The percentages of state Nos. 1, 3, and the D states are also given in the tables. These numbers should not be taken literally, of course, since wave functions which have not even converged for purposes of the ground-state energy have very doubtful validity for finding quantities other than the energy. But the trend is clearly towards larger admixtures of state No. 3, albeit not as large as the 4% which Schiff would like for fitting the electron scattering data; we feel that discussion of the significance of any such discrepancy should await the inclusion of the D states into Schiff's calculations.

We are grateful to the Courant Institute, New York University, for a very generous allocation of IBM-7094 machine time, and to the staff of the Courant Institute for much appreciated help and advice. We thank Professor Schiff for communicating his results prior to publication, and for useful discussions.

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[2]This means Formula (9) of reference 1.

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EXISTENCE OF A NEW MESON OF MASS 960 MeV†

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In this note we present evidence for the existence[1] of a new meson of strangeness-zero, which we temporarily call the "X^0."[2] Its mass and full width are $M \approx 960$ MeV and $\Gamma < 25$ MeV; its isospin is either 0 or 1. Data relevant to determination of its other quantum numbers are now being analyzed and the results will be reported in a subsequent paper.

The data discussed here come from a bubble chamber study of the K^--p interactions at 2.3 BeV/c. The general features of this study have been described elsewhere.[3] The evidence for the existence of X^0 comes primarily from effective-mass studies in the following reaction channels:

$$K^- + p \to \Lambda + \text{neutrals}, \tag{1}$$

$$K^- + p \to \Lambda + \pi^+ + \pi^- + \pi^+ + \pi^- + \pi^0, \tag{2}$$

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

The number of events in each[4] channel are 1277, 43, and 415, respectively, all coming from a complete sample occurring within a suitable fiducial region. We discuss each of these channels in sequence below.

A histogram of the squared missing mass of the neutrals emitted in Reaction (1), denoted by M^2(neutrals), is shown in Fig. 1. As indicated in the figure, there are peaks of varied size corresponding to the known two-body production of a Λ^0 and a π^0, η^0, ω^0, and φ^0. From an ideogram of the data of Fig. 1, we find that these peaks occur at 130 ± 30 MeV, 550 ± 20 MeV, 780 ± 15 MeV, and 1020 ± 15 MeV, respectively, in excellent agreement with the accepted masses of these mesons. In addition, one sees a new peak at 960 ± 15 MeV of width ≈ 40 MeV corresponding to the reaction

$$K^- + p \to \Lambda + X^0. \tag{4}$$

We have investigated other possible production mechanisms such as $Y^* + \eta^0$, $Y^* + \omega^0$, $\Sigma^0 + \omega^0$, etc., and find that none of them is capable of giving rise to a peak of width as narrow as that observed.

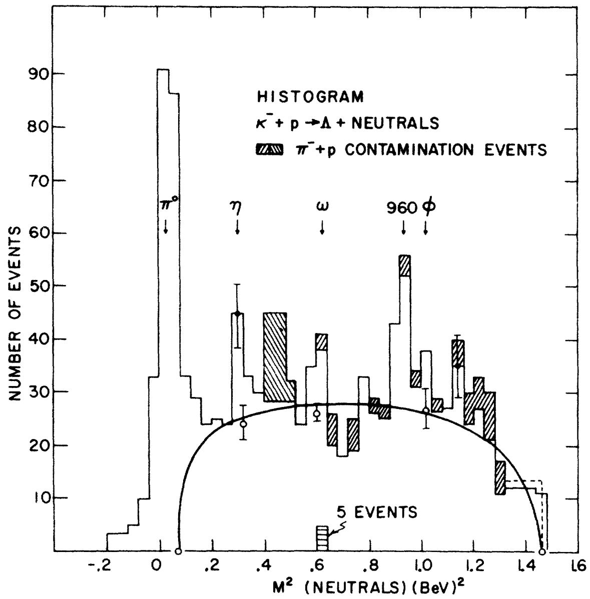

FIG. 1. A histogram of the M^2(neutrals) in Reaction (1), $K^- + p \to \Lambda$ + neutrals. The crosshatched peak at $M^2 \approx 0.5$ (BeV)^2 is due to the fitted pion reaction $\pi^- + p \to \Lambda^0 + K^0$. The solid curve is the estimated background.

