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Characteristics of the S-Wave $\bar{K}K$ Enhancement at 1300 MeV*

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Our high-statistics experiment on $\pi^-p\to K^-K^+n$ and $\pi^+n\to K^-K^+p$ at 6 GeV/c confirms the $\bar{K}K$ S-wave enhancement near 1300 MeV recently observed by Cason *et al.* in $\pi^-p\to K_S^0K_S^0n$. Using the F-wave amplitude and the isospin dependence of interfering $\bar{K}K$ states, we resolve partial-wave ambiguities and find the S wave to be dominantly isospin $I=0$, with a slow variation of phase. This excludes the interpretation of Cason *et al.* that the S wave enhancement is a narrow $I=1$ state.

A new $\bar{K}K$ S-wave state with mass 1255 ± 5 MeV and width 79 ± 10 MeV has been reported by Cason *et al.*[1] in an experiment which studied the reaction

$$\pi^-p\to K_S^0K_S^0n, \tag{1}$$

at 6 and 7 GeV/c. The mass and width were determined from one of two phase-shift solutions by using the phase variation with mass given by the S-D interference in the Y_2^0 moment of the $K_S^0K_S^0$-decay angular distribution for $-t<0.2$ GeV^2. Measurement of Reaction (1) alone does not determine the isospin I of the S wave. While Cason *et al.* suggested that the effect has $I=1$, our results show that the isospin is zero. We also find that the more slowly varying phase solution is preferred, and not the rapidly varying solution which yielded the above values for the mass and width.

We have performed a high-statistics comparison of

$$\pi^-p\to K^-K^+n \quad (110\,000 \text{ events}), \tag{2}$$

and

$$\pi^+n\to K^-K^+p \quad (50\,000 \text{ events}), \tag{3}$$

at 6 GeV/c using the Argonne effective-mass spectrometer. We studied the region of K^-K^+ mass $M<1750$ MeV and momentum transfer $-t<0.40$ GeV^2; details are given elsewhere.[2,3] Comparison of the K^-K^+-decay moments from Reactions (2) and (3) directly isolates contributions from interferences between K^-K^+ states of differing isospin. It has been shown[2-4] that if A_0 and A_1 are the amplitudes for production of $I=0$ and $I=1$ K^-K^+ states in Reaction (2), then the amplitude for Reaction (2) is A_0+A_1, while for Reaction (3) the amplitude is A_0-A_1. Symbolically, we can write the cross sections for Reactions (2) and (3) as

$$\sigma^\mp \propto |A_0\pm A_1|^2=|A_0|^2+|A_1|^2\pm 2\,\mathrm{Re}(A_0A_1^*),$$

where $\sigma\equiv(4\pi)^{1/2}d^2\sigma/dtdM$ and the superscripts $-$ and $+$ refer to Reactions (2) and (3), respectively. Summing the two cross sections eliminates the $A_0A_1^*$ interference term; taking the difference isolates that term:

$$\sigma_{\text{sum}}\propto|A_0|^2+|A_1|^2,$$

$$\sigma_{\text{dif}}\propto\mathrm{Re}(A_0A_1^*),$$

where $\sigma_{\text{sum}}\equiv\sigma^-+\sigma^+$, $\sigma_{\text{dif}}\equiv\sigma^--\sigma^+$. Similar relations hold for the various K^-K^+-decay moments $\sigma\langle Y_l^m\rangle$.

By charge independence, the amplitude for $\pi^-p\to\bar{K}^0K^0n$ is the same as that for Reaction (3), and the even partial-wave amplitudes for Reactions (1) and (3) are the same except for a factor of $\sqrt{2}$ (since $K_S^0K_S^0$ and $K_L^0K_L^0$ each take one half of the even partial-wave cross section for $\pi^-p\to\bar{K}^0K^0n$).

We can determine the S-wave contribution to the cross section at small t. In Ref. 3 we have identified the non-S-wave contributions to the sum cross section $\sigma_{\text{sum}}\langle Y_0^0\rangle$ and these can be subtracted off to give $\sigma_{\text{sum}}^S\langle Y_0^0\rangle=2(|I=0\ S\text{ wave}|^2+|I=1\ S\text{ wave}|^2)$, which is shown in Fig. 1. The S^* peak below 1100 MeV is clearly exhibited, as well as a second peak of mass ~ 1300 MeV and width ~ 150 MeV. The S wave accounts for nearly half of the K^-K^+ cross section at 1300 MeV, and the systematic uncertainty in $\sigma_{\text{sum}}^S\langle Y_0^0\rangle$ is about ± 10% in this region.

