Four-quark nature of the scalar S^* meson

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The strong coupling of S^* meson with $K\bar{K}$ and $\eta\eta$ channels favors the four-quark model. Thre is no justification for the generally accepted behavior of the phase of the elastic $\pi\pi$ scattering above the threshold of the $K\bar{K}$ channel.

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The quark-bag model predicts an octet of scalar mesons in the four-quark system ($qq\bar{q}\bar{q}$) with masses of about 1 GeV.[1] The most accurate experimental manifestations of these are S^* [980, $0^+(0^+) \to \pi\pi, K\bar{K}$] and δ [980, $1^-(0^+) \to \pi\eta, K\bar{K}$] resonances with [2]$\Gamma_{S^*} \approx \Gamma_\delta \approx 50$ MeV. Until now, however, there have been no definite theoretical conclusions about this calculation.

In this paper we analyze new data with high statistics for the $\pi\pi \to K\bar{K}$ reaction[3] by using parametrization of the coupled two-particle channels. In contrast to the approach of all the preceding authors, we take into account the corrections for the finite width of the S^* resonance whose role in this case is so large that new possibilities of interpreting it as a threshold effect, a cusp, arise.

1. The results of our analysis definitely favor strong coupling between S^* and the $K\bar{K}$ channel, as predicted by the four-quark model.[1]

2. We show that the data for the $\pi\pi \to K\bar{K}$ reaction near the $\eta\eta$ threshold (1.1 GeV) favor strong coupling between S^* and the $\eta\eta$ channel, which is also a characteristic feature of the four-quark structure of the S^* meson.[1] It was predicted that the cross sections $\pi N \to \eta\eta N$ and $\eta N \to K^+K^-N$ for the s waves of $\eta\eta$ and K^+K^- have the same order of magnitude as $m_{\eta\eta} = m_{K^+K^-} > 2m_\eta$.

3. Finally, we conclude that there is no compelling reason to trust the generally accepted[2] behavior of the elastic $\pi\pi$-scattering phase above the $K\bar{K}$ threshold, since the phase rapidly changes in the region of 20 to 30-meV width near the $K\bar{K}$ threshold. To resolve this problem, a new, more comprehensive experimental investigation of the $\pi\pi \to \pi\pi$ process near the $K\bar{K}$ threshold must be performed.

$$T(\pi\pi \to \pi\pi) = \frac{\eta_0^0\, l^{2i\delta_0^0} - 1}{2i\rho_{\pi\pi}} = \frac{e^{2i\delta_B} - 1}{2i\rho_{\pi\pi}} + l^{2i\delta_B}\, T^{S^*}_{\pi\pi \to \pi\pi}\ . \tag{1}$$

$\delta_0^0 = \delta_B + \delta_S^*$, $\delta_B = a + s^{1/2}$, b is the well-known phase of the smooth background and δ_S^* is the resonance-amplitude phase $T^{S^*}_{\pi\pi\to\pi\pi}$. For $2m_K \leqslant s^{1/2} \leqslant 2m_\eta$

$$T(\pi\pi \to K\bar{K}) = e^{i\phi}\,|\,T^{S^*}_{\pi\pi \to K\bar{K}}\,| = e^{i\phi}(1 - \eta_0^{0\,2})^{1/2} / (\rho_{\pi\pi}\rho_{K\bar{K}})^{1/2}, \tag{2}$$