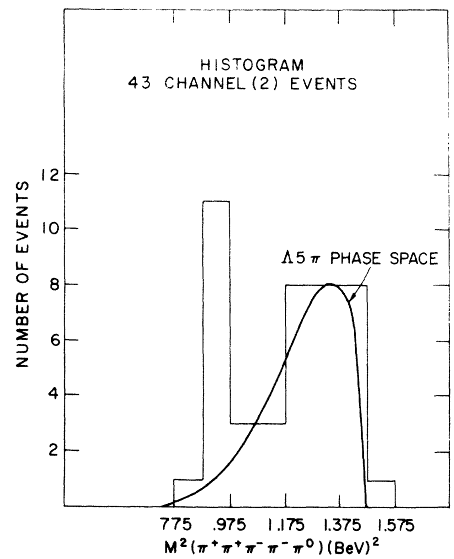

FIG. 2. Histogram of the $M^2(\pi^+\pi^-\pi^+\pi^-\pi^0)$ for 43 events in Reaction (2), $K^- + p \to \Lambda + \pi^+ + \pi^- + \pi^+ + \pi^- + \pi^0$. The solid curve is the mass distribution predicted by invariant phase space for five pions from the above final state.

In order to assess further the significance of the X^0 peak, the background contribution must be estimated. The background events are due both to pion-produced[5] reactions of the types $\pi^- + p \to \Lambda^0(\Sigma^0) + K^0$ and $\pi^- + p \to \Lambda^0 + K^0 + \pi^0$ and to the kaon-produced "phase-space" channels: $K^- + p \to \Lambda^0 +$ (2 or more π^0). The contribution of the pion-induced channels is ascertained from a study of kinematically fitted $\pi^- + p$ events in which both the Λ^0 and the K^0 decay visibly[6] in the chamber. From this study we find that in Fig. 1 there should appear 37 ($\pi^- + p \to \Lambda^0 + K^0$) events and 60 ($\pi^- + p \to \Lambda^0 + K^0 + \pi^0$) events. We have therefore subtracted the shaded areas of Fig. 1 in accord with the $M^2(K^0)$ or $M^2(K^0\pi^0)$ missing mass spectra observed in this fitted pion-induced sample.

After subtraction of the pion contamination, the $K^- + p \to (\Lambda^0$ or $\Sigma^0) + n\pi^0$ background may be estimated by drawing a smooth curve under the peaks. The normalization for this curve can be obtained from the observed rates[7] of the charged decay modes of the various resonances, since their neutral/charged branching ratios are known.[8] These points for the η, ω, and φ are shown as open circles in Fig. 1. The number of events[9] in the X^0 peak, representing ($X^0 \to$ neutrals), is 40 ± 10. This amounts to a three-standard deviation effect.

Next, we turn to the five-pion channel (2), which contains only one π^0, so that all events are kinematically fitted with one constraint. The effective-mass spectrum of the five pions is shown in Fig. 2. The presumed X^0 peak occurs at 960 ± 10 MeV and has a width of ~30 MeV, consistent with the behavior observed in channel (1) (considering the poorer mass resolution in the latter). Five-pion phase space fits the spectrum of Fig. 2 quite well, if the 960-MeV region is omitted. Moreover, we have studied the two- and three-particle mass spectra of channel (2) and find that intermediate resonance production[10] cannot account for any appreciable distortion in $M^2(5\pi)$, let alone the 960-MeV peak itself. Using the 5π phase-space curve as the background level, we find that the number of events[11] in the X^0 peak, representing ($X^0 \to \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^0$), is 10 ± 3 events, again a three-standard deviation effect.

