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RECENT RESULTS IN STRANGEONIUM SPECTROSCOPY*

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ABSTRACT

Data from exclusive $s\,\bar{s}$ meson final states are shown. The data were obtained in a 4.1 ev/nb exposure of K^-p interactions at 11 GeV/c in the LASS spectrometer at SLAC. The results from the analyses of these data is presented and the spectrum of strangeonium states is discussed.

1. INTRODUCTION

Interest in the $s\,\bar{s}$ meson spectrum stems not only from the need to understand that sector of light meson spectroscopy, but also from the need to discriminating between normal $s\,\bar{s}$ states and possible exotic states. The strangeonium spectrum is not well understood compared to the spectrum of the other light mesons. One reason for this is that ordinary and strange mesons are more easily produced in pion and kaon beam experiments, while $s\,\bar{s}$ mesons are produced with lower cross section.

In this paper recent results on strangeonium spectroscopy will be presented and discussed. These data were obtained from an exposure of the Large Aperture Superconducting Solenoid (LASS) spectrometer at SLAC to a K^- beam of 11 GeV/c. The raw data sample contains $\sim$ 113 million triggers, and the resulting useful beam flux corresponds to a sensitivity of 4.1 events/nb. The acceptance is approximately uniform over almost the full 4π solid angle. The spectrometer and relevant experimental details are described elsewhere.[1,2]

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♮ Speaker.

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2. THE DATA CHANNELS

The strangeonium states which will be discussed are observed in the interactions

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

$$K^- p \to K^\circ_S K^\circ_S \Lambda \tag{2}$$

and

$$K^- p \to K^\circ_S K^\pm \pi^\mp \Lambda \ . \tag{3}$$

In all three cases the final states are fully observed in the spectrometer; the Λ and all K°_S decays are seen. The final states are reconstructed and fit to the specific topology with full kinematic constraints. The tight constraints yield very small errors on the reconstructed quantities, with the mass of the $K\overline{K}$ pair measured to an accuracy of $10 - 20\,\mathrm{MeV/c^2}$. The constraints also give good rejection of final states coming from other processes. These three channels are dominated by peripheral production, which is enhanced by requiring low t'. The peripheral production and the Λ in the final state are indicative of hypercharge exchange and thus an $s\overline{s}$ pair recoiling against the Λ.

The $K\overline{K}$ mass spectra from reactions (1) and (2) are shown in Figs. 1(a) and 1(b) respectively. The distributions differ in that the $K^\circ_S K^\circ_S$ final state is limited to $J^P = (even)^+$. The $K^\circ_S K^\circ_S$ data mainly shows the production of the $f'_2(1525)$, while in the $K^- K^+$ distribution the $\phi(1020)$ and $f'_2(1525)$ can be seen along with a small enhancement at the $\phi_J(1850)$ mass.[3] Neither mass distribution shows any evidence for the $f_2(1720)$, which dominates the $K\overline{K}$ spectra from radiative J/ψ decay[4], and the background free $K^\circ_S K^\circ_S$ data shown in Fig. 1(a) gives the 95% confidence level upper limit[2]

$$\sigma(K^- p \to f_2(1720)\Lambda) \cdot BR(f_2(1720) \to K\overline{K}) < \ 94\,\mathrm{nb}.$$

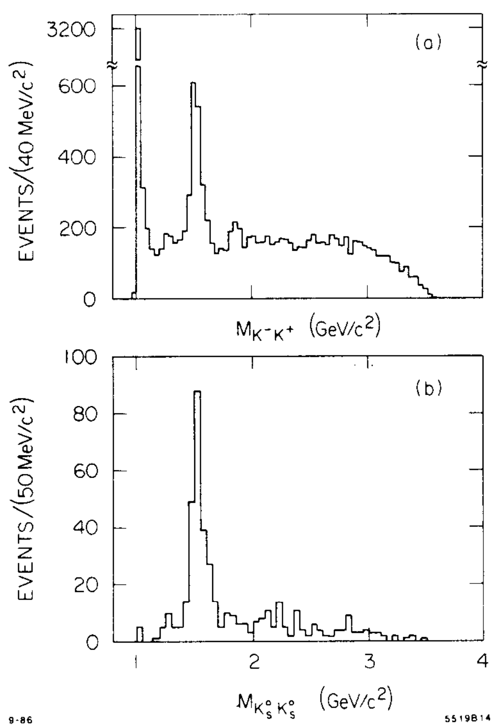

FIG. 1. The $K\overline{K}$ mass projections for reactions (1) (a) and (2) (b).

