ANALYSIS OF THE $K(1300)$ SYSTEM PRODUCED IN 5.5-GeV/c K^+p INTERACTIONS*

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Several groups have investigated the reaction $Kp \to K\pi\pi p$ at high K momentum and all have found that there is a low-mass enhancement in the $K^*(890)\pi$ system.[1-14] It has been interpreted variously as a resonance,[1] a series of resonances,[2] and a "kinematic" enhancement.[11] We find that the diffraction-dissociation mechanism[15] (without form factors) gives reasonable results for the K^* decay distribution but fails to fit the $K^*\pi$ mass distribution. We have also studied the spin and parity properties of the 1300-MeV $K^*\pi$ enhancement and find it to be predominantly 1^+.

The data are from a study of four-prong events in an exposure of K^+ at momentum 5.438 ± 0.025 BeV/c incident upon hydrogen in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber. We are concerned with the final states

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

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

The events in the subsequent analyses consist of 6500 unambiguous fits to Reaction (1) and 900 unambiguous fits to Reaction (2). The cross sections are 1.79 ± 0.10 mb and 1.45 ± 0.15 mb, respectively. The number of ambiguous fits in both reactions is approximately 5%.

In the ensuing analysis we have restricted the events to have a $K^{*0}(890)$ [840 MeV $\leq M(K^{+,0}\pi^{-,0}) \leq$ 940 MeV] and to have π^+p mass greater than 1500 MeV. We have, also, restricted the magnitude of the momentum transfer to the proton to be less than 0.5 $(\text{BeV}/c)^2$.

The diffraction-dissociation model.—We have applied the Ross-Yam diffraction-dissociation model[15] to the reaction

$$K^+p \to K^{*0}(890)\pi^+p \to K^+\pi^-\pi^+p \tag{3}$$

using a coherent sum of three amplitudes corresponding to the three diagrams shown in Fig. 1(a). In our Monte Carlo analysis of the model, we have used at the upper (dissociation) vertex in each diagram the coupling factor $g_{K^*K\pi} = (5\pi)^{1/2}$ with no form-factor corrections. At the lower (diffraction-scattering) vertex in each diagram, the vertex function is assumed to be of the form $\sigma_i \exp(\frac{1}{2}a_it)$, where σ_i and a_i are the total interaction cross section and the slope of the forward diffraction peak appropriate to each diagram. The values of σ_i and a_i used in our computations are shown in Fig. 1(a).

In Fig. 1(b) we show the $K^*\pi$ mass spectrum of Monte Carlo events generated according to the diffraction-dissociation model at beam momenta of 5.44, 7.3, 9.0, and 12.6 GeV/c. The curves are absolutely normalized, and the same values of the parameters σ_i and a_i were used in all cases. The predicted cross section for production of $K^*\pi$ masses below 1500 MeV seems to approach a constant value of about 0.3 mb. However, our calculations indicate that, at least up to a beam momentum of 200 GeV/c, the total $K^*\pi p$ diffraction-dissociation cross section increases linearly with the beam momentum with a slope of $\Delta\sigma/\Delta p = 0.11$ mb/(GeV/c); in particular σ(5.44 GeV/c) = 0.34 mb, and σ(200 GeV/c) = 21 ± 2 mb. This unreasonable increase in cross section is