Let us now consider the evidence for the existence of X^0 in channel (3). Events in this channel are defined by the following criteria: (a) The V^0 is a Λ^0, (b) each of the charged prongs is consistent with a pion identity, (c) no kinematic fit consistent with any of the hypotheses $K^- + p \to \Lambda^0 + \pi^+ + \pi^-$, $\to \Sigma^0 + \pi^+ + \pi^-$, $\to \Lambda^0 + \pi^+ + \pi^- + \pi^0$, or $\pi^- + p \to \Lambda^0 + K^+ + \pi^-$ ($+\pi^0$) is possible[12] with a χ^2 probability greater than 1%, and (d) the calculated missing mass of the neutral(s) is greater than m_{π^0}.

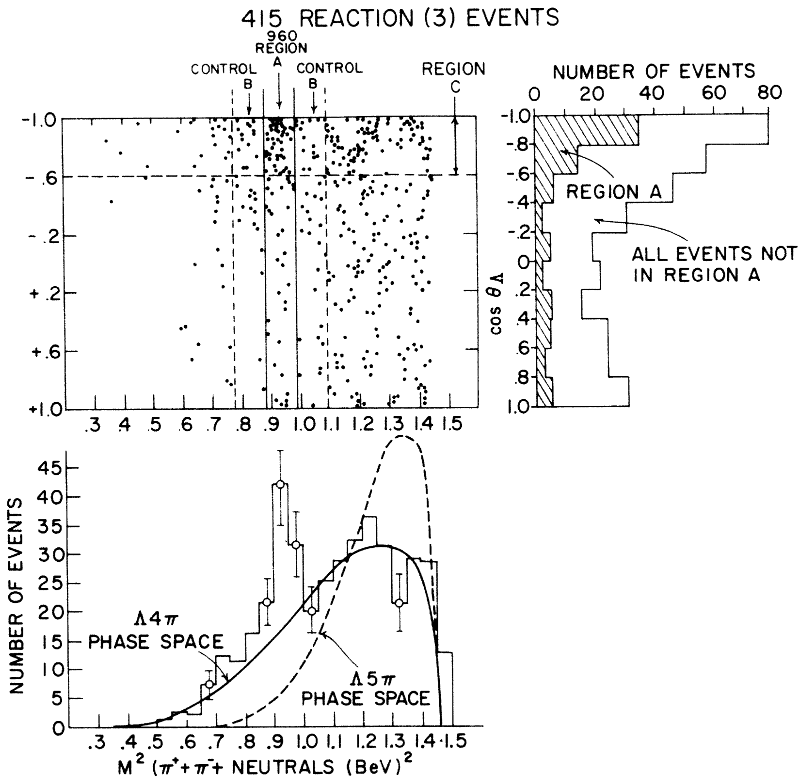

FIG. 3. Two-dimensional plot of $M^2(\pi^+\pi^-$ neutrals) vs $\cos\theta$ for the 415 events in channel (3), $K^- + p \rightarrow \Lambda + \pi^+ + \pi^-$ + (neutrals with mass $>m_{\pi^0}$). See text for description of included curves and regions A, B, and C.

The mass spectrum $M^2(\pi^+ + \pi^- +$neutrals) from Reaction (3) is shown as the lower projection of Fig. 3. There is once again a very clear three-standard deviation peak at ~960 MeV, of width comparable to that observed in Figs. 1 and 2. The solid curve of Fig. 3, which is an excellent fit to the background, is the phase-space distribution, i.e., $M^2(\pi^+ + \pi^- + 2\pi^0)$ from the "$\Lambda 4\pi$" reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + 2\pi^0$. For contrast, the $M^2(\pi^+ + \pi^- + 3\pi^0)$ phase space from the "$\Lambda 5\pi$" reaction $K^- + p \rightarrow \Lambda + \pi^+ + \pi^- + 3\pi^0$ is shown as the dashed curve of Fig. 3. From this comparison as well as other studies of the mass "subspectra" [i.e., M^2(neutrals) from $\Lambda 5\pi$ vs $\Lambda 4\pi$], we conclude that in the region of the 960-MeV peak the $\Lambda 5\pi$ background is negligibly small, and thus accept the $\Lambda 4\pi$ phase space as accurately representing the background level.[13] Then, defining the "960 region" (region A of Fig. 3) by

