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[20]To distinguish the two protons in the final state, the following notation is used: p_1 is the proton which combined with the π^+ gives an effective mass closer to the Δ^{++} than the other proton designated as p_2. As the two invariant masses $p_1\pi^+$ and $p_2\pi^+$ are generally very different, usually only one combination per event, i.e., $p_1\pi^+\pi^-$, will contribute to the $p\pi^+\pi^-$ spectrum below 2.0 GeV as seen in Fig. 1. Thus $p_1\pi^+\pi^-$ is almost always the lower mass $p\pi^+\pi^-$ combination.

INTERFERENCE ANALYSIS OF THE $K^*(1400)$†

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A study of the $K^+\pi^-$ decay mode of the $K^*(1400)$ produced with an N^{*++} has been made using the reaction $K^+p \to K^+\pi^-\pi^+p$ at 5.5 BeV/c. We have fitted the $K^*(1400)$ angular distributions using a model involving interference between 1^- and 2^+ $K^+\pi^-$ states. In this model a considerable amount of 1^- is needed in the $K^*(1400)$ mass region, suggesting that there is a $J^P = 1^-$ resonance under the $K^*(1400)$. Such a $J^P = 1^-$ resonance could be the first daughter of the $K^*(1400)$.

The analysis of high-energy interactions composed of two final particles of which one or both are resonances is complicated by the presence of nonresonant background. The situation can be remedied to a certain extent by assuming that the background, as estimated from mass regions bordering the resonance, may be directly subtracted from the resonance data.[1] This procedure fails in cases where the nonresonant background and the resonance interfere. An example of such an interference is the observation of a backward-forward asymmetry in the decay of the $K^*(890)$ in the process $K^+p \to K^{*0}\Delta^{++}$.[2] This asymmetry is an important aspect of work on a $K\pi$ phase-shift analysis.[3] However, the nonzero value of $\mathrm{Re}\rho_{10}$ [observed in $K^*(890)$ decay] makes apparent the need for more than single π exchange in $K^{*0}\Delta^{++}$ production.[4] $\mathrm{Re}\rho_{10}$ not equal to zero can be achieved by more complicated exchanges or by using an absorptive pion-exchange model.[5,6] We have also found that in our $K^*(1400)\Delta^{++}$ sample, the $K^*(1400)$ decay exhibits characteristics which indicate more than one spin and parity is in the $K\pi$ system and other than π-type exchanges are present. Consequently, we have made an analysis of the $K^*(1400)$ region taking into account both the above effects. This analysis leads in a plausible way to evidence for a $J^P = 1^-$-type structure in the $K^*(1400)$ mass region as well as the presumed $J^P = 2^+$ $K^*(1400)$.

The data are taken from a 3.3-event/μb K^+p exposure at 5.5 BeV/c taken in the Brookhaven National Laboratory 80-in. bubble chamber.

We have examined the properties of the $K^+\pi^-$ system in the reaction

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

where the presence of an N^{*++} in an event is defined by the $p\pi^+$ mass being in the interval 1150 to 1340 MeV. In Fig. 1 the $K^+\pi^-$ mass distribution is presented for all events of Reaction (1), and also for the subsample of these events which have $-t$, the square of the four-momentum transfer from the initial proton to the final N^{*++}, in the interval 0.2 to 0.5 $(\mathrm{BeV}/c)^2$. The $K^*(890)$ and $K^*(1400)$ peaks are clearly seen in both histograms. Furthermore, this momentum-transfer cut greatly enhances the apparent signal-to-background ratio in the $K^*(1400)$ region. It is evident from these mass distributions and from momentum-transfer distributions (not shown) that the $K^*(1400)$ is produced at higher momentum transfer than the $K^*(890)$.[8] To utilize the relatively clean $K^*(1400)$ signal found above, we shall limit our analysis to events of the type

$$K^+p \to K^+\pi^- N^{*++}, \quad 0.2 < \Delta^2 < 0.5\ (\mathrm{BeV}/c)^2,$$

and we shall refer to this class of events as Reaction (2) throughout the remainder of this paper.