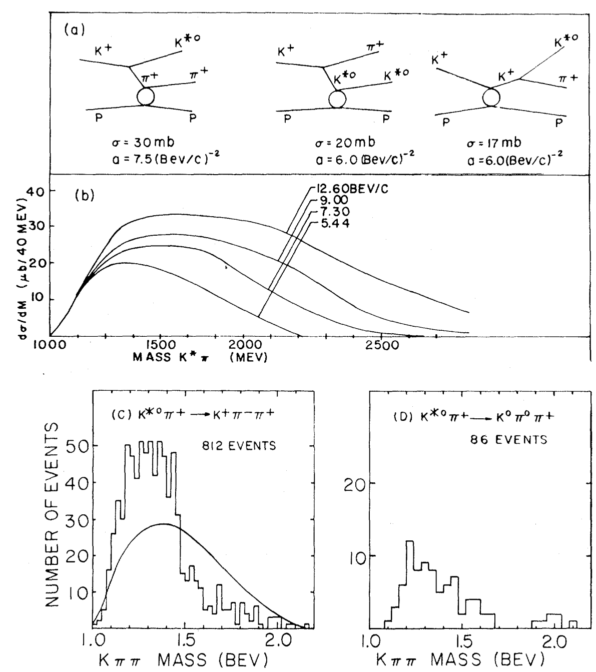

FIG. 1. (a) Three diagrams used in the diffraction-dissociation calculation. (b) Expected $K^*\pi$ mass distribution for various incident K^+ momenta. (c) $K^+\pi^-\pi^+$ mass distribution with cuts as given in text. (d) $K^0\pi^0\pi^+$ mass distribution with cuts as given in text.

Table I. The $K^{*0}(890)$ density-matrix elements for $K^+\pi^-\pi^+p$ events with $0.84<M(K^+\pi^-)<0.94$, $M(p\pi^+)>1.5$, $|t|<0.5$.

Coef.	$M(K\pi\pi)<1200$	$1200<M(K\pi\pi)<1400$	$M(K\pi\pi)>1400$	All $M(K\pi\pi)$
		(A) Real events		
ρ_{00}	0.86 ± 0.10	0.79 ± 0.06	0.65 ± 0.08	0.76 ± 0.04
$\mathrm{Re}\rho_{1-1}$	0.05 ± 0.06	-0.06 ± 0.04	-0.05 ± 0.05	-0.04 ± 0.03
$\mathrm{Im}\rho_{1-1}$	0.00 ± 0.05	-0.04 ± 0.04	-0.01 ± 0.01	-0.02 ± 0.03
$\frac{1}{2}\mathrm{Re}(\rho_{10}-\rho_{-10})$	-0.03 ± 0.08	-0.04 ± 0.05	-0.12 ± 0.07	-0.06 ± 0.04
$\frac{1}{2}\mathrm{Im}(\rho_{10}+\rho_{-10})$	-0.14 ± 0.08	-0.04 ± 0.05	0.11 ± 0.06	-0.01 ± 0.04
		(B) Diffraction-dissociation events		
ρ_{00}	0.99	0.98	0.89	0.93
$\mathrm{Re}\rho_{1-1}$	0.00	−0.01	−0.05	−0.04
$\mathrm{Im}\rho_{1-1}$	0	0	0	0
$\frac{1}{2}\mathrm{Re}(\rho_{10}-\rho_{-10})$	−0.07	−0.13	−0.24	−0.18
$\frac{1}{2}\mathrm{Im}(\rho_{10}+\rho_{-10})$	0	0	0	0

evidently associated with high $K^*\pi$ masses, and probably points to the need for a form factor at the dissociation vertex.[16]

To compare the predictions of the model with our data at 5.44 GeV/c, we first examine the $K^+\pi^-\pi^+$ mass spectrum with the following cuts applied to both the real events and the Monte Carlo events: $0.84<M(K^+\pi^-)<0.94$, $M(p\pi^+)>1.5$, $|t|<0.5$. The resulting curves (absolutely normalized) are shown in Fig. 1(c), and it is clear that the diffraction-dissociation mechanism, as currently formulated, does not produce the necessary enhancement in the $K^{*0}\pi^+$ mass region from 1150 to 1400 MeV. The failure of the model to account fully for this enhancement has been observed at other beam momenta, and also with K^- as the beam particle.[4,8-12]

We have also examined the diffraction-dissociation model predictions concerning the K^* density matrix. The density-matrix elements for the model and the data were found in that K^{*0} rest frame which has $\hat{Z}\propto\vec{P}_b$ and $\hat{Y}\propto\vec{P}_{\pi^+}\times\vec{P}_b$, where $\vec{P}_b$ and $\vec{P}_{\pi^+}$ are the momenta of the beam particle and the π^+ particle, respectively, as seen in the K^{*0} rest frame. With this orientation of the K^{*0} rest frame, the model predicts that ρ_{1-1}, ρ_{10}, and ρ_{-10} are real, and $\rho_{10}=-\rho_{-10}$. Thus, we expect for the K^{*0} decay distribution

$$P(\cos\theta,\varphi)=(3/4\pi)[\tfrac{1}{2}(1-\rho_{00})+\tfrac{1}{2}(3\rho_{00}-1)\cos^2\theta-\rho_{1-1}\sin^2\theta\cos2\varphi-\sqrt{2}\rho_{10}\sin2\theta\cos\varphi]. \quad (4)$$

