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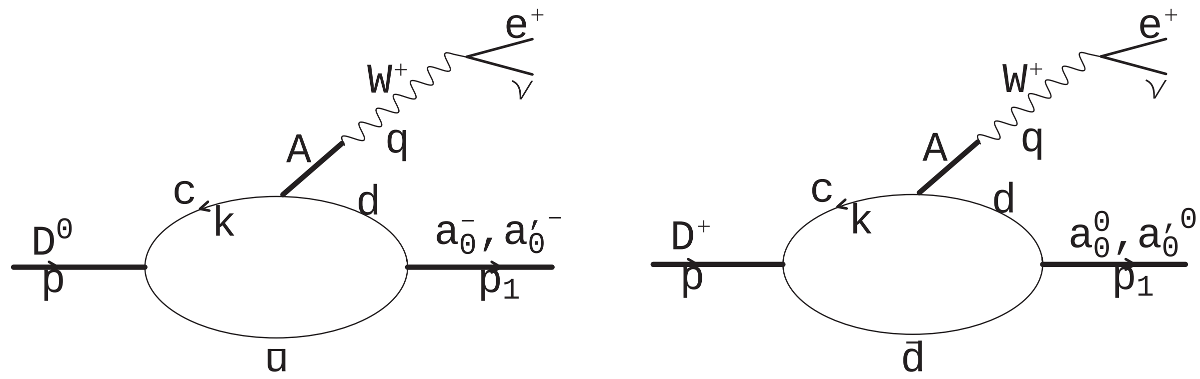
Semileptonic D^0 and D^+ decays as a probe of the $a_0(980)$ nature

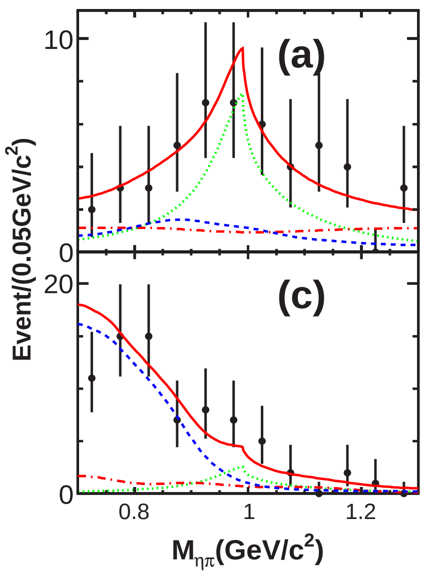
N.N. Achasov and A.V. Kiselev, Phys. Rev. **D98**, 096009 (2018)



Model of the $D^0 \to (a_0^-, a_0'^-)\, e^+\nu$ and $D^+ \to (a_0^0, a_0'^0)\, e^+\nu$ decays.

$D^0 \to \pi^- \eta e^+ \nu$ and $D^+ \to \pi^0 \eta e^+ \nu$ decays

Recently BES Collaboration measured the decays $D^0 \to d\bar{u}\, e^+\nu \to a_0^-\, e^+\nu \to \pi^- \eta e^+ \nu$ and $D^+ \to d\bar{d}\, e^+\nu \to a_0^0 e^+\nu \to \pi^0 \eta e^+ \nu$ for the first time.



Experimental data on (a) $D^0 \to (a_0^-, a_0'^-)\, e^+\nu \to \eta\pi^- e^+\nu$ and (c) $D^+ \to (a_0^0, a_0'^0)\, e^+\nu \to \eta\pi^0 e^+\nu$ decays. Direct copy of Figs. 2(a) and 2(c) from BESIII paper. Dotted curves are signals, solid ones represent total contribution, and the other ones represent backgrounds.

It turns out that in the scenario, based on the four-quark model, it is possible to describe the data on different reactions in agreement with the BESIII data, while $a_0(980)$ has no constituent two-quark component at all, that is, $g_{d\bar{u}a_0^-} = g_{d\bar{d}a_0^0} = 0$, $g^{(0)}_{a_0\gamma\gamma} = 0$. More precise data would allow to check this variant better.