An examination of the decay properties of the N^{*++} indicates that vector exchange is not enhanced in the $K^*(1400)$ mass region and is relatively small from 1270 to 1570 MeV. However, that some nonzero spin exchange is necessary is found from examination of the $K^+\pi^-$ system. It seems natural to assume that pion (zero-spin) ex-

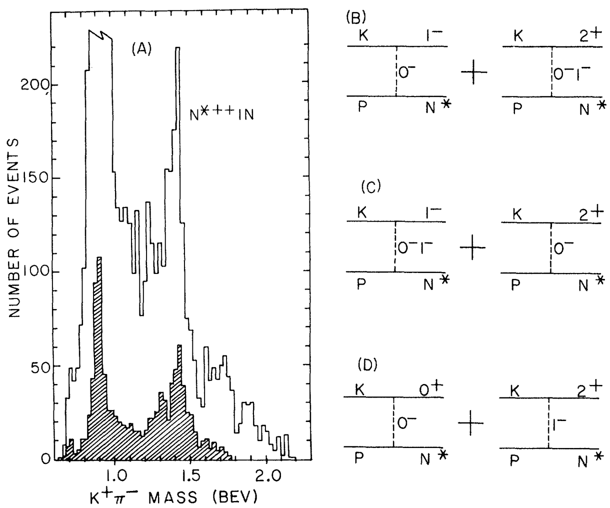

FIG. 1. (a) The $K^+\pi^-$ invariant-mass spectra for events with the π^+p mass in the interval 1150 to 1340 MeV. The shaded area is the subsample in which the momentum transfer from the target proton to the N^{*++} is between 0.2 and 0.5 $(\mathrm{BeV}/c)^2$. (b) Diagrams representing the produced $K^+\pi^-$ spin states and the allowed exchanges for model I. (c) Diagrams representing the produced $K^+\pi^-$ spin states and the allowed exchanges for model II. (d) Diagrams representing 0^+, 2^+ interference (model III).

change dominates but that there is a background of vector exchange.

The angular distributions we have used to study the $K^+\pi^-$ properties are $\cos\theta_\pi$ and φ_π distributions. θ_π and φ_π are the polar and azimuthal angles of the π^- as observed in that $K^+\pi^-$ center-of-mass system which has the beam direction as the Z axis and the normal to the production plane as the Y axis. These distributions for our three $K^+\pi^-$ mass intervals are shown in Fig. 2.

In order to parametrize the coherent interference between different $K\pi$ angular momentum states we have used a generalization due to Griffiths and Jabbur[9] of the Jackson-Gottfried expression[10] for the two-body decay angular distribution expanded in terms of the spin-density matrix elements. The general form of this expansion for a $K\pi$ final state is

$$W(\theta,\varphi)=\sum_{J,J'}\sum_{m,m'}\rho_{mm'}(J,J')\times d^{J}_{m0}\,d^{J'}_{m'0}\,e^{i(m-m')\varphi},$$

where J and J' are the angular momentum states which are assumed to be interfering and the m's are their projections. Specializing this formula

