Table II. Results of calculation. All numbers are to be multiplied by $10^{-7} M_\pi$.

Amplitude	Experiment[a]	Prediction	Prediction assuming Eq. (1′) instead of (1)
$A(\Lambda_-^0)$	3.3	2.9	4.6
$A(\Xi_-^-)$	−4.4	−2.4	−4.4
$A(\Sigma_+^+)$	−0.1	0.4	0[b]

[a]See Ref. 11.
[b]Implicitly assumed.

[as in Eq. (1′)]. This would lead us to prefer the universal form of H_W given by Eq. (1).

To improve this calculation one might take careful account of mass differences among the baryons and contributions from higher intermediate states. Further developments will be given elsewhere.

We wish to thank Professor Y. Nambu for helpful encouragement and discussions and the members of the high-energy group at Chicago for stimulating conversations.

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OBSERVATION OF AN ENHANCEMENT IN THE $I=0$ $K_1^0K_1^0$ SYSTEM AT 1068 MeV*

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We report the observation of an enhancement in the $K_1^0K_1^0$ spectrum with strangeness zero, isospin zero, even parity, and even charge conjugation, which we refer to as the S^*. The mass of the S^* is 1068 ± 10 MeV with a width of 80 ± 15 MeV. Our analysis favors a zero spin for the S^*. The cross section for S^* production with both K_1^0 decays observed in the reaction

$$\pi^- + p \to n + S^*, \quad S^* \to K_1^0K_1^0$$

is approximately 1.5 μb at 6 GeV/c.

The differences between the S^* and the previously reported $K_1^0K_1^0$ threshold effect in lower energy experiments[1] will be discussed below.

The data were obtained from exposures of the Brookhaven National Laboratory 80-inch liquid-hydrogen bubble chamber to 6-GeV/c π^+ and π^- mesons. We have film equivalent to approximately 4 events per μb for π^+ and 18 events per μb for π^-. The final states rele-

Table I. Number of events in each final state.

Final state	Number of events
$\pi^+ + p \to K^+ + K_1^0 + p$	60
$\pi^- + p \to K^- + K_1^0 + p$	40[a]
$\to K_1^0 + K_1^0 + n$	178
$\to K_1^0 + K_1^0 + \text{others}$	206
$\to \pi^+ + \pi^- + n$	1383[b]

[a]From 16% of the film.
[b]From 5% of the film.

vant to this investigation are

$$\pi^+ + p \to K^+ + K_1^0 + p, \quad (1)$$

$$\pi^- + p \to K^- + K_1^0 + p, \quad (2)$$

$$\to K_1^0 + K_1^0 + n, \quad (3)$$

$$\to K_1^0 + K_1^0 + \text{neutrals}, \quad (4)$$

$$\to \pi^+ + \pi^- + n. \quad (5)$$

Reactions (1) and (2) are four-constraint fits and Reactions (3), (4), and (5) are identified by missing mass and χ^2 probability for the one-contraint fit. The number of events in each of the above final states is shown in Table I.

In subsequent analysis, the three-body final states from Reactions (1), (2), and (3) are used unless stated otherwise. Figure 1(a) is the Dalitz plot for the $K^{\pm}K_1^0p$ final states. There is no obvious Y^* formation in the $K^{\pm}p$ system. The mass projection of the $K^{\pm}K_1^0$ system in Fig. 1(b) shows a cluster of events at a mass of 1310 MeV which can be related to the $K^{\pm}K_1^0$ decay mode of the $A_2^{\pm}$.[2] Figure 1(c) is a Dalitz plot for the $K_1^0K_1^0n$ final state. Each event is plotted twice since there are two identical K_1^0 particles in the final state. Again there is no obvious Y^* production in the K_1^0n system. The striking feature of the mass projection, shown in Fig. 1(d), is that there are three distinct peaks in the $K_1^0K_1^0$ mass at 1068, 1310, and 1480 MeV. The peak at 1068 MeV is the S^*. The broad peak at 1310 MeV is probably due to contributions from the $K_1^0K_1^0$ decay modes of the two established resonances, the $I=0$ f^0 and the $I=1$ A_2.[2] We tentatively associate the peak at 1480 MeV with the other known $J^P=2^+$ nonstrange meson, the f^*.[3] It is to be noted that approximately three quarters of the $K_1^0K_1^0n$ events are in the first half of the phase space as shown in Fig. 1(d). This, in effect, reflects the strong production of the S^* and the $J^P=2^+$ resonances. The situation is different in the charged $K^{\pm}K_1^0$ states [see Fig. 1(b)] because only the $I=1$ state is allowed. This charged

