Is there evidence for the four-quark nature of the δ meson?

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It is shown that experimental data for the scalar δ meson can be interpreted in favor of the four-quark model $(qq\bar{q}\bar{q})$.

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The title of this paper has been put in the form of a question because all the analyses[1–4] of the experimental data for the δ $[I^G(J^P) = 1^-(0^+)]$ 980-MeV meson[1,5] thus far have contradicted the four-quark $(qq\bar{q}\bar{q})$ model[6] of the δ resonance. This statement must be clarified, since no such conclusions have been reached. The fact is that the four-quark model definitely predicts the relation[6]:

$$g_{\delta^- K^- K^\circ} = -\sqrt{\frac{3}{2}}\, g_{\delta^- \pi^- \eta} = \sqrt{2}\, g_{\delta^\circ K^+K^-} \, . \tag{1}$$

for the coupling constants of the δ meson with pseudoscalar mesons. All analyses taking into account the relation (1) (see Refs. 1–4) give $\Gamma_{\delta\pi\eta} = 80$ MeV and a relatively smaller value $\Gamma_{(\text{eff})} \approx 50$ MeV for the total effective width, because of the influence of the $K\bar{K}$ channel. It is clear that in this case we cannot regard as "superallowed" the $\delta \to \pi\eta$ decay, which is not suppressed because of the phase volume of the decay products. Such assumption contradicts the spirit of the four-quark model, which predicts a "superallowed" (i.e., strong) coupling of scalar mesons with pseudoscalar mesons.[6] The scalar mesons in the four-quark model "consist" of pseudoscalar mesons[6] in some sense; for example,

$$\delta^- = s\bar{s}n\bar{p} \text{ ,and} K^- \otimes K^\circ = \bar{p}s \otimes \bar{s}n, \; \pi^- \otimes \eta = \bar{p}n \otimes (\bar{p}p + \bar{n}n$$

$$- 2\bar{s}s\,)\,/\,\sqrt{6}, \; \pi^- \otimes \eta' = \bar{p}n \otimes (\bar{p}p + \bar{n}n - \bar{s}s\,)\,/\,\sqrt{3}\,. \tag{2}$$

Therefore, the total widths of the scalar mesons should be of the order of 500 MeV, if their "superallowed" decay channels are not suppressed because of the phase volume.

In this paper we show that the experimental data[1] (see Fig. 1) indeed are in agreement with the four-quark model. How is the information extracted from the data of Ref. 1? We assume at the outset that the data for the $\pi\eta$ mass spectrum (Fig. 1a) are described by a narrow resonance above the high background that is proportional to the $\pi\eta$ phase volume.[1–4] In this case a high background is needed to account for the $K\bar{K}$ spectrum. Such an analysis, however, cannot be used to look for the tracks of the $(qq\bar{q}\bar{q})$ states. We must attempt to explain the data by assuming a strong coupling ("superallowed") with the $\pi\eta$ and $K\bar{K}$ channels. The peak in the $\pi\eta$ mass spectrum in

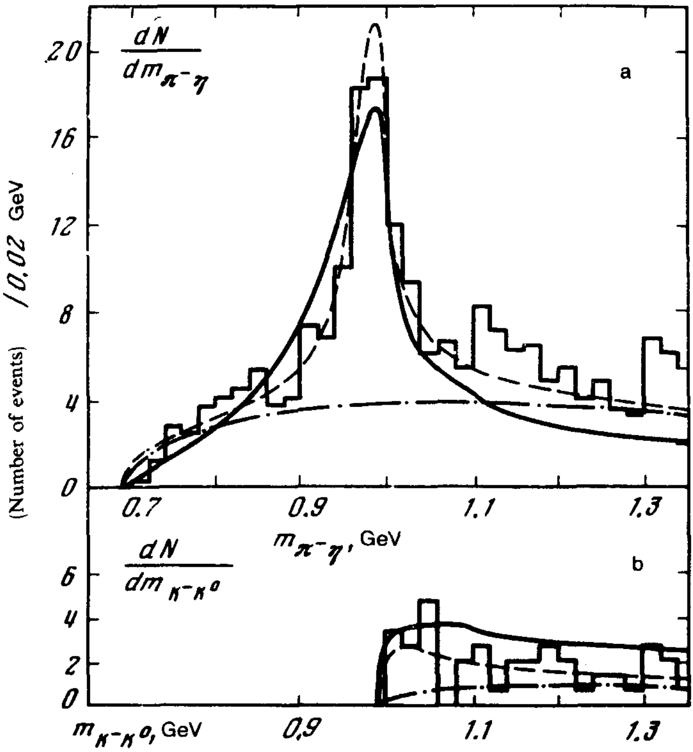

FIG. 1. Mass spectra of (a) $\pi^-\eta$ and (b) K^-K^0 systems in the reaction $K^-p \to \sigma^-\Sigma^+_{1385} \to (\pi^-\eta, K^-K^0)\Sigma^+_{1385}$.[1] The solid lines represent our results and the dashed line shows the fit of the data from Ref. 1, which were obtained by assuming that the δ resonance is narrow ($\Gamma_{\delta\pi\eta} \approx 72$ MeV) and the background is large (see ---- curves) in the $\pi^-\eta$ and K^0K^- mass spectra.