The amplitude of the $D^0 \to S(\mathbf{scalar})\, e^+\nu$ decay reads

$$M[D^0(p) \to S(p_1)W^+(q) \to S(p_1)\, e^+\nu] = \frac{G_F}{\sqrt{2}} V_{cd} A_\alpha L^\alpha \,, \qquad (1)$$

$$A_\alpha = f_+^S(q^2)(p+p_1)_\alpha \,,$$
$$L_\alpha = \bar{\nu}\gamma_\alpha(1+\gamma_5)e \,, \qquad q = (p - p_1) \,. \qquad (2)$$

$$f_+^S(q^2) = f_+^S(0)\frac{m_A^2}{m_A^2 - q^2} = f_+^S(0) f_A(q^2) = g_{D^0 c\bar{u}} F_S g_{d\bar{u}S} f_A(q^2) \,, \qquad (3)$$

where $A = D_1(2420)^\pm$, F_S - loop integral, assumed to be constant in the region of interest.

The decay rate into the stable S state is

$$\frac{d\Gamma(D^0 \to S\, e^+\nu)}{dq^2} = \frac{G_F^2|V_{cd}|^2}{24\pi^3} p_1^3(q^2)|f_+^S(q^2)|^2, \tag{4}$$

$$p_1(q^2) = \frac{\sqrt{m_{D^0}^4 - 2m_{D^0}^2(q^2 + m_S^2) + (q^2 - m_S^2)^2}}{2m_{D^0}}. \tag{5}$$

The amplitude of the $D^0 \to d\bar{u}\, e^+\nu \to [a_0^-(980) + a_0'^-]\, e^+\nu \to \eta\pi^-\, e^+\nu$ **decay is**

$$M(D^0 \to d\bar{u}\, e^+\nu \to \eta\pi^-\, e^+\nu) = \frac{G_F}{\sqrt{2}} V_{cd}\, L^\alpha\, (p + p_1)_\alpha\, g_{D^0 c\bar{u}}\, f_A(q^2)$$

$$\times \frac{1}{\Delta(m)} \left(F_{a_0^-} g_{d\bar{u}a_0^-} D_{a_0'^-}(m) g_{a_0\eta\pi} + F_{a_0^-} g_{d\bar{u}a_0^-} \Pi_{a_0^- a_0'^-}(m) g_{a_0'\eta\pi} \right.$$

$$\left. + F_{a_0'^-} g_{d\bar{u}a_0'^-} \Pi_{a_0'^- a_0^-}(m) g_{a_0\eta\pi} + F_{a_0'^-} g_{d\bar{u}a_0'^-} D_{a_0^-}(m) g_{a_0'\eta\pi} \right), \qquad (6)$$

where m **is the invariant mass of the** $\eta\pi^-$ **system,** $\Delta(m) = D_{a_0'^-}(m) D_{a_0^-}(m) - \Pi_{a_0'^- a_0^-}(m) \Pi_{a_0^- a_0'^-}(m)$**,** $D_{a_0^-}(m)$ **and** $D_{a_0'^-}(m)$ **are the inverted propagators of the** a_0^- **and** $a_0'^-$ **mesons, and** $\Pi_{a_0^- a_0'^-}(m) = \Pi_{a_0'^- a_0^-}(m)$ **is the nondiagonal element of the polarization operator, which mixes the** a_0^- **and** $a_0'^-$ **mesons.**

The double differential rate of the $D^0 \to d\bar{u}\, e^+\nu \to [a_0^-(980) + a_0'^-]\, e^+\nu \to \eta\pi^-\, e^+\nu$ **decay is**

$$\frac{d^2\Gamma(D^0 \to \eta\pi^-\, e^+\nu)}{dq^2 dm} =$$

$$= \frac{G_F^2\, |V_{cd}|^2}{192\, \pi^5}\, g^2_{D^0 c\bar{u}}\, |f_A(q^2)|^2\, p_1^3(q^2, m)\, \rho_{\eta\pi^-}(m)\, m\, |\frac{1}{\Delta(m)}|^2$$

$$\times\, |F_{a_0^-} g_{d\bar{u}a_0^-} D_{a_0'^-}(m) g_{a_0\eta\pi} + F_{a_0^-} g_{d\bar{u}a_0^-} \Pi_{a_0^-\, a_0'^-}(m) g_{a_0'\eta\pi}$$

