distribution. With the weaker constraints in Reactions (1), the momentum distribution for unmeasured protons tends to peak at zero; the distribution for measured protons ($p_L > 80$ MeV) is consistent with the Hulthén distribution superimposed on a smooth background.

Since all three pion momenta are measured, mass resolution in the $\pi^-\pi^-\pi^+$ system, $\delta M \simeq \pm 20$ MeV, is not significantly affected by this distortion. An estimate for the mass resolution in the $\pi^-\pi^-\pi^0$ system, $\delta M \simeq \pm 30$ MeV, is obtained from the related fitting procedure used by W. J. Fickinger, T. C. Bacon, D. G. Hill, H. W. K. Hopkins, D. K. Robinson, and E. O. Salant, Bull. Am. Phys. Soc. 10, 587 (1965).

[8]Where the impulse approximation applies, more than 90% of the spectator nucleons have $p_L \leq 220$ MeV/c. In 167 events, $p_L \leq 220$ MeV/c for both the neutron and the proton; since the assignment of events is ambiguous in this case, alternative selections were tried. For the present analysis, 30 "double spectator" events are used in Fig. 2(d) only, 46 in Fig. 2(e) only, and 23 in both. The second selection, in which each event is assigned only to the final state corresponding to the lower momentum nucleon, leads to distributions which are not significantly different. An additional 700 events which contain no nucleon with $p_L \leq 220$ MeV/c have not been used.

[9]Although Chung et al.[3] observed separate A_1 and A_2 peaks for $\Delta^2(p) \leq 0.65$ (BeV/c)^2, they find that after deletion of events with $\Delta^2(p) \leq 0.15$ (BeV/c)^2 there is a strong emphasis of the A_2 peak with respect to the A_1. Private communication.

[10]When events with $M(N\pi_2)$ in the N^* interval are not removed, all final states contain a strong $\pi\rho$ enhancement throughout the A_1 region at $\Delta^2(\pi\rho) \leq 0.15$ (BeV/c)^2.

[11]M. Abolins, R. L. Lander, W. A. Melhop, Ng.-h. Xuong, and P. M. Yager, Phys. Rev. Letters 11, 381 (1963).

[12]Alternatively, a genuine $\pi\rho$ enhancement at low mass erroneously attributed to Fig. 3(a) will simulate virtual πN scattering. Abolins et al., in Proceedings of the Second Topical Conference on Resonant Particles, Ohio University, Athens, Ohio, 10-12 June 1965 (to be published), have described a test for the mechanism proposed by Deck.[5] In the πN c.m. system, events in the N^* interval are divided into those in which the nucleon goes forward or backward with respect to the target-nucleon direction. They find that the low-mass $\pi\rho$ enhancement occurs only in the forward events. However, this correlation is simply a restatement of the fact that the A_1 enhancement occurs at low $\Delta^2(\pi\rho)$.

[13]H. O. Cohn, W. M. Bugg, and G. T. Condo, Phys. Letters 15, 344 (1965).

[14]In a more complete analysis, C. Geobel, Phys. Rev. Letters 13, 143 (1964), has shown that this mechanism is not likely to produce an enhancement by virtual ρ exchange.

[15]Similar conclusions have been reached by the La Jolla group in a study of π^-d interactions at 3.7 BeV/c (N. Xuong and R. Lander, private communication. See also reference 12.)

SEARCH FOR C-NONCONSERVING DECAYS $\varphi \to \rho + \gamma$ AND $\omega + \gamma$*

James S. Lindsey and Gerald A. Smith

Lawrence Radiation Laboratory, University of California, Berkeley, California
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In an attempt to explain the observed CP nonconservation in K_2^0 decay, a number of authors have suggested the existence of a C-nonconserving (but P-nonviolating) interaction.[1,2] Bernstein, Feinberg, and Lee (BFL) have noted that "all existing experimental results are compatible with the possibility of a very large violation of C and T invariance in the electromagnetic interaction of the strongly interacting particles."[3] C and T represent the usual charge-conjugation and time-reversal operators. BFL and others have considered possible C-nonconserving effects that would manifest themselves in the partial decay rates and resulting final-state asymmetries for the pseudoscalar and vector mesons.[4] Several experiments testing these predictions for pseudoscalar mesons are currently in progress, and the preliminary indication is that in at least one of these cases [$\eta(548) \to \pi^0 + e^+ + e^-$] the prediction is not fulfilled.[5]

