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THE STRANGE 0^{++} and 2^{++} RADIAL EXCITATIONS: A REVIEW OF LASS DATA*

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ABSTRACT

The experimental status of the strange 0^{++} and 2^{++} mesons is briefly reviewed and compared with expectations from the quark model. The results are taken from a high statistics study of strange mesons produced in LASS by an 11 GeV/c K^- beam.

INTRODUCTION

The non-relativistic quark model provides a rather good description of the known light quark spectra.[1,2] The experimental situation is particularly well understood in the strange meson sector where $q\bar{q}$ mesons appear to be dominantly produced and there is high quality data available from the LASS collaboration at SLAC.[3] This talk reviews the evidence in this data for radial excitations of the 0^{++} and 2^{++} mesons. Details of these analyses can be found elsewhere.[4–8] The radial excitations of the strange 1^{--} mesons are discussed elsewhere at this conference.[9]

MOTIVATION

The search for light quark radial excitations is confounded by a number of experimental difficulties. The radial states are expected to be rather broad, and to lie in the 1–2 GeV/c^2 mass region. However, this region contains higher lying spin excited states and a large number of states in total that overlap and can cause experimental confusion. Thus, high statistics experiments with large acceptance spectrometers and full Partial Wave Analyses (PWA) in several different channels are required to sort out the many states and to determine their quantum numbers. For the particular case of the strange sector, the experiments also require a strange beam which reduces the flux available into most spectrometers.

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There are also a number of somewhat more "theoretical" problems. The 0^{++} ground state sector continues to confuse and amuse, with more (non-flavored) states available than $q\bar{q}$ models desire. In addition, even when candidate radial states are found, there is generally a classification ambiguity. That is, in the "naive" quark model,[1] the first radially excited $q\bar{q}$ state (with orbital angular momentum $L = l$) generally is expected to lie very near in mass to the lowest-spin triplet ground state member with $L = l + 2$ which has exactly the same quantum numbers. However, a 0^{++} state can only occur in a $q\bar{q}$ system with $L = 1$. Thus, it is only a "little" surprising that one of the clearest candidates in the entire light quark sector for a radial excitation should be the 0^{++} strange state, as is discussed below. There is also a good candidate for a radial 2^{++} strange meson which will be described.

LASS RESULTS

The evidence discussed today comes from the reactions[4,5,6]

$$K^- p \rightarrow K^- \pi^+ n \tag{1}$$

$$K^- p \rightarrow \overline{K}^0 \pi^- p \tag{2}$$

$$K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n \quad . \tag{3}$$

0^{++} GROUND STATE (1^3P_0)

As shown in Fig. 1, the magnitude and phase of the $K^-\pi^+$ S-wave amplitude from reaction (1) rise slowly in the region below 1.3 GeV/c^2 and are compatible with unitarity. The first inelastic two-body threshold, the $K\eta$, is at about 1.05 GeV/c^2, but this channel appears to be very weakly coupled to the S-wave K^* system, as is predicted by SU(3). The magnitude peaks just below 1.4 GeV/c^2, and then drops precipitously, while the phase varies rapidly in the same mass region. This structure has been observed by several earlier experiments,[2,10,11] and is generally agreed to be due to the 0^{++} ground state resonance. However, determination of the resonance parameters is complicated by the large elastic phase shift in the low mass region and by the proximity of the $K\eta'$ threshold, which leads to model dependence in the parameters of perhaps 0.1 GeV/c^2. For example, using the coupled channel model of Estabrooks,[12] we obtain

$$M_{K^-\pi^+} = 1.412 \pm 0.001 \text{ GeV/c}^2$$
$$\Gamma_{K^-\pi^+} = 0.294 \pm 0.004 \text{ GeV/c}^2$$
$$\epsilon = 1.0 - 0.05 \quad ,$$

where M is the invariant mass, Γ is the width, ϵ is the elasticity, and the errors are statistical only. More recently, a PWA of reaction (2) in LASS has corroborated this amplitude behavior. Reaction (2) is dominated by the natural parity exchange amplitudes, and also contains very different contributions in the total S–wave amplitude from the $I = 3/2$ amplitude. However, the agreement of a simple model, which includes the Estabrooks coupled channel model with the above parameters and an effective range fit to the measured $I = 3/2$ data, with the $\overline{K}^0\pi^-$ data is very good indeed, as can be seen by comparing the line with the data in Fig. 2.