$$\phi = \delta_B + \tilde{\delta}_B + \text{phase}\ (1/D_{S^*}), \tag{3}$$

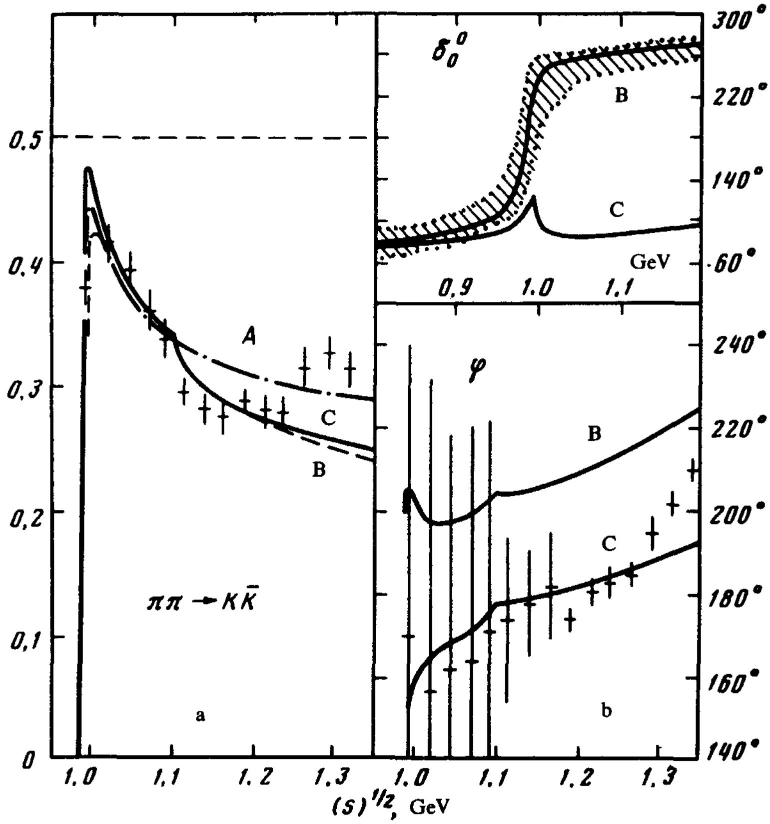

FIG. 1. (a) $|T(\pi\pi\to K\bar{K}|(\rho_{\pi\pi}\rho_{K\bar{K}})^{1/2}=(1-\eta_0^{02})^{1/2}/2$ and (b) is the phase ϕ of the amplitude of the $\pi\pi\to K\bar{K}$ reaction. The data were taken from Ref. 3. (c)-The δ_0^0 phase for the $\pi\pi\to\pi\pi$ reaction, the shaded band corresponds to data (see Ref. 2) obtained in different experiments. The curves correspond to the fits in Table I.

$\tilde{\delta}_B$ is the phase of the amplitude background of $K\bar{K}\to K\bar{K}$, which henceforth will be disregarded because $\tilde{\delta}_B \ll \delta_B$ is near the $K\bar{K}$ threshold.

$$T^{S^*}_{\beta\to a} = (g_{aS^*}\, g_{S^*\beta}/16\pi)/D_{S^*}(s), \tag{4}$$

$$D_{S^*}(s) = m^2_{S^*} - s + \sum_a \mathrm{Re}\,\Pi^a_{S^*}(m^2_{S^*}) - \sum_a \Pi^a_{S^*}(s), \tag{5}$$

α and β are the indices of the two-particle channels ($\pi^+\pi^-$, K^+K^-,...) $\rho_\alpha = 2q_\alpha/s^{1/2}$, and q_α is the pulse of one of the particles in the c.m.s. of the α channel. The unitarity condition requires that

$$g_{aS^*} = g_{S^*a}, \quad \mathrm{Im}\Pi^a_{S^*} = s^{1/2}\,\Gamma_{S^*a} = \frac{|g_{S^*a}|^2}{16\pi}\,\rho_a \begin{cases} 1, & a \neq \pi^0\pi^0, \eta\eta, \\ 1/2, & a = \pi^0\pi^0, \eta\eta. \end{cases} \tag{6}$$

TABLE I. Characteristics of the S^* resonance.

