DIRECT PROOF OF θ_1^0 NEUTRAL DECAY*

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Although the neutral decay mode $\theta_1^0 \to \pi^0 + \pi^0$ is expected to occur in addition to the well-known charged mode $\theta_1^0 \to \pi^- + \pi^+$, there has been no complete experimental proof of its existence because of the difficulty of detecting the neutral decay products with high efficiency. Ridgway, Berley, and Collins[1] and Osher, Moyer, and Parker[2] have reported counter experiments in which they observed gamma rays of roughly the correct energy originating several centimeters downstream of internal targets in the Cosmotron and Bevatron. The latter authors also report that the decrease in the numbers of such gamma rays with distance downstream from the target is consistent with the assumption that the gamma rays originate from Σ^+, θ^0, and Λ^0 decays whose lifetime is roughly that measured for the ordinary charged decays of these particles. Eisler et al.[3] have reported some gamma rays associated with strange particle production in a propane bubble chamber; Crawford et al.[4] have reported similar results from a hydrogen bubble chamber; and Boldt et al.[5] have observed showers occurring in conjunction with charged Λ^0 and θ^0 decays in a multiplate cloud chamber. In none of these experiments has it been possible to observe individual events in which all four gamma rays arising from the neutral θ^0 events were detected.

In order to study this process in detail, as well as others involving gamma rays, we have constructed a liquid xenon bubble chamber 30 cm in diameter and 25 cm in depth. The chamber operates at -21°C at a vapor pressure of 370 psi. The liquid xenon has a density of 2.18 g/cm³ and a radiation length of 3.9 cm. We have taken about 160 000 photographs of this chamber exposed to a 1.0-Bev π^- beam at the Berkeley Bevatron.

Figure 1 shows the production of a Λ^0 followed by the decay $\Lambda^0 \to p + \pi^-$. Also visible in the picture are four electron pairs whose parent gamma rays appear to have originated at a common point about 1.2 cm from the origin of the Λ^0. If the measured directions of the pairs are used to extend the lines of flight of the gammas back toward their origin, it is found that these lines all pass through a cube less than 5 mm on a side. The volume of this cube is fully accounted for by

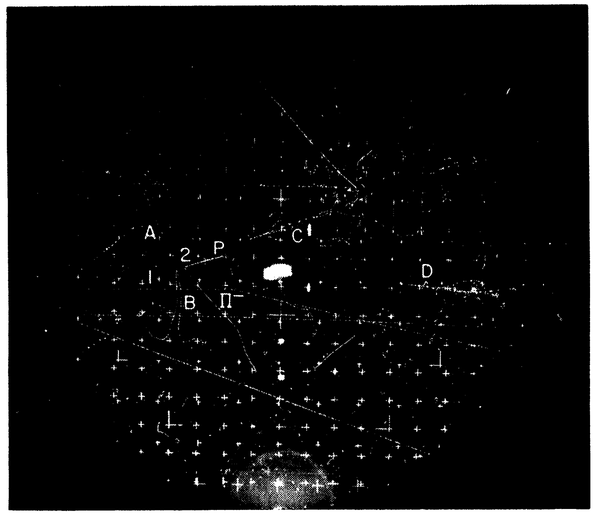

FIG. 1. Example of the decay $\theta_1^0 \to 2\pi^0 \to 4\gamma$. The θ^0 is produced at point 1 in association with a Λ^0 which decays into a proton and π^- (as indicated) both of which stop in the chamber. The lines of flight of the four gamma rays, given by the measured direction of the electron pairs A, B, C, and D, intersect near 2 where the θ_1^0 decay took place.

measurement errors, and therefore it can be concluded that within these errors the four gammas do originate at a common point. These four gamma rays are interpreted most naturally as arising from the decays $\theta_1^0 \to \pi^0 + \pi^0$, $\pi^0 \to 2\gamma$; the θ^0 having been produced in association with the Λ^0. We have found nine other four-gamma events of this same type in analyzing about one-half of the pictures.