Turning to the vector mesons, BFL show that if the Hamiltonian describing the electromagnetic interaction violates C, T invariance strongly, and if the isoscalar part of the C, T-nonconserving current exists, then the rate for $\varphi \to \omega + \gamma$ should be ≈ 1.9% of the total φ-decay rate, and if the isovector current exists, the rate for $\varphi \to \rho + \gamma$ should be ≈ 2.4% of the total φ-decay rate. Prentki and Veltman state that the rate $\varphi \to \pi^+ + \pi^- + \gamma$ (pions in S or P wave) may be as large as 10 to 20%.[6] Lee has further noted that in the limit of perfect SU(3) symmetry, one has $\Gamma(\varphi \to \omega + \gamma) \approx 0.79\,\Gamma(\varphi \to \rho + \gamma)$.[7] Owing mainly to phase-space limitations, the predicted branching ratio for $\omega \to \rho + \gamma$ is significantly suppressed below that for φ decay, and is undoubtedly consistent with the recent results of Flatté et al., giving $\Gamma(\omega \to \pi^+ + \pi^- + \gamma) < 0.05\,\Gamma(\omega \to \pi^+ + \pi^- + \pi^0)$.[8] The remainder of this paper deals with our experimental observations on φ decay.

We have analyzed approximately 70% of 740 000 pictures taken of the 72-in. hydrogen bubble chamber exposed to an incident K^- beam at momenta of 2.1 to 2.7 BeV/c at the Bevatron. We consider the reactions

$$K^- + p \to \Lambda^0 + \varphi^0; \quad \varphi^0 \to K^+ + K^-, \tag{1}$$

$$K^- + p \to \Lambda^0 + \varphi^0; \quad \varphi^0 \to K_1{}^0 + K_2{}^0, \tag{2}$$

and

$$K^- + p \to \Lambda^0 + \pi^+ + \pi^- + (\text{all neutrals}). \tag{3}$$

In Figs. 1, 2, and 3 we present those events with the square of the momentum transfer to the Λ ($\Delta_{p,\Lambda}{}^2$) less than 0.8 (BeV/c)^2. As observed in Reactions (1) and (2), φ production is concentrated ($\approx$70%) in this momentum-transfer region.[9]

$\varphi \to \rho + \gamma$.—Figure 1(a) is a scatter plot of the square of the (all neutrals) mass versus the square of the effective mass of the ($\pi^+\pi^-$ all neutrals) combination from measured (unfitted) data for Reaction (3). The striking feature of this plot is the evidence for a π^0 at M^2(all neutrals)$=0.018$ BeV^2 for all values of $M^2(\pi^+\pi^-$ all neutrals). However, for $M^2(\pi^+\pi^-$ all neutrals)≈ 0.92 BeV^2, one notices evidence for an enhancement of M^2(all neutrals)≈ 0.0 BeV^2. This enhancement has been previously identified as the $\pi^+\pi^-\gamma$ decay mode of the $\eta(959)$ (or X^0 meson).[10,11] In Fig. 1(b) we retain only those events in which the $\pi^+\pi^-$ combination is in the ρ band (0.42 to 0.72 BeV^2). The $\eta(959)$ enhancement remains, consistent with the results of Kalbfleisch, Dahl, and Rittenberg[11] on the existence of the decay mode $\eta(959) \to \rho + \gamma$. No enhancement is observed at or near the known location of the φ, $M^2(\pi^+\pi^-$ all neutrals)$=1.038$, and M^2(all neutrals)$=0.0$ BeV^2. To demonstrate this more clearly the projections onto the $M^2(\pi^+\pi^-$ all neutrals) scale are shown in Fig. 2. Only events in the range $-0.01 \leq M^2$(all neutrals)≤ 0.01 BeV^2 are shown. The shaded area contains events in the ρ band