this case must be related to the $K\bar{K}$ threshold situated next to the resonance mass. We have performed such an analysis in this paper by using the following mass spectra:

$$\frac{dN}{dm_{\pi^-\eta}} = N\frac{2}{\pi}\frac{s\,\Gamma_{\delta-\pi^-\eta}}{|D_\delta(s)|^2}, \quad s = m^2_{\pi^-\eta}, \tag{3}$$

$$\frac{dN}{dm_{K^-K^0}} = N\frac{2}{\pi}\frac{s\,\Gamma_{\delta-K^0K^-}}{|D_\delta(s)|^2}, \quad s = m^2_{K^-K^0}. \tag{4}$$

$$D_\delta(s) = m^2_\delta - s + \sum_{(ab)}\left[\mathrm{Re}\,\Pi^{ab}_\delta(m^2_\delta) - \Pi^{ab}_\delta(s)\right],$$

$$\mathrm{Im}\,\Pi^{ab}_\delta(s) = \sqrt{s}\,\Gamma_{\delta ab} = \frac{g^2_{\delta ab}}{16\pi}\rho_{ab} \tag{5}$$

We assume that $m_a > m_b$, $m_\pm = m_a \pm m_b$; thus for $s > m_+^2$

$$\Pi_\delta^{ab}(s) = \frac{g_{\delta ab}^2}{16\pi}\left[L + \rho_{ab}\left(i + \frac{1}{\pi}\ln\frac{(s-m_-^2)^{1/2}-(s-m_+^2)^{1/2}}{(s-m_-^2)^{1/2}+(s-m_+^2)^{1/2}}\right)\right], \quad (6)$$

$$\rho_{ab} = (s-m_+^2)^{1/2}(s-m_-^2)^{1/2}/s, \quad L = \frac{1}{\pi}\ \frac{m_+ m_-}{s}\ \ln\frac{m_b}{m_a}.$$

$\Pi_\delta^{ab}(s)$ for $s < m_+^2$ can be obtained by analytical extrapolation. $(ab) = (\pi\eta, K\bar{K}, \pi\eta')$.

$$\mathrm{BR}(\delta^- \to \pi^-\eta) + \mathrm{BR}(\delta^- \to K^-K^0) + \mathrm{BR}(\delta^- \to \pi^-\eta')$$

$$= \frac{2}{\pi}\int_{(m_\pi + m_\eta)}^{\infty} \frac{s\Gamma_{\delta\pi\eta}\, ds^{1/2}}{|D_\delta(s)|^2} + \frac{2}{\pi}\int_{2m_K}^{\infty} \frac{s\Gamma_{\delta K\bar{K}}\, ds^{1/2}}{|D_\delta(s)|^2}$$

$$+ \frac{2}{\pi}\int_{(m_\pi + m_{\eta'})}^{\infty} \frac{s\Gamma_{\delta\pi\eta'}\, ds^{1/2}}{|D_\delta(s)|^2} = 1. \quad (7)$$

$\Pi_\delta^{ab}(s) - \mathrm{Re}\,\Pi_\delta^{ab}(m_\delta^2)$ is the contribution from the (ab)-loop to the self energy of the δ resonance. This value takes into account the corrections for the finite width of the $\delta \to ab$ decay. We should emphasize that the corrections for the finite width are highly important for scalar mesons, since we are dealing here with "superallowed" coupling constants for the first time.

The results of our analysis are shown in Fig. 1. As seen in Fig. 1, a completely satisfactory description is obtained without the introduction of any background. We have also taken into account the $\pi\eta'$ channel which has a noticeable influence on the $K\bar{K}$ spectrum for $s^{1/2} \geqslant m_\pi + m_{\eta'} = 1.1$ GeV. We used for this channel the prediction of the $(qq\bar{q}\bar{q})$ model, $g_{\delta\pi\eta'} = g_{\delta^- K^- K^0}/\sqrt{3}$ [see (2)]. We obtained the parameters

$$m_\delta = 985\ \text{MeV}, \quad \frac{g_{\delta^- K^- K^0}^2}{4\pi} = 2.66\ (\text{GeV})^2;$$

$$\Gamma_{\delta\pi\eta}(m_\delta^2) \approx 280\ \text{MeV}, \quad \Gamma_{\delta^- K^- K^0}(s = 1.2\ (\text{GeV})^2) \approx 250\ \text{MeV}. \quad (8)$$

With the existing statistics a choice cannot be made between our description and that using a narrow δ resonance and a large background.

We have recently obtained evidence favoring the four-quark model of the S^* meson.[7] The $(qq\bar{q}\bar{q})$ model predicts that $g_{S^*K^+K^-} = g_{\delta^0 K^+K^-}$. The value obtained in this investigation for $g_{\delta^0 K^+K^-}$ is in good agreement with our results for the S^* meson (see A, C, H', E, and G in Ref. 7).

In the near future, we shall investigate at Serpukhov the rare decays of the $D[1285, 0^+(1^+)]$-meson. It would also be extremely interesting to investigate the $\pi\eta$ and $K\bar{K}$ mass spectra of the basic decays $D \to \delta\pi \to K\bar{K}\pi$, $\eta\pi\pi$ in connection with an analysis of the scalar mesons.

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