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EVIDENCE FOR $\rho_1(1270)$ PRODUCTION IN THE REACTION $K^-p \rightarrow \pi^+\pi^-\Lambda$*

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Preliminary results are presented from an analysis of the $\pi^+\pi^-$ system produced in the reaction $K^-p \rightarrow \pi^+\pi^-\Lambda$ at 11 GeV/c observed with the LASS spectrometer at SLAC. A clear $\rho - \omega$ interference effect is observed, and a fit to the natural parity exchange mass distribution yields a branching fraction estimate of (1.7 ± 0.5) % for the decay $\omega \rightarrow \pi^+\pi^-$. An amplitude analysis reveals that the bump in the mass distribution in the vicinity of the $f_2(1270)$ actually contains a significant P-wave component. The mass dependence of the corresponding amplitude and phase is well described by a resonant Breit-Wigner line-shape with mass (1266 ± 14) MeV/c^2, width (166 ± 35) MeV/c^2, and estimated elasticity ~ 5 %. The interpretation of this state as the first radial excitation of the $\rho(770)$ is discussed.

1. INTRODUCTION

This paper presents preliminary results from an analysis of the $\pi^+\pi^-$ system observed in the reaction

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

at an incident beam momentum of 11 GeV/c. In section 2, the data sample and characteristics of the final state are briefly discussed, and in section 3 an analysis of the $\rho - \omega$ interference effect is presented. In section 4, amplitude analysis results pertaining to the P-wave $\pi^+\pi^-$ system produced by natural parity exchange are shown; the observed resonant state is discussed with respect to other experimental information, and also in the context of the quark model level structure. Finally, section 5 contains concluding remarks together with comments on relevant future LASS analyses.

2. THE $\pi^+\pi^-\Lambda$ FINAL STATE

The data derive from an exposure of the Large Aperture Superconducting Solenoid (LASS) spectrometer at SLAC to a K^- beam of 11 GeV/c. The spectrometer and relevant experimental details are described elsewhere.[1,2] 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.

Four-constraint fits to events of the two-prong V^0 topology yield $\sim$ 32,000 events corresponding to reaction (1). The present analysis involves only those events for which the $\pi^+\pi^-$ system is peripherally produced

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with respect to the incident K^-; the selection criterion, $t_{p\to\Lambda} \leq 2(\mathrm{GeV/c})^2$, results in a data sample consisting of 26462 events. The Dalitz plot for these events is shown in Figure 1. Clear resonance bands are observed for the $\pi^+\pi^-$ system in the vicinity of the $\rho(770)$ and $f_2(1270)$, and there is also some indication of a faint band at the $\rho_3(1690)$. Strong production of $\Sigma^+(1385)$ is observed in the $\Lambda\pi^+$ system (Figure 2a), and there is clear evidence of the production of several higher mass Σ states in the mass range 1.7-2.1 GeV/c^2 (Figure 2b). No production of low-mass $\Lambda\pi^-$ states can be seen in Figure 1; this is to be expected for slow (i.e. $t_{p\to\Lambda} \leq 2(\mathrm{GeV/c^2})$) Λs, since the production of such states would require the exchange of a doubly- charged meson system in the t-channel. The Dalitz plot of Figure 1 is very similar to those observed for reaction (1) at lower energies,[3-6] and this clearly demonstrates the uniformity of acceptance of the LASS spectrometer, trigger and software.

The $\pi^+\pi^-$ mass distribution corresponding to Figure 1 is shown in Figure 3 for the mass region below 2 GeV/c^2. The peak in the ρ region is severely distorted with respect to a single Breit-Wigner line-shape; this is a consequence of $\rho - \omega$ interference, and will be discussed in the next section. There is a second peak in the vicinity of the $f_2(1270)$; however, the analysis discussed in section 4 shows that this is not due entirely to the production of this resonance. Finally, there is perhaps a small, broad enhancement at $\sim$ 1.7 GeV/c^2; this would correspond to the faint band observed in Figure 1, but its presence is masked to a large extent by the reflection of Σ production into the $\pi^+\pi^-$ mass spectrum (cf. Figure 1).