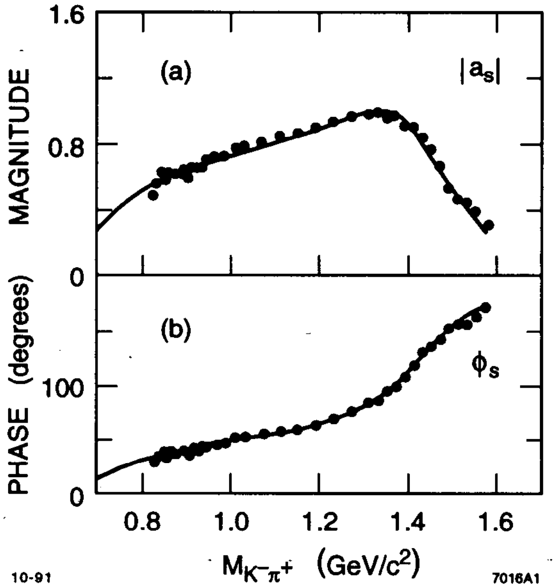

Fig. 1. The magnitude (a) and phase (b) of the $I = 1/2$ $K^-\pi^+$ S-wave amplitude in the mass region below 1.6 GeV/c^2. The curves show the results of the fit described in the text.

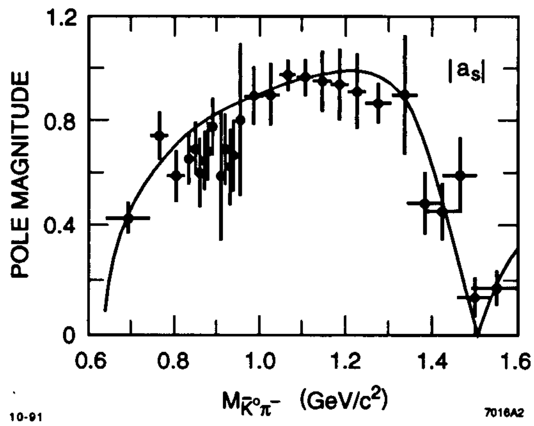

Fig. 2. The magnitude of the total $\overline{K}^0\pi^-$ S-wave amplitude. The curve is a prediction derived from the $K^-\pi^+$ S-wave as described in the text.

0^{++} RADIAL EXCITATION (2^3P_0)

Above 1.85 GeV/c^2, the $K^-\pi^+$ amplitudes from reaction (1) have two solutions that differ in detailed structure, but both S-wave amplitude solutions show classic resonance behavior—a peak in the magnitude just above 1.9 GeV/c^2 along with rapidly varying phase motion—as can be seen in Fig. 3. The Argand diagrams (not shown) also display rapid circular motions in these same mass regions. As discussed earlier, within the quark model such a resonance can only be classified as a radial excitation, and its mass value is compatible with the value expected for the first radial excitation in the naive quark model. As shown by the curves in Fig. 3, the ambiguous amplitudes (A and B) separately fit a simple Breit-Wigner model very well, with parameters as follows:

$$M_{K^-\pi^+} = 1.934 \pm 0.022 (A); 1.955 \pm 0.013 (B) \text{ GeV/c}^2$$
$$\Gamma_{K^-\pi^+} = 0.174 \pm 0.081 (A); 0.228 \pm 0.040 (B) \text{ GeV/c}^2$$
$$\epsilon = 0.55 \pm 0.14 \ (A); 0.48 \pm 0.03 \ (B) \quad ,$$

where the indicated errors combine statistical errors and a simple estimate of the systematic error within the model in quadrature. In general, the parameters obtained from the two solutions are consistent within errors.

