ON THE ANALYSIS OF HIGH-ENERGY SHOWERS

Ya. I. GRANOVSKIĬ and I. Ya. CHASNIKOV

Nuclear Physics Institute, Academy of Sciences, Kazakh S.S.R.

Submitted to JETP editor September 6, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 1119-1122 (April, 1959).

The double-valued dependence of the shower particle energy on the angle of emission in the laboratory system is explained. A method is suggested for a more precise determination of γ_c taking into account the energy and angular distribution of shower particles.

THE dependence of the energy of shower particles on their angle of emission in the laboratory system of coordinates (l.s.)[1] has been analyzed by Huzita.[2] The resulting double-valued dependence is interpreted as a consequence of two or more collisions taking place in the interaction between the primary particle with the nucleons of the target nucleus.

If this conclusion is accepted, then the dependence should be multi-valued for other showers, especially when the primary is multiply charged. However, for a shower produced by a multi-charged particle (a case found and analyzed in our laboratory) the dependence $pv = f(1/\sin\theta)$ (where p and v are the momentum and velocity of the particle and θ is the spatial angle of emission in l.s.), is also found to be double-valued (see Fig. 1, curves A and B). The double-valued dependence is also observed for the shower described by Boos et al.,[3] produced in a nucleon-nucleon collision.

The observed character of the dependence of the energy of shower particles on the angle of their emission in certain showers can probably be explained by kinematic considerations without any assumptions concerning the mechanism of interaction of the primary particle with one or several nucleons of the target nucleus.

In the observed high-energy showers (jets), there are no shower particles emitted in the backward direction in the l.s. This indicates that, in such cases,

$$V_c > V^*, \tag{1}$$

where V_c is the velocity of the center-of-mass system (c.m.s.) and V^* is the velocity of the shower particles in c.m.s. From the Lorentz transformation, we have

$$E^* = \gamma_c (E - pV_c \cos\theta), \qquad \gamma_c = 1 / \sqrt{1 - V_c^2}$$

and it follows that

$$\frac{E}{m} = \frac{E^*/m\gamma_c \pm V_c \cos\theta \sqrt{(E^*/m\gamma_c)^2 - (1 - V_c^2 \cos^2\theta)}}{1 - V_c^2 \cos^2\theta}, \tag{2}$$

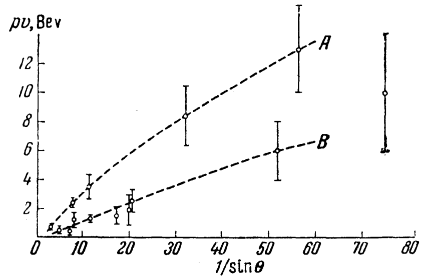

FIG. 1. Dependence on the energy of shower particles on their angle of emissions in the l.s. for a shower produced by multiply charged particles.

where $E (E^*)$—is the energy of the shower particle in l.s. (c.m.s.), and m is the particle mass (π meson). Under condition (1) one should take both signs in formula (2). Assuming various values of $a = E^*/m\gamma_c$, one can construct the graph of the dependence $y = E/m$ on $x = 1 - V_c^2 \cos^2\theta = \sin^2\theta + \gamma_c^{-2} \cos^2\theta$ according to formula (2). A family of such curves is shown in Figs. 2 and 3; the value of the parameter a is indicated on the curves. In formula (2), the sign + is taken for those particles for which $0 < \theta^* < \theta_0^*$, and the sign − for $\theta_0^* < \theta^* < \pi$ (where θ_0^* is the angle in c.m.s. corresponding to the limiting angle in l.s.) For $\theta^* = \theta_0^*$, we have $x = \sqrt{a}$ and $y = 1/\sqrt{x}$. On a logarithmic scale, $y = 1/\sqrt{x}$ is represented by a straight line (Figs. 2 and 3) below which lie the points corresponding to particles with an angle $\theta^* > \theta_0^*$. If, in the shower under study, there are no such particles, then all experimental points on the graph are above the limiting straight line, and there is no double-valued dependence $E(\theta)$ in the l.s.