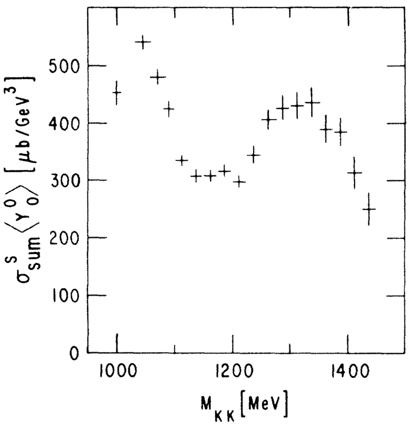

FIG. 1. The S-wave contributions to $\sigma_{sum}\langle Y_0^0\rangle$ for $-t < 0.08$ GeV^2, from the subtraction procedure described in the text.

The Y_2^0 moments for all three reactions are very similar at small momentum transfer, as shown in Fig. 2. Below 1200 MeV these moments are dominated by a negative S-D interference; above 1200 MeV the positive $|D|^2$ term from the f meson becomes dominant. For $-t < 0.08$ GeV^2 the S-D interference seen in Y_2^0 near 1200 MeV is about 3 times larger in the sum spectrum than in the difference spectrum. Since the D-wave cross section is mainly $I=0$ at small t (Ref. 2), the Y_2^0 moments suggest that the $I=0$ part of the S-wave cross section shown in Fig. 1 is of the order of 10 times the $I=1$ contribution.

To investigate this in more detail, we have used the same assumptions as those made in Ref. 1 to perform an amplitude analysis[5] of the K^-K^+ system produced in Reactions (2) and (3) for $-t \leq 0.08$ GeV^2. For each reaction there is a fourfold ambiguity in the partial-wave amplitudes, two solutions giving the S-wave enhancement near 1300 MeV, and the remaining pair giving a large P-wave amplitude in this region. The latter solutions can be rejected in a model-independent way for Reaction (3), since they are incompatible[6] with the results from Reaction (1).

By choosing the P-wave solution to be that expected theoretically, we can resolve the remaining ambiguities. Morgan[7] has shown that the P wave is consistent with the tail of the ρ^0 decaying into K^-K^+, with a ρKK coupling that agrees with SU(3), including the sign. To show better this consistency we have fitted $\sigma_{dif}\langle Y_3^0\rangle$ for $-t < 0.08$ GeV^2 to ρ-f interference, for $M < 1450$ MeV. We used a relativistic Breit-Wigner form for the f and the Roos[8] parametrization of the $\pi^-\pi^+$ P wave, corrected for K^-K^+ phase space and barrier effects,[3] with arbitrary normalization. The couplings of both ρ and f to K^-K^+ relative to $\pi^-\pi^+$ were chosen to be positive in accord with SU(3).[9] The data are well described by this prescription, as shown by the curve in Fig. 2(h). In addition, the magnitude of the SU(3) prediction can be independently checked by looking at the ratio between the ρ-f interference observed here in $\frac{1}{2}\sigma_{dif}\langle Y_3^0\rangle$ and that found in our companion $\pi^-p \to \pi^-\pi^+n$ experiment,[10] $\sigma_{\pi\pi}\langle Y_3^0\rangle$. After correcting for f-g interference in the $\pi\pi$ reaction, we get a ratio of 0.029 ± 0.008, in good agreement with the

