ON THE NATURE OF THE BIMODALITY OF THE ANGULAR DISTRIBUTION OF SHOWER PARTICLES IN THE ENERGY REGION 10–20 GeV

PHYSICS

1969

SovietRxiv

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

UDC 539.126.4

PHYSICS

Academician of the Academy of Sciences of the Kazakh SSR Zh. S. TAKIBAEV

ON THE NATURE OF THE BIMODALITY OF THE ANGULAR DISTRIBUTION OF SHOWER PARTICLES IN THE ENERGY REGION 10–20 GeV

As early as 1957–1958 it was discovered ([1]) that there is a substantial deviation in the representation $\lg \operatorname{tg} \theta$ of the angular distribution of shower particles in jets from the normal distribution, which had been predicted by almost all variants of the theory ([2]) of multiple meson production. The essence of this deviation is the presence of two maxima of the distribution (bimodal), in contrast to one maximum (unimodal) for the normal distribution. Bimodality occurs rather often, in approximately 10–15% of cases of nucleon–nucleon inelastic interaction in the energy region 10^{12} eV and above. It was subsequently clarified that bimodality is not always clearly detected, in the sense that, with insufficient statistics, the number of showers with such an anomalous angular distribution and the reliability of manifestation of bimodality may be explained by an ordinary fluctuation. Therefore the detection of bimodality on the basis of an averaged statistical approach may prove erroneous.

Fig. 1

The author of this article advanced ([3]) the hypothesis of a connection between bimodality and the generation, alongside pions, of heavy meson, baryon, and antibaryon resonance particles. We tried to explain the distribution with two maxima by these heavy particles, without resorting to the hypothesis of the existence of the so-called fireballs, put forward in 1958 by a number of authors ([4]) specifically to explain bimodality.

At first it was assumed that bimodality is characteristic of the region of high energies (10^{12} eV), which seemed to follow from experiment ([1]); however, a study in the energy region of 20 GeV showed*, that bimodality is also observed at such an energy. In the present work we shall show that bimodality is indeed caused by baryon or meson resonance particles.

Fig. 2

Figure 2: Fig. 2

To clarify the connection between bimodality and resonance particles, we had to carry out the processing in the way this is done for cosmic rays. About 700 proton–proton inelastic interactions at an energy of 10 GeV/c, recorded in an 81-centimeter hydrogen bubble chamber, were analyzed. From this large number of showers we selected showers satisfying the conditions $\sigma > 0.6$ and $D > 0$. For the showers selected in this way (about 20 of them), bimodality is observed—

* This result was reported by the author of the article at the All-Union Conference on Cosmic Rays in Alma-Ata in 1966.

range (Fig. 1). Analysis of pion–nucleon showers at the same energy confirms this result.

Let us try to establish a connection between resonant particles and bimodality. In the center-of-mass system (c.m.s.) of the colliding particles, the scattering of the particles is usually almost symmetric. In other words, the particles whose angular distribution is given in Fig. 1 fly apart in the c.m.s. in such a way that in the forward hemisphere there is, as a rule, one proton, and in the backward hemisphere another. In bimodal showers it does not happen that both protons fly forward or both backward. On the basis of this experimental fact we have the right to combine a proton and a pion into a single formation and to determine its mass. The number of combinations depends on the sign of the pion and on its emission angle. As a result of such a treatment of the 20 bimodal stars presented in Fig. 1, at least 10 stars turn out to be the result of the decay of excited baryons N^0, N^+, and N^{++}; moreover, in mass they are approximately concentrated in the regions 1.2 and 1.4. In other words, the particles of the "two-humped" stars belong to one of the groups $pp\pi^+\pi^-$, $pp\pi^+\pi^-\pi^0$, $p\pi^+\pi^+\pi^-n$, which are the result of the decay of the indicated baryons, as is evident from the mass distribution (Fig. 2).

Fig. 2

The angular and momentum distributions of baryons in the c.m.s. are presented in Fig. 3. The angular distribution of particles in the rest system of the baryons themselves is anisotropic (Fig. 4), which is in qualitative agreement with the calculated data given in Ref. ([5]). A strict comparison with the calculated data for different values of the baryon spin, and allowance for the contribution of fluctuations, is possible only if statistically secure data are available. However, approximately one may say, based, for example, on comparison of Fig. 2 with the background curve, that half of all bimodal showers is explained by ordinary fluctuations and half by resonant particles. Analysis ([6]) of four-prong $\pi^- p$ interactions in an 81-centimeter hydrogen bubble chamber at a momentum of 10 GeV/c also makes it possible to clarify the connection of bimodality with the production of resonant particles. As a result of scanning 10,000 photographs,

Fig. 3

Figure 3: Fig. 3

Fig. 4

Figure 4: Fig. 4

883 four-prong interactions were selected for measurements. Four-prong $\pi^- p$ interactions without neutral particles and with one neutral particle were analyzed:

Fig. 3

Fig. 4

$$\pi^- p \to \pi^- p \pi^- \pi^+, \tag{1}$$

$$\to p \pi^- \pi^+ \pi^- \pi^0, \tag{2}$$

$$\to n \pi^- \pi^+ \pi^- \pi^+. \tag{3}$$

For example, the spectrum of effective masses of the systems $\pi^+ p$ and $\pi^+ \pi^-$ from reaction (1) has peaks in the region of N^{++} and the ρ^0-meson.

Taking the background into account, it is quite possible to derive quantitative ratios between the channels with formation of ρ^0 and N^{++} (see (6)).

The ρ^0-mesons and N^{++} baryons in the c.m.s. are strongly collimated, with the ρ^0-mesons emitted forward and the N^{++} backward. If, for orientation, one selects stars with $\sigma > 0.6$ and $D > 0$, then one obtains an almost bimodal distribution in which all stars contain ρ^0-mesons. It is interesting that, in the mirror coordinate system, these same conditions (i.e., $\sigma > 0.6$ and $D > 0$) select different stars, in which the N^{++} baryons are predominantly represented, since their strong collimation in this system is in fact what gives rise to the manifestation of bimodality.

In conclusion, the author expresses his gratitude to the CERN Chamber Committee for providing photographs from the 81-centimeter hydrogen chamber, and to M. Izbasarov and T. Temiraliev for assistance in processing the materials.

Institute of Nuclear Physics
Academy of Sciences of the Kazakh SSR

Received
11 X 1968

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