$$+\, F_{a_0'^-} g_{d\bar{u}a_0'^-} \Pi_{a_0'^-\, a_0^-}(m) g_{a_0\eta\pi} + F_{a_0'^-} g_{d\bar{u}a_0'^-} D_{a_0^-}(m) g_{a_0'\eta\pi}|^2\, , \quad (7)$$

where $\rho_{\eta\pi^-}(m) = \sqrt{(1 - (m_\eta + m_{\pi^-})^2/m^2)(1 - (m_\eta - m_{\pi^-})^2/m^2)}$**.**

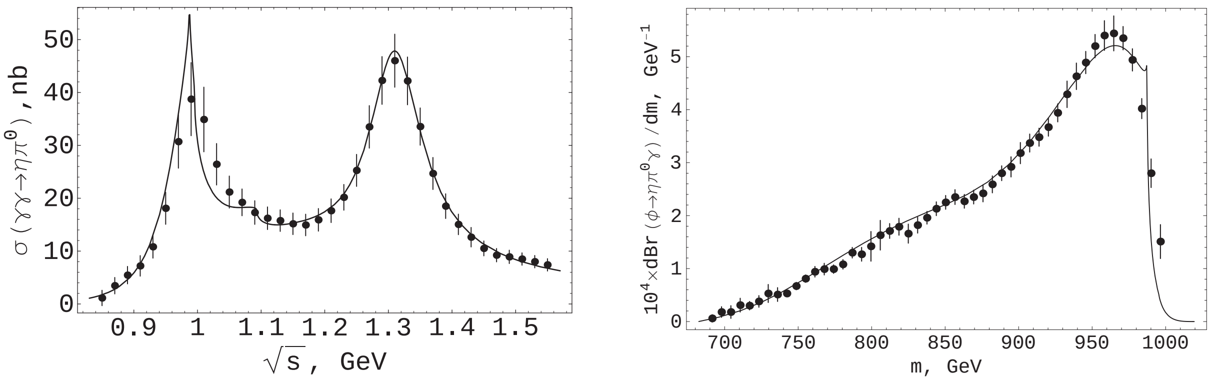
If a_0 does not contain two-quark state, then

$$\frac{d^2\Gamma(D^0 \to \eta\pi^- \, e^+\nu)}{dq^2 dm} =$$

$$= \frac{G_F^2 \, |V_{cd}|^2}{192 \, \pi^5} \, g^2_{D^0 c\bar{u}} \, |f_A(q^2)|^2 \, p_1^3(q^2, m) \, \rho_{\eta\pi^-}(m) \, m \, |\frac{1}{\Delta(m)}|^2$$

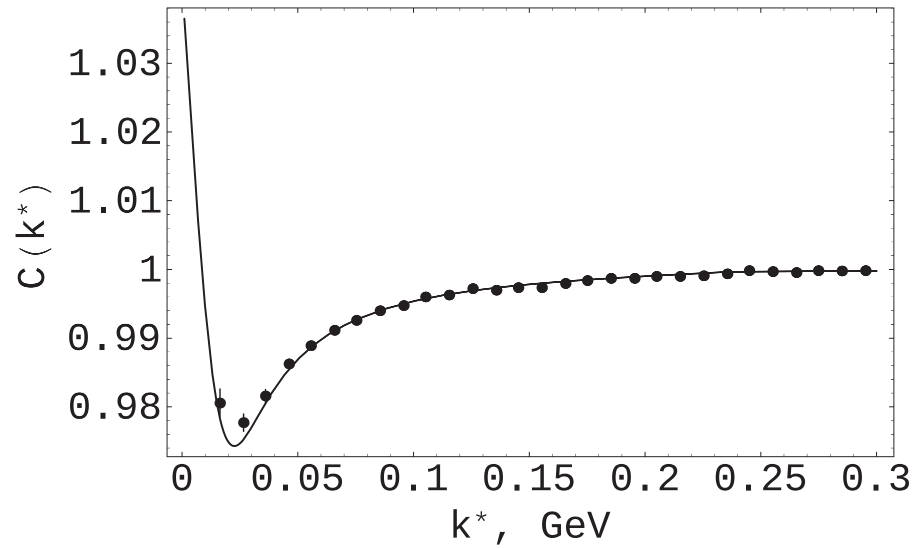
$$\times \, |F_{a_0'^-} g_{d\bar{u}a_0'^-}|^2 \, |\Pi_{a_0'^- a_0^-}(m) g_{a_0\eta\pi} + D_{a_0^-}(m) g_{a_0'\eta\pi}|^2 \, , \qquad (8)$$

