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D. Duane Carmony, Arthur H. Rosenfeld, and Remy T. Van de Walle

December 26, 1961

EVIDENCE THAT THE η MESON HAS I-SPIN ZERO*

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Pevsner et al. have reported the existence of the η meson (mass 550 Mev) produced by 1.23-Bev/c positive pions on neutron targets in deuterium[1]

$$\pi^{+} + n\ (+p) \rightarrow p(+p) + \eta^{0}. \tag{1}$$

The η^0 then decays by its charged mode

$$\eta^{0}_{ch} \rightarrow \pi^{+} + \pi^{-} + \pi^{0} + 135\ \text{Mev}. \tag{2}$$

The η is also produced by[2]

$$K^{-} + p \rightarrow \Lambda + \eta^{0}. \tag{3}$$

It is observed that the η^0 has a width $\Gamma \leqslant 15$ Mev and a neutral decay mode, which in fact is the dominant branching fraction. That is, the charged branching fraction f^0_{ch} is less than 1/3, where $f^0_{ch} \equiv (\eta^0 \rightarrow \pi^+\pi^-\pi^0)/(\text{all modes})$. As discussed by Bastien et al., this means that radiative modes must be present in η^0 decay.[2] From reaction (3), we see that η can have only I-spin 0 or 1. The purpose of this Letter is to rule out I = 1.

Using the impulse approximation, the Hulthen wave function for the deuteron, and the experimental cross section for the sequence of reactions (1) and (2), Pevsner et al. calculated the cross section for the reaction

$$\pi^{+} + n \rightarrow p + \eta^{0}_{ch} \tag{1'}$$

They found $\sigma(\eta^0) f^0_{ch} \approx (150 \pm 30)$ µb.[3] If we assume $f^0_{ch} \leq 1/3$, it follows that $\sigma(\pi^+ + n \rightarrow p + \eta^0)$ is greater than $3(150 - 30)$ µb = 360 µb.

To rule out I = 1, we now postulate that η is an I-spin triplet: η_1^+, η_1^0, η_1^-. Then it must also be produced on proton targets by the reactions $\pi^\pm + p \rightarrow p + \eta^\pm$ induced by pions of the same momentum,[4] and a triangle inequality requires

$$\left[\sigma(\eta_1^+)\right]^{1/2} + \left[\sigma(\eta_1^-)\right]^{1/2} \geq \left[2\sigma(\eta_1^0)\right]^{1/2} = (2 \times 360\ \mu b)^{1/2}. \quad (4)$$

The final state $p + \eta^\pm$ will produce events with both two and four visible prongs, since $\eta^\pm$ can decay into three charged particles (branching fraction $f_3^\pm$) or into one charged particle plus neutrals ($f_1^\pm$).

We have used data from two-prong events made by 1.25-Bev/c $\pi^\pm$,[5]

$$\pi^\pm + p \rightarrow p + \pi^\pm + \text{neutrals}, \quad (5)$$

and have looked for a peak near 550 Mev in the mass spectrum of ($\pi^\pm$ + neutrals). In studying the ρ meson, we previously obtained a sample of 3200 mainly inelastic events of the type (5) yielding a slow proton ($p_{lab} \leq 400$ Mev/c).

About one-fifth of the η mesons of Pevsner et al. are associated with protons with $p_{lab} \leq 400$ Mev/c;[3] now the triangle inequality (4) applies at all production angles. Thus, in terms of partial cross sections σ' for slow protons, Eq. (4) becomes

$$\left[\sigma'(\eta_1^+)\right]^{1/2} + \left[\sigma'(\eta_1^-)\right]^{1/2} > \left[\frac{2}{5}\sigma\ (\eta_1^0)\right]^{1/2} = ([illegible] \times 144\ \mu b)^{1/2}. \quad (4')$$

Since the dominant decay mode of η^0 is radiative, ($\eta_1^0 \rightarrow \pi^0 + \gamma$, $\gamma + \gamma$, etc.), it seems likely that the charged η decays dominantly by its branching fraction $f_1^\pm$ at least half the time ($f_1^\pm > 1/2$). For simplicity, we shall assume this here; below we show that the assumption is not necessary. Assuming $f_1^\pm > 1/2$, we must find

$$\left[\sigma'(\eta_1^+ f_1^\pm)'\right]^{1/2} + \left[\sigma'(\eta_1^- f_1^\pm)'\right]^{1/2} > (72\ \mu b)^{1/2}. \qquad (4'')$$

Among our 3200 two-prong measurements, we found ≈ 350 that would not fit single π^0 production (or elastic scattering) and hence must be mainly reactions such as

$$\pi^\pm + p \to p + \pi^\pm + 2\pi^0$$

or else might correspond to (6)

$$\pi^\pm + p \to p + \eta^\pm.$$

Integrated over all (π^+ + neutral) masses, the total cross section $\sigma'(\pi^+$ + neutrals) is 160 μb, and $\sigma'(\pi^-$ + neutrals) is 71 μb. These events display a smooth mass spectrum, as one would expect for $\pi^\pm + 2\pi^0$. Our mass resolution is ±11 Mev. In the region 550 ± 16 Mev, we find $8 \pm \sqrt{8}\ \pi^+$ events, representing 5.4 ± 2 μb. This sets the scale for our estimate that we would have detected a superimposed peak of 6 μb among the π^+ events. Similarly, we find $2 \pm \sqrt{2}\ \pi^-$ events (1.2 ± 1 μb), and would have noticed an extra 3 μb. Thus we find

$$\left[\sigma'(\eta_1^+ f_1^\pm)\right]^{1/2} + \left[\sigma'(\eta_1^- f_1^\pm)\right]^{1/2} \leq (6\ \mu b)^{1/2} + (3\ \mu b)^{1/2} = (16.4\ \mu b)^{1/2}. \qquad (4''')$$