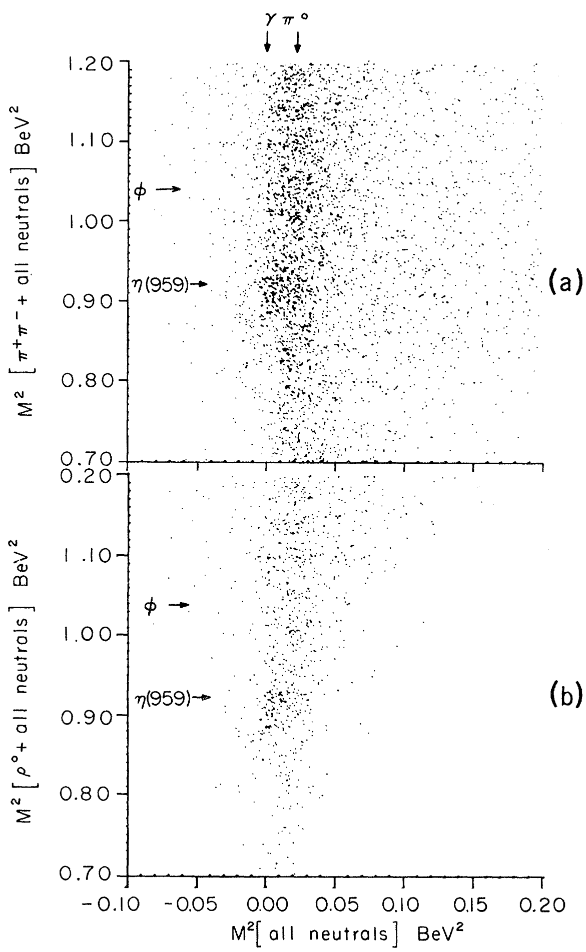

FIG. 1. (a) Scatter plot for 3468 examples of the reaction $K^- + p \to \Lambda^0 + \pi^+ + \pi^- +$ (all neutrals) with the square of the momentum transfer to the Λ less than 0.8 (BeV/c)^2, and (b) the same as (a), with the exception that only events with $M^2(\pi^+\pi^-)$ in the range 0.42 to 0.72 BeV^2 (ρ band) are retained.

only. The curves are a smooth approximation to the background. Using the $\eta(959)$ peak as a measure of our experimental resolution in this region, we find we can attribute no more than 20 events to $\varphi \to \pi^+ + \pi^- + \gamma$ and 12 events to $\varphi \to \rho + \gamma$ with a confidence of 99%. Based on 209 examples of $\varphi \to K^+ + K^-$ and our measured branching ratio $\Gamma(\varphi \to K^+ + K^-) = (1.22 \pm 0.22)\Gamma(\varphi \to K_1{}^0 + K_2{}^0)$, we conclude that[12]

$$\Gamma(\varphi \to \rho + \gamma) \leq 0.03\,\Gamma(\varphi \to K + \bar{K}) \text{ and } \Gamma(\varphi \to \pi^+ + \pi^- + \gamma) \leq 0.05\,\Gamma(\varphi \to K + \bar{K}). \tag{4}$$

$\varphi \to \omega + \gamma$.—In as much as the neutrals of Reaction (3) contain both the π^0 from the ω decay and the photon, this all-neutrals combination has a wide variance of phase space for φ decay (0.018 to 0.55 BeV^2). Therefore, the scatter plot is not a particularly sensitive means of looking for this decay mode. In Fig. 3 we

