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SPECTROSCOPY OF THE D–WAVE $q\bar{q}$ SYSTEM; EVIDENCE FOR TWO $J^P = 2^-$ STRANGE MESON STATES DECAYING TO $K^-\omega$*

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ABSTRACT

Evidence is presented for two $J^P = 2^-$ strange mesons; one at ~ 1.77 and the other at ~ 1.82 GeV/c^2. These states have been observed in a partial wave analysis of the $K^-\omega$ system in the reaction $K^-p \to K^-\pi^+\pi^-\pi^0 p$ where the strange mesons decay into $K^-\omega$ and the ω then decays to $\pi^+\pi^-\pi^0$. The data set contains $\sim 10^5$ $K^-\omega p$ events at 11 GeV/c taken with the LASS spectrometer at SLAC.

INTRODUCTION

Even though evidence for the quark model is very strong, the correct $q\bar{q}$ quark model assignments of all the known mesons are far from clear. There are a number of states that are experimentally "missing," even for the low spin multiplets, and there is considerable controversy in the assignment of several of the light non-strange mesons. This is particularly true for the 0^{++} multiplet where there are "too many" candidate states. Table 1 reproduces the suggested assignments of the Particle Data Group (PDG).[1] The most obvious "hole" is in the D-wave 2^- sector, where there is no specific $q\bar{q}$ combination with good candidates for both singlet and triplet 2^- states. This is true even for the strange meson spectrum, which is the best understood of any $q\bar{q}$ system. Figure 1 shows the strange meson spectrum from the LASS/SLAC Kp program before the analysis presented here today. Even though the number of strange states observed is quite large, with orbitally excited states up to 5^- and with a significant number of triplet and radially excited candidates, the expected level structure is only complete for the $L = 0$ and $L = 1$ ground states. Completing the D-wave ($L = 2$) singlet and triplet levels would sharpen comparison of the experimental data with the models considerably,[2] particularly for the spin-dependent forces.

In this paper, we present evidence for two strange 2^- states in the $K_2(1770)$ region. These results are taken from a high-statistics study of the $K\omega$ system produced in the reaction

$$K^-p \to K^-\pi^+\pi^-\pi^0 p \qquad (1)$$

at 11 GeV/c. The data were obtained with the Large Aperture Superconducting Solenoid

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Table I. From PDG Phys. Rev. D III. 69 1 June (1992)									
$N^{2S+1}L_J$	J^{PC}	$u\bar{d}$, $u\bar{u}$, $d\bar{d}$ $I=1$	$u\bar{u}$, $d\bar{d}$, $s\bar{s}$ $I=0$	$c\bar{c}$ $I=0$	$b\bar{b}$ $I=0$	$\bar{s}u$, $\bar{s}d$ $I=1/2$	$c\bar{u}$, $c\bar{d}$ $I=1/2$	$c\bar{s}$ $I+0$	$\bar{b}u$, $\bar{b}d$ $I+1/2$
1^1S_0	0^{-+}	π	η, η'	η_c		K	D	D_s	B
1^3S_1	1^{--}	ρ	ω, ϕ	$J/\psi(1S)$	$\Upsilon(1S)$	$K^\star(892)$	$D^\star(2010)$	$D_s(2110)$	$B^\beta(5330)$
1^1P_1	1^{+-}	$b_1(1235)$	$h_1(1170), h_1(1380)$			K_{1B}†	$D_1(2420)$	$D_{s1}(2536)$	
1^3P_0	0^{++}	$a_0(980)$	$f_0(1400), f_0(975)$	$\chi_{c0}(1P)$	$\chi_{b0}(1P)$	$K_0^\star(1430)$			
1^3P_1	1^{++}	$a_1(1260)$	$f_1(1285), f_1(1510)$	$\chi_{c1}(1P)$	$\chi_{b1}(1P)$	K_{1A}†			
1^3P_2	2^{++}	$a_2(1320)$	$f_2(1270), f_2'(1525)$	$\chi_{c2}(1P)$	$\chi_{b2}(1P)$	$K_2^\star(1430)$	$D_2^\star(2460)$		
1^1D_2	2^{-+}	$\pi_2(1670)$							
1^3D_1	1^{--}	$\rho(1700)$	$\omega(1600)$	$\psi(3770)$		$K^\star(1680)$			
1^3D_2	2^{--}					$K_2(1770)$			
1^3D_3	3^{--}	$\rho_3(1690)$	$\omega_3(1670), \phi_3(1850)$			$K_3^\star(1780)$			
1^3F_4	4^{++}	$a_4(2040)$	$f_4(2050), f_4(2220)$			$K_4^\star(2045)$			
2^1S_0	0^{-+}	$\pi(1300)$	$\eta(1295)$	$\eta_c(2S)$		$K(1460)$			
2^3S_1	1^{--}	$\rho(1450)$	$\omega(1390), \phi(1680)$	$\psi(2S)$	$\Upsilon(2S)$	$K^\star(1410)$			
2^3P_2	2^{++}		$f_2(1810), f_2(2010)$		$\chi_{b2}(2P)$	$K_2^\star(1980)$			
3^1S_0	$0^{\pm}$	$\pi(1770)$	$\eta(1760)$			$K(1830)$			
† The K_{1A} and K_{1B} are nearly 45^o mixed states of the $K_1(1270)$ and $K_1(1400)$.									