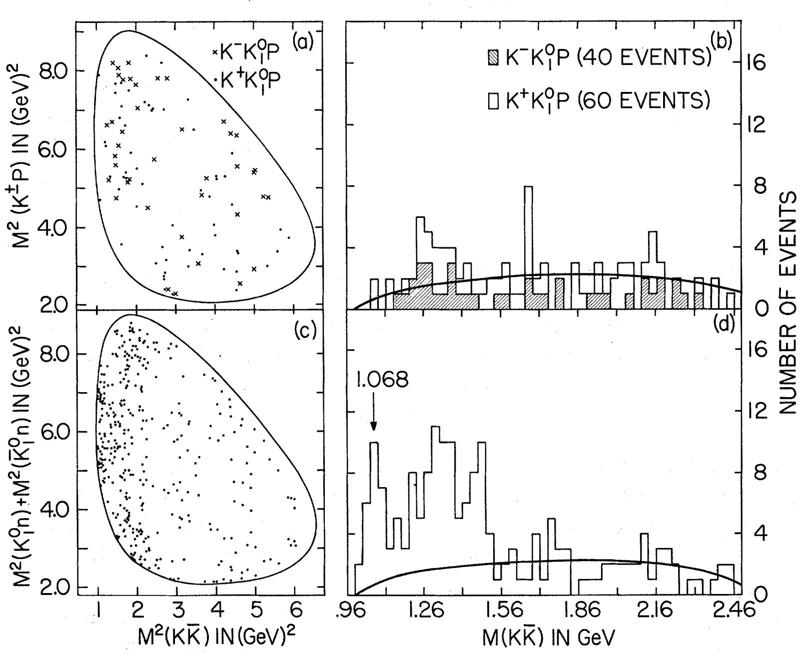

FIG. 1. (a) The $M^2(K^{\pm}p)$-vs-$M^2(K^{\pm}K_1^0)$ Dalitz plot of 100 $K^{\pm}K_1^0p$ events and (b) the mass projection $M(K^{\pm}K_1^0)$, with a phase-space curve (solid) normalized to the events above 1.56 GeV. (c) The $M^2(K_1^0n)$-vs-$M^2(K_1^0K_1^0)$ Dalitz plot of 178 $K_1^0K_1^0n$ events plotted twice (two K_1^0n masses per event) and (d) the mass projection $M(K_1^0K_1^0)$, with a phase-space curve (solid) normalized to the events above 1.56 GeV. The S^* enhancement at 1.068 GeV is indicated.

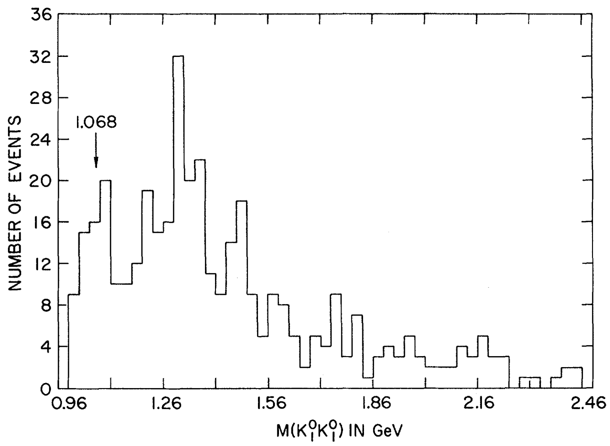

FIG. 2. The combined mass spectrum $M(K_1^0K_1^0)$ for 206 events from the reactions $\pi^- + p \rightarrow K_1^0 + K_1^0 +$neutrals and 178 events from the reaction $\pi^- + p \rightarrow K_1^0 + K_1^0 + n$. The S^* mass value of 1.068 GeV from Fig. 1(d) is indicated.

distribution agrees well with the phase-space curve with the exception of the $A_2^{\pm}$ formation. The solid line in Fig. 1(d) is the phase-space curve normalized to the events in the second half of the $K_1^0K_1^0$ mass spectrum. There are 26 $K_1^0K_1^0$ events below 1120 MeV, where 0 to 6 events are expected. The significance of this peak is approximately four standard deviations. The mass of the S^* as determined from a Gaussian ideogram (not shown) is 1068 ± 10 MeV with a full width at half-maximum of 80 ± 15 MeV.