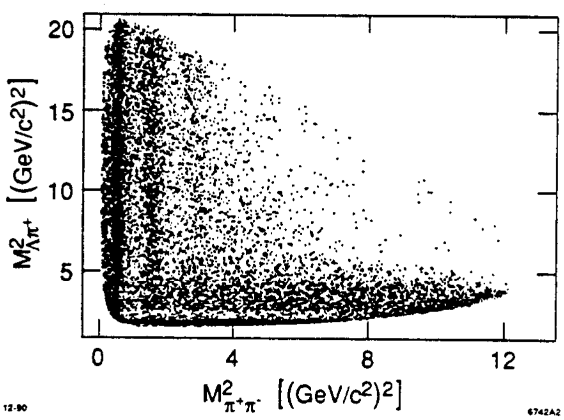

FIGURE 1
The Dalitz plot for the events of reaction (1) for which $t_{p\to\Lambda} \leq 2(\mathrm{GeV/c})^2$ (26462 events).

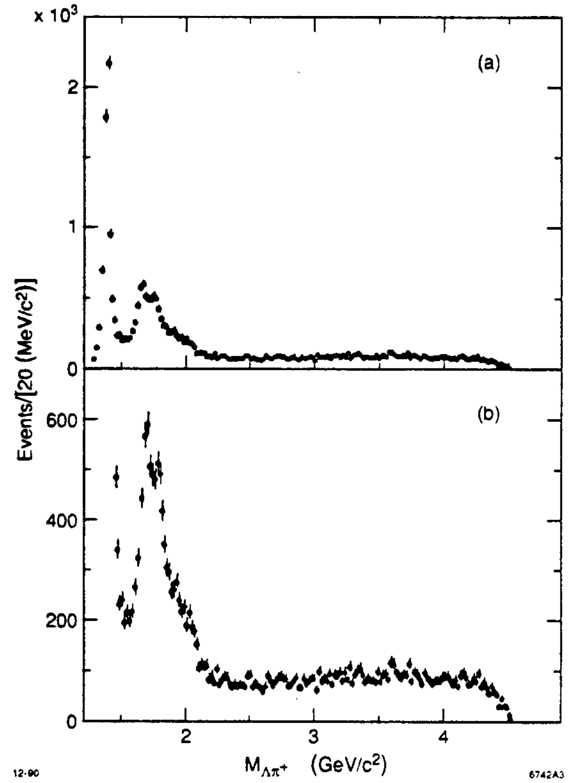

FIGURE 2
The $\Lambda\pi^+$ mass projection corresponding to Figure 1; (a) for all events, and (b), with the $\Sigma(1385)$ region removed.

3. $\rho - \omega$ INTERFERENCE

In order to analyze the $\pi^+\pi^-$ system, the observed events must first be corrected for acceptance losses. This is accomplished by weighting each event by the inverse of the acceptance function (determined by Monte Carlo study) evaluated at the point in phase space corresponding to the event in question. Since the acceptance is only slowly varying, the resulting $\pi^+\pi^-$ mass spectrum is almost indistinguishable in shape from that of Figure 3; also, the spherical harmonic moments describing the

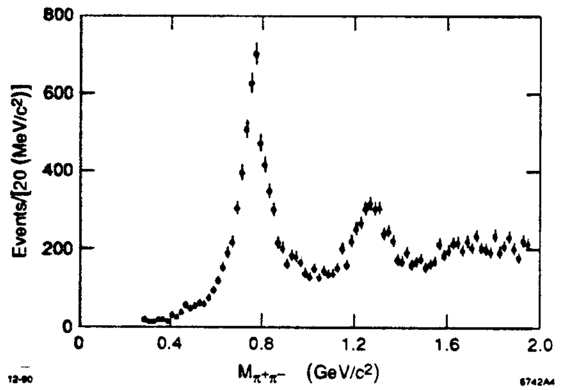

FIGURE 3
The $\pi^+\pi^-$ mass projection corresponding to Figure 1.