By using a weighted angular averaging technique, we have calculated the average density-matrix coefficients in Eq. (4) for both the real events and the Monte Carlo diffraction-dissociation events. The calculations are performed for different regions of the $K^{*0}\pi^+$ effective mass, and the results are displayed in Table I. Generally speaking, there is fair agreement. The value of ρ_{00} for the diffraction-dissociation events is somewhat larger than for the real events. The $\cos\theta$ distribution of the data is compared with the fit to the model in Fig. 2(a). The agreement is remarkable considering that there is undoubtedly $K\pi\pi$ without $K^*(890)$ in the data. The facts

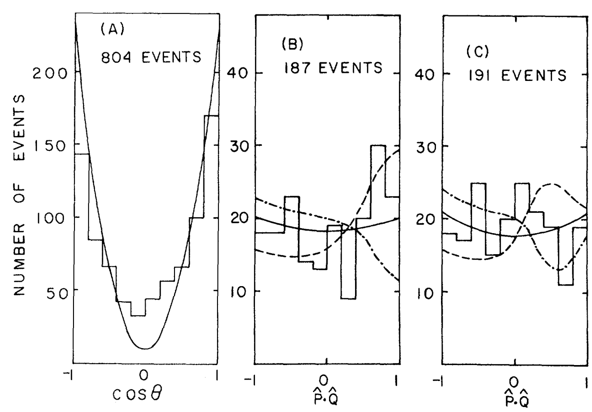

FIG. 2. (a) The distribution in the cosine of the angle between the beam and the outgoing K^+ as viewed in the $K^+\pi^-$ c.m. system for Reaction (1). The cuts are given in the text. (b) The distribution in $\hat{p}\cdot\hat{q}$ (see text) with cuts as given in text. In addition the $K^+\pi^-\pi^+$ mass is restricted to the interval 1200 to 1300 MeV. The curves are (i) pure $K^*\pi$ (solid line); (ii) SU(3) F-type mixture of $K^*\pi$ and $K\rho$ (dashed line); (iii) SU(3) D-type mixture of $K^*\pi$ and $K\rho$ (dot-dashed line). (c) Same as (b) with $K^+\pi^-\pi^+$ mass in the interval 1300 to 1400 MeV.

that, for both sets of events, $\mathrm{Re}\rho_{1-1}$ is small and $\mathrm{Im}\rho_{1-1}$ is zero imply that the φ distribution will be nearly isotropic. The density matrix would be affected in the region of a resonance. However, the agreement between the model and data inside the 1300 mass region seems, on the whole, to be no better nor no worse than outside the 1300 region.

We are led to consider the possibility that the low-mass $K\pi\pi$ region is dominated by resonance effects with a definite spin and parity. We have ignored possible interference with background and have assumed that the $K\pi\pi$ system decays via $K^*\pi$ and $K\rho$. An analysis of the Dalitz plot[17] and angular distributions of the $K^+\pi^-\pi^+$ region (1200 MeV, 1400 MeV) with $|t| < 0.2$ $(\mathrm{BeV}/c)^2$ has yielded the following results:

(i) The data are inconsistent with a 0^- $K^*\pi$ plus $K\rho$ system as the predicted depletion of events in the central region of the Dalitz plot is not realized in the data.

(ii) The data are inconsistent with both 1^- and 2^+ since the data do not have a predicted depletion of events at low $\pi^+\pi^-$ mass squared.

(iii) 1^+ s wave and 2^- p wave both fit rather well.

(iv) The alignment of the $K^*(890)$ [see Fig. 2(a)] can be achieved by a 2^- p-wave state with $\rho_{00}=1$ in the form $1+3\cos^2\theta$ assuming pure $K^*\pi$. However, this also predicts the cosine of the angle of the $K^*(890)$ relative to the beam in the $K^*\pi$ c.m. system to be distributed as $1+3\cos^2\theta$ which is not seen in the data.

