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Abstract

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PHYSICS

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ON THE INTERACTION OF HIGH-ENERGY PARTICLES WITH NUCLEI

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At present there is no theory that could satisfactorily describe the mechanism of production of elementary particles in nucleon–nuclear interactions in the energy region 10^{11}–10^{13} eV. Therefore, an experimental study of these interactions is of great interest. Below we describe preliminary results of an analysis of seven jets with a relatively large number of shower particles, formed in the interaction of nucleons with nuclei of the emulsion.

As a result of scanning part of an Ilford G-5 emulsion stack, exposed for 7 hours at an altitude of about 30 km, we selected jets caused by neutral and charged particles. In analyzing these cases, the most reliable data were obtained only on the number of shower particles and their angular distribution. The angles between the direction of motion of the primary particle and the tracks of secondary particles were measured under an MBI-8 microscope by the coordinate method ([1]). The characteristics of these disintegrations are presented in Table 1.

Table 1

Characteristics of disintegrations*

No.	n_λ	N_T	Z_{prim}	$\theta_{1/2}$, rad.	φ, deg.	l, μ	Type
1	28	8	0	$1.9 \cdot 10^{-2}$	14	760	1
2	18	10	≤ 2	$3.2 \cdot 10^{-2}$	6	500	1
3	27	9	0	$3.4 \cdot 10^{-2}$	13	900	1
4	46	16	≤ 2	0.13	4	1000	2
5	52	37	≤ 2	0.23	3	320	2

Fig. 1. Integral angular distribution of shower particles in jets of type I (laboratory coordinate system)

Figure 1: Fig. 1. Integral angular distribution of shower particles in jets of type I (laboratory coordinate system)

No.	n_λ	N_T	Z_{prim}	$\theta_{1/2}$, rad.	φ, deg.	l, μ	Type
6	46	9	0	0.20	8	130	2
7	17	27	≤ 2	0.155	17	100	3

* Notation: n_λ is the number of tracks of shower particles; N_T is the number of black and gray tracks; Z_{prim} is the presumed charge of the primary particle; $\theta_{1/2}$ is the angle in which half of the tracks of shower particles are contained; φ is the angle of inclination of the shower axis to the plane of the developed emulsion; l is the distance from the beginning of the shower to the point where measurements were made.

In order to obtain a visual representation of the angular distribution of shower particles in the jet in the laboratory coordinate system, we plotted the dependence

$$\frac{1}{N}\int_0^\theta N(\theta)\,d\theta$$

on θ (in radians). In doing this, all the jets were divided into three types. Type I jets, which are characterized by the presence of a narrow cone, have a symmetric integral distribution (see Fig. 1). Type II (see Fig. 2) includes jets with a much wider cone and a larger number of charged particles. It is seen that each curve of this type breaks up into two parts: one of them is similar to the curves of Fig. 1, while the other does not possess the property of symmetry. Figure 3 presents the angular distribution of shower particles for one jet in which symmetry is not observed even in the region of small angles.

Any theoretical consideration of the mechanism of production of elementary particles ([2,3]) starts from a symmetric decay of the produced particles in the system

center-of-mass system. As was shown in work ([4]), such a distribution in the center-of-mass system should be obtained if the integral angular distribution in the laboratory system has a symmetry of a definite kind. In this case there exists a point on the curve with respect to which the relation $\ln\theta_f = -\ln\theta_{1-f}$ is fulfilled.

Fig. 1. Integral angular distribution of shower particles in jets of type I (laboratory coordinate system)

In three cases, as is seen from Fig. 1, this symmetry is observed experimentally. The point of symmetry corresponds approximately to the angle within which one half of the observed shower particles is contained. Thus, the basic propositions of the Fermi—Landau theory can be applied to these cases, the energy of the primary particle can be calculated, the multiplicity coefficient estimated, and the angular distribution in the center-of-mass system constructed. The calculated values of the energies of the primary particles and the multiplicity coefficients (see Table 2) agree well with the theoretical conclusions ([3]). With the exception of jet 3 (Fig. 4), the angular distribution in the center-of-mass system proved to be isotropic. This result disagrees with the predictions of Landau' s theory, but is in agreement with other experimental data ([5–7]).