The $K_1^0K_1^0$ mass spectrum from the Reactions (4) gives additional evidence for the S^* and is added to the spectrum from Reaction (3) in Fig. 2. The statistical evidence for the S^* is even stronger in this combined spectrum. It is evident that the $J^P = 2^+$ resonances as well as the S^* are also produced in multibody final state.

Next, we determine the isospin of the S^*. The absence of a peak at 1068 MeV in the charged $K^{\pm}K_1^0$ state [Fig. 1(b)] suggests strongly that the isospin of the S^* is zero. If the isospin of the S^* is one, charge independence gives the following relation:

$$\sigma_1^{1/2} + \sigma_2^{1/2} \geq (2\sigma_3)^{1/2},$$

where the cross sections are

$$\sigma_1 = \sigma(\pi^+ + p \rightarrow S^{*+} + p),$$

$$\sigma_2 = \sigma(\pi^- + p \rightarrow S^{*-} + p),$$

$$\sigma_3 = \sigma(\pi^- + p \rightarrow S^{*0} + n).$$

There are 26 $K_1^0K_1^0$ events and two $K^{\pm}K_1^0$ events in the S^* region below 1120 MeV. Correcting for the difference in path length and $K\bar{K}$ decay modes, we expect a minimum of 16 ± 4 $K^{\pm}K_1^0$ events in the corresponding region. The observation of only two events implies the $I = 0$ assignment for the S^*.

The $K_1^0K_1^0$ state exhibits a unique feature: even charge-conjugation (C) and parity (P) quantum numbers.[4] Any peak observed in this system, therefore, can be identified as a state with $J^P = 0^+$, 2^+, etc. Because of the low Q value (72 MeV) in the decay mode $S^* \rightarrow K_1^0 + K_1^0$, we examine only the possibilities of $J^P = 0^+$ and 2^+. The G parity of a neutral $K\bar{K}$ state is related to J and I by $G = (-1)^{J+I}$. The zero isospin of the S^* requires even G parity. One would expect then that the S^* can be produced by one-pion exchange (OPE). Figure 3(a) shows a section of the Chew-Low plot for Reaction (3). The Δ^2 distribution of the events in the S^* peak is extremely peripheral (most of the events are below 0.1 GeV^2), and the Treiman-Yang angle shown in Fig. 3(b) is consistent with isotropy. These results are in good agreement with the G-parity assignment. For $J^P = 0^+$ we expect complete isotropy in all possible angular distributions, whereas for $J^P = 2^+$ characteristic decay distributions are expected depending upon its alignment. Assuming an OPE model, the distribution of the scattering angle ($\cos\theta = \hat{K} \cdot \hat{B}$) for $J^P = 2^+$ is $A(\cos\theta) = (3\cos^2\theta - 1)^2$, where $\hat{K}$ is the direction of K_1^0 and $\hat{B}$ is that of incident π^- in the S^* rest frame. The data shown in Fig. 3(c), however, agree well with a flat distribution. This evidence coupled with the low Q value of the S^* decay into $K_1^0K_1^0$ favors zero spin for the S^*.

We fit the data to two interpretations, an s-wave resonance and a constant s-wave scattering length.[5] The better fit is the dashed resonance curve (80% probability) shown in Fig. 3(d), and the dotted curve is the scattering-length fit (20% probability) for $a_0 + ib_0 = \pm 1.4 + 0.2i$ F. The qualitative difference between the two fits is the narrowness of the resonance fit in contrast with the broad s-wave scattering fit. Such a sharp rise and fall can be obtained in the scattering-length interpretation by increasing the magnitude of a_0, say to 4 F, the solid line in Fig. 3(d). This sharper peak is closer to the threshold and is not consistent with our data. We note that our data differ from the previous-