The $D^+ \to d\bar{d} \, e^+\nu \to S \, e^+\nu$ and $D^+ \to \eta\pi^0 \, e^+\nu$ decays are described in the same way. It is enough to substitute $D^0 \to D^+, d\bar{u} \to d\bar{d}$, $a_0^- \to a_0^0$, $a_0'^- \to a_0'^0$, and $\pi^- \to \pi^0$. The coupling $g_{d\bar{d}a_0'^0} = g_{d\bar{u}a_0'^-}/\sqrt{2}$.



(a) (b)

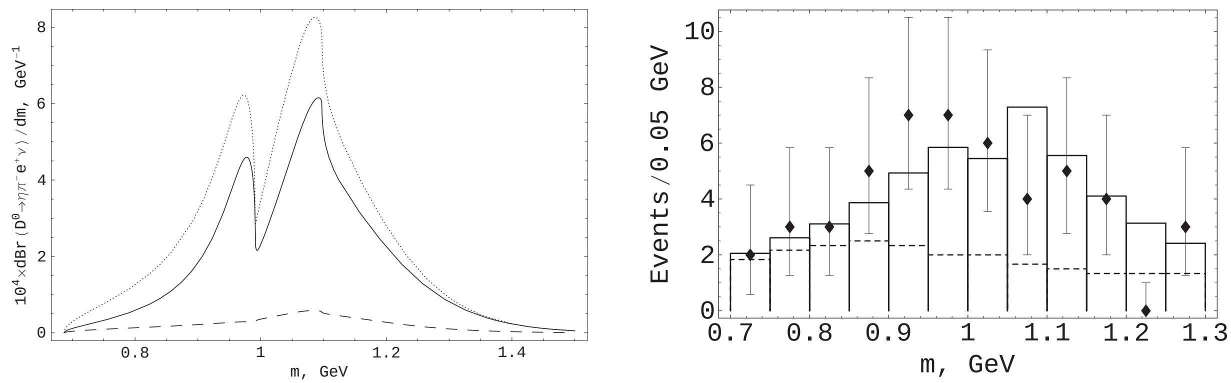
Results of our fit on (a) the Belle data on the $\gamma\gamma \to \eta\pi^0$ cross section, and (b) the KLOE data on the $\phi \to \eta\pi^0\gamma$ decay.



The $K_S^0 K^+$ correlation $C(k^*)$. The solid line represents our fit, and points are ALICE experimental data.

Properties of the resonances and the description quality.

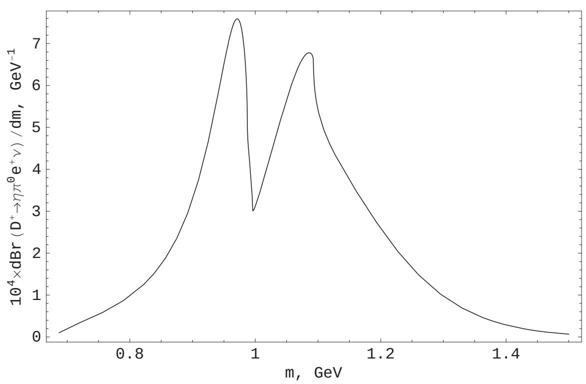
$m_{a_0^0}$, **MeV**	988.3	$m_{a_0'}$, **MeV**	1423.9	R, **fm**	6.3
$g_{a_0^0 K^+K^-}$, **GeV**	4.06	$g_{a_0'^0 K^+K^-}$, **GeV**	4.19	λ	1
$g_{a_0\eta\pi}$, **GeV**	3.99	$g_{a_0'\eta\pi}$, **GeV**	0.80	$\chi^2_{\gamma\gamma}$ / 36 **points**	13.8
$g_{a_0\eta'\pi}$, **GeV**	-4.24	$g_{a_0'\eta'\pi}$, **GeV**	1.27	χ^2_{sp} / 49 **points**	65.5
$g^{(0)}_{a_0^0\gamma\gamma}$	0	$g^{(0)}_{a_0'^0\gamma\gamma}$, 10^{-3} **GeV**$^{-1}$	-12.90	χ^2_{corr} / 29 **points**	28.4
$m_{a_0^+}$, **MeV**	997.6	$C_{a_0 a_0'}$, **GeV**^{2}	-0.163	$(\chi^2_{\gamma\gamma}+\chi^2_{sp}+\chi^2_{corr})$**/n.d.f.**	107.8/99