Table 2

Energy of the primary particle and multiplicity coefficients for jets of types I and II

No.	F_{lab} at $\theta_{1/2}$, in eV	$k = N_{\text{expt}}\gamma^{-1/4}A^{-0.19}$	E_{lab} by the symmetrical part of the curve, in eV	k by the symmetrical part
1	$5.2 \cdot 10^{12}$	1.4	$5.2 \cdot 10^{12}$	1.4
2	$1.8 \cdot 10^{12}$	1.2	$1.8 \cdot 10^{12}$	1.2
3	$1.6 \cdot 10^{12}$	2.4	$1.6 \cdot 10^{12}$	2.4
4	$1 \cdot 10^{11}$	7	$1 \cdot 10^{13}$	2.0
5	$4 \cdot 10^{10}$	5	$1 \cdot 10^{12}$	3.6
6	$4 \cdot 10^{10}$	4	$2 \cdot 10^{12}$	2.9

The next three cases are characterized by a wide cone. The energy estimated from the angle $\theta_{1/2}$ turns out to be small and does not agree with even the roughest estimate of the lower energy limit from the total number of particles. The multiplicity coefficient turns out to be large (Table 2). The experimental value of the multiplicity cannot be considered overestimated, since the contribution of electron-positron pairs may be neglected, because the distances at which the angular measurements were made are considerably smaller than the radiation unit length in the emulsion. As indicated above, all three curves split into two parts. This indicates a more complex character of the angular distribution of shower particles in nucleon-nucleus interactions as compared with that predicted by the theory ([3]). Apparently, by a more correct kinematic method one can estimate the energy of the primary particle if only the symmetric parts of the obtained curves are used, since from theoretical considerations and experimental data ([8]) it follows,

that the major fraction of the primary particle' s energy is carried away by shower particles moving in a very narrow cone. However, if the values of the energies of the primary particles obtained in this way are used to estimate the

Fig. 2. Integral angular distribution of shower particles in type-II jets. Symmetric parts of the distribution in the small-angle region are highlighted.

Figure 2: Fig. 2. Integral angular distribution of shower particles in type-II jets. Symmetric parts of the distribution in the small-angle region are highlighted.

Fig. 3 and Fig. 4.

Figure 3: Fig. 3 and Fig. 4.

multiplicity coefficient, it turns out that their values (Table 2) are several times larger than those usually adopted: $k = 1.2 \div 2.3$. This fact, and the observed angular distribution in type-II jets, can be interpreted as an indication that, in the interaction of shower particles with the nuclear matter, not only their scattering occurs, but also the production of new particles. It is obvious that the mechanism of production in jets of this type is more complicated than the mechanism of multiple production.

Fig. 2. Integral angular distribution of shower particles in type-II jets. Symmetric parts of the distribution in the small-angle region are highlighted.

Fig. 3. Integral angular distribution of shower particles in disintegration 7 (see Table 1)
Fig. 4. Angular distribution of shower particles in the center-of-mass system for disintegrations 1, 2, 3 (see Table 1)

In the latter case the angular distribution of the shower particles, in our opinion, appears still more complicated. In studying the jet it is seen that the shower particles are grouped in the form of two cones. Observation of such a phenomenon in the collision of a nucleon even with a heavy nucleus in the energy region of approximately 10^{13} eV and higher seems improbable. The kinematic method of determining the energy of the primary particle is inapplicable in this case, but it can be estimated roughly if one takes into account the phenomenon of contraction of jets with increasing energy of the primary particle. On this basis it may be established that the energy of the primary particle in case 7 is smaller than in cases 1–3 (Table 1). Taking into account the energy of the primary particle,

the reduced angular distribution and the number of particles produced, one may conclude that the theory of multiple production of elementary particles is not capable of explaining this case. Apparently, in the last four jets the number of shower particles and the nature of their angular distribution could be explained if one assumes a multiple-multiplicity character of the process of particle production. It is clear that further accumulation of experimental data will make it possible to obtain a more definite picture of the mechanism of elementary-particle production in nucleon–nuclear interactions in the high-energy region.

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Note: Figure translations are in progress. See original paper for figures.