Table 1. The $q\bar{q}$ quark model assignments suggested by the PDG[1] for most of the experimentally known low spin meson systems.

(LASS) spectrometer at SLAC, which is described in detail elsewhere.[3] Since the LASS spectrometer was not equipped with a photon detector, the π^0 in the final state is not seen directly, but is reconstructed in the missing π^0 channel. The $K^-\omega p$ sample of $\sim 10^5$ events obtained in this experiment is at least 25 times larger than that obtained in any previous experiment.

DATA AND ANALYSIS

The $\pi^+\pi^-\pi^0$ mass spectrum of Figure 2 shows a clear ω signal, with signal to background ratio about one to one in the signal region (0.72–0.84 GeV/c^2). It is clear from the Dalitz plot (not shown) that the high-mass $K\omega$ region overlaps with substantial production of several baryon resonances, so events with $M_{p\omega} < 2.28$ or $M_{pK} < 2.0$ GeV/c^2 are eliminated. The $K^-\pi^+\pi^-\pi^0$ effective mass distribution in the ω region [Fig. 3(a)] shows peaks in the $K^-\omega$ threshold region and in the region around 1.75 GeV/c^2. The shaded histogram shows the events with the baryon resonance region removed. Most of the high mass $K^-\omega$ events lie in the overlap region and are removed by this cut.

The analysis, more details of which can be found elsewhere,[4] is performed using joint decay spherical-harmonic moments in the $K^-\omega$ Gottfried-Jackson frame and the ω rest frame, using the normal to the decay plane as the analyzer. The $\pi^+\pi^-\pi^0$ mass spectrum shown in Fig. 2 contains a significant background under the ω peak region (6.72 to 0.84 GeV/c^2). Each moment is background subtracted using the ω sideband regions indicated (0.64 to 0.70 GeV/c^2 and 0.86 to 0.92 GeV/c^2) and acceptance corrected, after which the partial waves for J^P of the $K^-\omega$ system up to 3^- are determined.

The background and acceptance corrected $K^-\omega$ mass distribution obtained is shown in Fig. 3(b). The main features are similar to those observed for the uncorrected data. There is a strong peak at threshold, and a large bump in the 1.7 to 1.8 GeV/c^2 region, with some evidence for a smaller structure around 1.5 GeV/c^2.