$\pi^+\pi^-$ angular distribution exhibit the same structure before and after correction.

The next step requires the removal of the overlap with Σ production (cf. Figure 1). Events having $\Lambda\pi^+$ mass less than 2.1 GeV/c^2 are removed from the data sample, and, for each $\pi^+\pi^-$ mass bin, the spherical harmonic moments describing the $\pi^+\pi^-$ angular distribution are corrected for the corresponding loss of real $\pi^+\pi^-$ events. These moments are then expressed in terms of the underlying amplitudes describing the $\pi^+\pi^-$ system,[7] and a chi-squared minimization method used to extract estimates of the relevant amplitudes and phases.

For reaction (1), both the moments and the resulting amplitude analysis reveal that the $\pi^+\pi^-$ system is produced predominantly via natural parity (i.e. K^*) exchange in the t-channel. In the ρ region, only S- and P-waves are required, and the combination of moments, σ_+, which projects the natural parity exchange cross section yields the mass distribution shown in Figure 4; σ_+ actually corresponds to $|P_+|^2 + |S|^2/3$, but the S-wave contribution is negligible compared to that due to P_+ (the subscript denotes natural parity exchange in the t-channel).

The distribution of Figure 4 cannot be described well by a single Breit-Wigner line-shape, and shows clear evidence of $\rho-\omega$ interference. Similar effects are observed for the corresponding much smaller unnatural parity exchange cross sections; however, the associated uncertainties are larger, and so these will not be considered further here.

The possibility of significant $\rho-\omega$ mass mixing has been recognized for many years,[8] and early estimates were that the resultant $\omega \rightarrow \pi^+\pi^-$ branching fraction might be $\sim$ 1-5 %.[8-10] The fit to the distribution of Figure 4 of the expression describing, to first order, the line-shape incorporating $\rho-\omega$ interference (equation (3) of ref. 11) yields the value (2.29 $\pm$ 0.35) MeV/c^2 for the mass-mixing term. This implies a branching fraction of (1.7 $\pm$ 0.5) % for the decay $\omega \rightarrow \pi^+\pi^-$, in excellent agreement with the original estimates[8-10] and with the present world average.[12] In order to obtain these results, complete coherence of the ρ and ω production amplitudes has been assumed; also, these production amplitudes have been assumed to be equal, as expected from SU(3). This is justified to some extent by the fact that the fitted value of the relative production phase is (-4 $\pm$ 10) degrees. The quality of the fit, as indicated by the open dots in Figure 4, is excellent, and the underlying line-shape, represented by the solid curve, exhibits a rather spectacular interference effect. The ρ

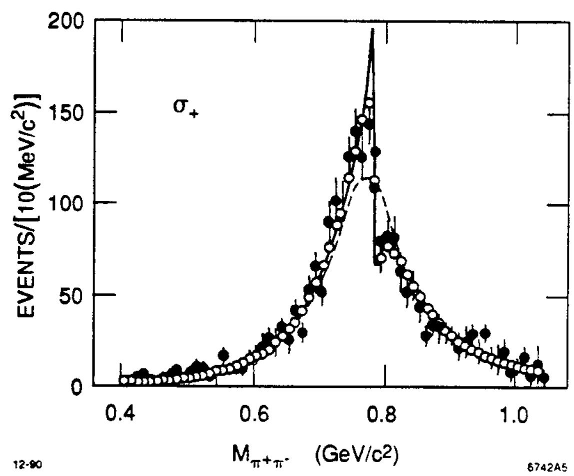

FIGURE 4
The σ_+ projection for the $\rho-\omega$ interference region of Figure 3. The data are shown as solid dots, the solid curve represents the fit expression described in the text, and the open dots correspond to the integral of this curve, after smearing for resolution, over each 10 MeV/c^2 bin. The dotted curve shows the contribution to the solid curve resulting from the ρ Breit-Wigner line-shape.

Breit-Wigner line-shape (dotted curve) clearly does not provide a good description of the data.