Data	Fits	m_{S^*} MeV	$\frac{g^2_{S^*K^+K^-}}{4\pi}$ GeV²	$\frac{g^2_{S^*\pi^+\pi^-}}{4\pi}$ GeV²	$\frac{g^2_{S^*\eta\eta}}{4\pi}$ GeV²	$\Gamma_{S^*\pi\pi}$ MeV for $s^{1/2} = 1$ GeV	$R_1 = \frac{g^2_{S^*K^+K^-}}{g_{S^*\pi^+\pi^-}}$
$\pi^+\pi^- \to \to K^+K^-$	A	1460 cusp	4.72	0,45	0	160	10.5
[3]	B	984	2,2	0,27	1,86	96	8.15
	C	1400 cusp	4,32	0,4	3,2	144	10,8

A correction for the finite width of the α channel is contained in the expression $\pi^\alpha_{S^*}(s) - \mathrm{Re}\Pi^\alpha_{S^*}(m^2_{S^*})$, which is a α-channel contribution to the self energy of the S^* resonance. We emphasize that the corrections for the finite width are essentially attributable to the dispersion relation for $D^*_S(s)$. In contrast to the vector resonances,[4] for scalar resonances they are uniquely determined by the renormalized resonance mass m_{S^*}.

We fitted the data from Ref. 3 for $|T(\pi\pi\to K\bar{K})|$ for $s^{1/2} < 1.25$ (see Fig. 1a). For $s^{1/2} > 1.25$ the situation is not clear: on the one hand, the data apparently require the introduction of a new resonance; on the other hand, there are serious doubts that the s wave of $\pi\pi\to K\bar{K}$ can be correctly isolated from the $\pi N\to K^+K^-N$ reaction in this region.[3] We did not include into the fit the data for the phase ϕ of the amplitude $\pi\pi\to K\bar{K}$, because they have a large error in the region of interest (see Fig. 1b which shows our prediction for ϕ at $\tilde{\delta}_B \ll \delta_B$. The results of our fit are shown in Fig. 1 and in Table I. In all the cases we obtained a strong coupling between S^* and the $K\bar{K}$ channel ($R_1 \gg 1$, see Table I). From our viewpoint, a sharp break in $|T(\pi\pi\to K\bar{K})|$ at $s^{1/2} \approx 1.1$ GeV (see Fig. 1a) is due to inclusion of the $\eta\eta$ channel. In any case, $\chi^2 \approx 6$ for eleven experimental points of cases (B) and (C) which take the $\eta\eta$ channel into account; this is one-half the value of that for case (A) in which the $\eta\eta$ channel is disregarded. The coupling of S^* with $\eta\eta$ is of the same order of magnitude as that with K^+K^-. Note that case (C) is a typical cusp: the broad resonance is located at $s^{1/2} = 1400$ and a peak in the amplitude appears at the threshold of the $K\bar{K}$ channel.

To describe the phase of the elastic $\pi\pi$ scattering δ^0_0, we used the parameters of the (B) and (C) fits. Here, discovered an extremely important fact. The cases (B) and (C), which describe $|T(\pi\pi\to K\bar{K})|$ equally well, reveal basically different behavior of δ^0_0 (see Fig. 1c). The case (B) describes rather well the standard[2] behavior of the phase, whereas the case (C), which is more preferable from the viewpoint of description of data for the phase of the amplitude $\pi\pi\to K\bar{K}$ (see Fig. 1b), could describe the δ^0_0 data if we would subtract 180° from them at $s > 4m^2_K$. We believe that the generally accepted behavior of δ_0^0 is not justifiable. The fact is that δ_0^0 is determined experimentally at each s point with an accuracy to πn, and its relative value for the two neighboring points is determined from the continuum. In our case, δ_0^0 varies rapidly in the region of 20 to 30-meV width near the $K\bar{K}$ threshold, and hence we do not know whether δ_0^0 lies in the third[2] or first quadrant.

Let us summarize the discussion. To explain the experimental data, we must introduce a scalar S^* meson that has been "mutilated" by corections for the finite width, as compared with the ordinary resonances. Note that an analogous analysis of much poorer data for the δ meson does not exclude the four-quark structure δ. On the basis of our analysis, we believe there is a chance that all the data for ϵ, S^*, δ, and κ mesons[1] can be explained by taking into account the corrections for finite width. We are now trying to do this.

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