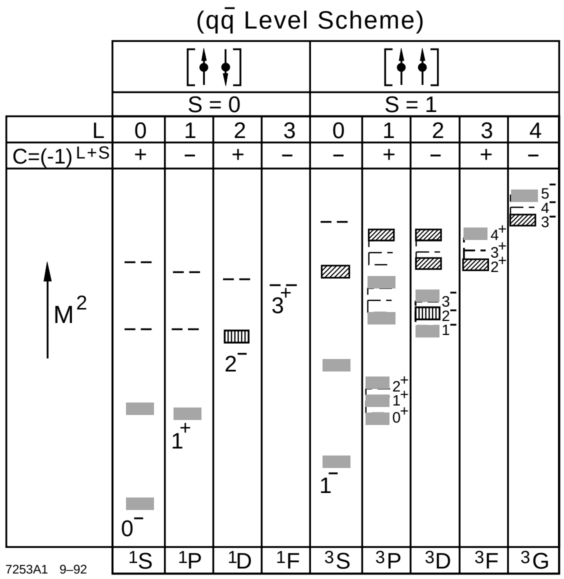

Figure 1. Level diagram (Grotrian plot) for the strange meson states known before this analysis. All of these states have been observed in the LASS/SLAC group B program. The dashed lines indicate the lowest lying states expected in the quark model. The mass levels are illustrative only. The states indicated by cross-hatching are clearly observed, and have generally been confirmed; in a few cases there are possible classification ambiguities. Only one strange 2^- meson has been confirmed. It could be either the S=0 or the S=1 state, or perhaps a mixture, as shown by the vertically lined boxes. The states indicated by diagonal lines are more speculative and require confirmation.

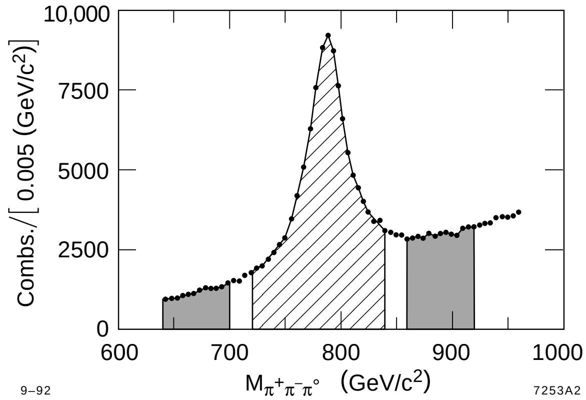

Figure 2. The $\pi^+\pi^-\pi^0$ invariant mass distribution; the signal region is diagonally lined while the background region is shaded.

THE PARTIAL WAVE STRUCTURE

The low mass $K^-\omega$ region is dominated by 1^+ waves (not shown), while the mass bump around 1.75 GeV/c^2 is dominantly 2^-. Figure 4 shows the incoherently summed intensity of all the 2^- waves. There is a large and rather broad bump centered around 1.75 GeV/c^2. The much smaller $K^-\omega$ decays of the leading $K_2^*(1430)$ (not shown) and the $K_3^*(1780)$ are also observed with branching ratios which are consistent with predictions from SU(3). Figure 5 shows the real and imaginary parts of the PWA amplitudes for the $J^P = 2^-$ and 3^- waves that are significant in the 1.75 GeV/c^2 region. In addition to the bump in the 3^- amplitude corresponding to $K_3^*(1780)$ production, there is a substantial and rather complicated structure in the different 2^- amplitudes.

However, this structure can be explained in a straightforward manner as follows: First, the 3^- amplitudes are fit to a single Breit-Wigner (B-W) resonance model to define a phase reference in the 1750 MeV/c^2 mass region. Then the 2^- and 3^- amplitudes are fit simultaneously with their relative phases and magnitudes as free parameters. Two different models are compared: (1) that the 2^- waves observed in the 1750 mass region come from a

