ever, the predictions of this scheme are different, in general, from those of the dynamical model discussed here.

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RECENT RESULTS ON STRANGENESS-ONE RESONANCES*

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In the last two years a number of strangeness-one resonances have been reported in the literature. There have been resonances involving one K meson and two π mesons reported at energies of 1170,[1,2] 1215,[3,4] 1275,[5] 1320,[6-8] and 1400 MeV.[9-12] Except for the case of the $K^*(1400)$, relatively little firm information exists so far as spin and parity quantum numbers are concerned. If one could make definite quantum number assignments to these rather numerous resonances, then it might be possible to establish the existence of families of such resonances and perhaps understand what sort of symmetry scheme is valid for these relatively energetic systems.

In the process of studying K^+-proton interactions at an energy of 3.54 BeV/c in the 80-inch Brookhaven National Laboratory bubble chamber, we have found evidence for several of these resonant states. We have measured all events consisting of two and four prongs with associated V^0's in a series of 50 000 pictures. These topologies are particularly useful ones in that they present less ambiguous cases than the other topological classes. The reactions that we have studied are listed below.

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

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

$$\to K^0 + n + \pi^+ + \pi^+, \tag{3}$$

$$\to K^0 + p + \pi^+ + \pi^+ + \pi^-, \tag{4}$$

$$\to K^0 + p + \pi^+ + \pi^+ + \pi^- + \pi^0. \tag{5}$$

$K\pi\pi$-1170.—A $K\pi\pi$ interaction at 1170 MeV was first reported by Wangler, Erwin, and Walker[1] in the reaction $\pi^- + p \to K + Y + 2\pi$. This particular peak was later verified by Miller et al.[2] at Purdue. Higher energy πp interactions did not seem to show the presence of such an enhancement in the $K\pi\pi$ mass spectra. We have observed a peak in the $K^0\pi^+\pi^+$ mass spectrum from Reaction (4) which agrees in mass and width with the $K^*(1170)$ previously reported. The interaction is predominantly associated with $K^0\pi^+\pi^+$ combinations in which one $K^0\pi^+$ pair forms a $K^*(892)$. The data are shown in Fig. 1(a). This establishes the isotopic spin of our peak as $\frac{3}{2}$, but its existence as a resonant particle is more in doubt.

An analysis of a Dalitz plot of the $K^0\pi^+\pi^+$ combinations in the 1170-MeV region suggests that this enhancement may be caused by the final-state interaction shown in the inset in Fig. 1(a). The triangle diagram causes a $K\pi\pi$ enhancement for the range of 1030 to ~1180 MeV and also forces the $\pi^+\pi^+$ system into a mass range less than $\sim 2.5 m_\pi$.[13] We find a 3.8-standard-deviation excess of $\pi^+\pi^+$ pairs in this mass range for $K^0\pi^+\pi^+$ combinations in the 1170-MeV peak. This enhancement occurs at the low-mass end of the $K^*(892)$ band in a Dalitz plot of $M^2(K^0\pi^+)$ versus $M^2(\pi^+\pi^+)$. No such effect is observed for $K^0\pi^+\pi^+$ combinations in a control mass region above 1170 MeV.

$K^*(1400)$.—The $K^*(1400)$, which was initially reported by Haque et al.[9] and later seen in a number of experiments,[10-12] has been assigned to a 2^+ nonet by Glashow and Socolow.[14] We see the effect of the $K^*(1400)$ resonance in several channels; in particular, the mass spectrum of the $K^0\pi^+$ system from Reaction (1) shown in Fig. 1(b).[15] We also see an indication of the 1400-MeV resonance in Reaction (2) in which there is a peak above phase space in the region of 1400 MeV for the $K^0\pi^0\pi^+$ mass spectrum as shown in Fig. 1(c). Although we have also looked for the presence of the decay of the $K^*(1400)$ into $K^0 + \omega^0$ and $K^0 + \eta^0$, we have found no definite evidence for such decay modes, but can only set an upper limit for the branching ratio into these channels. We have also sought evidence for the $K^*(1400)$ in Reaction (3). A plot of the mass distribution for the $K^0\pi^+\pi^+$ in Fig. 1(d) yields no indication of the $K^*(1400)$ in this channel which has an I_Z of $\frac{3}{2}$. This is strong evidence that the isospin of this system is $\frac{1}{2}$ and not $\frac{3}{2}$ in agreement with other workers.

