GENERATION OF NEUTRAL PIONS IN THE INTERACTION BETWEEN 9 Bev PROTONS AND PHOTOGRAPHIC EMULSION NUCLEI

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The mean energy of π^0 mesons produced in collisions between protons of energy ~ 9 Bev and photographic emulsion nuclei was determined to be $\overline{E}_\pi = 750 \pm 180$ Mev. The fraction of the energy carried off by $\pi^{\pm,0}$ mesons in such reactions lies between 0.33 ± 0.08 and 0.27 ± 0.07.

THE question of the fraction of energy k carried off by secondary π mesons is of great importance to the study of the mechanism of interaction of high-energy particles. Investigations of interactions between cosmic-ray particles and light nuclei in the $\sim 10^{10}$ ev energy region have shown that the value of k is $\sim 30\%$.[1] It is of interest to evaluate k for conditions in which the energy and nature of the primary particles are exactly known.

In the present investigation the mean energy was determined for π^0 mesons produced by the interaction of 9-Bev protons with emulsion nuclei.

Electron-positron pairs produced by γ rays from π^0-meson decay were analyzed in a stack of layers, each $450\,\mu$ thick, of type "R" NIKFI emulsion, which had been irradiated with protons in an inner beam of the proton synchrotron of the Joint Institute for Nuclear Research. The pairs were found by tracing the separate relativistic tracks selected from a strip perpendicular to the beam and at a distance of 30 mm from the edge of the stack. Tracks with $1° < \varphi \leq 30°$, where φ is the emulsion-plane angle relative to the beam direction and with a projection length $l \geq 1600\,\mu$ in one plate were selected. Tracks that met these conditions were extended back to the generation point of the pair, or to a star, or to a point outside the stack. This line of research had been suggested by King.[2] It suited our purposes because it obviated the necessity of energy discrimination of pairs.

To find the mean energy of γ rays originating directly from π^0 meson decay, one must exclude the background due to bremsstrahlung γ rays. For this reason the area around the generation point of each pair was inspected for an electron track parallel to the pair. Pairs that had such tracks were discarded as secondary. These amounted to $\sim 10\%$, in agreement with the predicted number of secondary pairs for our conditions as based on cascade theory.[3] Moreover, the background due to the γ rays that entered the stack from outside was evaluated and found to be insignificant. The number of pairs found, excluding the secondary ones, was 93. There were 116 relativistic tracks leading to stars.

In both cases distributions were constructed for the emission angles in relation to the primary beam. These distributions are shown in Fig. 1. Also shown is the angular distribution for the tracks of relativistic particles in stars found by tracing along the primary proton tracks. All three distributions coincide within experimental error. Since the distributions for γ rays and π^0 mesons roughly coincide* in the energy region studied, the angular distributions for neutral and charged π mesons can be assumed to be similar to one another.

Evaluation of the ratio $R = n\pi^0/n_s$, taking into account the geometric conditions and γ-ray conversion probability, indicates that $R \sim 0.5$. The exact value of R could be found if there were much more statistical data.

Values of 4.3 ± 0.2 and 7.8 ± 0.7 were found for $\overline{n}'_s$ and $\overline{N}_h$ respectively for the stars located by extending the secondary relativistic tracks. For the present system for locating stars, some increase should be expected in $\overline{n}'_s$ in relation to the value of $\overline{n}_s$ which corresponds to stars found by extension along the primary proton tracks, or specifically

$$\overline{n'_s} = \overline{n_s} + D/\overline{n_s},$$

where D is the dispersion of the star distribution

*The analysis given here confirm this supposition (see also King[2]).

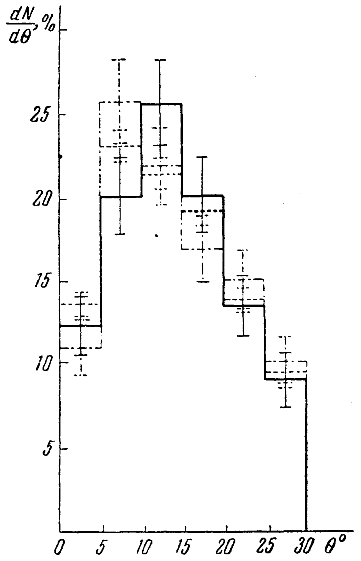

FIG. 1. Distribution of angles of emission for electron-positron pairs (solid line) and for fast charged particles from stars found by extending primary proton tracks (dotted line) and from stars found by tracing secondary fast particles (dash-dot line).