(v) In Figs. 2(b) and 2(c) are presented the $\hat{p}\cdot\hat{q}$ distribution[3] for events with $K^+\pi^-\pi^+$ mass in the intervals 1200 to 1300 and 1300 to 1400 MeV, respectively. $\hat{p}\cdot\hat{q}$ is the cosine of the angle between the π^- and π^+ in the $K^{*0}(890)$ c.m. system. This is a Dalitz-plot variable and, hence, for a resonant state is independent of the production mechanism and beam momentum. The curves plotted for each of the two $K^+\pi^-\pi^+$ mass regions are the predictions for a $J^P=1^+$ $K\pi\pi$ system decaying via s wave to pure $K^*\pi$; 1^+ s wave to an SU(3) F-type mixture of $K^*\pi$ and $K\rho$; and 1^+ s wave to an SU(3) D-type mixture of $K^*\pi$ and $K\rho$.[17] We have not plotted the 2^- p-wave predictions but remark that all the possibilities (pure $K^*\pi$ and F-type and D-type mixtures) fit the $\hat{p}\cdot\hat{q}$ distributions rather well. Looking in more detail at the 1^+ case, we find that the lower mass region is consistent both with pure $K^*\pi$ and with SU(3) F-type coupling but is inconsistent with an SU(3) D-type coupling. The upper mass region is consistent both with pure $K^*\pi$ and with SU(3) D-type coupling ($\chi^2=10$ for nine degrees of freedom) but has a somewhat poorer fit to SU(3) F-type coupling ($\chi^2=19$ for nine degrees of freedom). The quark model predicts the existence of two 1^+, positive-strangeness, boson resonances which could have F- and D-type couplings to $K^*\pi$ and $K\rho$.[18] Under the assumption that one of our two mass regions is F type and the other D type, we strongly favor the 1200- to 1300-MeV region being F type and the 1300- to 1400-MeV region being D type.

Under the assumption of two 1^+ s-wave resonances, the SU(3) prediction for the ratio $K\rho/(K\rho+K^*\pi)$ in our $K^+\pi^-\pi^+$ final state is 23 % (this includes both mass regions). The SU(3)-predicted fraction of $K\rho$ in the $K^*(890)$ band is 9 %. The SU(3)-predicted fraction of events in the $K^*(890)$ band due to the $K\rho$-$K^*\pi$ interference term is +18 % for F and −18 % for D coupling. We stress, however, that our data are not inconsistent with a pure $K^*\pi$ final state both in the 1^+ s-wave and in the 2^- p-wave cases.

(vi) The Berman-Jacob[19] angular-averages analysis for two-step decay processes was applied to the data for $K^*\pi p$ events of (1) and yielded

$$-\eta(-1)\frac{j(j+1)}{3-j(j+1)}=2.2\pm0.4,$$

where 0, +2, −2, $-\frac{4}{3}$ are expected for 0^-, 1^+, 2^-, 3^+, respectively, and −2, +2, $+\frac{4}{3}$ for 1^-, 2^+, 3^-, respectively. Hence, we are consistent with 1^+ and 2^+ and inconsistent with 0^-, 1^-, 2^-. In this analysis we have made the assumption that background events and decay modes of the $K(1300)$ other than $K^*\pi$ can be neglected. Thus the conclusions are valid only insofar as this is true.

A comparison of the two mass intervals brings out no statistically meaningful differences at this point. Uretsky[20] has shown that the ${}^3P_1$ and ${}^1P_1$ 1^+ states in the quark model would give, respectively, $\sin^2\theta$ and $\cos^2\theta$ dependences in $\hat{p}\cdot\hat{q}$ distribution if the states were not mixed. If our data are interpreted as two 1^+ resonances at roughly 1250 and 1350 MeV, then our flat $\hat{p}\cdot\hat{q}$ distribution indicates that these states are mixtures of Uretsky's quark-model states. Finally, we remark that comparison of $\hat{p}\cdot\hat{q}$ distributions for different beam momenta will give important indications about the interference of the resonances and the background.

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[17]We have used the program COMPLOT written by David Griffiths. The method is a generalization of that of W. R. Frazer, J. R. Fulco, and F. R. Halpern, Phys. Rev. 136, 1207 (1964). The $K^*\pi$ and $K\rho$ decays of the $K\pi\pi$ system were considered. For the K^* and ρ, widths of 50 and 150 MeV were assumed. The SU(3) predictions were given to us by David Griffiths. The F and D convention is that of M. Gell-Mann, Phys. Rev. 125, 1067 (1962).

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