$$0.880 \text{ (BeV)}^2 \leq M^2(\pi^+ + \pi^- + \text{neutrals}) \leq 0.985 \text{ (BeV)}^2,$$

we find that this region contains 39 background events and 39 ± 10 events due to $(X^0 \rightarrow \pi^+ + \pi^- +$neutrals).

Additional evidence indicating that the "960 events" are different from others in channel (3) comes from two sources. Firstly, we find that the mass subspectra [i.e., M^2(neutrals) or $M^2(\pi^+\pi^-)$] for events in region A (not shown) are very different from those events in a control region which surrounds region A. This control region B defined in Fig. 3 is chosen to contain the same number of events as in region A. A second indication of the special nature of the "960" events comes from a study of the correlation of $M^2(\pi^+ + \pi^- +$neutrals) vs momentum transfer (or equivalently, vs $\cos\theta_\Lambda$, the center-of-mass production angle of the Λ). This correlation is exhibited for channel (3) in Fig. 3. One sees that the percentage of extremely backward Λ's, i.e., peripheral events, is much higher in region A than it is for the remainder of the M^2 distribution, indicating that different production mechanisms are involved.

To recapitulate, the "960" peaks in the appropriate M^2 spectra of channels (1), (2), and (3) give strong evidence for the existence of the X^0. In addition, the behavior of the mass subspectra and peripheral nature of the "960" events in channel (3)[14] give further support to this conclusion.

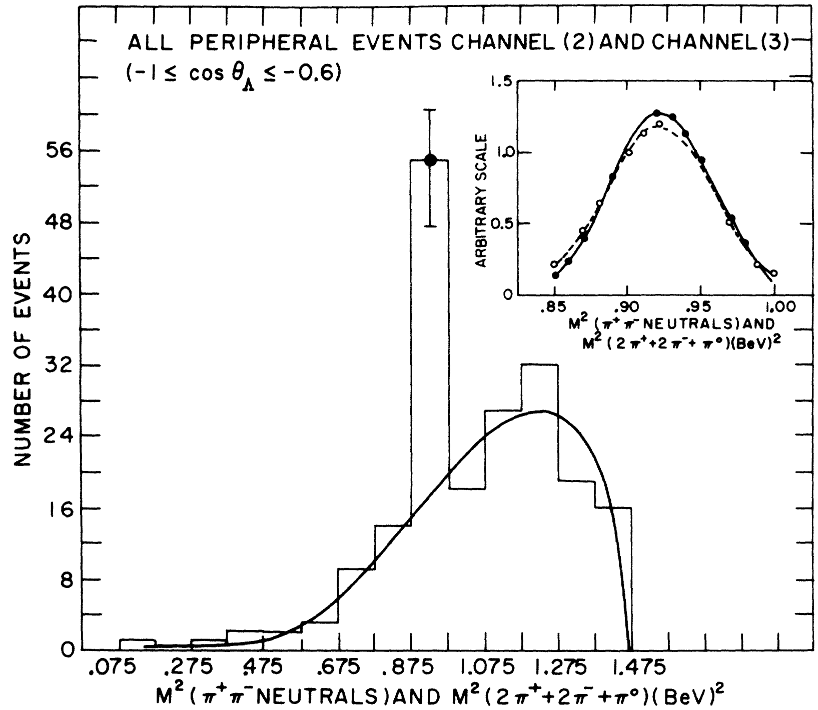

FIG. 4. Histograms of $M^2(\pi^+\pi^-$ neutrals) and $M^2(\pi^+\pi^-\pi^+\pi^-\pi^0)$ for peripheral events in channels (2) and (3). Also included in the insert is a Gaussian ideogram of the events in the "960" peak as well as their experimental resolution function.

