# *FLUCTUATIONS IN THE ANGULAR DISTRIBUTION OF SECONDARY PARTICLES OF EXPLOSIVE SHOWERS*

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Submitted to JETP editor November 6, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **38**, 1507-1511 (May, 1960)

Calculations are carried out on the fluctuations in the angular distribution of shower particles which imitate the "two-center" shower production mechanism. It is concluded that most experimentally observed showers possessing a "two-center" angular distribution can be explained by natural statistical fluctuations in the angular distribution. The calculations are performed by the Monte Carlo method.

In recent literature there has been a rather broad discussion on the so called "two-center" model for the production of shower particles in explosive showers of high energy ($10^{10} - 10^{14}$ ev).[1-7] According to this model, the secondary particles of the explosive shower originate in the decay of two "excited centers" produced in the collision of the primary particles and moving in opposite directions (in the c.m. system), the angular distribution of the secondary particles in the rest system of the excited center being isotropic. The experimental basis of the "two-center" model for the production of explosive showers was provided by the characteristic shape of the angular distribution of the secondary particles observed in a number of showers. The clearest "two-center" shape of the angular distribution is disclosed when drawn in the coordinates $\log[F/(1-F)] = f(\lambda)$, where we use the following notation: $\lambda = \log\tan\vartheta$; $\vartheta$ is the angle of emission of the shower particle in the laboratory system of coordinates, $F(\vartheta)$ is the fraction of shower particles with angles smaller than the given angle. In these coordinates an angular distribution isotropic in the c.m. system is represented in the form of a straight line making an agle of $\alpha = 65°$ with the axis of abscissas.

The anisotropy in the angular distribution of the shower particles in the c.m. system (which corresponds to that experimentally observed — see Fig. 3 below) is represented by a line whose slope $\alpha$ decreases with an increase in the fraction of shower particles emitted at angles close to 0° and 180° in the c.m. system, i.e. with a greater anisotropy. The "two-center" angular distribution is represented in these coordinates by a stepped curve with a more or less distinct horizontal segment dividing the angular distribution curve into two parts. This horizontal segment reflects the absence of shower particles in some angular interval separating the "narrow" and "wide" cones of the shower particles in the laboratory system. It is assumed that the "narrow" and "wide" cones separated in this way consist of shower particles produced in the decay of the two "excited centers." According to the "two-center" model of shower production, the angular distribution of the particles of the "narrow" and "wide" cones, when drawn separately, should be isotropic in their respective c.m. systems, i.e. in the coordinates $\log[F/(1-F)] = f(\lambda)$ they should be represented by straight lines of slope $\alpha = 63°$.

Figure 1 shows characteristic examples of "two-

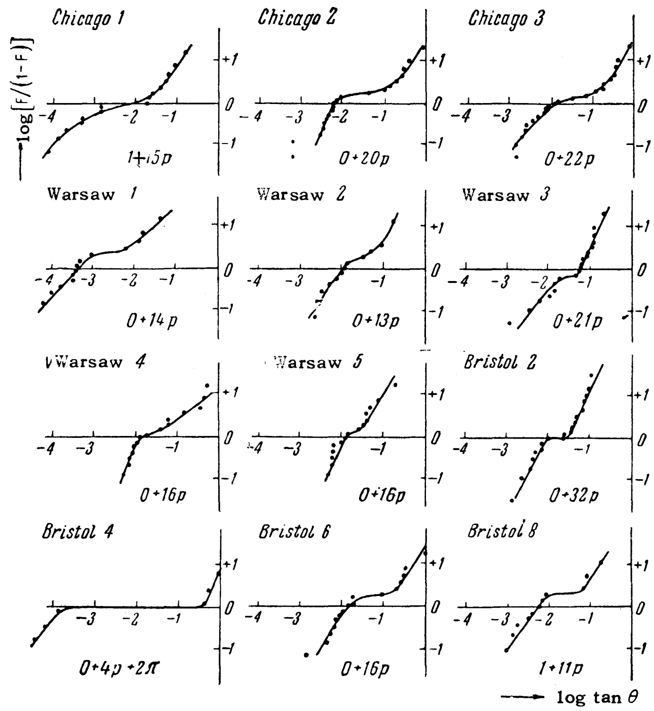


FIG. 1. Experimentally observed "two-center" angular distributions of shower particles.[6]