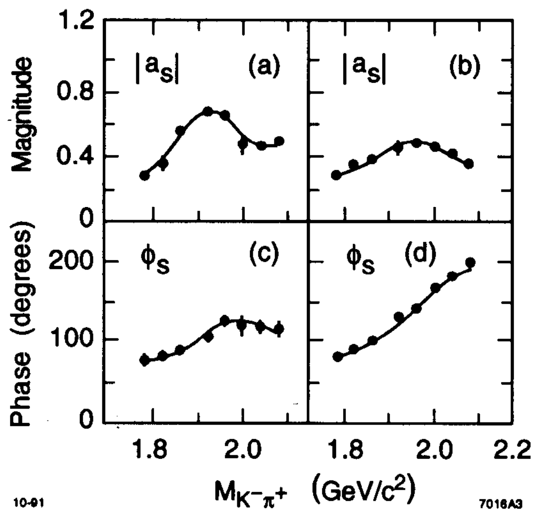

Fig. 3. The magnitudes and phases of the $K^-\pi^+$ S-wave amplitude for solutions A, (a) and (c); and B, (b) and (d), in the mass region between 1.76 and 2.14 GeV/c^2. The curves show the results of the Breit-Wigner fits described in the text.

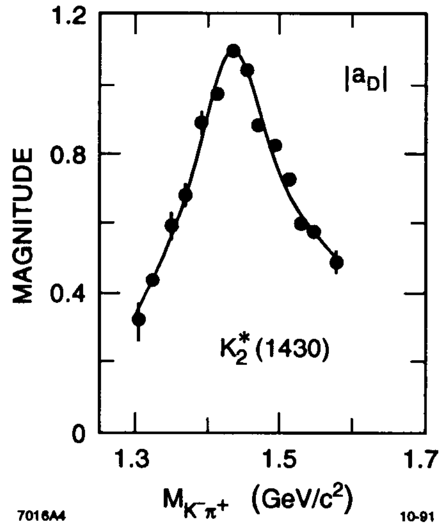

Fig. 4. The magnitude of the $K^-\pi^+$ D-wave amplitude in the $K_2^*(1430)$ region. The curve shows the result of a Breit-Wigner fit.

2^{++} GROUND STATE (1^3P_2)

The well established $K_2^*(1430)$ has been studied in all three of the above reactions at LASS with consistent results. For example, a fit to the $K^-\pi^+$ D-wave amplitude of Fig. 4 gives the following resonance parameters:

$$M_{K^-\pi^+} = 1.4312 \pm 0.0019 \text{ GeV/c}^2$$
$$\Gamma_{K^-\pi^+} = 0.1165 \pm 0.0039 \text{ GeV/c}^2$$
$$\epsilon = 0.485 \pm 0.021 \quad ,$$

where statistical and systematic errors have been summed in quadrature.

2^{++} EXCITED STATE (2^3P_2 RADIAL CANDIDATE)

The summed 2^{++} intensity from reaction (3), shown in Fig. 5, shows a clear resonance signal for the $K_2^*(1430)$ and a large bump around 2.0 GeV/c^2 that also appears to be resonant.

The individual $2^+0^-K^*\,D$ and $2^+0^-\rho\,D$ wave intensities and phases shown in Fig. 6 also show resonance structure around 2.0 GeV/c^2. The simplest fit to the data requires a resonant term plus a coherent background, and agrees well with the data as shown in Fig. 6. The parameters obtained are:

$$M_{\overline{K}^0\pi^+\pi^-} = 1.973 \pm 0.033\ GeV/c^2$$
$$\Gamma_{\overline{K}^0\pi^+\pi^-} = 0.373 \pm 0.093\ GeV/c^2,$$

where statistical and systematic errors have been summed linearly. The data cannot exclude a two-resonance model with the second resonance being somewhat higher in mass; and, in fact, the naive quark mode predicts two 2^+ states in this mass region; (1) a 2^3P_2 radial recurrence of the $K_2^*(1430)$, and (2) a 1^3F_2 partner of the $K_4^*(2060)$.

