Of the three, none can be attributed to the direct decay $\mu^+ \rightarrow e^+ + e^- + e^+$ since the total energy of the secondaries was less than 106 Mev and there was a net momentum unbalance. If the events from this decay mode were distributed according to a Poisson distribution, this would correspond to a branching ratio

$$R = (\mu^+ \to e^+ + e^- + e^+) / (\mu^+ \to e^+ + \nu + \overline{\nu}) = 1 \times 10^{-5}$$

for 90% confidence.

According to the previous criteria, the threeprong events are all examples of the decay $\mu^+ \rightarrow e^+ + \nu + \overline{\nu} + e^+ + e^-$. This gives a ratio

$$R' = (\mu^+ \to e^+ + \nu + \overline{\nu} + e^+ + e^-) / (\mu^+ \to e^+ + \nu + \overline{\nu})$$

= (1.5 ± 1.0) × 10⁻⁵.

This ratio R' can be estimated using the internal conversion probability, ρ_T , as given by Kroll and Wada,⁶

$$\rho_T = \frac{2\alpha}{3\pi} \left[\ln \left(\frac{2E_{\gamma}}{m} \right) - \frac{11}{6} - \frac{5}{24} \left(\frac{E_{\gamma}}{m_{\mu}} - \frac{E_{\gamma}}{2} \right)^2 \right],$$

where E_{γ} = photon energy, m = electron mass, m_{μ} = meson mass [terms of order $(E_{\gamma}/m_{\mu})^2$ have been neglected], and using also the transition probability for the radiative decay as given by references 3 and 4. Using a lower energy cutoff of 5 Mev for the γ ray, this gives for R' a value of approximately 5×10^{-5} which is essentially in agreement with the experimental result.

An accurate determination of the branching ratio is not feasible by means of a bubble-chamber experiment of this type, the purpose of the present endeavor being to show the existence of the decay mode and an order of magnitude of the decay rate.

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PION PRODUCTION BY PIONS*

Walton A. Perkins, John C. Caris, Robert W. Kenney, Edward A. Knapp, and Victor Perez-Mendez

Lawrence Radiation Laboratory, University of California, Berkeley, California (Received June 4, 1959)

The existence of a pion-pion interaction has been postulated to explain the nucleon structure¹ and the peak²⁻⁴ in the π^- -proton total cross section near 1 Bev. The direct interaction of the incident pion and a virtual pion in the meson cloud surrounding the nucleon could contribute significantly to the production of an extra pion in pionnucleon collisions. In order to study this interaction, we have investigated the reaction $\pi^- + p$ $\neg \pi^+ + \pi^- + n$ in the energy region from 260 to 430 Mev. The π^+ meson in the final state provides a unique signature for this reaction, since the highest energies are just barely above the threshold for the production of two secondary pions.

The experimental arrangement is shown in Fig. 1. Negative pion beams produced by the 730-Mev proton beam of the Berkeley synchrocyclotron striking an internal target were magnetically selected and collimated as shown in the figure. The resulting pion beams, with kinetic energies of 260, 317, 371, and 427 Mev and energy spread of $\pm 2.5\%$, impinged on a 4-inch-thick liquid hydrogen target.

The positive pion was unambiguously identified by its characteristic μ decay, by use of the electronic gating equipment described elsewhere.⁵ In this experiment the coincidence 12345 triggered the delayed gate which made a coincidence with the μ pulse; the energy band of the detected pions was determined by the thickness of the copper absorber placed between counters No. 3 and No. 4. The detection efficiency of the counter tele-



FIG. 1. Experimental arrangement (not to scale).

scope was previously determined by using a magnetically analyzed beam of positive pions.

Measurements were taken for π^+ mesons emitted at 60°, 90°, 125°, and 160° in the barycentric system for incident π^- kinetic energies of 317, 371, and 427 Mev; for π^- kinetic energy of 260 Mev only a single measurement was made at 90° (lab). To obtain the angular differential cross section an integration was performed over the energy of the π^+ meson at each angle. The angular differential cross sections are nearly isotropic at 317 and 371 but are peaked forward at 427 Mev. The differential cross sections were integrated over the angle of the π^+ meson to give the total cross sections shown in Fig. 2. The errors shown are the combined errors of counting statistics and of integration over energy and angle.

Recent measurements have been made by Zinov and Korenchenko⁶ at incident energies of 307, 333, and 370 Mev for the combined reactions $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ and $\pi^- + p \rightarrow \pi^- + \pi^0 + p$. These measurements, taken for charged pions emitted at 106° (c.m.), are in reasonable agreement with the results presented here.

The dashed line in Fig. 2 represents the theoretical prediction according to Rodberg⁷ and Kazes⁶ based on the static model which assumes only a direct pion-nucleon interaction. We interpret the large systematic discrepancy between this theory and experiment as evidence for a pion-pion interaction (i.e., here the π^- interacts directly with the π^+ in the meson cloud surrounding the nucleon).

The following Letter⁹ discusses the effect of a pion-pion interaction on the total cross section for this reaction. The solid line in Fig. 2 shows the result of including this interaction in the



FIG. 2. Total cross section for $\pi^- + p \rightarrow \pi^+ + \pi^- + n$ as a function of the incident π^- kinetic energy. The dashed curve represents the static-model prediction by Rodberg⁷ and Kazes⁸; the solid curve is the pion-pion interaction result by Rodberg.⁹

theoretical prediction.

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