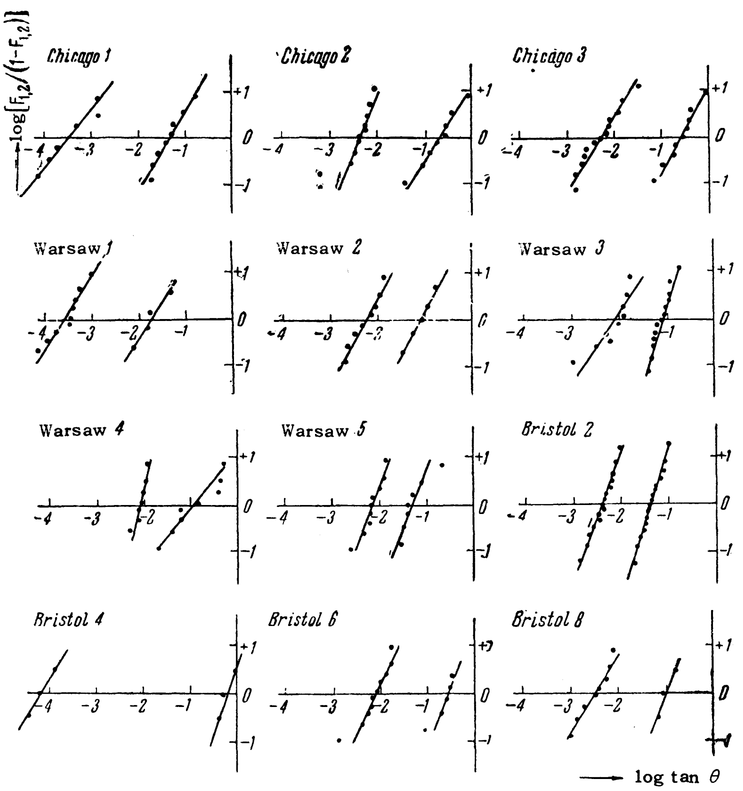


FIG. 2. Angular distributions of "narrow" and "wide" parts of the experimentally observed[6] "two-center" showers shown in Fig. 1.

center" angular distributions observed in various laboratories.

Figure 2 shows graphs of the two parts of these showers, corresponding to the narrow and wide cones in the laboratory system, which may be interpreted as the isotropic decay of two "excited centers."*

It should, however, be pointed out that the interpretation of the angular distribution of the individual showers should take into account the natural statistical fluctuations, which may lead to significant deformations of the angular distribution curves. In particular, the angular distributions of the shower particles shown in Fig. 1 may be the result of such fluctuations. In order to estimate the probability that statistical fluctuations lead to angular distributions imitating the "two-center" mechanism of shower production, we carried out a calculation by the method of random samples (Monte Carlo method). As the initial angular distribution of shower particles we took the experimentally observed distribution $f(\vartheta)$ which has been based on a large number of showers.[8] Figure 3 shows the distribution $f(\vartheta)$ in the c.m. system of the colliding particles ($\gamma_c = \cot \vartheta_{1/2}$). In the same figure the experimental angular distribution curve is also given in the coordinates $\log[F/(1 - F)] = f(\lambda)$ for a half angle $\vartheta_{1/2}$

*The curves in Figs. 1 and 2 were taken from the report of Piccioni at the 8th Conference on High-Energy Physics.

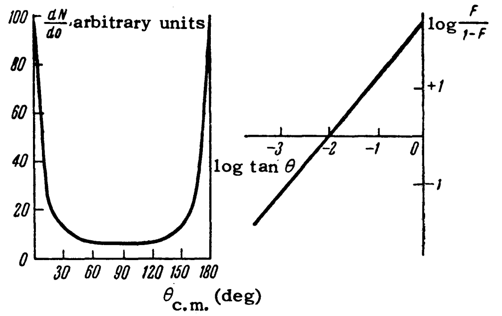


FIG. 3. Experimental angular distribution of shower particles according to data from a large number of showers of energies $10^{11}$ ev.[8]

= 0.01 rad. From this distribution were drawn 100 random samples of angular distributions consisting of $n_s = 20$ shower particles and another 100 with $n_s = 10$.

From the 200 angular distribution curves obtained in this way, we chose 16 curves for the case $n_s = 20$ and 19 curves for the case $n_s = 10$. These imitated to a satisfactory degree, the angular distributions of the "two-center" model. Nine of the angular distributions that were chosen are shown in Fig. 4 in the coordinates $\log[F/(1 - F)] = f(\lambda)$ for the case $n_s = 20$. In Fig. 5 are shown the corresponding angular distributions drawn separately for the two parts of these showers ("narrow" and "wide" cones in the laboratory system). The 19 curves of the "two-center" angular distribution for the case $n_s = 10$ are of similar shape.