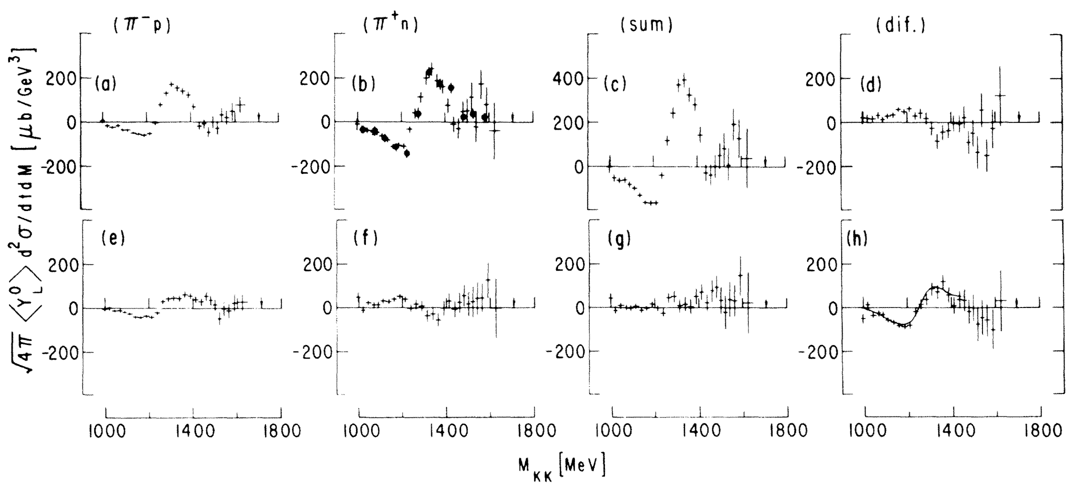

FIG. 2. Moments for Reactions (2) and (3), their sum and difference, as functions of M for $-t < 0.08$ GeV^2; the arrow at 1690 MeV indicates the point at which $t_{min} = -0.08$ GeV^2. The moments are calculated in the t-channel (Jackson) frame. (a)–(d) $\sigma\langle Y_2^0\rangle$. The solid points in (b) are the data of Cason *et al.* (Ref. 1) on Reaction (1) for $-t < 0.20$ GeV^2, renormalized so that $\sigma\langle Y_4^0\rangle$ for $1250 < M < 1400$ MeV agrees with $\sigma^+\langle Y_4^0\rangle$ for $-t < 0.08$ GeV^2. (e)–(h) $\sigma\langle Y_3^0\rangle$. The curve in (h) is the result of the ρ-f interference fit described in the text.

SU(3) value of 0.019.[11]

Only one of the ambiguous solutions corresponds to the SU(3) prediction, and the others can all be rejected since they result in very different P-wave amplitudes. The one remaining solution was used to calculate the S-wave cross section shown in Fig. 1 and leads to a dominantly $I=0$ S wave with values of $|\varphi_D - \varphi_S|$ in good agreement with those found by Cason *et al.*[1] It further resolves the ambiguity of the sign of the difference between φ_D and φ_S in favor of the slow steady variation of the S-wave phase shown by "solution 2" of Cason *et al.* Since other solutions do not give the P-wave behavior expected, we conclude that the solution with a large $I=0$ S wave and slowly varying phase is by far the preferred solution.

In their amplitude analysis Cason *et al.* found a relatively shallow t dependence for the S-wave cross section, a slope of 3.7 ± 0.8 GeV^{-2} in the mass range 1.22 to 1.32 GeV, compared with 11.9 ± 1.2 GeV^{-2} for the D wave. This was used to argue that one-pion exchange was not important for the S-wave enhancement, and that it therefore had odd G parity and $I=1$. The cross sections for our two reactions (2) and (3) show a difference in slope indicating that both $I=0$ and $I=1$ waves are important at large t. Since the $\sigma\langle Y_4^0\rangle$ moments do not show a difference, this is not a D-wave effect, but is primarily due to interferences in the S-wave amplitudes. The slope of the S-wave cross section observed in any one reaction is then difficult to interpret, since it is due to a coherent sum of the $I=0$ and $I=1$ amplitudes. The interpretation of the slope is further complicated by the fact that the assumptions required for the amplitude analysis may not be valid at large t where terms other than one-pion exchange can become important.

With $I=0$, the small-t enhancement in $\sigma_{\rm sum}{}^S\langle Y_0^0\rangle$ around 1300 MeV has the same quantum numbers as the S^*, namely, $I^GJ^{PC}=0^+0^{++}$, and we refer to this enhancement as the S'. Since the S^* and S' can interfere with one another, the $\sigma_{\rm sum}{}^S\langle Y_0^0\rangle$ spectrum should not be interpreted in terms of two incoherent peaks. Indeed, the slow phase variation of our solution argues against interpretation in terms of a narrow S' state. Using Flatte's parametrization[12] of the S^* with $M\approx 960$ MeV and $\Gamma\approx 100$ MeV, we find that the intensity and phase of the total $I=0$ S wave can be described by adding to the S^* a very slowly varying S' amplitude. The intensity minimum in $\sigma_{\rm sum}{}^S\langle Y_0^0\rangle$ around 1150 MeV is caused by destructive interference between the S^* (Im$S^*>0$) and the S' (near-constant S' phase $\sim 270°$). The properties of the S' would then be consistent with the broad ϵ effect seen in $\pi\pi\to\pi\pi$ in this mass region,[7,13] the ϵ having a negative coupling to K^-K^+ relative to $\pi^-\pi^+$. This explanation is of course not unique since the mass and width of the S^* are uncertain. We should also point out that with its large coupling to $K\bar{K}$, the S' does not fit well into a conventional SU(3) framework in which this decay would be strongly suppressed.

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