EVIDENCE FOR SPIN ZERO OF THE η FROM THE TWO GAMMA-RAY DECAY MODE*

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Recent experiments by Pevsner et al.[1] and others[2] report the existence of a mass 546-MeV particle (called the η) which has both charged and neutral modes of decay. The charged mode of decay is $\eta^0 \rightarrow \pi^+ + \pi^- + \pi^0$. Present experimental evidence[3,4] assigns isotopic-spin zero to this particle.

The original work was done in the reaction

$$\pi^+ + d \rightarrow p + p + \eta^0. \tag{1}$$

The proton in the deuteron plays a spectator role, hence the primary reaction is $\pi^+ + n \rightarrow p + \eta^0$. The cross section reported for the charged mode of decay of the η is[4] 0.22 ± 0.06 mb and the cross section measured for the neutral modes of decay is[5] 0.8 ± 0.2 mb. The experiment of reference 4 reports a flat plateau for the cross section in the region from 1700-1850 MeV, total energy in the center-of-mass system.

The experiment reported here makes use of the reaction

$$\pi^- + p \rightarrow n + \eta^0. \tag{2}$$

From charge symmetry, Reaction (2) will have the same cross section as Reaction (1) at the same energy. This experiment covers an energy band from 1707-1740 MeV and thus one expects a production cross section for the η of about 1 mb.

The film for the present experiment was taken using the Cambridge Bubble Chamber Group's 50-liter methyl iodide bubble chamber with an incident negative pion beam of incoming momentum of 1140 MeV/c. The chamber filling was propane, methyl iodide, and ethane with 0.061 g/cc of H, 0.252 g/cc of C, and 0.948 g/cc of I, resulting in a radiation length of 8.2 cm. The average probability of converting a 100-MeV γ ray in the chamber is 0.6. Since the density of our mixture is 1.26 g/cc, the dE/dX loss of the incoming pions gives us interactions spread over ±30 MeV/c about the value 1096 MeV/c in the center of the chamber.

The reactions under consideration are of the type

$$\pi^- + p \rightarrow X^0 + n,$$

where the X^0 subsequently decays into two γ rays. Since the X^0 has a unique momentum in the π^-p center of mass one can calculate the mass of the X^0 with the knowledge of the incoming π^- momentum and the opening angle distribution made by the two-gamma-ray mode of decay.[6] In this system the opening angle distribution will have a minimum angle that is characteristic of the mass of the X^0 and the initial π^- momentum. Figure 1 gives the characteristic distribution for pion momentum of 1133 MeV/c and a X^0 mass of 135 MeV. This figure and all others are plotted for the π^-p center-of-mass system.

The experimental technique consists of scanning for all π^- interactions with no prongs, "stops," associated with converted γ rays. The majority

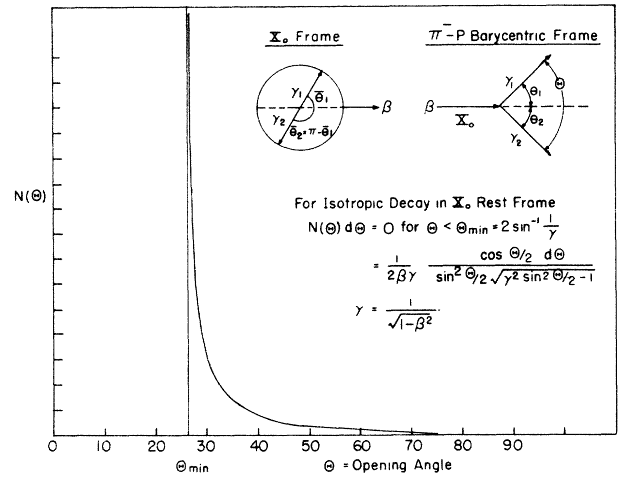

FIG. 1. Theoretical opening angle distribution for the 2γ-ray decays in π^-p center-of-mass system of a 135-MeV particle produced by 1133 MeV/c pions.

of these events are on hydrogen or are quasi-elastic.[7] The γ-ray directions are then transformed into the π^-p center-of-mass system. The transformed opening angle distribution for the 2γ sample is shown in Fig. 2(a). Events with three, four, five, and six converted γ rays have been observed also and have been used to determine the background.