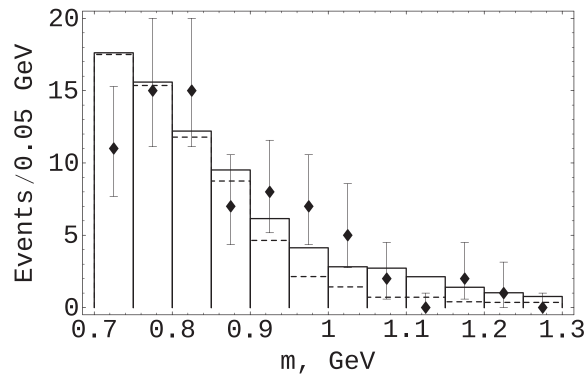
(a) (b)

(a) The plot of $D^0 \to (a_0^-, a_0'^-)\, e^+\nu \to \eta\pi^- e^+\nu$ spectrum with parameters of our fit. The solid line is the total contribution, the dotted line is the term $\sim F_{a_0'^-} g_{d\bar{u}a_0'^-} \Pi_{a_0'^- a_0^-}(m) g_{a_0\eta\pi}$ contribution, and the dashed line is the term $\sim F_{a_0'^-} g_{d\bar{u}a_0'^-} D_{a_0^-}(m) g_{a_0'\eta\pi}$ contribution.

(b) The data on the $D^0 \to (a_0^-, a_0'^-)\, e^+\nu \to \eta\pi^- e^+\nu$ decay and our fit. The solid histogram is the total contribution, and the dashed histogram represents the sum of backgrounds.



(a)



(b)

(a) The spectrum of the $D^+ \to (a_0^0, a_0'^0)\, e^+\nu \to \eta\pi^0 e^+\nu$ decay with parameters of our fit.

(b) The spectrum of the $D^+ \to (a_0^0, a_0'^0)\, e^+\nu \to \eta\pi^0 e^+\nu$ decay. The solid histogram is the total contribution, and the dashed histogram represents the sum of backgrounds.

In papers N.N. Achasov and A.V. Kiselev, Phys. Rev. D 86, 114010 (2012); Int. J. Mod. Phys. Conf. Ser. 35, 1460447 (2014) the program of studying light scalars in semileptonic D and B decays was suggested.

Processes of interest are:

$D_s^+ \to s\bar{s}e^+\nu \to [\sigma(600) + f_0(980)]e^+\nu \to \pi^+\pi^-\, e^+\nu$
$D^+ \to d\bar{d}\, e^+\nu \to [\sigma(600) + f_0(980)]e^+\nu \to \pi^+\pi^- e^+\nu$
$D^0 \to d\bar{u}\, e^+\nu \to a_0^-\, e^+\nu \to \pi^-\eta e^+\nu$
$D^+ \to d\bar{d}\, e^+\nu \to a_0^0 e^+\nu \to \pi^0\eta e^+\nu$
$B^0 \to d\bar{u}\, e^+\nu \to a_0^-\, e^+\nu \to \pi^-\eta e^+\nu$
$B^+ \to u\bar{u}\, e^+\nu \to a_0^0 e^+\nu \to \pi^0\eta e^+\nu$
$B^+ \to u\bar{u}\, e^+\nu \to [\sigma(600) + f_0(980)]e^+\nu \to \pi^+\pi^- e^+\nu$