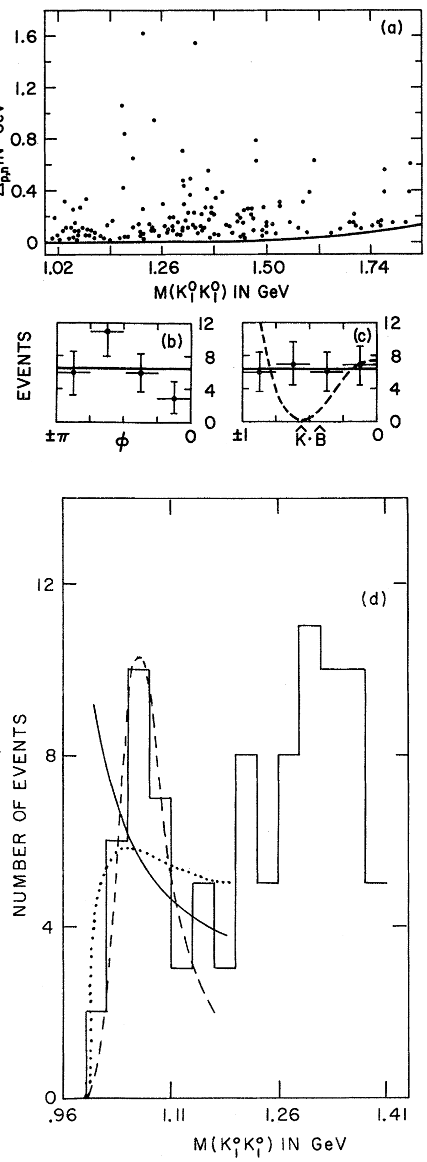

FIG. 3. (a) A section of the Chew-Low plot of $\Delta_{p,n}^2$ vs $M(K_1^0K_1^0)$ for the reaction $\pi^- + p \rightarrow K_1^0 + K_1^0 + n$. All of the 26 events in the S^* region (below 1.12 GeV) have $\Delta^2 \leqslant 0.34$ GeV^2; most of the S^* events have $\Delta^2 \leqslant 0.1$ GeV^2. (b) The Treiman-Yang angular distribution φ (folded about zero) of the 26 S^* events, which is consistent with the flat curve shown. (c) The scattering angle $\cos\theta = \hat{K}\cdot\hat{B}$ (folded about zero) of one K_1^0 relative to the incident pion in the S^* rest frame. The distribution is consistent with isotropy (solid curve), as expected for $J^P = 0^+$. The dashed curve shown is the $(3\cos^2\theta - 1)^2$ distribution expected for a $J^P = 2^+$ meson produced by a one-pion exchange mechanism. (d) A section of the $M(K_1^0K_1^0)$ spectrum from the reaction $\pi^- + p \rightarrow K_1^0 + K_1^0 + n$ is shown. An s-wave resonance curve (dashed) and constant s-wave scattering length fits [dotted ($\pm 1.4 + 0.2i$ F) and solid ($\pm 4 + 0.2i$ F)] are also shown (see text).

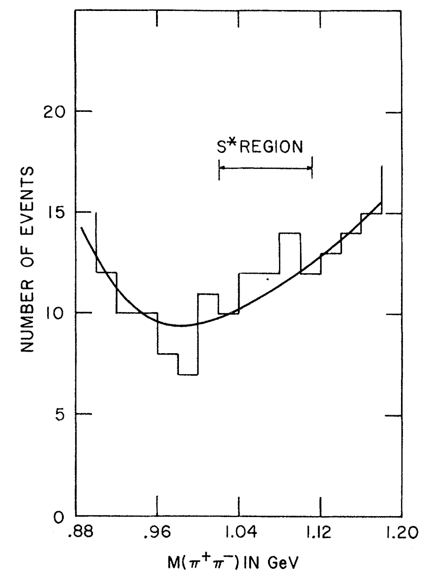

FIG. 4. A section of the $M(\pi^+\pi^-)$ spectrum (with $\Delta_{p,n}^2 \leqslant 0.34$ GeV^2) from 1383 events from the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$. A smooth curve is drawn through the data, and the S^* region is indicated. An upper limit to the two-pion decay mode of the S^* is given in the text.

ly reported $K_1^0K_1^0$ enhancement in the lower energy experiments[1] in this way, namely, that the earlier data do rise sharply at threshold (peaking at 1025 MeV) and can be fitted adequately by this larger scattering length. In addition, strong $Y^*(1520\text{ MeV}) \rightarrow K_1^0 + n$ formation was observed by Alexander et al.,[1] whereas we see no obvious Y^* formation.

To search for the $\pi\pi$ decay mode of the S^*, we have examined 1383 events from the reaction $\pi^- + p \rightarrow \pi^+ + \pi^- + n$. Figure 4 is a section of the di-pion mass spectrum, where a $\Delta^2 \leqslant 0.34$ GeV^2 cut has been made in order to reduce the background. A smooth curve is drawn through the data and the S^* region is indicated. We estimate the upper limit for the decay branching ratio corrected for neutral decay modes and path length to be

$$\frac{S^* \rightarrow \pi + \pi}{S^* \rightarrow K + \bar{K}} \leqslant 2.5$$

(with 90% confidence).

In summary we have observed a nonstrange $I = 0$, $C = P = G = +1$ enhancement for which $J = 0$ is favored. In the framework of SU(3) the S^* can be identified as an isosinglet of a scalar multiplet.

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