A major source of background arises from $2\pi^0$ production, with two of the resultant γ rays escaping from the chamber. Figure 2(b) is a histogram of the opening angles generated by taking pairs of γ rays from our sample of 3 and 4γ-ray events. Each 3γ-ray event furnishes three opening angles, while each 4γ-ray event furnishes six. A Monte-Carlo calculation based on a phase-space distribution for two π^0's and the chamber properties gives the same shape. Using Fig. 2(b), the known energy-dependent conversion probability, and Monte-Carlo methods, we are able to make a subtraction. Figure 3 is the result of this subtraction. Superimposed on this histogram is the theoretical shape of the opening angle distribution for a mass 135-MeV particle. The proper experimental resolution function has been folded into the theoretical curve. We use the data in the histogram to determine masses. From the known energy spread and angular resolution, we find that the first peak at 25° corresponds to a mass of 144 ± 16 MeV. This is clearly the elastic π^0 peak produced in the reaction $\pi^- + p \rightarrow \pi^0 + n$ with subsequent decay of the π^0 into two gamma rays. The peak at 100 degrees corresponds to a mass of 545 ± 30 MeV.

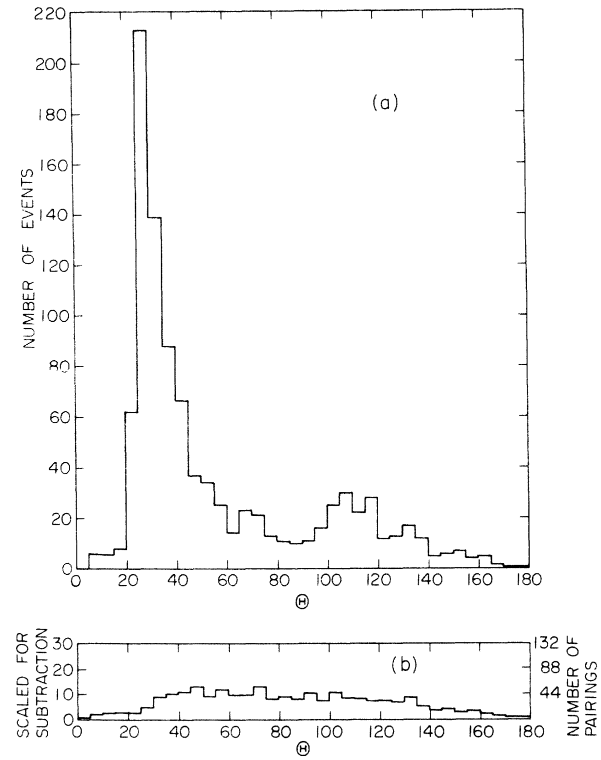

FIG. 2. (a) Histogram of the transformed opening angles of all 2γ events observed. (b) Histogram of the opening angles of the 2γ combinations from all 3 and 4γ events. The left ordinate has been scaled for the correct subtraction and the right ordinate represents the actual number of pairings.

This second mass is in excellent agreement with 546 ± 14 MeV [4] and 550 ± 14 MeV [2] reported for the η. Thus, we assume that the events with opening angles in the region of 100° are indeed 2γ decays of the η. On this assumption it is clear that the spin of the η is either 0 or 2. Since the presently available Dalitz plots[2,5] do not indicate as marked an asymmetry as would be expected from a spin-2 particle, we conclude that the most reasonable assignment for the spin is 0.

Figure 4 is an expanded reproduction of the part of Fig. 3 between 60° and 180° with the single π^0 contribution in this region subtracted. Included are the error bars and the theoretical opening angle distribution (with resolution function folded in) for a mass 550-MeV particle. The χ^2 probability of this sample compared to the theoretical curve is 85%. This analysis gives us a total of 101 ± 17 η's in our sample.

We have considered two sources of background which might contribute to the distribution in the region around 100 degrees. First, Λ^0's produced

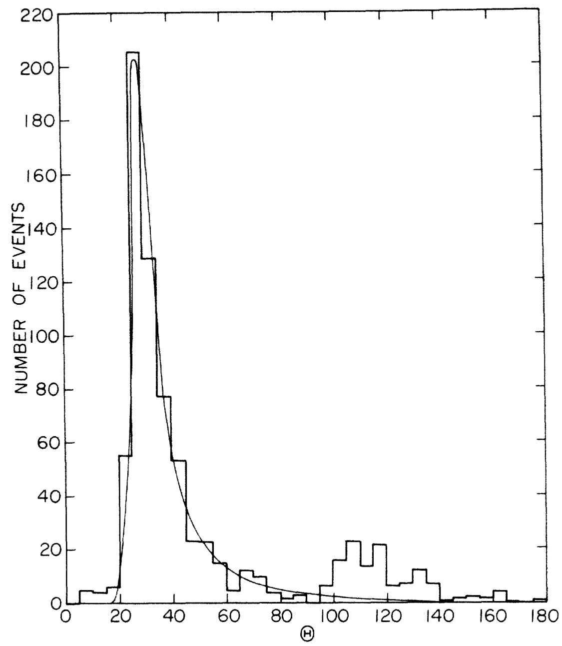

FIG. 3. The opening angle distribution of Fig. 2(a) corrected by subtracting the background arising from $2\pi^0$ production as estimated in Fig. 2(b). The theoretical curve for the π^0 with the proper resolution function folded in is superimposed.

