Observations on Neutral π Mesons Produced in Nuclear Interactions of 24-Gev Protons with Carbon Nuclei

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Energy-angle characteristics of neutral π mesons produced in interactions of 24-Gev protons with carbon nuclei have been studied by detecting the γ rays from π^0 decay in a small emulsion stack. The energy of the γ rays was obtained from the opening angles of electron-positron pairs, using a special measuring criterion which was justified by making multiple scattering measurements on a fraction of the pairs. The average energy of neutral π mesons in the c.m. system has been found to be 470 ± 35 Mev. The most probable value of their transverse momentum is 230 Mev/c and the average value is 398 ± 25 Mev/c. It is concluded that at 24 Gev the fraction of the available energy in the c.m. system spent in pion production is 0.43 ± 0.07.

MOST of the γ rays arising from a meson-producing interaction are from the decay of π^0 mesons. Therefore, a study of the energy and angular distribution of γ rays from high-energy interactions can be used to investigate the most predominantly occurring secondary particles, the π mesons. Such a study was made for interactions produced in graphite by 24-Gev protons from the proton synchrotron at CERN. The experimental setup consisted of a stack of 12 stripped Ilford G5 emulsions, each of size 2 in.$\times$3 in.$\times$600 μ, placed immediately behind a graphite block of thickness 1 in. The beam was parallel to the emulsion surface. The exposure intensity was 2×10^4 particles/cm^2.

The emulsions were scanned under a total magnification of 15$\times$25, in a direction parallel to the beam, starting 1 mm from the leading edge of the emulsion for a distance of 1 cm only; this is to avoid pairs resulting from interactions in emulsion. All pairs originating in the emulsion and having a projected angle of $<45°$ with respect to the beam direction were noted. The space angle of each pair with respect to the beam direction was accurately determined. Since, in this method of scan, the tracks belonging to each pair are encountered in several fields of view, the efficiency of the scan is believed to be quite good. (However, for purposes of this paper, the exact value of this efficiency is irrelevant.) A total of 282 pairs have been found and analyzed. It may be remarked that a good scanner could locate 5 to 8 pairs per day.

The most convenient method of estimating the energy of a γ ray, producing a pair in emulsion, is by measuring the opening angle of the pair. The opening angle is usually determined by measuring the separation between the two electron tracks at a known distance from the origin of the pair. This leads to an overestimate of the true opening angle, and hence an underestimate of the energy, because part of the separation between the two electron tracks arises from multiple scattering. This problem of the contribution of multiple scattering to the opening angle of the pair has been investigated by Lohrmann.[1] It can be shown that the underestimate in the energy will become more serious as the energy of the γ ray increases. Also, the error in the estimate of the energy is the smaller the less the distance from the origin of the pair at which the separation is measured. In this experiment the opening angle was determined by measuring the distance from the origin to a point where the projected separation between the tracks was 0.6 μ and determining the exact separation at the point; 0.6 μ is the minimum conveniently measurable separation under 100$\times$ objective. The most probable energy of the pair was obtained by using Borsellino's formula,[2]

$$E=(4mc^2/\theta)\Phi,$$

where θ is the opening angle of the pair, mc^2 is the rest energy of the electron, and Φ is a parameter depending on the disparity in energy between the two electrons and is not much different from unity for not too large values of disparity. As a check on the energy measurement, multiple scattering measurements were performed on 25 pairs selected at random. For most pairs the "multiple scattering energy" was taken to be the sum of the energies of the two electrons. Where the energies of the electrons were comparable the "multiple scattering

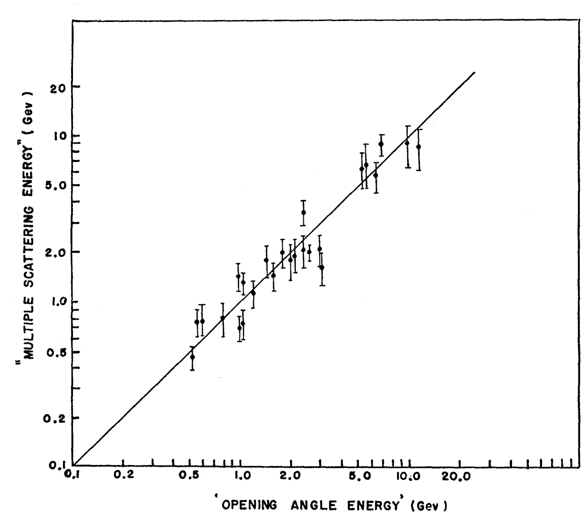

FIG. 1. Plot showing "opening angle energy of the electron pair" vs "multiple scattering energy."

[1] E. Lohrmann, Nuovo cimento 2, 1029 (1955).

[2] A. Borsellino, Phys. Rev. 76, 1023 (1953).

