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Fig. 1

Figure 1: Fig. 1

## Abstract

## Full Text

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# GENERATION OF HEAVY PARTICLES AND THEIR ROLE IN EXPLAINING EXPERIMENTAL RESULTS IN THE REGION OF ULTRAHIGH ENERGIES

In the collision of a nucleon with a nucleon (or with a nucleus) in the region of ultrahigh energies ($E > 10^{12}$ eV), a number of characteristic phenomena are observed. For example, in the analysis of jets recorded by means of nuclear emulsions exposed to cosmic rays at high altitudes, in a number of cases two maxima are found in the differential angular distribution of narrow tracks in the coordinates ($\lg\tan\theta - \lg\tan\bar{\theta}$) (1–4). As was noted in papers (1,3,4), such a distribution does not agree with the predictions of the theories (5,6) of multiple pion generation. The model of excited nucleons (7) explains the indicated formula for the angular distribution, but in this model the inelasticity coefficient

$$K = \frac{\gamma_c - \bar{\gamma}}{\gamma_c} \sim 0.8 \div 0.9$$

is much larger than that observed experimentally, which is on the average $0.3 \div 0.4$. In connection with this, Polish authors (2), as well as in papers (8,9), advanced the hypothesis of the formation of two generation centers–pion clusters (fireballs, f.b.) torn away from the nucleons and decaying isotropically into pions in their own system. This model was called the fireball model (f.b.m.). The f.b.m., having a large number of degrees of freedom, has a number of advantages over other models (for example, the absence of two maxima can be explained by the small relative velocity of the two f.b.), although the physical cause of the formation of pion clusters remains completely unclear.

Fig. 1

Further investigations show the limitations of the f.b.m. First, two maxima in the angular distribution are observed only for jets specially selected according to the criteria $\sigma/\sigma_{is} \geqslant 2,\ D > 0$. Second, the formation of energetically isolated pions does not fit into the f.b.m. scheme. Two maxima are also observed in

Fig. 2

Figure 2: Fig. 2

the collision of a nucleon with a nucleus (3,10,11). This fact requires at least a physical substantiation and a generalization of the f.b.m., which is only a convenient kinematic scheme.

Finally, it turns out that the f.b.m., even in the case of nucleon-nucleon interactions, describes too crudely angular distributions with clearly expressed two maxima, i.e., it does not agree with experiment in the specific sphere of its application.

In recent years we have been carrying out systematic processing of a large number of jets recorded in our laboratory and in other laboratories. In doing so, the following results have been obtained, indicating disagreement of the f.b.m. with experiment.

1. If one selects jets with $E \geqslant 10^{13}$ eV and $\sigma/\sigma_{is} \geqslant 2$, $D > 0$, then in their total angular distribution the number of particles in the narrow cone proves to be 1.4 times greater than in the diffuse one (Fig. 1). This fact is not explained by the model, since

as, according to the statistical theory, the number of particles in the narrow and diffuse cones should be the same.

2. Approximately 20% of the particles in jets with two maxima are not covered by the statistical theory, as is illustrated in Fig. 2, where the particles in the upper right corner (and in the lower left corner) remain outside the "tracks" following from the statistical theory. These particles are energetically selected. This can be verified directly by estimating the energies from the condition of constancy of the transverse momentum. The number of such particles in different jets varies, but on average there are two per shower; each of these particles carries away of the order of 10% of the total energy.

Fig. 2

3. According to the statistical theory, the value $D$ should increase with increasing $\sigma/\sigma_{is}$. However, the experimental observations do not give a regular relation between these two parameters (12,13), as is clear from Fig. 3, where the solid curve shows the dependence following from the statistical theory (under the assumption of a power-law energy spectrum of pions in the rest frame of the statistical theory). The deviations of most of the points from the curve exceed the limits of statistical fluctuations.

It appears necessary to find a new explanation for the observed characteristics of jets, one that would make it possible to establish the causes of the discrepancy between the statistical theory and experiment. This explanation can be

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

reduced, as shown below, to the hypothesis of a sufficiently intense generation, and energetic selection, of particles heavier than pions, such as various types of resonances, baryons, and antibaryons. In this case there is no need to introduce new unknown particles; it is sufficient to take into account the role of the so-called resonance particles observed in accelerator-energy experiments ([14]).

Fig. 3

We suppose that, as a result of the collision of a nucleon with a nucleon (through an intermediate pion-pion or "central" nucleon-nucleon interaction), an excited system is formed which decays into pions, $K$-mesons, resonances, and baryon pairs. The expansion of the system can be described by the hydrodynamic theory of multiple particle production ([6]).