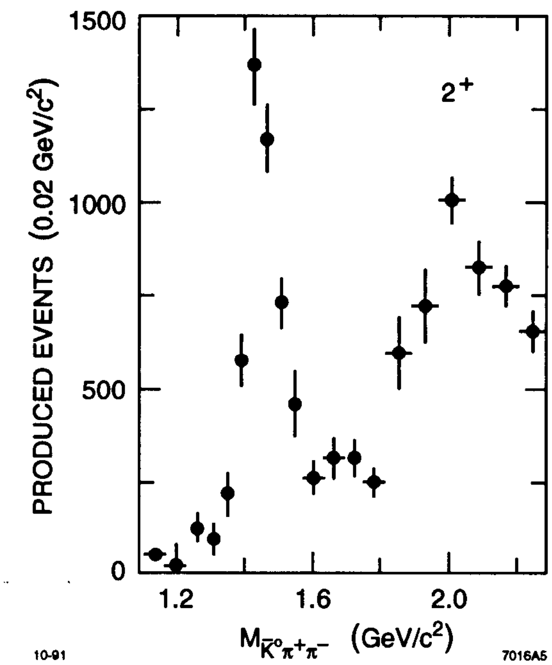

Fig. 5. The summed intensity of the 2^+ $\overline{K}^0\pi^+\pi^-$ D-wave amplitudes.

However, even though this interpretation is attractive in the quark model context, only the one resonance is demanded by the data. The measured mass of this resonance is close to the mass expected for the radial state in the model, and is also close to the observed mass for the 2^3P_0 states discussed above. Thus, the observed $L \bullet S$ splitting is small under the assumption that the state is a radial excitation while it would be atypically large if it is the orbitally excited partner of the $K_4^*(2060)$. The absence of a $K_2^*(1970)$ signal in the $K^-\pi^+$ D-wave amplitude also demonstrates that this state has a rather small $K\pi$ coupling (see the following section). Models have been proposed which explain the suppression of the two-body decays from light quark radial vector states as arising from nodes in the radial wave function,[13] and it is possible that similar suppressions of certain decay modes could be a general property of radial states. However, we are aware of no models which demonstrate this explicitly, and in any case the model would need to explain both the suppression of the elastic decay of the $K_2^*(1970)$ and the relatively large elasticity of the $K_0^*(1950)$. Thus, though each of these arguments favor a radial interpretation, they can only be considered as suggestive, and the classification of this state as a radial excitation can not be considered as definitive.

The evidence for the $K_2^*(1970)$ is corroborated by the behavior of the the $\overline{K}^0\pi^-$ amplitudes shown in Fig. 7. The $|D_+|$ amplitude is dominated by the $K_2^*(1430)$ around 1.4 GeV/c^2 but does not agree well with the expected tail from the $K_2^*(1430)$, shown by the dotted line, in the higher mass region. Moreover, the relative phase between the D_+ and F_+ amplitudes, Fig. 7(e), is also poorly reproduced by a fit which includes only the $K_2^*(1430)$ and $K_3^*(1780)$ resonances, as shown by the dotted line.