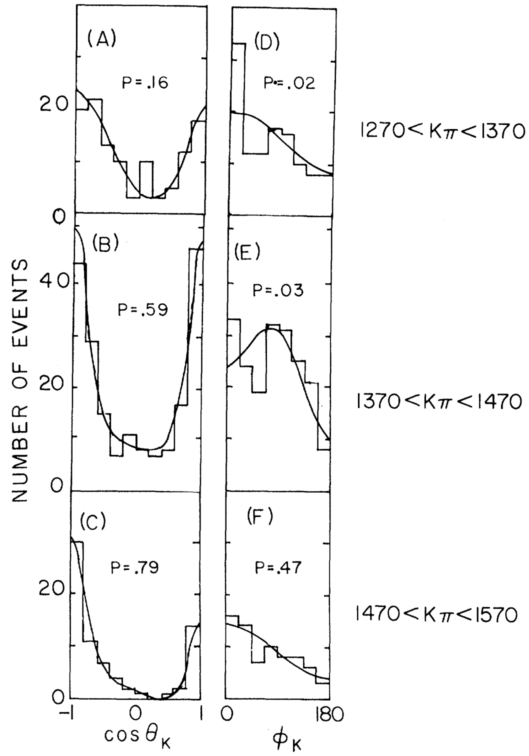

FIG. 2. Decay distributions for the $K^+\pi^-$ system in three $K^+\pi^-$ mass regions. θ and φ are defined in the text. The curves are the fits of models I and II, the two fits being identical. The chi-squared fit probabilities are given for each distribution.

to the case of angular momentum states $J \leq 2$ produced by pseudoscalar and/or vector exchange leads to the θ and φ distributions of the form

$$W(\theta)=f_0+f_1\cos\theta+f_2\cos2\theta+f_3\cos3\theta+f_4\cos4\theta, \qquad (2)$$

$$W(\varphi)=g_0+g_1\cos\varphi+g_2\cos2\varphi, \qquad (3)$$

where the f's and g's are linear combinations of the spin-density matrix elements, $\rho(J,J')_{m,m'}$.[11]

In this paper we will consider the following two cases: (I) The $K^+\pi^-$ system is produced with spin 2 by pseudoscalar-plus-vector exchange, and with spin 1 by pseudoscalar exchange; (II) the $K^+\pi^-$ system is produced with spin 2 by pseudoscalar exchange, and with spin 1 by pseudoscalar-plus-vector exchange. Diagrams are shown in Figs. 1(b) and 1(c). In (I) the density matrix elements which are calculated from the data for this model are $\rho_{00}(11)$, $\rho_{00}(22)$, $\rho_{11}(22)$, $\rho_{1-1}(22)$, $\rho_{00}(21)$, and $\rho_{10}(21)$; in case (II) they are $\rho_{00}(11)$, $\rho_{11}(11)$, $\rho_{00}(22)$, $\rho_{1-1}(11)$, $\rho_{00}(21)$, and $\mathrm{Re}\rho_{01}(21)$. The validity of these models cannot be established in a rigorous fashion since the 1^- and 2^+

contributions to the $K^+\pi^-$ system can only be found if one makes assumptions as in the models (I) and (II) above. The addition of more partial waves or of more types of exchanges makes the size of the 1^- and 2^+ contributions intractable.

We have found that the other models, (i) a pure spin state made by pseudoscalar-plus-vector exchange, or (ii) a 2^+ state with 0^- background [as shown in Fig. 1(d)], failed to fit the 1400-MeV $K^+\pi^-$ region.

Several salient features of Eqs. (2) and (3) in the case of our two specific models are of special importance. First, the coefficients of the $\cos[(2n+1)\theta]$ and the $\cos\varphi$ terms depend only on the quantities $\rho_{m0}(J,J')$, where $J \neq J'$. In models I and II, $J=1^-$ and $J'=2^+$ final states intefere allowing asymmetries in the $\cos\theta$ distribution and a $\cos\varphi$ dependence in the φ distribution. In addition, vector exchange must contribute to produce a $\cos\varphi$ dependence. The model of 2^+ with 0^- background cannot produce such asymmetries. Secondly, the presence of a $\cos 4\theta$ dependence and a $\cos\varphi$ dependence corresponds to the presence of a $J=2$ $K\pi$ final state since g_2 and f_4 depend on the $\rho_{mm'}(22)$ exclusively. Finally, the separate fitting of the φ and $\cos\theta$ distribution of the $2^+, 1^-$ interference model does not distinquish whether vector exchange contributes to 2^+ or to 1^-.

The curves representing the best fits of the angular distributions predicted by the models of Fig. 1(b) to the data are shown superimposed against the data in Fig. 2. As indicated by the χ^2 probabilities the models I, II fit reasonably well.

