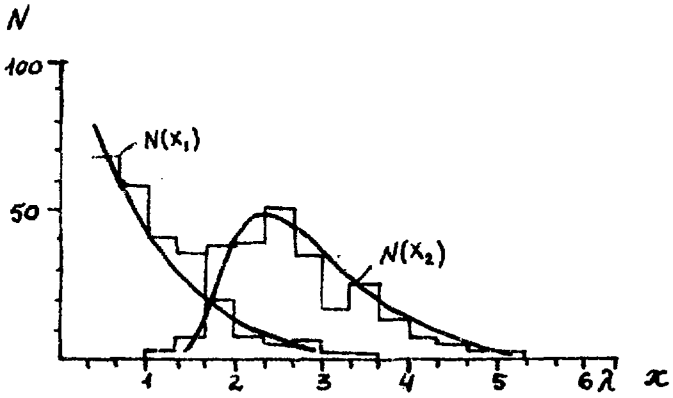


Fig.3

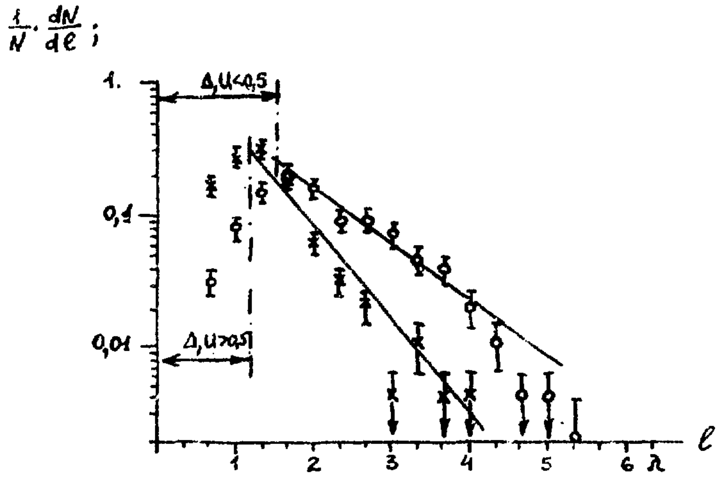


Fig.4

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К ВОПРОСУ О НОВОМ МЕХАНИЗМЕ ГЕНЕРАЦИИ ЯДЕРНЫХ КАСКАДОВ ПРИ ВЫСОКИХ ЭНЕРГИЯХ.

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