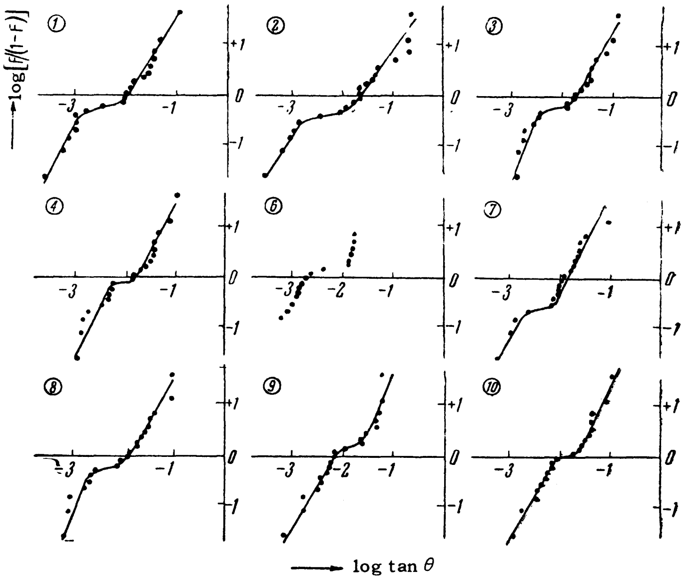


FIG. 4. Results of the calculation by the Monte Carlo method for shower particles imitating the "two-center" mechanism of production of showers for the case $n_s = 20$ (the numbers in the circles are for identification purposes).

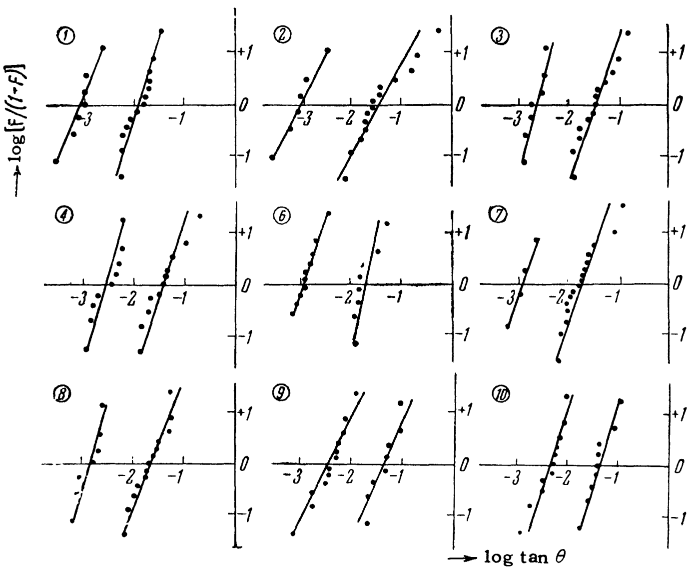


FIG. 5. Angular distribution of "narrow" and "wide" parts of calculated showers shown in Fig. 4.

From the comparison of the angular distributions shown in Figs. 1 and 4 it is seen that the deformations of the angular distribution caused by statistical fluctuations imitate sufficiently well a large number of the experimentally observed cases of the "two-center" angular distribution. From the calculations it further follows that the number of randomly chosen angular distributions that imitate the "two-center" model make up 15 — 20% of the total number of showers for which the number of shower particles is $n_s = 10 - 20$. This figure is in approximate agreement with the experimentally observed fraction of "two-center" angular distributions of shower particles, which, according to the data given by Power,[7] is $\sim 20\%$.

Hence the obtained results indicate, at least, that the greater part of the experimentally observed cases of a "two-center" angular distribution of shower particles can be explained by natural statistical fluctuations. Of course, the comparison of the calculated and experimental data is basically of a qualitative character. At the same time, it is obvious that any reliable evidence in favor of the existence of a "two-center" mechanism for the production of explosive showers can be obtained only by a fuller space — energy analysis of the showers. Proof of the "two-center" mechanism of shower production based only on the analysis of the angular distribution of the shower particles is quite difficult, since it is necessary to take into account correctly the influence of statistical fluctuations, which is possible only by substantially increasing the available experimental data.

In conclusion the authors express their gratitude to I. I. Gurevich for his constant interest in this work, to N. A. Lobachev for help in the calculations. We also wish to thank G. Cocconi and M. Miesowicz for sending us preprints of their work prior to publication.

[1] Ciok, Coghen, Gierula, Holynski, Jurak, Miesowicz, and Saniewska, Nuovo cimento **10**, 741 (1959).

[2] Z. Koba and S. Takagi, Nuovo cimento **10**, 755 (1959).

[3] K. Niu, Nuovo cimento **10**, 994 (1959).

[4] Burmeister, Lanius, and Meier, Nuovo cimento **11**, 12 (1959).

[5] G. Cocconi, Phys. Rev. **111**, 1699 (1958).

[6] O. Piccioni, 1958 Annual Internation Conference on High Energy Physics at CERN, Geneva, 1958, p. 75.

[7] C. F. Powell, Report at the 9th International Conference on High Energy Physics, Kiev, July, 1959.

[8] A. P. Mishakova and B. A. Nikol'skiĭ, JETP (U.S.S.R.) **37**, 1594 (1959), Soviet Phys. JETP **10**, 1130 (1960).

Translated by E. Marquit
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