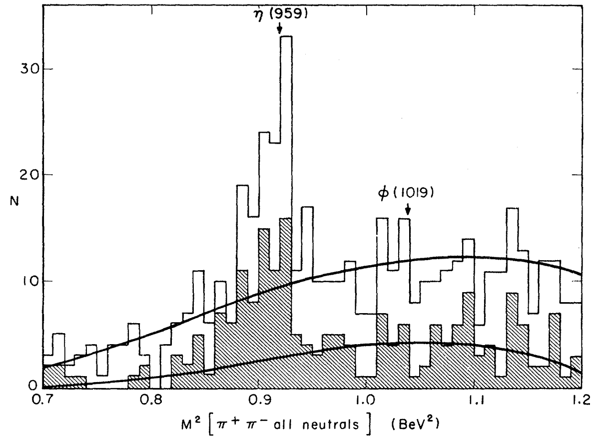

FIG. 2. Projection of the events of 1(a) in the interval $-0.01 \leq M^2$(all neutrals)≤ 0.01 BeV^2 onto the $M^2(\pi^+\pi^-$ all neutrals) scale. The shaded events are those plotted in 1(b) for the same intervals.

present the $M^2(\pi^+\pi^-$ all neutrals) distribution, again at low momentum transfer. Events with M^2(all neutrals) less than 0.073 BeV^2($4m_{\pi^0}{}^2$) have been removed, since the $\Lambda^0\pi^+\pi^-\pi^0$ final state is such a large fraction of the background [see Fig. 1(a), for example]. Only events with a $\pi^+\pi^-$ mass squared less than 0.420 BeV^2, the upper limit for $\omega \to \pi^+ + \pi^- + \pi^0$ decay, are included. A large enhancement is observed at 959 MeV, due to the decay $\eta(959) \to \eta(548) + \pi^+ + \pi^-$, $\eta(548) \to$ all neutrals, whereas no signal is observed at 1019 MeV, the location of the φ. A further cut is made on the $\pi^+\pi^-$ mass squared less than 0.172 BeV^2, the upper bound for $\eta(548) \to \pi^+ + \pi^- + \pi^0$ decay. The remaining events are shaded [the $\eta(959)$ peak is further pronounced in reference to background by this selection because the $\pi^+\pi^-$ must have

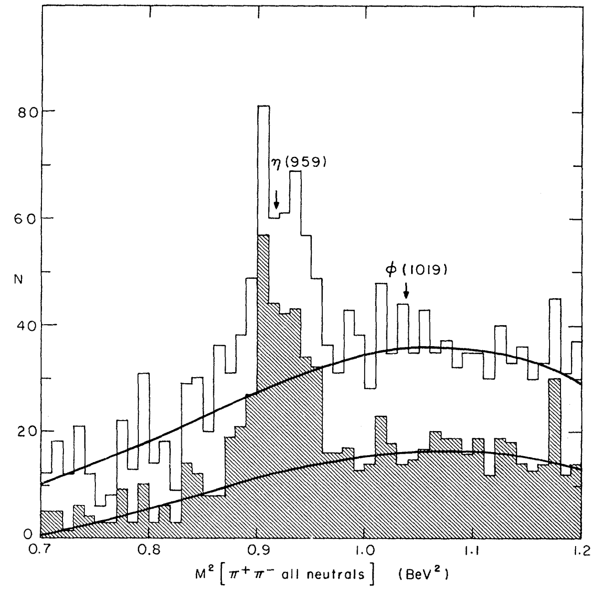

FIG. 3. Projection of the events of 1(a) in the intervals M^2(all neutrals) ≥ 0.073 BeV^2 ($4m_{\pi^0}{}^2$) and $M^2(\pi^+\pi^-)$ ≤ 0.420 BeV^2 (upper bound for ω decay). The shaded events have the further restriction $M^2(\pi^+\pi^-) \leq 0.172$ BeV^2 [upper bound for $\eta(548)$ decay].

a mass squared less than 0.169 BeV^2 for this particular decay mode of the $\eta(959)$]. It should be noted at this point that if there existed a substantial C-nonconserving strong decay $\varphi \to \eta(548) + \pi$ or a C-nonviolating electromagnetic decay $\varphi \to \eta(548) + \gamma$, these would show an enhancement at the φ mass, particularly in the shaded data. We find no evidence for these modes, and can attribute no more than 35 events to $\varphi \to \omega + \gamma$ and 25 events to $\varphi \to \eta(548) + \pi$ or $\eta(548) + \gamma$ with a confidence of 99%. We thus conclude[13]

$$\Gamma(\varphi \to \omega + \gamma) \leq 0.09(\varphi \to K + \bar{K}) \text{ and } \Gamma[\varphi \to \eta(548) + \pi \text{ or } \eta(548) + \gamma] \leq 0.15\Gamma(\varphi \to K + \bar{K}). \tag{5}$$