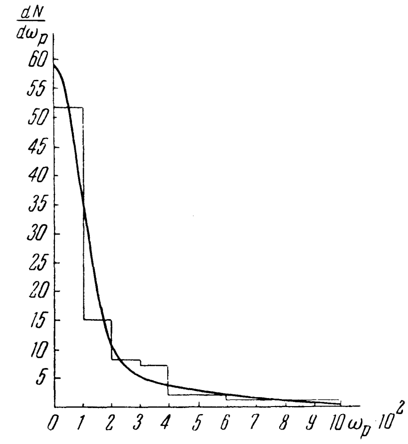

FIG. 2. Distribution of projected divergence angle.

in n_s. According to Gramenitskii et al.,[4] $\overline{n}_s = 3.21 \pm 0.1$ and $D = 3.64 \pm 0.15$, which means that the value of $\overline{n}'_s = 4.3$. This is in good agreement with the experimental value for $\overline{n}'_s$ and indicates that there was no discrimination when the relativistic tracks were selected.

The mean γ ray energy $\overline{E}_\gamma$ can be evaluated from the distribution of the divergence angle ω between the components of a pair, since $\overline{E}_\gamma = \kappa(\overline{1/\omega})$. The coefficient κ was computed by means of the theoretical angular distribution for the given γ-ray energy.[5] The partition of energy between the electron and positron was also taken into account.[6] The numerical value for κ is 4.15, if ω is expressed in radians and the energy in Mev.

For our experimental conditions it was practically impossible to measure the spatial angle ω for narrow pairs. Therefore, the method proposed by Weil et al.,[7] which reduces the influence of multiple scattering, was used to measure the projected divergence angles. The error in the determination of the divergence angle of an individual pair, including the error due to multiple scattering and observation error, amounts to 25%. The distribution of projected divergence angles shown in Fig. 2 was approximated by a linear combination of two Gaussian distributions. Then a transformation was made from this distribution to a distribution for spatial angles ω, and the quantity $(\overline{1/\omega})$ was computed. The value of $(\overline{1/\omega})$ was found equal to 120 ± 10 (the error is purely statistical). Thus, the mean value of the γ-ray energy was $\overline{E}_\gamma = 420 \pm 100$ Mev. The error includes the measuring error, inaccuracy in determining κ, inaccuracy in the approximation, and the statistical error in the determination of $(\overline{1/\omega})$.

To obtain the mean π^0-meson energy $\overline{E}_{\pi^0}$ it is necessary to determine the ratio $f = \overline{E}_{\pi^0}/\overline{E}_\gamma$, where $\overline{E}_\gamma$ is the mean energy of the γ rays entering the examined solid angle. The value of f depends to a rather slight extent on the energy spectrum of the π^0 mesons. The upper limit of f, for a reasonable assumption for the spectrum, would be 1.8. Consequently, the upper limit for the mean energy of the π^0 mesons moving within the examined solid angle is 750 ± 180 Mev.

The mean energy transferred to the π mesons in a single disintegration is determined as follows:

$$\overline{E}_\pi = {}^3/_2(\overline{n}_s - \alpha)\,\overline{E}_{\pi^0},$$

where α is the average number of fast protons, which is 0.5. If one substitutes the proper value for $\overline{n}_s$ and assumes that the mean π-meson energy does not depend on the emission angle, an upper limit of 3.0 ± 0.7 Bev is obtained for $\overline{E}_\pi$.

A more exact value of $\overline{E}_\pi = 2.5 \pm 0.6$ can be obtained if one assumes that the transverse momentum (i.e., perpendicular to the direction of the primary particles) of the secondary particles* is constant (see, for example, Zhdanov[8]). Since the magnitude of $p_\perp$ does in fact increase somewhat with an increase in the emission angle, the value given here determines the lower limit of the mean energy carried off by the π mesons.

Thus, the fraction of energy carried off by π mesons in interactions between 9-Bev protons and emulsion nuclei lies between 0.33 ± 0.08 and 0.27 ± 0.07.

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*Under our conditions the mean value for the transverse momentum $p_\perp$ is (1 to 2) $\mu_\pi c$.

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