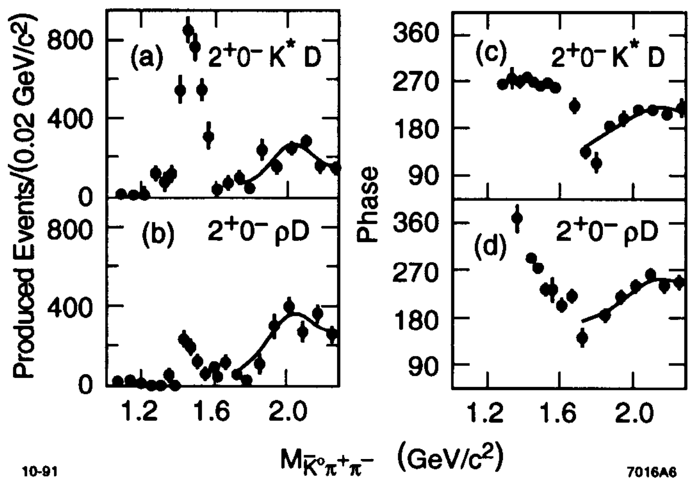

Fig. 6. The 2^+ $\overline{K}^0\pi^+\pi^-$ D-wave amplitudes showing the fitted lineshapes and phases at high mass.

The inclusion of a second D-wave resonance does allow an excellent description of the data as shown by the solid curves. The parameter values of this second resonance are:

$$M_{\overline{K}^0\pi^-} = 1.978 \pm 0.040 \text{ GeV/c}^2$$
$$\Gamma_{\overline{K}^0\pi^-} = 0.398 \pm 0.047 \text{ GeV/c}^2 \quad ,$$

where the errors are statistical only, in excellent agreement with the values obtained from reaction (3).

IS THERE A SECOND 2^{++} EXCITED STATE ABOVE 2.0 GeV/c^2?

In addition to the data described in the previous section, the $K^-\pi^+$ D-wave amplitude from reaction (1), shown in Fig. 8, also provides information about possible high mass resonant behavior. Clearly there is little activity in the mass region around 1.95 GeV/c^2, but above 2.0 GeV/c^2, there is suggestive evidence for phase motion, though little structure in the magnitude. At best this provides a hint of a "possible" high mass 2^{++} which could be the same as the possible "second" state seen in reaction (3). If it exists, it is clearly different from the $K_2^*(1970)$; as described above, the absence of any obvious elastic $K\pi$ coupling of the $K_2^*(1970)$ is consistent with the data from reactions (2) and (3).

CONCLUSION

A great deal has been learned about the 0^{++} and 2^{++} strange mesons in the last few years. Good candidates for radial excitations of both the 0^{++} and the 2^{++} have been observed and, in general, the properties of the ground and radial states fit expectations from the non-relativistic quark model quite well, as shown in Table I.

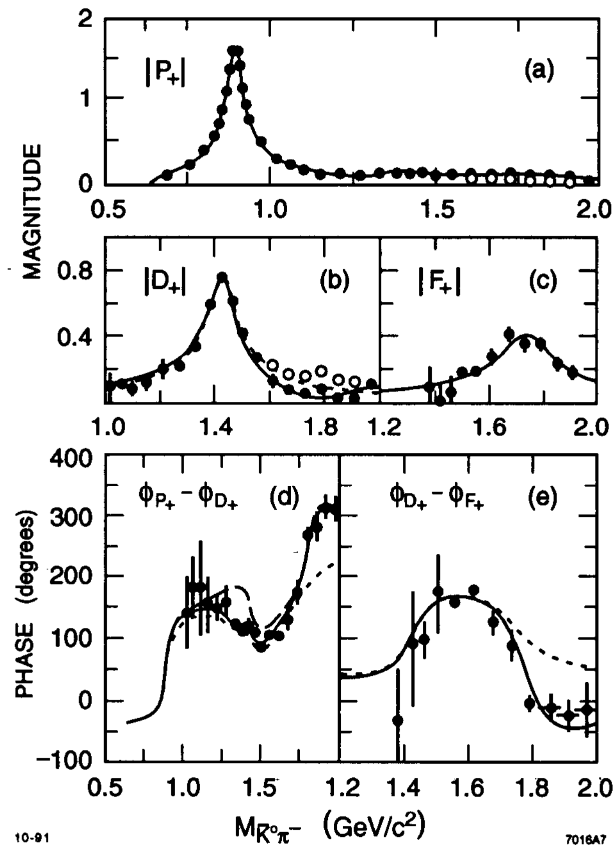

Fig. 7. The natural-parity $\overline{K}^0\pi^-$ amplitudes. The fitted curves are the result of a simultaneous fit to all the amplitudes. The solid curve includes six resonances–three P-wave, two D-wave, and one F-wave. The dashed curve in the relative P-D phase (d) shows the behavior if there is only one high mass P-wave. The dotted curve in the relative D-F phase (e) shows the behavior without a high mass D-wave.