Our results on the branching ratios for $\varphi \to \rho + \gamma$ and $\omega + \gamma$ are compatible with the predictions of BFL. However, inasmuch as we establish only upper limits on these ratios, it would be meaningless to compare them with Lee's prediction on the relative rates of these two modes. Our results on $\pi^+\pi^-\gamma$ (<5%) appear to be incompatible with the prediction of Prentki and Veltman (10 to 20%).

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[12]We must point out two minor qualifications to these results: (a) The cut on $|M^2(\text{all neutrals})| \leq 0.01$ results in the loss of a small fraction of $\eta(959)$ events due to resolution. Thus, we would expect this effect with approximately the same magnitude to occur in the case of the φ; (b) our data at this time do not rule out the possibility of a weak alternate decay mode, $\varphi \to \rho + \pi$ (branching ratio $= 18 \pm 8\%$). Again due to resolution we may be including a small amount of $\rho^0\pi^0$ in our $\rho^0\gamma$ and $\pi^+\pi^-\gamma$ determinations. The effect of (a) is to underestimate and (b) to overestimate the limits on $\rho\gamma$ and $\pi^+\pi^-\gamma$. However, the net effect can alter our conclusions on the branching ratios by no more than ±1 to 2%.

[13]We have assumed an all-neutrals branching ratio of 69% for the $\eta(548)$ and 10% for the ω in arriving at these branching ratios. We have introduced a slight bias in the $\omega\gamma$ and $\eta(548)\gamma$ determinations because of the removal of events with $M^2(\text{all neutrals}) < 4m_{\pi^0}^2$, inasmuch as the lower bound for these cases would be $m_{\pi^0}^2$ [ω or $\eta(548) \to \pi^+ + \pi^- + \pi^0$] or zero [$\eta(548) \to \pi^+ + \pi^- + \gamma$]. Therefore, the branching ratios for these modes should be somewhat larger, but probably by no more than 1 to 2%.

SPIN OF THE $Y_0^*(1405)$*

A. Engler, H. E. Fisk, R. W. Kraemer, C. M. Meltzer, and J. B. Westgard
Carnegie Institute of Technology, Pittsburgh, Pennsylvania

and

T. C. Bacon, D. G. Hill, H. W. K. Hopkins, D. K. Robinson, and E. O. Salant
Brookhaven National Laboratory, Upton, New York
(Received 9 June 1965)

A study has been completed of three-body final states, hyperon $+K+\pi$, in pion-nucleon collisions at an incident pion momentum of 1.68 BeV/c. The purpose of this investigation was to obtain information on the spin of the $Y_0^*(1405)$ resonance by observing angular correlations in its decay. Our results, by use of a moments analysis,[1] are consistent with spin $\frac{1}{2}$, but our statistics at present are too poor for a parity determination. We have also examined the decay of the $Y_1^*(1385)$ resonance and find, in agreement with other authors,[2] that spin $\frac{1}{2}$ is ruled out, spin $\frac{3}{2}$ is acceptable, and spin $\frac{5}{2}$ is not required by these data.

The data were obtained from approximately 2×10^5 π^-p and 1.2×10^5 π^+d pictures in the Brookhaven National Laboratory 20-in. bubble chamber exposed at the AGS. The incident beam momentum corresponds to a c.m. energy 50 MeV below the threshold for the reaction $K^*(890)+\Sigma$.

Table I gives the number of events in the various final states. For the reaction $\pi^+ + d \to$ hyperon $+K+\pi+$ nucleon, only events with a nucleon momentum of ≤ 200 MeV/c are included.[3] In these events the nucleon is considered to be a "spectator" not affected by the primary π-nucleon interaction, except for energy-momentum conservation. The Dalitz plot and its mass-squared projections for 220 events in