This is in evident contradiction to Eq. (4''), which was based on the postulate that the η_1 had I-spin 1.

Next we drop the assumption that η decay is dominantly radiative. (For instance, if η is a spinless meson, the mode $\eta \to \pi + \gamma$ is forbidden. Then η^0 could decay radiatively into two gamma rays, but $\eta^\pm$ might decay entirely into three pions.) If three-pion modes dominate, it can be shown that, for any spin assignment, our experiment loses sensitivity only by a factor of three, so I = 1 is still ruled out (see Appendix).

It should be pointed out that Prowse et al. have done a similar experiment looking for the other (τ) decay mode of $\eta_1^\pm$ and have failed to find it.[6] These two experiments, taken together, seem to exhaust all possibility that the η meson has I-spin 1.

APPENDIX: CONSIDERATIONS IF THE CHARGED η DOES NOT DECAY VIA A γ-RAY

Since the Q-value for $\eta \to 3\pi$ is only 135 Mev, we assume that this mode will dominate only if it is allowed by G parity. Then I-spin will be conserved. We must then discuss the three possible three-pion states, $J = 0^-$, 1^+, and 1^-, all with $I = 1$.

First we discuss $J = 0^-$. (Apart from Q value, this is the familiar τ meson.) Its I-spin state is mainly the symmetric vector

$$\underline{I}_s = \underline{\pi}_1(\underline{\pi}_2 \cdot \underline{\pi}_3) + \underline{\pi}_2(\underline{\pi}_3 \cdot \underline{\pi}_1) + \underline{\pi}_3(\underline{\pi}_1 \cdot \underline{\pi}_2)$$

$$= \underline{\pi}_1(\pi_2^+ \pi_3^- - \pi_2^0 \pi_3^0 + \pi_2^- \pi_3^+) + \cdots + \cdots .$$

Collecting all these terms (some cancel), we can calculate the branching fractions f_{ch}^0 for the η_1^0

$$f_{ch}^0 = \frac{\pi^+\pi^-\pi^0}{\pi^+\pi^-\pi^0 + \pi^0\pi^0\pi^0} = \frac{2}{5} .$$

and f_3^+ for the η_1^+

$$f_3^+ = \frac{\pi^+\pi^+\pi^-}{\pi^+\pi^+\pi^- + \pi^+\pi^0\pi^0} = \frac{4}{5} .$$

Thus, in their four prong events, Pevsner et al. see two-fifths of all 0^- η events produced; in our two-prong events we see one-fifth, i.e., our sensitivity is half as good as theirs, whereas for the radiative assumption our sensitivity was three-halves theirs. They see $\sigma(\eta_1^0) \cdot f_{ch}^0 = (150 \pm 30\ \mu b)$, so their partial cross section associated with slow protons $\sigma^1(\eta_1^0) \cdot f_{ch}^0$ is $(30 \pm 6\ \mu b)$. Our sensitivity being half as good as theirs $(f_1^+/f_{ch}^0 = 1/2)$ we expect $\sigma'(\eta_1^0) \cdot f_1^+ = (15 \pm 3\ \mu b)$. Inequality (4'') then becomes

$$\left[\sigma'(\eta_1^+ f_1^{\pm})\right]^{1/2} + \left[\sigma'(\eta_1^- f_1^{\pm})\right]^{1/2} > \left[(30 \pm 6\ \mu b)\right]^{1/2} ,$$

which is again in contradiction to Eq. (4''). Some added radiative decays will only increase our relative sensitivity.

Next we discuss the $1^{\pm}$ states. These can have some component of the I-symmetric form $\underline{I}_s$, but there will also enter one of the nonsymmetric form, of which a typical term is

$$\underline{I}_N = \underline{\pi}_3 \times (\underline{\pi}_1 \times \underline{\pi}_2)$$

$$= \underline{\pi}_1 (\underline{\pi}_2 \cdot \underline{\pi}_3) - \underline{\pi}_2 (\underline{\pi}_1 \cdot \underline{\pi}_3).$$

In the total rates, the I_A and I_s parts will not interfere, since they are associated with different spatial symmetries. Since I_N is antisymmetric in one pair of pions, it can contain no $3\pi^0$ component, and its branching fraction f_{ch}^0 is 100%. Collecting terms, we find $f_3^+ = 1/2$. Thus again our sensitivity compared to that of Pevsner et al. is one-half, regardless of which I-states are present, and again $1^{\pm}$ states (I = 1) are ruled out.

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FOOTNOTES AND REFERENCES

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