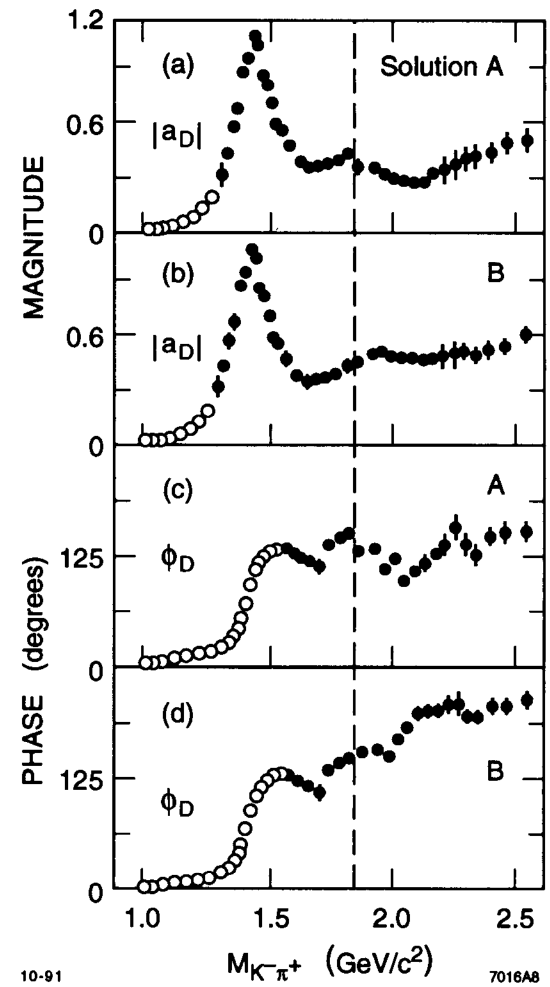

Fig. 8. The magnitudes and phases of the $K^-\pi^+$ D.-wave amplitude for solutions A, (a) and (c); and B, (b) and (d).

Though the data quality is very good, even more high quality data in a variety of final states would be helpful in elucidating the high mass behavior of the amplitudes and in fixing the parameter values of the observed states more precisely.

State	Status	LASS Channels		Mass (GeV/c^2)		Classification	
	LASS	Primary	Other	Observed	Model	Preferred	Reliability
0^{++}	$***\!*$	$K^-\pi^+$	$\overline{K}^0\pi^-$	1.412 Model Dep.	1.24	1^3P_0	$***\!*$
2^{++}	$***\!*$	$K^-\pi^+$	$\overline{K}^0\pi^-\pi^+$ $\overline{K}^0\pi^-$ $K^-\omega$[8]	1.431	1.43	1^3P_2	$***\!*$
0^{++}	$***$	$K^-\pi^+$		~ 1.95	1.89	2^3P_0	$***\!*$
2^{++}	$***$	$\overline{K}^0\pi^-\pi^+$	$\overline{K}^0\pi^-$	1.973	1.94	2^3P_2	$**$
2^{++}	$*$	$K^-\pi^+$	$\overline{K}^0\pi^-\pi^+$	~ 2.1	2.15	1^3F_2	$*$

Table I. Summary of 0^{++} and 2^{++} strange states observed in LASS. The quoted "measured" mass values are those measured for the "primary" channel. The "model" mass values are those of Godfrey and Isgur[1]. The "$*$" ranking is suggestive only, and ranges from "1 $*$" (a hint) to "4 $*$'s" (clear, unequivocal, and well-understood).

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