From the Lorentz transformation, we have

$$E = \gamma_c (E^* + p^* V_c \cos\theta^*) \tag{3}$$

It follows that the points corresponding to particles emitted at the angle $\theta^* = 90°$ fall on one curve

$$y = \gamma_c^2 a. \tag{4}$$

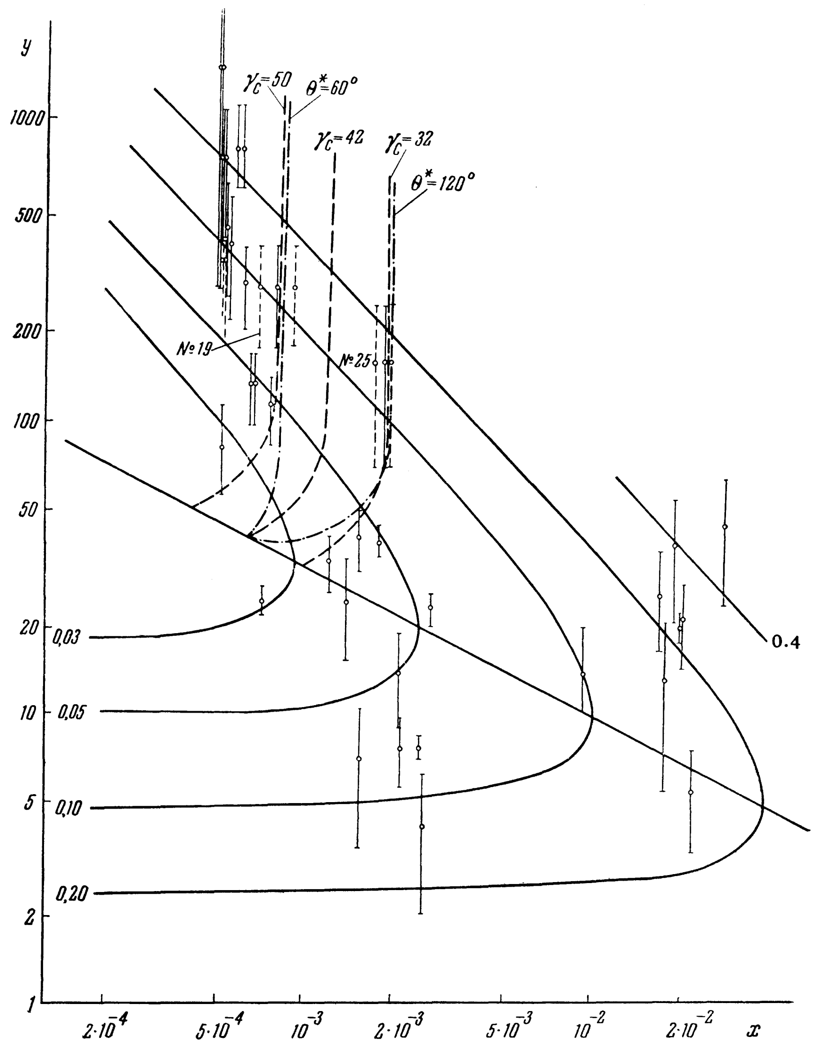

FIG. 2. Variation of y(x) for particles of the shower of De Benedetti et. al.[2] for $\gamma_c = 45$. For the particles No. 19 and 25 the points are plotted for 3 values of γ_c equal to 50, 45 and 40 respectively.

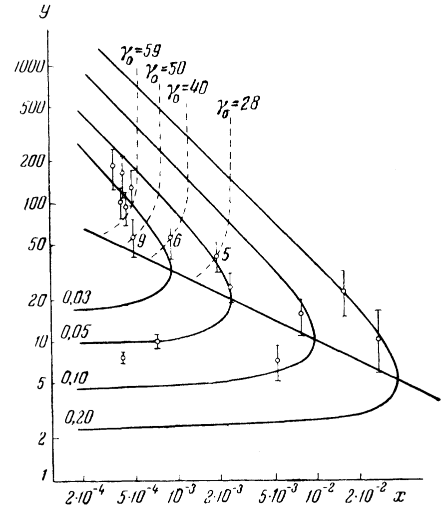

FIG. 3. The shower of Boos et. al.[3] The experimental points are plotted for $\gamma_c = 52$.