4. RESULTS OF THE AMPLITUDE ANALYSIS

The amplitude analysis described in section 3 was carried out using S-, P- and D-waves (i.e. 12 parameters) in the mass region up to 1.5GeV/c^2. The resulting S-wave is small and subject to large uncertainties. The ρ region is dominated by the P_+ amplitude, but P_- is also significant; P_0 is smaller than P_- and not very well defined. The D_+ and D_- waves show bumps at the $f_2(1270)$, but D_0 is somewhat non-descript. An unexpected feature is that P_+, and to a lesser extent P_-, also exhibit structure in this mass range. The mass dependence of the P_+ amplitude is shown in Figure 5a for the entire mass range analyzed; in the ρ region, the amplitude has the $\rho - \omega$ mixing structure discussed in section 3. However, at higher mass the amplitude does not simply decrease as the tail of the ρ Breit-Wigner (dotted curve), but shows a second maximum at ~1.27GeV/c^2. The solid curve corresponds to a simultaneous fit to the P_+ and D_+ amplitudes and relative phase (Figure 5b); in this fit, P_+ is described by the sum of the $\rho - \omega$ mixing amplitude and a Breit-Wigner describing the 1.27GeV/c^2 region, while the D_+ wave is represented by an $f_2(1270)$ Breit-Wigner. The fit yields mass and width values of (1266 ± 14)MeV/c^2 and (166 ± 35)MeV/c^2, respectively, for the new P-wave resonance (the $\rho_1(1270)$), and the resulting description of the data of Figures 5a and 5b is clearly very good. The dotted curve of Figure 5b corresponds to that of Figure 5a (i.e. has no $\rho_1(1270)$ contribution), and does not provide a good description of the relative phase in the range 1.2 -1.5GeV/c^2 within which it is quite well measured. Finally, the size of the $\rho_1(1270)$ amplitude relative to that of the $\rho(770)$ indicates an elasticity ~ 5 - 10 % for this state.

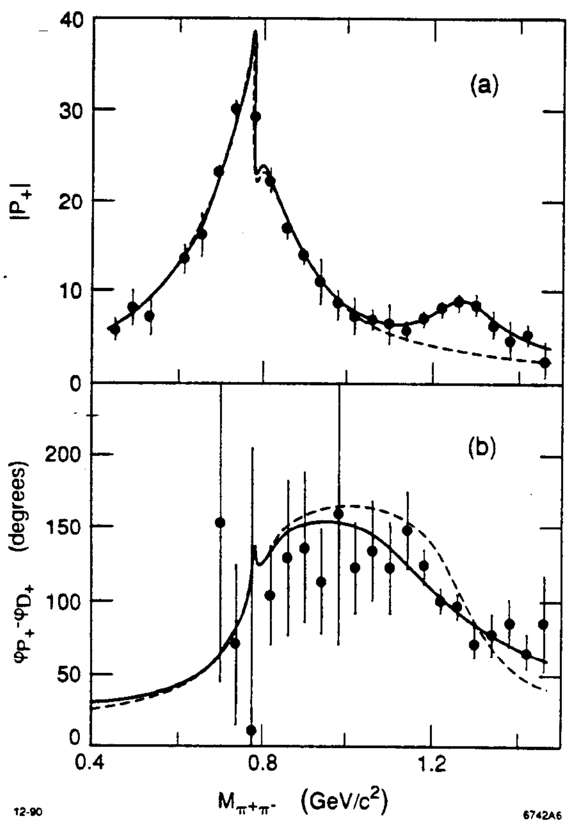

FIGURE 5
(a) The mass dependence of the magnitude of the P_+ amplitude resulting from the fits to the spherical harmonic moments described in the text. The solid curve represents the expression describing the $\rho - \omega$ region together with a P-wave Breit-Wigner centered at ~ 1.26 GeV/c^2. The dotted curve corresponds to the solid curve with the additional Breit-Wigner contribution set to zero. (b) The mass dependence of the relative phase between the fitted P_+ and D_+ amplitudes. The solid and dashed curves represent the phase difference between the amplitudes corresponding to the solid and dashed curves of Figure 5a, and a D-wave Breit- Wigner amplitude describing the $f_2(1270)$.