We believe, then, that the entire profile of evidence unequivocally establishes the existence of the X^0.

The observation of ~90 X^0 events corresponds[15] to a cross section of $\sigma \sim 60\ \mu b$, comparable to that for η and φ production.

In order to obtain the best possible determination of the X^0 mass and width from our data, we take advantage of the peripheral nature of X^0 production. From the $\cos\theta_\Lambda$ projection plot of Fig. 3, it is clear that the X^0 events lie predominantly in region C, defined by $-1.0 \leq \cos\theta_\Lambda \leq -0.6$. The X^0 purity in this region is $\geq 70\%$. Moreover, the mass resolution in region C is inherently better than that for the entire "960" sample of region A because the peripheral Λ's emerge slowly in the laboratory system. To determine the mass, M, and width, Γ, we use the region-C events from both channels (2) and (3). The mass histogram of this selected sample is shown in Fig. 4. The solid curve represents our estimation of the background. Also included is a Gaussian ideogram of (a) events in the region of the "960" peak and (b) the experimental resolution function for these events.[16] These are shown as the solid and dashed curves in the insert of Fig. 4. The best values of the mean mass and experimental width are

$$M = 960 \pm 5 \text{ MeV}, \quad \Gamma_{\text{exp}} = 30 \pm 5 \text{ MeV}.$$

As is noted from Fig. 4, the experimental width of the X^0 is consistent with that of the resolution function. From this we estimate the true width $\Gamma_{\text{true}} < 20$ MeV, and it is consistent with zero.

As far as the quantum numbers of the X^0 are concerned, at the present time we can only note that the isospin must be 0 or 1. This follows directly from the fact that the X^0 is produced in association with a Λ^0. This, in turn, is inferred from the narrowness of the "960" peak. We shall discuss additional information pertinent to the quantum numbers as well as the detailed nature of the decay modes of the X^0 in a subsequent publication.

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[1]M. Goldberg et al., Bull. Am. Phys. Soc. 9, 23

(1964).

[2]Final appellation should follow the convention of G. F. Chew, M. Gell-Mann, and A. H. Rosenfeld, Sci. Am. 210, 74 (1964). Since this convention depends upon the quantum numbers of the meson, the christening cannot take place until the former are definitely established.

[3]L. Bertanza et al., Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 285.

[4]Channels (1) and (3) contain Σ^0 as well as Λ^0 events in unknown proportion. The existence of Σ^0 contamination does not have a significant effect on the interpretation of the data. See reference 9.

[5]The pion contamination in the 2.3-BeV/c K^- beam is 7 ± 3 %. For details see J. Leitner, G. C. Moneti, and N. P. Samios, Nucl. Instr. Methods 20, 42 (1963).

[6]From such studies we find that the $\pi^- + p \rightarrow \Lambda^0(\Sigma^0) + K^0 + n\pi^0$ contamination is negligible.

[7]From a study of the $M^2(\pi^+ + \pi^- + \pi^0)$ spectrum from the reaction $K^- + p \rightarrow \Lambda + \pi^- + \pi^+ + \pi^0$, we determine the number of ω^0's and η^0's decaying via the charged $(\pi^+ + \pi^- + \pi^0)$ mode (see reference 3 for details). Similarly, the charged $K^+ + K^-$ mode of φ^0 decay is directly observed from $K^- + p \rightarrow \Lambda + K^+ + K^-$ (see reference 8 for details). From this information and the known charged/neutral branching ratio of the η^0, ω^0, and φ^0 (see reference 8), we predict that 30 ± 10, 20 ± 5, and 10 ± 3 events should appear in the η^0, ω^0, and φ^0 peaks of Fig. 1, respectively. Three of the five normalization points correspond to these numbers. The other two correspond to the onset of $\Lambda\pi^0\pi^0$ phase space and the end point of the neutral spectrum.