The $K^- K^+$ mass distribution shows a large background contribution above $\sim 1.8\,\mathrm{GeV/c^2}$ which is due to diffractive ΛK^+ production. This is clearly demonstrated in the Dalitz plots, shown in Fig. 2(a) for reaction (1) and Fig. 2(b) for reaction (2). This background tends to mask the signals from the $\phi_J(1850)$ and any other higher mass states in the $K^- K^+$ mass distribution, but as discussed below, it is possible to exploit the interference between the meson and nucleon production amplitudes to help determine the $K\overline{K}$ high spin structure.

3. AMPLITUDE ANALYSES

The amplitude analysis of reaction (2) is discussed in detail in Ref. 2, and the results are shown in Fig. 3. Fig. 3(b) shows the $|D_0|^2 + |D_+|^2$ production of the $f_2'(1525)$, and a fit to the intensity gives values for its mass, width and cross section which are in good agreement with published values.[3] The amplitude analysis also reveals substantial $|S_0|^2$ production, shown in Fig. 3(a), under the leading D-waves. The curve shown in Fig. 3(a) is simply the fit of Fig. 3(b) scaled by 1/3 and describes the data well. The S-wave contribution was fit in the mass range 1.4 − 1.7 GeV/c^2 resulting in the 95% confidence level limits

$$0.08\,\mu\text{b} < \sigma(K^- p \rightarrow (\text{S}-\text{wave})\Lambda) \cdot BR((\text{S}-\text{wave}) \rightarrow K\overline{K}) < 2.1\,\mu\text{b}.$$

This suggests the presence of a 0^+ state in this mass region, which would be the $^3\text{P}_0$ partner to the $f_2'(1525)$, the $f_0'(1525)$.

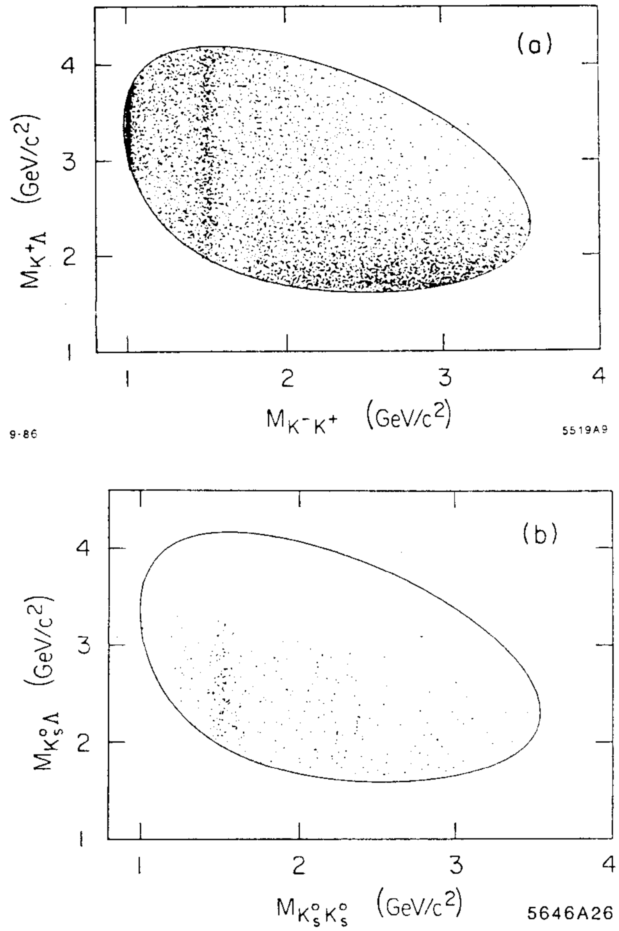

FIG. 2. The distributions of $K\overline{K}$ mass versus $K\Lambda$ mass for reactions (1) (a) and (2) (b).