In Table I we give deductions from our data concerning the branching ratios of the $K^*(1400)$ into different final states. The errors quoted are the results from checks on internal consistency of the data and statistics.

The $K^* \to K+\pi$ angular distributions are shown in Figs. 2(a) and 2(b) for the $K^*(1400)$ mass region resulting from Reactions (1), (2), and (3). The distribution from Fig. 2(b) shows the presence of a 2^+ amplitude dominantly produced peripherally in the exchange of a pseudoscalar particle. It is difficult from Fig. 3(b) to estimate the background in the 1400-MeV region; however, the histogram is consistent with a 1:2 signal-to-background ratio. The data in Fig. 2(a) show the strong perturbing influence of amplitude from the reaction $K^+ + p \to K^0 + N^*$ when compared with the results of Haque et al.[9] (our distribution is strongly asymmetric while theirs is symmetric). It is difficult to estimate the reliability of our branching ratios because of the presence of interfering amplitudes. An examination of the Dalitz plot for Reaction (1) does not indicate undue (quadratic) enhancement in the crossing of the $N^*(1238)$ and $K^*(1400)$ bands.

$K^*(1300)$.—Last summer Almeida et al.[6] reported the indication of a resonance in the $K\pi\pi$ system at an energy of about 1300 MeV. Rosenfeld,[13] in his review of resonances at the Oxford Conference, reported that further accumulation of data did not substantiate these results. We report here strong evidence for the existence of the $K^*(1300)$. We find indications of this resonance in both the $K\pi\pi$ and the $K\pi$ mass spectrum in Figs. 3(a) and 3(b). Shen et al.[7] reported similar evidence in a $K\pi\pi$ channel. They concluded that the spin-parity assignment of this system was 1^+. Since we find evidence for decay into $K\pi$ and $K^*\pi$, we conclude that the spin-parity assignment cannot be 1^+. By looking in Fig. 4 at the decay in the $K\pi$ rest system into the four-body states described above, we see angular distributions which are indicative of a strong d wave possibly attributable to the wing of the $K^*(1400)$ resonance mixed with p wave. We would conclude that a possi-