In the only other large statistics analysis of the $\pi^+\pi^-$ system in reaction (1),[5] no amplitude analysis was attempted because of the much more severe kinematic overlap with Σ production at 4.2 GeV/c incident K^- momentum; it was simply assumed that the bump at ~ 1.27GeV/c^2 was due to $f_2(1270)$ production. However, the P-wave amplitude structure obtained for $\pi^+\pi^-$ elastic scattering[13] does show some intriguing irregularity in this mass range. The value of the absorption parameter, η, is systematically below 1 throughout this region by an amount which is quite consistent with the presence of a $\rho_1(1270)$ state of elasticity ~ 5 %. Indeed, the parametrization in ref.13 of the P-wave amplitude in terms of the $\rho(770)$ and the $\rho_1(1590)$ (elasticity ~ 25 %)[13] provides a poor description of the mass dependence of η, and also of the Y_1^0 and Y_3^0 spherical harmonic moments, in this mass range; the addition of the $\rho_1(1270)$ with elasticity 5 % greatly improves the fit to the η mass dependence.

In the context of the $q\bar{q}$ level scheme, the $\rho_1(1270)$ is most naturally interpreted as the first radial excitation of the $\rho(770)$. Taken together with the $\rho_1(1590)$ of ref.13, this results in a level structure for the 1^- states in the isovector sector which is remarkably similar to that observed in the strange meson sector.[14] The mass splittings are almost identical, and the first radial excitation has elasticity $\sim$ 5-10 % in both cases. In this regard, it should be noted that the rest frame decay momenta for the $\rho_1(1270)$ and the $K_1^*(1410)$ are almost the same, so that, if the small elasticity is related to the nodal structure of the final state radial wave function,[14] it would be expected that BOTH states should be highly inelastic.

This picture of the isovector 1^- level structure agrees to some extent with that of ref.15, in that there are indeed two excited ρ_1 states, and each has width $\sim$ 200MeV/c^2. Furthermore, the elasticity of the lower mass state is $\sim$ 5%, while that of the higher mass state is $\sim$ 20% in each case. However, the mass values obtained in ref.13 and the present analysis are very different from those obtained in ref.15, namely $\sim$ 1.47GeV/c^2 and $\sim$ 1.7GeV/c^2. It is not immediately obvious how this disagreement might be resolved; however, it should be pointed out that the model of ref.15 does not reproduce the mass dependence of the P-wave η parameter in the $\rho_1(1270)$ region as measured in ref.13.

5. CONCLUSION

The present analysis of the $\pi^+\pi^-$ system in reaction (1) has revealed a rather striking corroboration of the phenomenon of $\rho - \omega$ interference. The resulting value of the $\omega \rightarrow \pi^+\pi^-$ branching fraction, $(1.7\pm0.5)\%$, agrees well with the present world average, and also with theoretical expectations.

An amplitude analysis of the spherical harmonic moments describing the $\pi^+\pi^-$ angular distribution has provided evidence for the existence of a new P-wave state, the $\rho_1(1270)$; this state has elasticity $\sim$ 5-10 %, and is most readily understood as the first radial excitation of the $\rho(770)$. The resulting level structure in mass of the known vector meson states exhibits a striking similarity between the isovector and strange meson sectors.

The LASS collaboration is presently beginning analyses of the final states $\Sigma^+(1385)\ \pi^-\pi^0$ and $\Sigma^+(1385)\ \pi^+\pi^-\pi^-\pi^0$ in order to further elucidate the nature of the $\rho_1(1270)$. However, it is clear that it is important to investigate these reactions and reaction (1) at a much higher statistical level, but under the conditions of uniform acceptance which obtain for the LASS data samples. It would also be highly desirable to repeat the analysis of ref.13 with data acquired under such conditions.

It is probable that such studies could be carried out only in the context of the hadron spectroscopy program envisioned for the proposed KAON factory. Consequently, a detailed understanding of the vector meson states may not be forthcoming until this facility is approved and constructed.

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