A moments analysis and an amplitude analysis of reaction (1) in the region of the $\phi_J(1850)$ has been performed.[5] At low t' the spherical harmonic moments, Y_l^0, show structure at 1.85 GeV/c^2 for $l \leq 6$, and no structure for $l \geq 7$. This indicates the presence of F-wave activity in the region. The results of the amplitude analysis of these data show a clear Breit-Wigner peak in $|F|^2_{tot} = |F_0|^2 + |F_+|^2 + |F_-|^2$ (Fig. 4) with a mass of $1.855 \pm .022$ and a width of $0.074 \pm .067$ GeV/c^2. This demonstrates the spin-parity of the $\phi_J(1850)$ as being $J^P = 3^-$, the $\phi_3(1850)$. The Y_l^0 moments from reaction (1) also show significant activity in the 2.2 GeV/c^2 region for $l \leq 7$, a small bump in the $l = 8$ moment, and no activity for $l \geq 9$. This indicates that G-wave is needed in this region, but the overlap from $K^+\Lambda$ diffractive production makes an amplitude analysis impossible. The leading G_0-wave can be projected out by forming the four particular linear combinations of the Y_l^m moments equal to $\text{Re}(\text{G}^0 A_0^*)$ + (*other terms*), where $A_0 = \text{S}_0, \text{P}_0, \text{D}_0$, or F_0 and the (*other terms*) contain no G-wave contributions. Each of the S_0, P_0, D_0, and F_0 terms are found to be approximately imaginary relative to G_0, consistent with the conjecture that they arise primarily from the diffractive overlap, and thus they can be summed to form an imaginary diffractive amplitude, A_{diff}.

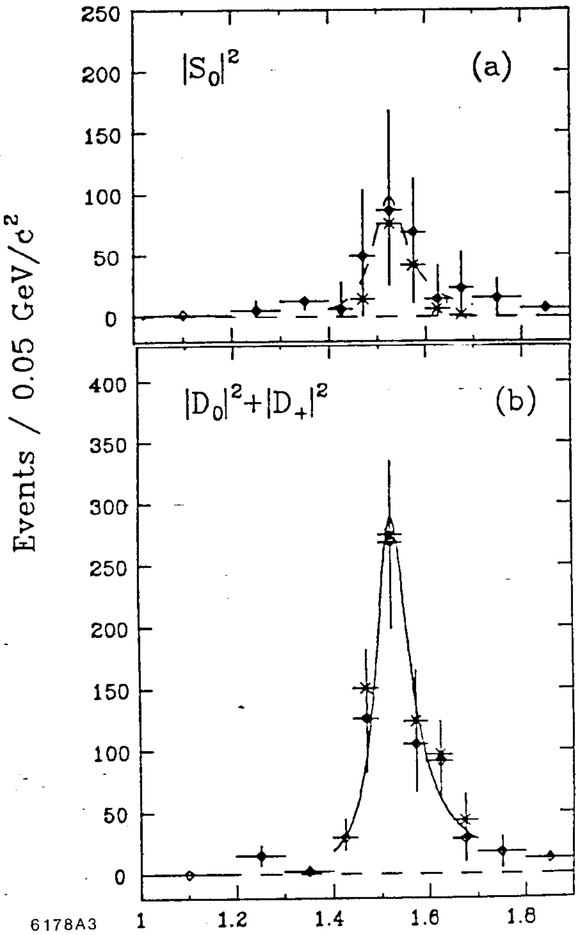

FIG. 3. The S-wave (a) and D-wave ($|D_-|^2$ is small) intensities from the amplitude analysis of reaction (2). The fits are described in the text. For details see Ref. 2.

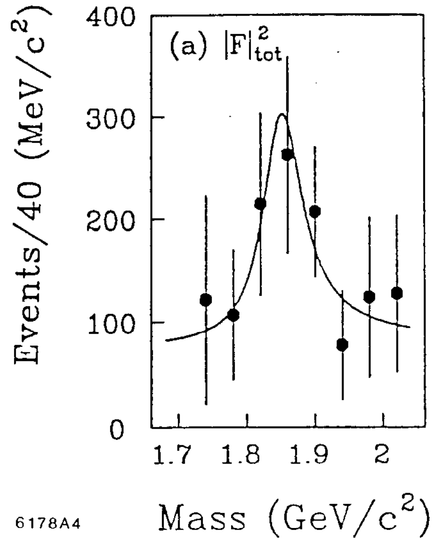

FIG. 4. The F-wave intensity, $|F|^2_{tot} = |F_0|^2 + |F_+|^2 + |F_-|^2$ from the analysis of reaction (1). For details see Ref. 5.

Figure 5 shows the sum of the moments which projects Re $(G^0 A^*_{\rm diff})$ + (*other terms*), showing a $\sim 3\sigma$ enhancement which is fit to a Breit-Wigner line shape with a linear background giving a mass of $2.21 \pm .02$ GeV/c^2 and a width of $0.06^{+.11}_{-.06}$ GeV/c^2. Details of this analysis can be found in Ref. 6.