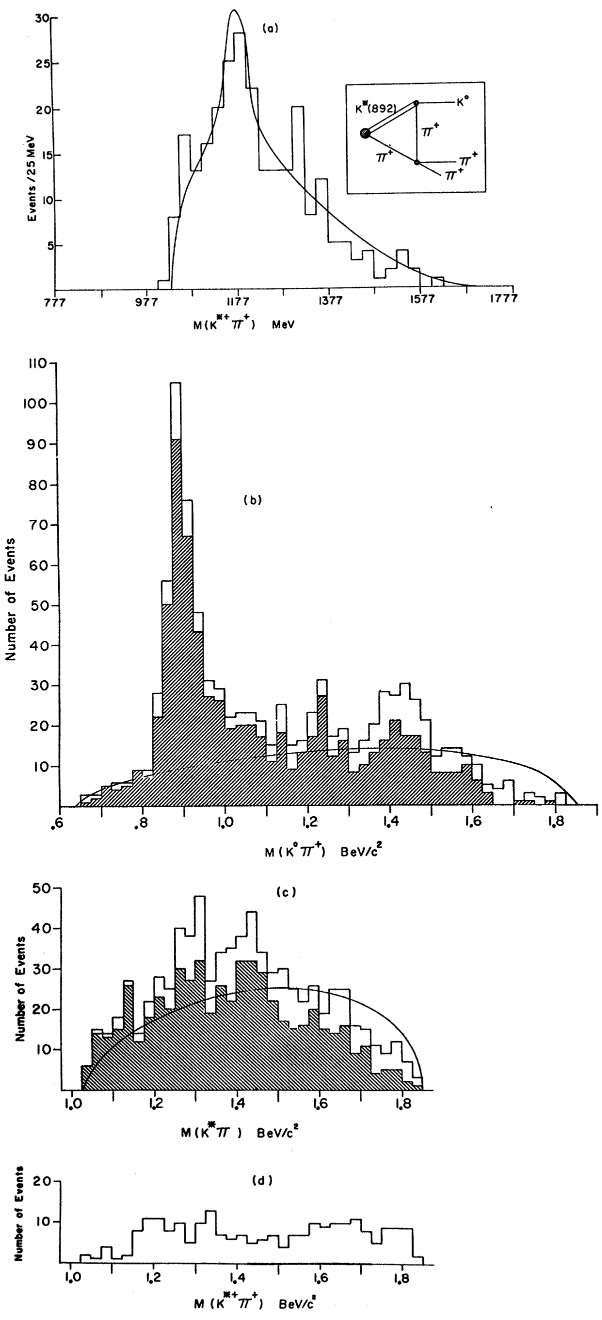

FIG. 1. (a) Histogram of $K^{*+}\pi^+$ invariant mass in Reaction (4) (456 events). The curve is phase space plus resonance at $m_0 = 1180$ MeV, $\Gamma_0 = 50$ MeV. (b) Histogram of $K^0\pi^+$ invariant mass in Reaction (1) (932 events). Hatched histogram (719 events) represents events with $\cos(\hat{p}_{\text{nucleon in}} \cdot \hat{p}_{\text{nucleon out}})_{\text{c.m.}} > 0.6$. The curve is phase space for $K^0\pi^+$ production, normalized to the upper histogram away from the peaks. (c) Histogram of $K^{*+,0}\pi^{0+}$ invariant mass in Reaction (2) (780 events). Hatched histogram (568 events) represents events with $\cos(\hat{p}_{\text{nucleon in}} \cdot \hat{p}_{\text{nucleon out}})_{\text{c.m.}} > 0.6$. The curve is phase space for $K^*(890)+\pi$ production, normalized to the upper histogram between 1.5 and 1.675 BeV/c^2. (d) Histogram of $K^{*+}\pi^+$ invariant mass in Reaction (3) (234 events).

Table I. Properties of the $K^*(1305)$ and $K^*(1425)$. The decay ratios assume that both resonances have isotopic spin $\frac{1}{2}$.

Resonance mass (MeV)	Resonance full width (MeV)	Decay modes (%) $K\pi$	$K^*\pi$	K	$K\eta$	$K\omega$
1305 ± 10	40 ± 15	68 ± 12	24 ± 9	6 ± 6	0 ± 3.0	2.0 ± 2.0
1425 ± 10	96 ± 10	33 ± 7	56 ± 10	10 ± 5	1.7 ± 2.0	0.7 ± 0.8

ble assignment of spin and parity is 1^-. However, one cannot rule out the possibility of a 2^+ or 3^- assignment for the $K^*(1300)$.

All our results are consistent with an isospin of $\frac{1}{2}$ for the $K^*(1300)$. We do not see a bump for it in the $(K^0\pi^+\pi^+)$ for Reactions (3) and (4), whereas we do see a bump at 1300 MeV for Reaction (4) in the $I_z = -\frac{1}{2}$ state.

The $K^*(1300)$ is not produced particularly peripherally at this energy. Indeed, there is no evidence of it in the three-body reaction. This would perhaps indicate a lack of coupling to the ρ or other vector particles. Estimates of the branching ratios for the different final states are given in Table I.

The results presented here are difficult to understand simply in terms of an $L = 1$ excitation of a quark-antiquark system as proposed by Dalitz at the Oxford Conference, if the $K^*(1300)$ has the same quantum numbers as either the $K^*(890)$ or the $K^*(1400)$. Perhaps it is possible that there can be s-wave quark excitations which would produce another set of 1^- or 0^- nonets.

