SEARCH FOR ρ-MESON DECAY INTO $\eta+\pi$*

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Pevsner et al.[1] discovered a meson of mass 550 Mev which decays into $\pi^+\pi^-\pi^0$ and has isospin = 0.[2] They called it η, the name given by Sakurai to his proposed second vector meson (i.e., a meson whose spin, parity, and G parity we write as 1^{--}).[3] However, any $I=0$ configuration of three pions must be antisymmetric in all pairs of pions. The original data were insufficient to make this test, but Bastien et al. later reported additional η events whose Dalitz plot tended not to satisfy this $I=0$ symmetry.[4] Their alternative postulate was that η had positive G parity and that the G-forbidden decay $\eta\to3\pi$ occurred only because virtual photons carry off one unit of isospin. They concluded that Dalitz plots did seem to rule out all assignments except 1^{--} and 0^{-+}, and that, of these two, 0^{-+} fit their data slightly better. At about the same time, Feinberg (prior to publication of the 0^{-+} evidence[4]) pointed out that the (1^{--}) η should be present in a so far unreported mode of ρ decay, $\rho\to\eta+\pi$.[5] We find experimentally that this mode has a branching fraction $f_{\eta\pi}$ less than 0.6% and point out that this may be evidence that η has even G parity, i.e., is 0^{-+}.

It is well established that ρ is a 1^{-+} meson with mass 750 Mev, width $\Gamma\simeq100$ Mev, and a two-pion decay mode,

$$\rho^+\to\pi^0+\pi^+, \tag{1}$$

via a p wave. Each π has a c.m. momentum $p_\pi=350$ Mev/c. If η is 1^{--}, then the $\eta\pi$ decay mode of ρ is allowed,

$$\rho^+\to\eta+\pi^+, \tag{2}$$

again via a p wave with $p=123$ Mev/c. A crude estimate of the decay rate is

$$\Gamma(\rho\to\eta\pi)\propto\frac{p^2}{1+(pR)^2}\left(\frac{p}{m_\rho}\right)(2S_\eta+1)R^3,$$

where the first factor accounts for p-wave barrier penetration, p/m_ρ is the Lorentz-invariant phase space, $(2S_\eta+1)=3$ is the multiplicity of the η spin, and R is some radius of interaction. We can write a similar expression for $\Gamma(\rho\to2\pi)$. If we assume equal radii $R=\hbar/2m_\pi$ for both processes, then we find[6]

$$\Gamma(\rho\to\eta\pi)/\Gamma(\rho\to2\pi)\approx\tfrac{1}{4}. \tag{3}$$

To compare the two decay modes, we chose a sample of 2000 events,

$$\pi^++p\to p+\pi^++\text{neutrals}, \tag{4}$$

produced in the 72-in. hydrogen bubble chamber[7] by 1.25-Bev/c π^+.

Of these, 1684 fit the hypothesis $\pi^++p\to p+\pi^++\pi^0$, and 1100 of the 1684 have a two-pion mass m_{+0} falling in the ρ peak. We attribute 500 of these to ρ production,

$$\pi^++p\to p+\rho^+, \tag{5}$$

and subsequent decay according to reaction (1).[8] Corresponding to these 500 $\rho\to2\pi$ events, our estimate (3) calls for 125 $\rho\to\eta\pi$ events. Now the η decays with a branching fraction $f_{\text{neutral}}\approx\frac{3}{4}$ entirely into neutrals, and with $f_{\text{charged}}\approx\frac{1}{4}$ into $\pi^+\pi^-\pi^0$. Hence 125 η should produce $125\times\frac{3}{4}\approx100$ two-prong stars fulfilling the two conditions:

(a) m(neutrals) = 550 ± 7 Mev,

(b) m(+, neutrals) = 750 ± 50 Mev.

Instead, if the events are plotted in a two-dimensional m(neutral), m(+, neutral) space, we find a flat distribution containing in the area of interest only five events, all of which appear to be $p\pi^+2\pi^0$ background and of which at most a few ($\approx\sqrt{5}$) can be attributed to $\rho\to\eta+\pi^+$.[9]

In summary of the experimental situation: 500 ρ yield $\leq(\sqrt{5})$ η decaying via f_{neutral}, and therefore $\leq\frac{4}{3}\sqrt{5}=3$ η altogether; i.e., $\Gamma(\rho\to\eta\pi)/\Gamma(\rho\to2\pi)\leq\frac{3}{500}=0.6\%$, with an uncertainty of 0.2%. Since our estimate (3) was 25% instead of 0.6%, we conclude either that our estimate must be too high by a factor $\simeq40$, or that $\rho\to\eta+\pi$ is forbidden by G parity and hence that η is 0^{-+}.