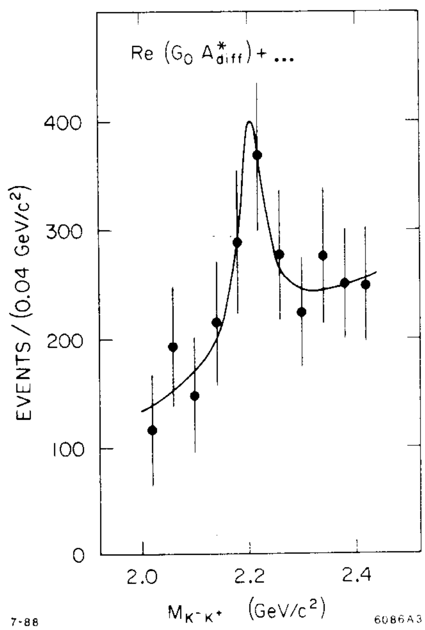

FIG. 5. The projection of the G_0 amplitude from reaction (1) beating against an effective imaginary amplitude, A_{diff}, from K^+p diffractive production. For details see Ref. 6.

A small enhancement in the 2.2 GeV/c^2 region is also seen in reaction (2) as shown in Fig. 6, where it is compared to the $X(2220)$ signal seen in radiative J/ψ decay by the Mark III collaboration.[4] The similarity of the two signals, together with the G-wave enhancement from reaction (1),

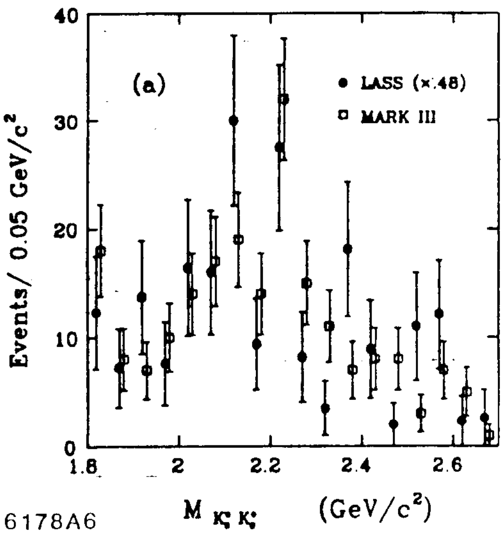

FIG. 6. The comparison of the $K^\circ_S K^\circ_S$ mass distribution from reaction (2) with that from radiative J/ψ decay[4] in the mass range 1.8-2.7 GeV/c^2.

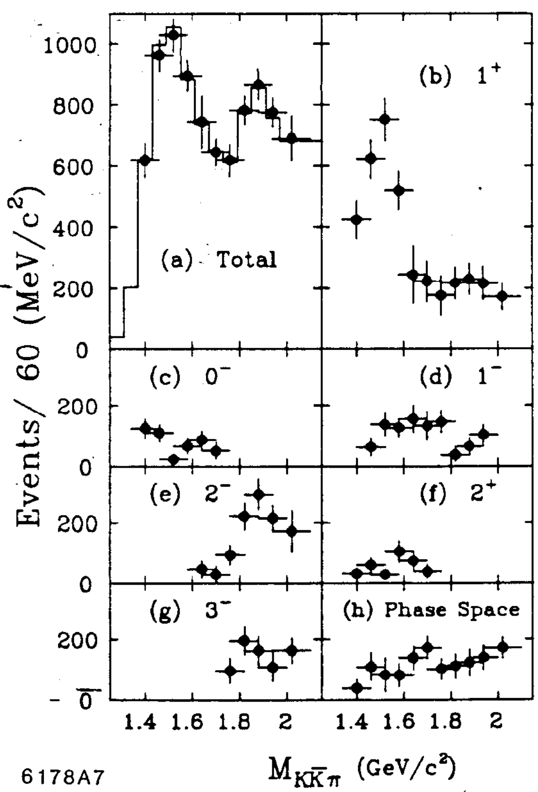

FIG. 7. The intensity distributions corresponding to the partial wave decomposition for the $K\overline{K}\pi$ system in reactions (3). For details see Ref. 7.

leads to the suggestion that the $X(2220)$ may be the $J^P = 4^+$ $f_4'(2210)$, the mainly $s\bar{s}$ member of the $^3F_4$ nonet.[6]