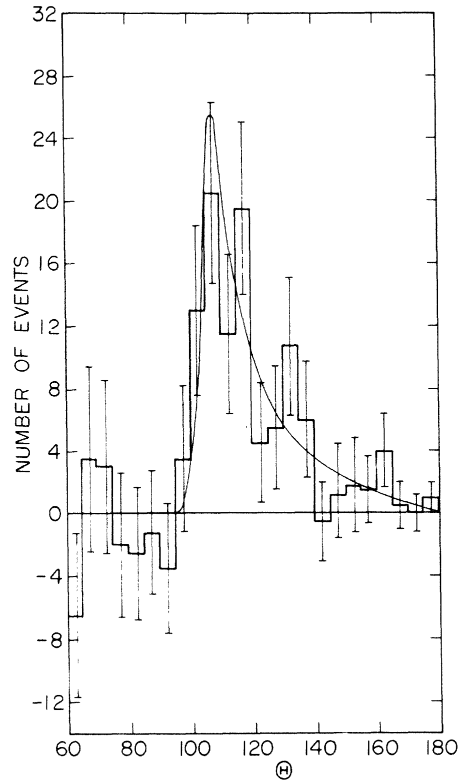

FIG. 4. The opening angle distribution in the region from 60°-180° after subtraction of all background including the π^0 decay events. The theoretical curve superimposed is for a mass 550-MeV particle with a resolution function folded and normalized to 101 events.

in the reaction $\pi^- + p \rightarrow \Lambda^0 + \theta^0$ and decaying in the neutral mode, associated with θ's which escape from the chamber, produce events preferentially in this region. Since we have used this film for a branching ratio study[8] of the θ the number and momentum distribution of all Λ^0's produced in the liquid in our chamber are known. A study of the pointing of electron pairs shows that in general a Λ^0 decay more than one centimeter from the production point can be separated from the events in which γ rays originate at the production point. We have estimated that an extreme upper limit of the number of Λ^0's in the sample is six. Hence, the Λ^0 is not a serious source of contamination. The second phenomenon which has been considered is

$$\pi^- + p \rightarrow \pi^0 + (\pi^0 + n),$$

where one π^0 and the neutron form an isobar. The decay of the isobar could produce a slow π^0 with wide opening angles. The theoretical calculations of Sternheimer[9] show that the opening angle distribution of the slow π^0 is very broad and centered between 77° and 84°. This and the data in Fig. 2(b) indicate that the effect is not important.

The present experiment establishes the existence of a radiative 2γ decay mode of a particle of mass near 550 MeV. Considering the mass and the mode of production it is reasonable to assume that we are observing a neutral decay mode of the η. Thus we conclude that the spin of the η is 0 or 2, with the choice of 0 much more likely.

Previous results, namely, that (1) the 2π decay of the η is not observed[2] and (2) the isotopic spin of the η is 0,[3,4] make it possible to assign the parity and G parity of a spin-0 particle. The absence of the 2π decay mode implies odd parity; the invariance of the system under charge conjugation requires the G parity be positive to be consistent with the 2γ decay mode. Therefore, the assignment for the η is 0^{-+}.

Using the data in Fig. 4 we calculate the ratio of the production cross section of the η which decays by the 2γ mode to the π^- charge exchange cross section to be 0.17 ± 0.03. Taking 3 mb for the charge exchange cross section at this energy[7] we calculate the production cross section of the η with subsequent 2γ decay to be 0.5 mb. This estimate involves both the uncertainty in the charge exchange cross section and the assumption that quasi-elastic nuclear collisions in the chamber liquid contribute to the charge exchange and η production in a similar way.

However, since the above estimate is very unlikely to be low by a factor of two, this is reasonable evidence that there are other neutral decay modes of the η. Other investigators have previously come to this same conclusion.[10] A possible candidate for another neutral mode is the decay into $3\pi^0$'s. We have observed 4 events with six γ rays and 24 events with five γ rays. Assigning all of these to the decay of the η gives an estimate of an upper limit on this decay mode. This limit, given as a ratio to our measured 2γ-ray mode of the η, is 1.1 ± 0.3. Crudely we estimate that there are roughly equal amounts of 2γ decays and all other neutral decays. An assignment of neutral decays into equal 2γ and $3\pi^0$ modes is not inconsistent with our data.

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