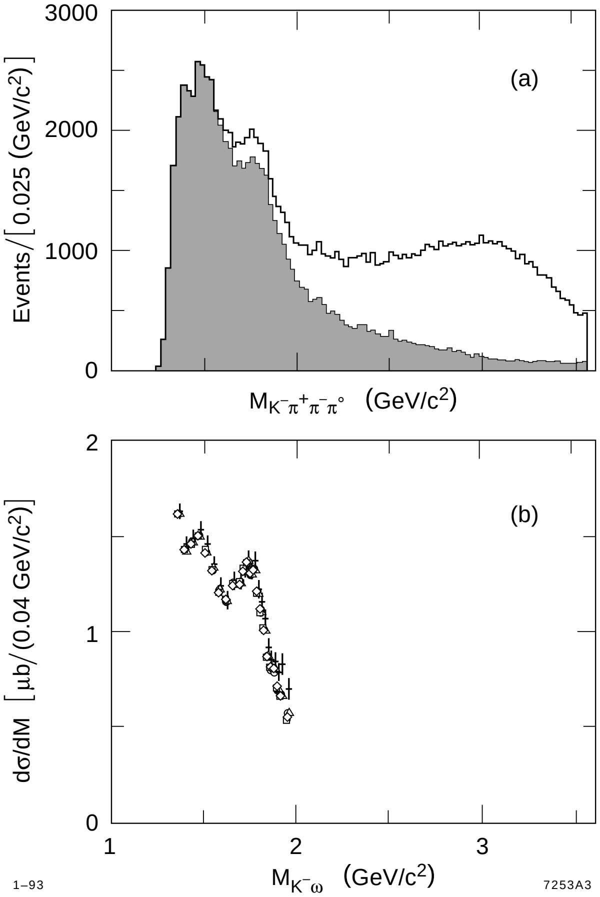

Figure 3. The $K-\pi^+\pi^-\pi^0$ invariant mass distribution for events with $0.1 < |t'| < 2.0$ (GeV/c)^2; (a) the unshaded curve contains all events that satisfy $0.72 < M_{3\pi} < 0.84$ GeV/c^2 while the shaded portion contains events with $M_{p\omega} > 2.28$ and $M_{pK} > 2.0$ GeV/c^2; (b) the background-subtracted and acceptance-corrected mass distribution; the points with error bars are the measured values and the other points are the values obtained in the PWA fit discussed in the text.

single resonance, and (2) that they come from two resonances. The dotted curves in Fig. 5 show the fit results of hypothesis (1). The fitted mass and width of the 2^- resonance are 1728 ± 7 MeV/c^2 and 221 ± 22 MeV/c^2, respectively. The χ^2 is 128.9 for 116 degrees of freedom. The one-resonance fit does not reproduce the 2^-1^+F wave at all well. Moreover,

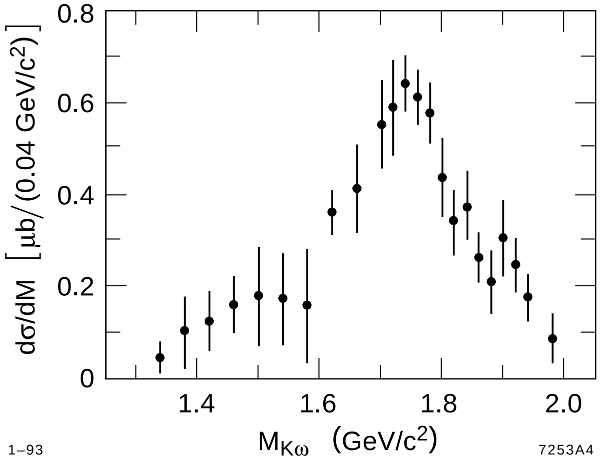

Figure 4. The summed intensities of the 2^- waves.

the dip at ~ 1.84 GeV/c^2 in the $Re(2^-0^+P)$ and the tail of $Re(2^-0^+F)$ are not well represented by the fit.

On the other hand, the fit results of hypothesis (2) represented by the solid curves in Fig. 5 reproduce all of the amplitudes very well and provide a significantly better fit to the data with a χ^2 of 70.6 for 110 degrees of freedom. The fitted masses of the two resonances are 1773 ± 8 and 1816 ± 13 MeV/c^2 and the fitted widths are 186 ± 14 and 276 ± 35 MeV/c^2, respectively. In this model, the 2^-1^+F wave is almost entirely the higher mass resonance, but the other amplitudes contain rather large contributions from both resonances, and overall, each resonance is observed with nearly equal strength into P and F waves. The χ^2 difference is almost 60 units between the one and two resonance models, which is a nominal "Gaussian" significance level for the second resonance of more than 7σ. In fact, since the PWA typically has a number of nearby solutions, the error bars shown and used in the fit tend to be overestimated compared to Normal errors. Thus, the absolute values of the χ^2 for these fits, the difference between the models, and the significance of the second resonance in the fit, will all tend to be underestimated. Clearly,

