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# $X(3872) \to D\bar{D}\gamma$ decays and the structure of $X(3872)$

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**Abstract**

It has been suggested that the radiative $X \to D\bar{D}\gamma$ decay modes are useful to shed light on the structure of the meson $X(3872)$, since the ratio $R = \frac{\Gamma(X\to D^+D^-\gamma)}{\Gamma(X\to D^0\bar{D}^0\gamma)}$ is expected to be small ($R \ll 1$) if $X$ is a molecular $D^{*0}\bar{D}^0$ state. We compute $R$ in a $\bar{c}c$ $J^{PC} = 1^{++}$ description of $X$ finding that it is tiny in a wide range of hadronic parameters governing the decay. A discrimination between the molecular and $\bar{c}c$ description can be obtained through the analysis of the photon spectrum.



The quark structure of the meson $X(3872)$ is a subject of discussions due to the various puzzling aspects this particle presents at a careful scrutiny [1]. The resonance was discovered in the invariant mass distribution of $J/\psi\pi^+\pi^-$ mesons produced in $B^\pm \to K^\pm X \to K^\pm J/\psi\pi^+\pi^-$ decays; it appeared as a narrow peak together with the structure corresponding to the $\psi(2^3S_1)$ charmonium level, with mass $M(X) = 3872.0 \pm 0.6 \pm 0.5$ MeV and width smaller than the experimental resolution: $\Gamma(X) < 2.3$ MeV (90% C.L.) [2]. Confirmation of the state in $B$ decays was obtained later on [3], after the observation of the structure in $p\bar{p}$ collisions at the Tevatron with mass $M(X) = 3871.4 \pm 0.7 \pm 0.4$ MeV [4] and $M(X) - M(J/\psi) = 774.9 \pm 3.1 \pm 3.0$ MeV [5], and width consistent with the detector resolution. The $\pi^+\pi^-$ spectrum displayed a maximum in the region of large invariant mass [2,3,6].

The meson $X(3872)$, whose average values of resonance parameters quoted by the Particle Data Group 2006 are $M(X) = 3871.2 \pm 0.5$ MeV and $\Gamma(X) < 2.3$ MeV (90% C.L.) [7], was not observed in $e^+e^-$ annihilation; moreover, searches for charged partners, made by looking at the $J/\psi\pi^\pm\pi^0$ channel, produced negative results [8]. The state was neither found in the $J/\psi\eta$ channel [9] nor in $\gamma\gamma$ fusion [10]. As for production in $B$ decays, the ratio $\frac{B(B^0\to K^0X)}{B(B^+\to K^+X)} = 0.50 \pm 0.30 \pm 0.05$ was measured [11].

On the basis of the observation of the radiative mode $X \to J/\psi\gamma$, with the measurement $\frac{B(X\to J/\psi\gamma)}{B(X\to J/\psi\pi^+\pi^-)} = 0.19 \pm 0.07$ [12], the charge conjugation of the state is established: $C = +1$; moreover, the angular distribution of the final state is compatible with the spin-parity assignment $J^P = 1^+$ (even though $2^-$ is not excluded) [13], so that the most likely quantum number assignment for $X(3872)$ is $J^{PC} = 1^{++}$.

Together with these measurements, a near-threshold $D^0\bar{D}^0\pi^0$ enhancement in $B \to D^0\bar{D}^0\pi^0 K$ decay was recently reported, with the peak at $M = 3875.4 \pm 0.7^{+1.2}_{-2.0}$ MeV and $B(B \to KX \to KD^0\bar{D}^0\pi^0) = (1.27 \pm 0.31^{+0.22}_{-0.39}) \times 10^{-4}$ [14]. If the enhancement is entirely due to $X(3872)$ one derives that $\frac{B(X\to D^0\bar{D}^0\pi^0)}{B(X\to J/\psi\pi^+\pi^-)} = 9 \pm 4$ [15], therefore $X$ mainly decays into final states with open charm mesons. Notice that the central value of the mass measured in the $D^0\bar{D}^0\pi^0$ mode is 4 MeV higher than the PDG value (although with a large asymmetric systematic error $\Delta M = +1.2, -2.0$ MeV).

