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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 $\eta \to 3\pi$ occured 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^{-+} fitted their data slightly better. At about the same time, Feinberg (unaware of the 0^{-+} evidence) 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 $\Gamma \simeq 100$ Mev, and a two-pion decay mode,

$$\rho^+ \to \pi^0 + \pi^+, \qquad (1)$$

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,

$$\rho^+ \to \eta + \pi^+, \qquad (2)$$

again via a p-wave with $p = 123$ Mev/c. A crude estimate of the decay rate is $\Gamma(\rho \to \eta\pi) \propto \frac{p^2}{1+(pR)^2} \cdot \frac{p}{m_\rho} (2S_\eta + 1) R^3$, 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 $\Gamma(\rho \to 2\pi)$. If we assume equal radii $R = \hbar/2m_\pi$ for both processes, then we find[6]

$$\Gamma(\rho \to \eta\pi)/\Gamma(\rho \to 2\pi) \approx 1/4. \qquad (3)$$

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

$$\pi^+ + p \to p + \pi^+ + \text{neutrals} \qquad (4)$$

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

$$\pi^+ + p \to p + \rho^+ \qquad (5)$$

and subsequent decay according to reaction (1).[8] Corresponding to these 500 $\rho \to 2\pi$ events, our estimate (3) calls for $500/4 \approx 125$ $\rho \to \eta\pi$ events. Now the η decays with a branching fraction $f_{neutral} \approx 3/4$ entirely into neutrals, and with $f_{charged} \approx 1/4$ into $\pi^+\pi^-\pi^0$. Hence 125η should produce $125 \times 3/4 \approx 100$ two-prong stars fulfilling the two conditions:

(a) m(neutrals) = 550 ± 7Mev, (b) m(+, neutrals) = 750 ± 50Mev.

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: 500ρ yield $\lesssim \sqrt{5}$ η decaying via $f_{neutral}$, and therefore $\lesssim \frac{4}{3}\sqrt{5} = 3$ η altogether; i.e.,

$\Gamma(\rho \to \eta\pi)/\Gamma(\rho \to 2\pi) < 3/500 = 0.6\%$, 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 $\simeq 40$, 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 $\Gamma(\pi^0 \to 2\gamma)$ via the dispersion theory diagram of Fig. 1. (If η is not a vector meson, the 1^{--} leg of the diagram can be only the ω, and Gell-Mann et al. already used this diagram to calculate the strength of 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 $500 \times 1\% \times 3/4 = 4$ 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 $\eta_{1^{--}}\gamma$ 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 "8-fold 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 eight-fold 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 of zero mesons

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

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FIGURE LEGEND

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

FOOTNOTES

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1. A. Pevsner, R. Kraemer, M. Nussbaum, C. Richardson, P. Schlein, R. Strand, T. Toohig, M. Block, A. Engler, R. Gessaroli, and C. Meltzer, Phys. Rev. Letters 8, 421 (1961).

2. D. D. Carmony, A. H. Rosenfeld, and R. T. Van de Walle, Phys. Rev. Letters 8, 117 (1962).

3. J. J. Sakurai, Phys. Rev. Letters 7, 355 (1961).

4. P. L. Bastien, J. P. Berge, O. I. Dahl, M. Ferro-Luzzi, D. H. Miller, J. J. Murray, A. H. Rosenfeld, and M. B. Watson, Phys. Rev. Letters, 8, 114 (1962).

5. G. Feinberg (submitted to Phys. Rev. Letters).

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

7. D. D. Carmony and R. T. Van de Walle, Phys. Rev. Letters 8, 73 (1962) and Lawrence Radiation Laboratory Report UCRL-9933, Feb. 1962 (submitted to Phys. Rev.); D. D. Carmony, Lawrence Radiation Laboratory Report UCRL-9886 (Thesis), Oct. 1961.

8. That is, we apportion the events in the peak region into 600 background events and 500 due to ρ production. We then estimate that 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. "Decay Rates of Neutral Mesons", M. Gell-Mann, D. Sharp, and W. G. Wagner, California Institute of Technology, Pasadena, Calif. (to be published).