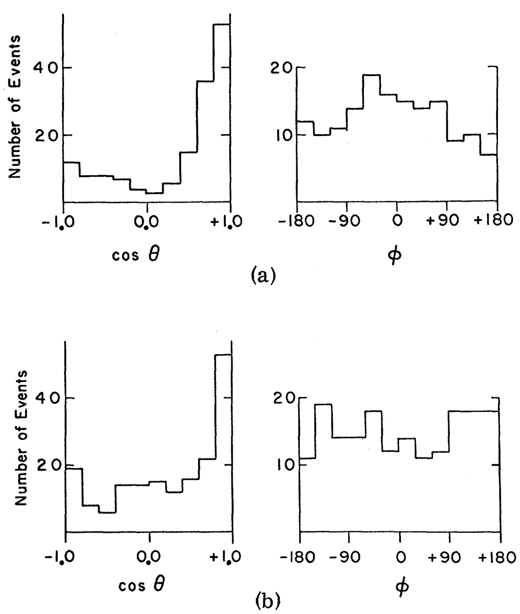

FIG. 2. (a) Histograms of $\cos(\hat{K}^+\cdot\hat{K}')$ and Treiman-Yang angle for $K^*(1400) \to K^0 + \pi^+$ in Reaction (1). $1.35 < M(K^0\pi^+) < 1.50$ BeV/c^2 (152 events). (b) Histograms of $\cos(\hat{K}^+\cdot\hat{K}')$ and Treiman-Yang angle for $K^*(1400) \to K^0 + \pi^{+,0}$ in Reactions (2) and (3). $1.35 < M(K^0\pi^{+,0}) < 1.50$ BeV/c^2 (179 events).

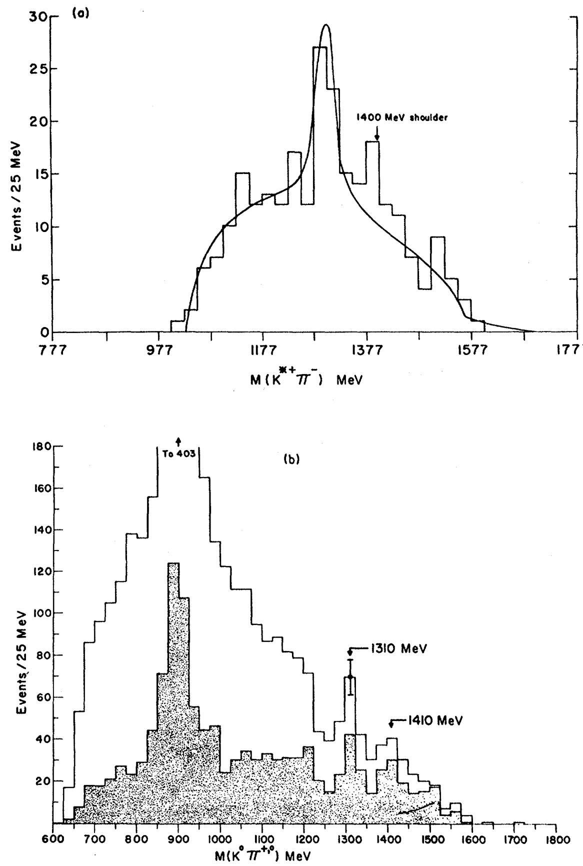

FIG. 3. (a) Histogram of $K^{*+}\pi^-$ invariant mass in Reaction (4) (256 events). The curve is phase space plus resonance at $m_0 = 1300$, $\Gamma_0 = 40$ MeV; the fit excludes the 1400-MeV region. (b) Histogram of $K^0\pi^{+,0}$ invariant mass in Reactions (2) and (3), all combinations (1823 events). Shaded area represents those combinations in which the other pion and the nucleon form $N^*_{3,3}(1235)$.

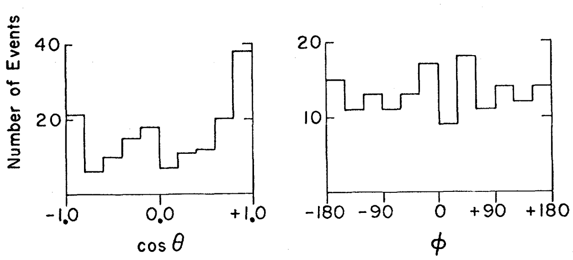

FIG. 4. Histograms of $\cos(\hat{K}^+\cdot\hat{K}')$ and Treiman-Yang angle for $K^*(1300)\to K^0\pi^{+,0}$ in Reactions (2) and (3). $1.275 < M(K^0\pi^{+,0}) < 1.35$ BeV/c^2 (158 events).

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