The variation of the relevant density matrix elements times the number of events per mass interval, $N\rho_{mm'}(JJ')$, is shown in Fig. 3 as a function of $K\pi$ mass. This quantity should reflect enhancements in resonant partial waves. The association of vector exchange with 2^+ production and the association of vector exchange with 1^- formation lead to similar behavior of the common important diagonal elements as is shown in Fig. 3. The $\mathrm{Re}\rho_{10}(21)$ and $\mathrm{Re}\rho_{01}(21)$ which are used in models I and II, respectively, are determined in the same way and are identical.

The maximum in $\rho_{00}(22)$ in the vicinity of 1400 MeV may be considered as evidence that there is a 2^+ resonance in that region. However, there is the same kind of behavior evident in the $\rho_{00}(11)$ matrix element. Since these elements contribute to orthogonal parts of the angular distribution, it is possible to separate them to within statistics. We interpret the $\rho_{00}(11)$ variation to be evidence for an appreciable enhancement of the

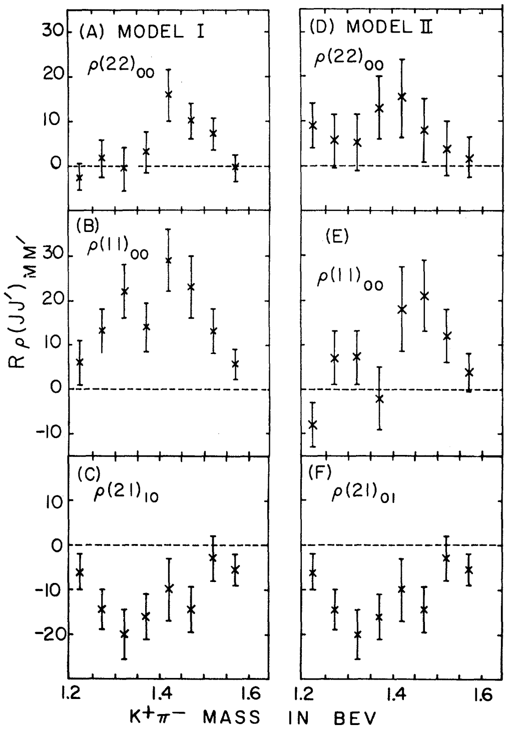

FIG. 3. Variations of the spin-density matrix elements of the $2^+, 1^-$ interference models I and II as a function of the $K^+\pi^-$ mass.

1^- background in the $K^*(1400)$ mass region. Other interpretations are possible if we discard the assumptions of models I and II. In any case, our analysis has demonstrated that the $K^*(1400)$ mass region is more complex than a single 2^+ resonance. Furthermore, the $1^-, 2^+$ interference model is a very plausible one and would contribute to the difficulty in determining branching ratios for the $K^*(1400)$.[12]

The $\rho_{10}(21)$ term is expected to have its largest magnitude in the $K^*(1400)$ mass region. However, it is seen from Fig. 3 that $\rho_{10}(21)$ has its largest magnitude at 1300 MeV. This may be due to a strong s- and p-wave interference which we could not include in our model. Possibly related to this effect is the rather narrow peaking at 1300 MeV in the $K^+\pi^-$ mass distribution as seen in Fig. 1. We do not have a clear interpretation of this effect at the present time.

In conclusion we would like to point out the relevance of a $J^P = 1^-$ structure under the $K^*(1400)$ to recent developments in boson resonances. It has been suggested that the apparent splitting of the A_2 into two peaks[13] is the result of the presence of two resonances in the A_2 mass regions, the $A_2{}^H$ with $J^{PC} = 2^{++}$ at 1315 MeV and the $A_2{}^L$

with $J^{PC}=1^{-+}$ at 1270 MeV.[14] The tentative 1^{-+} state, the A_2^L, which is so close in mass to the A_2^H, could be on the first daughter trajectory of the A_2^H.[15] In this case a similar 1^- daughter state is expected at nearly the same mass as the $K^*(1400)$. Such states were not allowed in the nonrelativistic quark model, whereas it has recently been found that they are expected in relativistic models.[16]

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