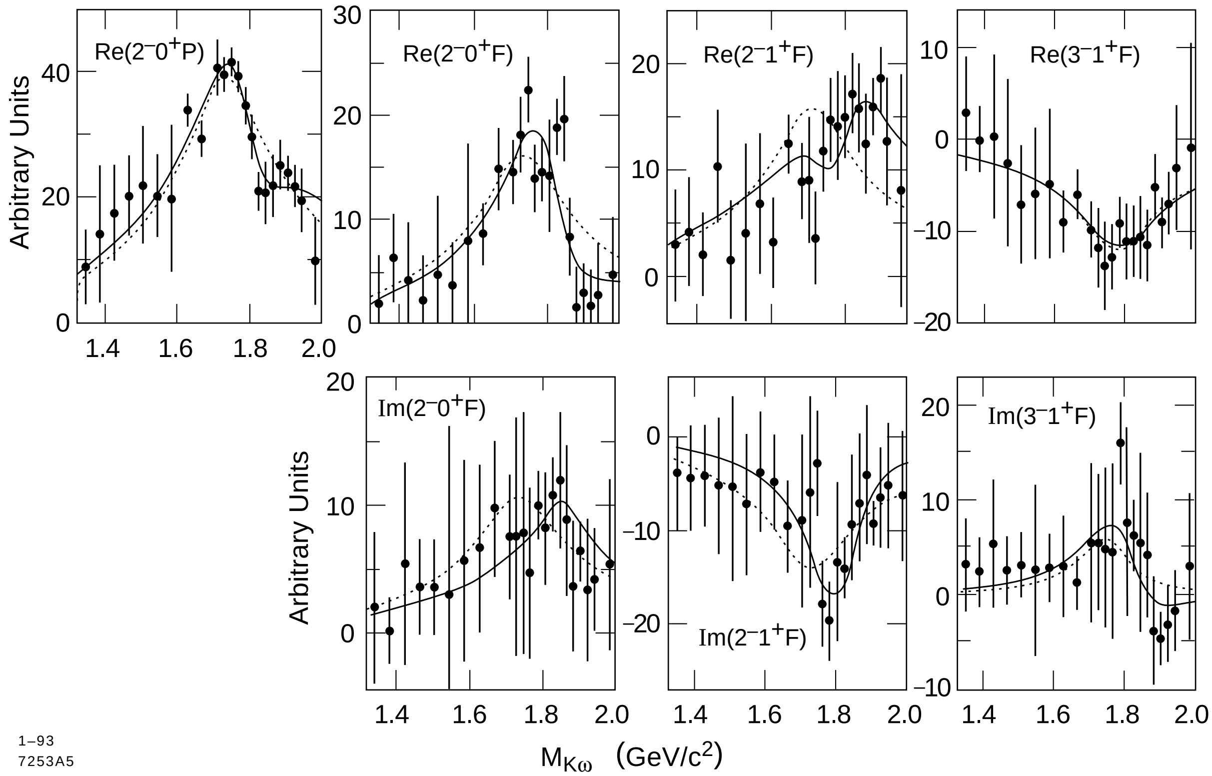

Figure 5. The real and imaginary parts of the $K^-\omega$ 2^- and 3^- amplitudes; the lines show the results of the fits described in the text.

the data strongly prefer the model with two 2^- resonances.

SUMMARY

A partial wave analysis of a high-statistics sample of $\sim 10^5 K^-\omega p$ events provides very good evidence for two 2^- strange resonances with masses around 1773 and 1816 MeV/c^2. This is the only $q\bar{q}$ D-wave spectrum with good candidates for all ground state singlet and triplet levels. The singlet/triplet classification of these states is unclear since strange mesons are not eigenstates of charge conjugation C, and the experimental states can therefore be mixed (as are the $^1P_1$ and $^3P_1$ strange states). It is interesting that Godfrey and Isgur[2] predict masses of 1780 and 1810 MeV/c^2 for the unmixed $^1D_2$ and $^3D_2$ states respectively, remarkably close to the experimental values. Kokowski and Isgur[5] also predict that the pure states are essentially decoupled, with the lower mass state decaying mostly to P-wave and the higher mass state to F-wave. Experimentally, production can complicate matters, but the 2^-1^+F wave is explained as mostly the higher mass state, as predicted. On the other hand, both resonances contribute significantly to the other P and F wave amplitudes and, overall, the resonances appear with roughly equal total strengths in the P and F wave amplitudes.

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