[8]G. Puppi, Ann. Rev. Nucl. Sci. 13, 287 (1963); P. L. Connolly et al., Phys. Rev. Letters 10, 371 (1963).

[9]We emphasize that possible Σ^0 contamination cannot appreciably affect these conclusions. Firstly, the $\Sigma^0 + n\pi^0$ contribution is included in the "smooth-curve" background. Secondly, as mentioned in the text, the 960-MeV peak cannot be due to a special Σ^0 production mechanism because the missing γ ray would give rise to an X^0 width eight times the observed one. For the same reason, $\Sigma^0 + X^0$ production would be much broader than the experimental peak.

[10]To further investigate the effect of such intermediate resonance production on multipion mass distributions, we studied the (80-event) $K^- + p \rightarrow \Lambda + 4\pi$ channel, which we know to contain a strong $Y_1^*(1385)$. The $M^2(4\pi)$ distribution from this reaction fits phase space very well, indicating that resonance effects do not markedly distort the $M^2(4\pi)$ spectrum.

[11]There is some indication that three of five pions are emitted as an η^0, but we defer such discussion to a subsequent Letter.

[12]From a study of kinematically fitted $\pi^- + p \rightarrow \Lambda^0 + K^0 + \pi^+ + \pi^-$ events (where both the Λ^0 and K^0 decay visibly), we estimate that only 6 ± 3 events of this type are contained in the 415-event sample of channel (3).

[13]For reasons similar to those given in reference 1, possible Σ^0 contamination does not affect the conclusions drawn here.

[14]Identical behavior is exhibited by the events in the "960" peaks in channels (1) and (2). These data are not exhibited only because of space limitations.

[15]This estimate omits possible additional X^0 events which may decay electromagnetically, i.e., $X^0 \rightarrow \pi^+ + \pi^- + \gamma$.

[16]The Gaussian ideogram of the experimental resolution function has been obtained by multiplying the error of each individual event by $\sqrt{2}$ and summing over the events in this "960" peak region.

WEAK CURRENTS AND BROKEN UNITARY SYMMETRY

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It is the purpose of this note to compute the relative strength of the strangeness-changing and -nonchanging currents which enter into the weak interaction. In this report we consider only mesonic matrix elements of these currents.

We assume that the weak current for the interaction with leptons consists of vector and axial-vector terms which correspond to the following components of a unitary octet[1]:

$$V_\alpha = \cos\theta_V[\hat{V}_\alpha^{(1)} + i\hat{V}_\alpha^{(2)}] + \sin\theta_V[\hat{V}_\alpha^{(4)} + i\hat{V}_\alpha^{(5)}],$$

and

$$A_\alpha = \cos\theta_A[\hat{A}_\alpha^{(1)} + i\hat{A}_\alpha^{(2)}] + \sin\theta_A[\hat{A}_\alpha^{(4)} + i\hat{A}_\alpha^{(5)}]. \quad (1)$$

Here the caret denotes the appropriately normalized currents. The weak interactions corresponding to Eq. (1) have been considered in detail by Cabibbo,[2] who finds that the experimental data for leptonic decays are consistent with an angle θ of about 0.26 radian, which is approximately the same for vector and axial-vector currents. In the following we want to give a theoretical explanation for this remarkable regularity. Our argument is based upon the equal-time commutation relations of the current densities, which have been discussed by Gell-Mann.[3] More specifically, we need the commutators of $V_4^{(i)}(x)$ and $A_4^{(i)}(x)$ with the divergence $\partial_\beta A_\beta^{(j)}(x)$, as well