In our experience, crude phase-space estimates such as expression (3) are seldom wrong by large factors: In other words, where strong interactions are involved, rates are usually controlled only by phase-space factors and selection rules. However, in this case we must point out that an independent estimate of the strength of the $\rho\pi\eta_{1--}$ vertex can be made based on the known π^0 decay rate $\Gamma(\pi^0\to2\gamma)$ via the dispersion theory diagram of Fig. 1. (If η is not a vector meson, the 1^{--} leg of the diagram

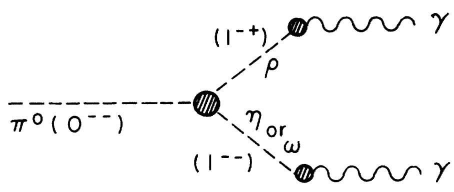

FIG. 1. Decay of π^0 via vector mesons.

can be only the ω, and Gell-Mann et al. already used this diagram to calculate the strength of the $\pi\rho\omega$ vertex.[10] If the η is a vector meson, then the $\pi\rho\eta_{1^{--}}$ vertex will presumably be the dominant factor in π^0 decay.) Glashow and Sakurai have used the $\pi\rho 1^{--}$ vertex as calculated by Gell-Mann et al. for the ω meson to calculate a width for the reaction we sought. They found $\Gamma(\rho\to\pi\eta_{1^{--}})\simeq 1$ Mev. Since we know $\Gamma(\rho\to 2\pi)\simeq 100$ Mev, their version of our estimate (3) is about 1% instead of our 25%, and we would have expected to see only $500\times 1\% \times \frac{3}{4}=4$ events even for a 1^{--} η meson. Hence, as we warned, if all these considerations involving Fig. 1 are correct, then our experiment may not be sufficiently sensitive to rule out the vector η.

As an alternate explanation for the slow rate of π^0 decay, Chew points out that the coupling between a state of odd G parity necessarily involves heavy intermediate particles, and that consequently the $\eta_{1^{--}}$-γ matrix element could be substantially less than e.[11] Then the $\pi\rho\eta_{1^{--}}$ coupling could be "normal," and our estimate (3) would still be justified.

We conclude that this experiment suggests that η has even G parity, but theoretical uncertainties are such that, with our data alone, we can claim no proof.[12]

In the "eightfold way" Gell-Mann[13] predicted the four strangeness-zero mesons listed in Table I,[11] and named them π-ρ, χ-ω. Accordingly, it begins to appear as though the η should be rechristened χ. Independent of the details of the eightfold way, we note that these four mesons have spins, parities, and G parity consistent with the model in which they can dissociate into $\bar{N}N$ pairs, bound in $^1S_0$ or $^3S_1$ states.

Table I. Strangeness-zero mesons.

Spin I	0^-(pseudoscalar)	1^-(vector)
0	$\chi(0^{-+})$	$\omega(1^{--})$
1	$\pi(0^{--})$	$\rho(1^{-+})$

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[5]G. Feinberg, Phys. Rev. Letters 8, 151 (1962).

[6]G. Feinberg (reference 5) also assumes $R=\hbar/2m_\pi$, but assumes a specific matrix element and estimates $\Gamma\eta\pi/\Gamma 2\pi\approx\frac{3}{4}$.

[7]D. D. Carmony and R. T. Van de Walle, Phys. Rev. Letters 8, 73 (1962) and Lawrence Radiation Laboratory Report UCRL-9933, 1962 [Phys. Rev. (to be published)]; D. D. Carmony, thesis, Lawrence Radiation Laboratory Report UCRL-9886, 1961 (unpublished).

[8]That is, we apportion the events in the peak region into 600 background events and 500 due to ρ production. We then estimate the number of ρ actually produced might be between 300 and 700. The large uncertainty arises because part of the background can interfere with the ρ events, changing the population of the peak and its central value.

[9]The weaker η-decay mode into $\pi^+\pi^-\pi^0$ leads to four-prong stars, which have not been measured; since they give a less sensitive test, it is doubtful that we would find any peak among them.

[10]M. Gell-Mann, D. Sharp, and W. G. Wagner, Phys. Rev. Letters 8, 261 (1962).

[11]B. R. Desai, Phys. Rev. 124, 1248 (1961).

[12]We must also admit our surprise that the three-pion η-decay modes are faster than the $\pi^+\pi^-\gamma$ and $\gamma\gamma$ modes (see reference 4).

[13]M. Gell-Mann, California Institute of Technology Scientific Laboratory Report CT-Sl-20, 1961 (unpublished) and Phys. Rev. 125, 1067 (1962).