Reaction (3) has been analyzed using the SLAC-LBL three-body partial wave analysis as described in Ref. 7. The $K^+\overline{K}^\circ\pi^-$ and $K^-K^\circ\pi^+$ final states were analysed separately and, as the results are found to be consistent, the figures are summed. Sets of partial waves, using K^*, $\overline{K^*}$ and $a_0(980)$ as isobars along with a three-body phase space term, are chosen via an iterative search, keeping only those wave sets which significantly improve the calculated likelihood. The resulting spin-parity intensities are shown in Fig. 7. Figure 7(a) shows the total calculated intensity (dots) compared to the observed mass spectrum corrected for the average acceptance (histogram) and shows that the PWA accurately reproduces the data. The largest contribution to the data below 1.6 GeV/c^2 comes from the $J^P = 1^+$ amplitudes [Fig. 7(b)], but here the contributions from the K^* and $\overline{K^*}$ isobar wave sets are observed to be unequal with the $1^+\,\overline{K}^*$ intensity being about double that of the $1^+\,K^*$. This implies that the 1^+ peak is not due to a single resonance, but to two or more states which interfere. The observed inequality can be qualitatively explained by two resonances of opposite C-parity, as the relative signs between $K^*\overline{K}$ and $\overline{K^*}K$ final states in a decay is $\pm$ for G$=\pm1$ ($C = G$ assuming $I = 0$). The $J^P = 1^+$ partial waves were combined to form G-parity eigenstates, which are shown in Fig. 8. Two clear peaks are seen and fit to S-wave Breit-Wigner forms, shown as the curves in Fig. 8. Figure 8(a) shows the $J^{PC} = 1^{++}$ solution which gives a mass of $1.53 \pm .01$ GeV/c^2 and a width of $0.10 \pm .04$ GeV/c^2, confirming the

$D'(1530)$ seen previously in reactions (3) at 4.2 GeV/c.[8] This is a good candidate for the $f_1'(1530)$ which would replace the $f_1(1420)$ as the mostly $s\bar{s}$ member of the $^3P_1$ nonet. The fit to the 1^{+-} solution shown in Fig. 8(b) gives a mass of $1.38 \pm .02\,\mathrm{GeV/c^2}$ and a width of $0.08 \pm .03\,\mathrm{GeV/c^2}$, which we identify as the $h_1'(1380)$, the mainly $s\bar{s}$ member of the $^1P_1$ nonet.

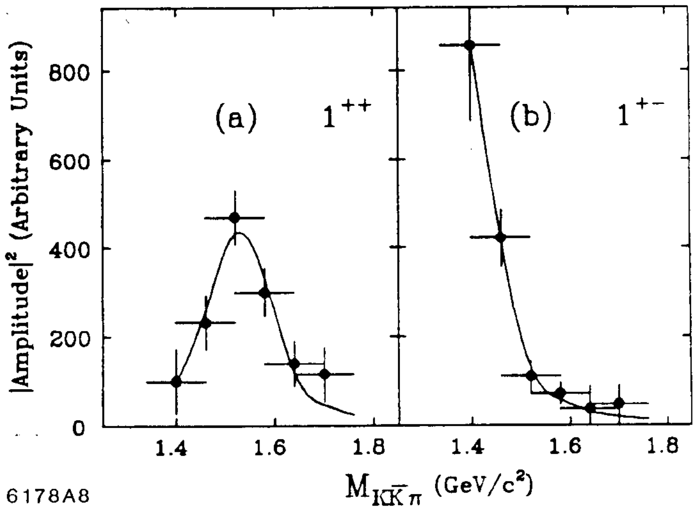

FIG. 8. The production amplitude combinations from reactions (3) giving positive (a) and negative (b) G-parity eigenstates. For details see Ref. 7.

4. CONCLUSIONS

This experiment has contributed greatly to the understanding of the $s\bar{s}$ spectrum. We have determined the spin-parity of the $\phi_3(1850)$.[5] We have shown evidence for the mostly $s\bar{s}$ member of the $^3F_4$ nonet, the $f_4'(2210)$.[6] We have candidates for the mostly $s\bar{s}$ members of all the $l = 1$ $q\bar{q}$ nonets: the spin triplet states—the well known $^3P_2$ $f_2'(1525)$, the $^3P_1$ $f_1'(1530)$,[7] and the $^3P_0$ $f_0'(1525)$[2] —which are seen to be nearly degenerate in mass, and the spin singlet $^1P_1$ $h_1'(1380)$.[7] For a more complete discussion of these analyses, please consult the references.

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