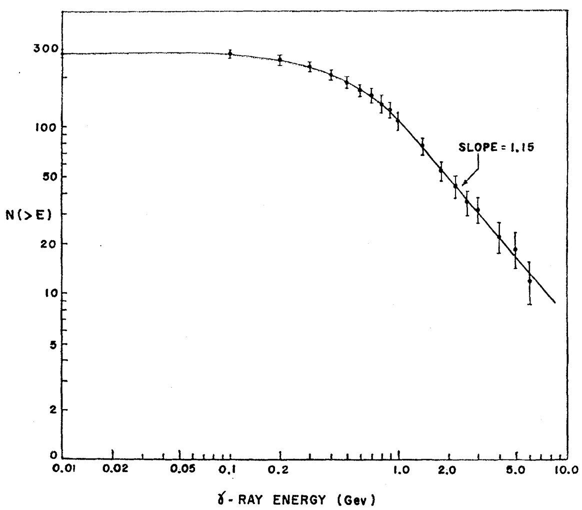

FIG. 2. Integral energy spectrum of γ rays in the laboratory system.

energy" was determined from the relative scattering between the electrons. In Fig. 1, "multiple scattering energy" of each of these 25 pairs has been plotted against "opening angle energy" as determined from Borsellino's formula. It is seen that, with the criteria used in this experiment, the opening angle method gives a fairly reliable estimate of the energy for γ rays encountered in this experiment (up to $\sim$10 Gev).

Figure 2 gives the integral energy spectrum for all the γ rays detected. For the energetic γ rays the spectrum can be represented by a power law with an exponent of $\sim$1.15. This implies that the differential energy spectrum of π mesons in the c.m. system can be represented as $dE/E^{2.15+\delta}$, where $\delta\approx0.25$. This spectrum,

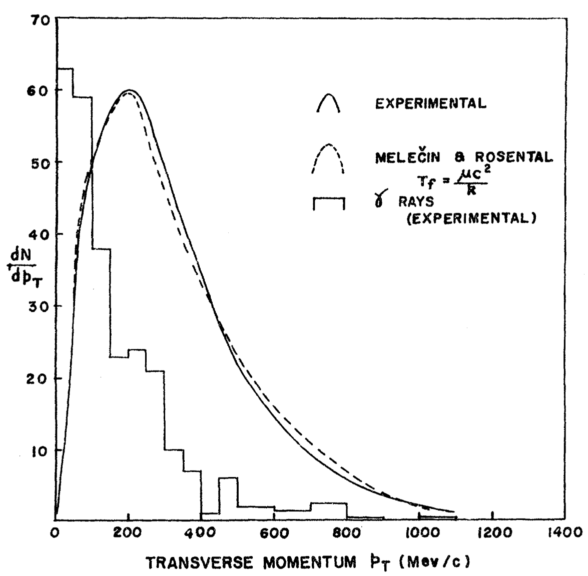

FIG. 3. Transverse momentum spectrum of γ rays and the transformed p_T spectrum of π^0 mesons in the laboratory system.

which is valid up to π-meson energies of the order of 10 Gev in the laboratory system, is slightly steeper than that given by Heisenberg's theory.

The collision of a proton with a small nucleus like carbon may be expected to be essentially like a nucleon-nucleon collision. The Lorentz factor γ_c for the c.m. system is 3.66. The energies of all the γ rays occurring within an angle $\theta_{\frac{1}{2}}=\tan^{-1}(1/\gamma_c)\approx15°$ have been transformed to the c.m. system. The average energy in the c.m. system is 235 Mev. This means that the average total energy of π mesons in the c.m. system is 470 ± 35 Mev. This is found to be almost the same as that obtained in collisions at very different energies. As already pointed out by Lal *et al.*,[3] the average π meson energy in the c.m. system is a parameter characteristic of meson-producing interactions which is very insensitive to the energy available for the production of π mesons. If one assumes that 75% of the charged particles produced in the collisions of 24-Gev protons are charged π mesons[4] and that the average charged-shower-particle production at 24 Gev is 4.1 ± 0.6 per collision,[5] one finds that at 24 Gev the fraction of the available energy in the c.m. system spent in pion production is 0.43 ± 0.07.

The transverse momentum distribution of γ rays is plotted in Fig. 3. The average transverse momentum of a γ ray is found to be 199 Mev/c. This gives an average transverse momentum for a π^0 meson of 398 ± 25 Mev/c. This value is almost the same as that obtained by various workers at several different energies. In the same figure we have given the transverse momentum distribution for π^0 mesons as obtained by transforming the distribution for γ rays. The most probable transverse momentum is 230 Mev/c. The dotted curve in Fig. 3 shows the π-meson transverse momentum spectrum given by Melecin and Rosental[6] on the basis of Landau's model for a break-up temperature $T_f=\mu c^2/k$. The π^0-meson p_T spectrum obtained by transforming the γ-ray p_T spectrum observed in this experiment gives a good fit to this curve.

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[6] G. A. Melecin and I. L. Rosental, Suppl. Nuovo cimento **8**, 770 (1958).