In support of the interpretation of these events as neutral decay modes of θ_1^0 particles the following points should be noted: (1) The background of such four-electron-pair events arising either from prongless neutron stars in which two π^0 are created, or from the chance association of unrelated gamma rays is completely negligible. (2) Although the photographs were scanned for all charged V^0 decays, with or without associated gamma rays, every charged V^0 decay associated with four electron pairs was a $\Lambda^0 \to p + \pi^-$, unaccompanied by any other visible strange-particle decay. This fact strongly indicates that the four gamma rays are indeed to be attributed to a particle of strangeness +1. (3) On the basis of the known θ_2^0 lifetime,[6] less than one of our ten events can be attributed to a neutral decay mode of the θ_2^0. Although these considerations leave little doubt as to the fact that the four-gamma events do arise from neutral θ_1^0 decay modes, some question may remain as to whether these decay modes are indeed of the type $\theta_1^0 \to \pi^0 + \pi^0$ followed by $\pi^0 \to 2\gamma$ or whether perhaps some of the gammas are produced directly in the decays. If one knows how to pair the gammas belonging to the same π^0, it is possible to compute the θ^0 mass from the observed directions of the θ^0 and the four gammas, thus making a direct check that the decay scheme $\theta_1^0 \to \pi^0 + \pi^0$ has really been observed. Unfortunately the results of this calculation are quite sensitive even to small measurement errors. Making use of the lower limit for the energy of each gamma ray imposed by the visible ionization loss of its associated electron shower, however, we were able to pick assignments of gamma rays which made the kinematics for the decays consistent with the mode $\theta_1^0 \to \pi^0 + \pi^0$ followed by $\pi^0 \to 2\gamma$ for both π^0's. We therefore believe that the decay scheme $\theta_1^0 \to 2\pi^0$ is the most likely interpretation of the events, although on the basis of our data such schemes as $\theta_1^0 \to \pi^0 + 2\gamma$ or $\theta_1^0 \to 4\gamma$ cannot be ruled out.

Work is in progress on other aspects of the experiment, including branching ratios for neutral decay of Λ^0 and θ^0.

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[1]Ridgway, Berley, and Collins, Phys. Rev. 104, 513 (1956).

[2]Osher, Moyer, and Parker, Bull. Am. Phys. Soc. 1, 185 (1956).

[3]Eisler, Plano, Samios, Schwartz, and Steinberger, Nuovo cimento 5, 1700 (1957).

[4]Crawford, Cresti, Douglass, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Letters 2, 266 (1959).

[5]Boldt, Bridge, Caldwell, and Pal, Phys. Rev. 112, 1746 (1956).

[6]Crawford, Cresti, Douglass, Good, Kalbfleisch, and Stevenson, Phys. Rev. Letters 2, 361 (1959).

EXPERIMENT ON CHARGE INDEPENDENCE IN PION INTERACTIONS

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Although the existing experimental results in pion physics are consistent with the assumption of charge independence of pion-nucleon forces, the statistical accuracy of the data leads to an uncertainty of $\pm 15\,\%$ in quantitative tests of the concept.[1] Direct experimental tests[2] offer the possibility of substantially reducing this uncertainty before being limited by the accuracy of theoretical calculations of the Coulomb and mass difference effects in the specific reactions studied.

The present paper describes an experiment at 600-Mev proton energy on the reactions

$$p + d \to H^3 + \pi^+,$$

$$p + d \to He^3 + \pi^0,$$

for which (apart from Coulomb and mass corrections) the charge independence hypothesis predicts the ratio of the differential cross sections to be 2 at any c.m. angle. The c.m. energy of the emerging pions is 220 Mev, well above the $(\frac{3}{2},\frac{3}{2})$ resonance. The cross sections are compared by detecting only the recoiling nuclei, which are identified by momentum and time-of-flight selection, with pulse-height analysis as an additional check.

A sketch of the experimental arrangement is given in Fig. 1. The 600-Mev proton beam traverses a 2-cm thick liquid deuterium target with 0.1-mm thick Mylar windows and then a secondary emission chamber monitor. The solid angle for the scattering is defined by a 2×3 cm^2 tungsten collimator, 4 cm thick, which is placed 500 cm from the target at an angle of 11.3° to the incident proton beam. Of the H^3 and He^3 nuclei transmitted, the higher energy group, corresponding to 52° in

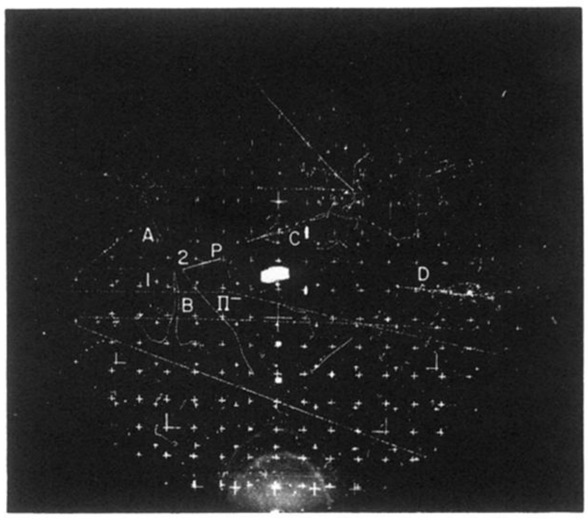

FIG. 1. Example of the decay $\theta_1^0 \rightarrow 2\pi^0 \rightarrow 4\gamma$. The θ^0 is produced at point 1 in association with a Λ^0 which decays into a proton and π^- (as indicated) both of which stop in the chamber. The lines of flight of the four gamma rays, given by the measured direction of the electron pairs A, B, C, and D, intersect near 2 where the θ_1^0 decay took place.