These curves for various values of γ_c are denoted in Figs. 2 and 3, by dashed curves. Analogous curves for different angles θ^* can be calculated using the same formula (3). In particular, the curves for the angles $\theta^* = 60°$ and $\theta^* = 120°$ are shown in Fig. 2.

Experimental data of references 2 and 3 are shown in Figs. 2 and 3. Comparing Fig. 2 with Fig. 7 of the article by Huzita, it is clear that the latter assumed that particles with the angles of emissions $\theta^* > \theta_0^*$ were produced as a result of a separate interaction. In Fig. 3 (shower observed by Boos et al.[3]), particles with angles of emission $\theta^* > \theta_0^*$ are also present. Their fraction in both cases is $\sim 20\%$ of the total number of particles, and increases, if among the shower particles, there are particles heavier than π mesons.

An analysis of showers using Eqs. (2) and (4) makes it possible to find the value of γ_c more accurately than determined by another method (for instance by the half-angle method). For this purpose, one draws curves (4) for various γ_c. Assuming the equality of the number of particles emitted in the forward and backward direction in c.m.s., we can determine the corresponding value of γ_c. Accounting for fluctuations of points near $\theta^* = 90°$, one can find the limits of possible values γ_c. It can be seen from Fig. 2 that the apparent lower limits of γ_c are equal to 50 and 32 correspondingly, the probable value of γ_c being equal to 42.2 (De Benedetti et al.[2] give the value of γ_c equal to 40 to 50). A more accurate value of γ_c can then be obtained by the method of consecutive approximations. It is sufficient, however, to do this only once, since the corrected value of γ_c almost does not change. Thus, if we assume $y_c = 40$, the corrected value of γ_c is 40.5. (It is shown in Fig. 2 how the position of particles number 19 and 25 changes in dependence of γ_c). In an analogous fashion, for $\gamma_c = 50$, one obtains a more accurate value of 43.5.

Applying the same method to the shower of Boos et al.[3] we obtain the upper and lower limits $\gamma_c = 40$ and 28 with the probable value of 34.5.

The possible fluctuations of particle No. 6 leads to variation of the limits of γ_c (see Fig. 3).

The advantage of the above method lies in the fact that, for the more accurate values of γ_c, one takes into account the experimental data for the angular and energy distribution of shower particles in the l.s. We do not make use of the usually-made assumption of symmetry (or isotropy) of the angular distribution in the c.m.s., nor do we assume that the particles are monoenergetic, etc. Only the equality of the number of particles emitted in the forward and backward directions in the c.m.s. is essential.

In all analyzed cases, the proposed method has led to a lowering of γ_c as compared to the half-angle method. This is in agreement with the data of other authors.[4,5]

In conclusion, the authors would like to express their gratitude to J. S. Takibaev for his interest in the work and helpful advice.

[1] De Benedetti, Garelli, Tallone, and Vigone, Nuovo cimento **4**, 1142 (1956).

[2] H. Huzita, Nuovo cimento **6**, 841 (1957).

[3] Boos, Vinnitskiĭ, Takibaev, and Chasnikov, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 622 (1958); Soviet Phys. JETP **7**, 430 (1958).

[4] Birger, Grigorov, Gusev, Zhdanov, Slavatinskiĭ, and Stashkov, J. Exptl. Theoret. Phys. (U.S.S.R.) **31**, 971 (1956); Soviet Phys. JETP **4**, 872 (1957).

[5] J. S. Takibaev, J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 277 (1958), Soviet Phys. JETP **8**, 191 (1959). A. I. Nikishov and I. L. Rozental', J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 165 (1958); Soviet Phys. JETP **8**, 115 (1959).

Translated by H. Kasha
217