The formation of energetically selected particles is associated with a simple wave ([15]); its role proves significant when the "viscosity" of the medium is taken into account ([16]).

An essential circumstance for the model being developed is that the formation of heavy particles should occur predominantly during the decay of the simple wave. Indeed, since the motion of a simple wave begins at the boundary with the vacuum (outflow into vacuum), there must be a peculiar edge effect—the temperature of the freely ex-

at this stage may be considerably higher than at the stage of hydrodynamic expansion described by the nontrivial solution, when the mean free path for interaction is much smaller than the dimensions of the system. On the other hand, as was shown by S. Z. Belen' kii [17], the relative probability of formation of heavy particles increases with increasing temperature of free expansion. At the same time, the fraction of the system' s energy and the fraction of the entropy carried away in a simple wave also increase. All the factors listed lead to an enhancement of the influence of the stage of passage of simple waves on the formation of the angular distribution of shower particles.

**Fig. 4**

The angular (Fig. 4, curve 1) and energy distribution of the particles before their decay (and annihilation) are described by hydrodynamic theory [6], with allowance for simple waves [15]. However, the distribution observed experimentally (curve 3) is determined by the decay (and annihilation) of energetically isolated heavy particles (curves 2). In this case, sometimes (the process has a statistical character) two maxima are obtained in the angular distribution (an imitation of two f.b.) against the background of the part of the angular distribution described by Landau' s theory [6]. From the point of view of the proposed model, it is possible to interpret the characteristics of the jets discussed above.

The result of Fig. 1 is easily explained by the transition into a narrow cone of low-energy pions formed in the stage after the passage of simple waves.

The energetically isolated pions (Fig. 2) may be regarded as having formed directly in the decay of simple waves.

The absence of a regular connection between the parameters $D$ and $\sigma/\sigma_{is}$ (Fig. 3) is explained by the contribution, into the interval between the two maxima, of particles formed at the stage of expansion of the system described by the nontrivial solution.

In connection with the possibility of explaining a number of experimental facts by the generation of heavy, rapidly decaying particles, several new questions arise. First, particles of the resonance type should be sought in jets with two maxima in the angular distribution. Second, energetically isolated pions, formed at a higher temperature, must have transverse momenta larger than the mean transverse momentum for all shower particles.

The model under discussion can be generalized to the case of nucleon-nucleus interactions.

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## CITED LITERATURE

1. Zh. S. Takibaev, *Tr. Inst. yadern. fiz. AN KazSSR*, 1, Alma-Ata, 1958.
2. P. Ciok, T. Coghen et al., *Nuovo Cim.*, **8**, 166 (1958).
3. Zh. S. Takibaev, *Vestn. AN SSSR*, **5**, 101 (1959); *DAN*, **127**, 67 (1959).
4. L. A. San' ko, Zh. S. Takibaev et al., *ZhETF*, **36**, 7 (1959).
5. W. Heisenberg, *Zs. Phys.*, **113**, 61 (1939); **126**, 569 (1949); **133**, 65 (1952).
6. L. D. Landau, *Izv. AN SSSR, ser. fiz.*, **17**, 51 (1953).
7. S. Takagi, *Progr. Theor. Phys.*, **7**, 123 (1952).

8. G. Cocconi, *Phys. Rev.*, **111**, 1699 (1958).

9. K. Niu, *Nuovi Cim.*, **10**, 994 (1958).

10. Zh. S. Takibaev, A. A. Loktionov, L. A. San' ko, Ts. I. Shakhova, *Tr. Mezhdunarodn. konf. po kosmicheskim lucham*, vol. 1, Moscow, 1959, p. 51.

11. J. Bartke, P. Ciok et al., *Nuovo Cim.*, **15**, 18 (1960).

12. J. Gierula, M. Miesowicz, P. Zielinski, *Nuovo Cim.*, **18**, 102 (1960).

13. K. Imaeda, *Nuovo Cim.*, **26**, 417 (1962).

14. M. Roos, *Rev. Mod. Phys.*, **35**, 314 (1963).

15. M. Gerasimova, D. S. Chernavskii, *ZhETF*, **29**, 372 (1955).

16. A. E. Emel' yanov, I. L. Rozental' , *ZhETF*, **38**, 194 (1960); A. E. Emel' yanov, *ZhETF*, **42**, 171 (1962).

17. S. Z. Belen' kii, *DAN*, **99**, No. 4, 523 (1954).

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