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, Jan. 20, 1961 and Phys. Rev. (to be published).

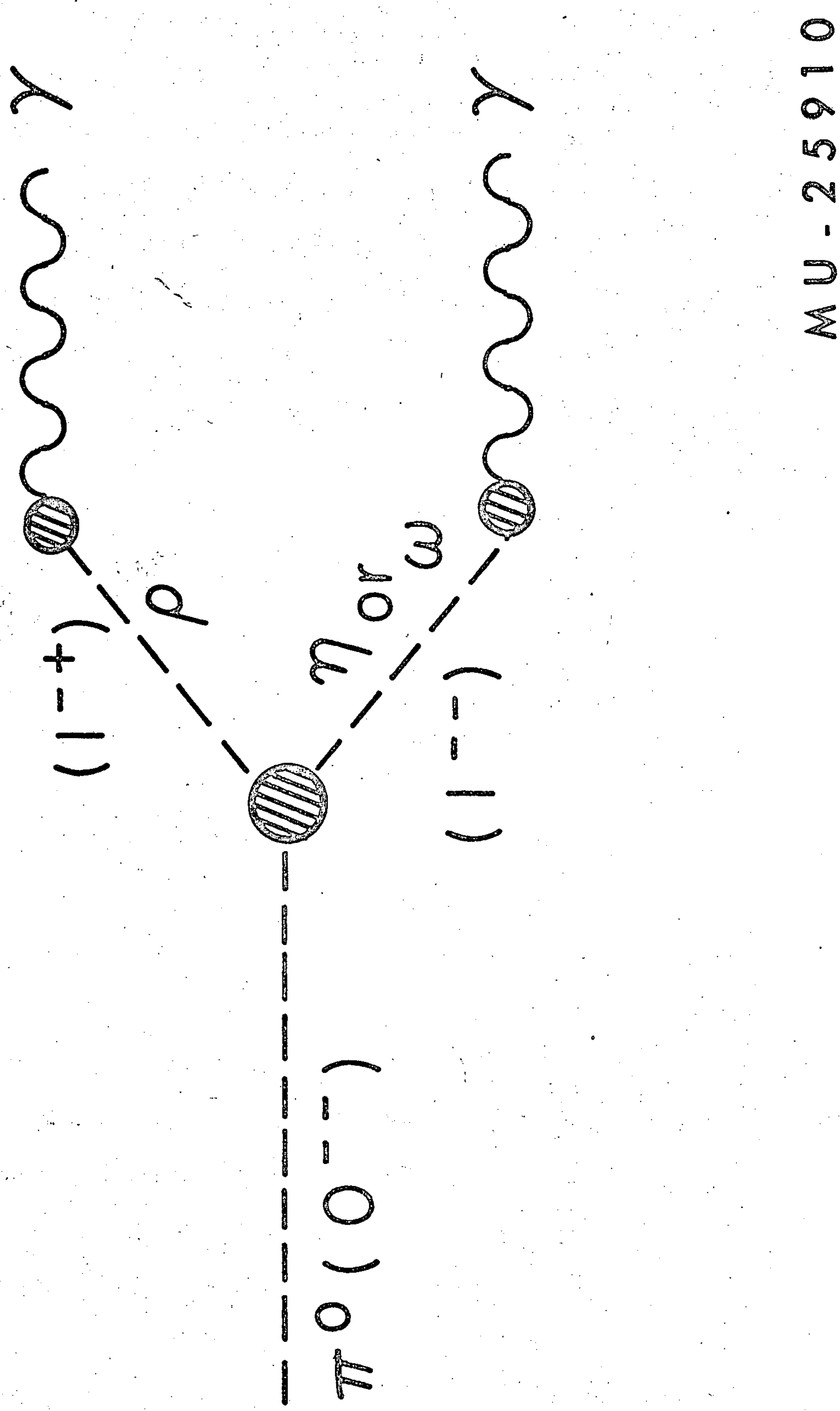

Fig. 1