These measurements, although not fully consistent with the expectations based on charmonium models (mainly as far as the mass of the state is concerned), do not contradict the interpretation of $X(3872)$ as a $\bar{c}c$ state. However, another hadronic decay mode was observed for $X(3872): X \to J/\psi\pi^+\pi^-\pi^0$ with $\frac{B(X\to J/\psi\pi^+\pi^-\pi^0)}{B(X\to J/\psi\pi^+\pi^-)} = 1.0 \pm 0.4 \pm 0.3$ [12,16]. Presence of

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both decay channels in two and three pions implies $G$-parity violation or, if the two modes are considered as induced by $\rho^0$ and $\omega$ intermediate states, isospin violation: this suggested the conjecture that $X(3872)$ is not a charmonium ($\bar{c}c$) state, but a hadron of more complex quark content. In the search of the right interpretation, the coincidence between the resonance mass as averaged by PDG and the $D^{*0}\bar{D}^0$ mass: $M(D^{*0}\bar{D}^0) = 3871.2 \pm 1.0$ MeV, inspired the proposal that $X(3872)$ could be a realization of the molecular quarkonium [17], a bound state of two mesons $D^{*0}$ and $\bar{D}^0$ with small binding energy [18,19],[1] an interpretation that would allow to account for a few properties of $X(3872)$. For example, describing the wave function of $X(3872)$ through various hadronic components [20]:

$$\left|X(3872)\right\rangle = a\left|D^{*0}\bar{D}^0 + \bar{D}^{*0}D^0\right\rangle + b\left|D^{*+}D^- + D^{*-}D^+\right\rangle + \cdots, \quad (1)$$

(with $|b| \ll |a|$) one could explain why this state seems not to have definite isospin, why the decay mode $X \to J/\psi\pi^0\pi^0$ has not been found, and why, if the molecular binding mechanism is provided by a single pion exchange, there are no $D\bar{D}$ molecular states: indeed no structures were found in the range of mass corresponding to $2m_{D^0}$ or $2m_{D^\pm}$. Moreover, non observation of a bound state of charged $D^{*+}D^-$ mesons can also be justified since a single pion exchange would produce a repulsive interaction in this channel [18].

Noticeably, in the molecular interpretation the resonance $X_b(10604)$ would be expected as a bound state of $B$ and $B^*$; this resonance has not been observed, so far, so that the prediction deserves experimental investigations. Moreover, it is also predicted that, since the decays of the $X(3872)$ resonance are mainly due to the decays of its meson components in case of peripheral transitions, the radiative decay in neutral $D$ mesons: $X \to D^0\bar{D}^0\gamma$ should be dominant with respect to $X \to D^+D^-\gamma$ [20].

The description of $X(3872)$ in a simple charmonium scheme, in which it would be identified as the first radial excitation of the $J^{PC} = 1^{++}$ state, presents alternative arguments to the molecular description [21]. A problem is that the molecular binding mechanism still needs to be clearly identified, and the role of single $\pi^0$ exchange has to be further investigated.[2] Concerning the isospin ($G$-parity) violation, in order to correctly interpret the large value of the ratio $\frac{B(X\to J/\psi\pi^+\pi^-\pi^0)}{B(X\to J/\psi\pi^+\pi^-)}$ one has to consider that phase space effects in two and three pion modes are very different. The ratio of the amplitudes is smaller: $\frac{A(X\to J/\psi\rho^0)}{A(X\to J/\psi\omega)} \simeq 0.2$, so that the isospin violating amplitude is 20% of the isospin conserving one, an effect that could be related to another isospin violating effect, the mass difference between neutral and charged $D$ mesons, considering the contribution of $DD^*$ intermediate states to $X$ decays. The prediction $\Gamma(B^0 \to XK^0) \simeq \Gamma(B^- \to XK^-)$, based on the charmonium description, is neither confirmed nor excluded by the available measurements. Admittedly, the $\bar{c}c$ interpretation leaves unsolved the issue of the eventual overpopulation of the level corresponding to the first radial excitations of $1^{++}$ $\bar{c}c$ states resulting from the possible assignment of these quantum numbers to another structure observed by Belle Collaboration, $Y(3930)$ [16]; however, this new resonance is still not confirmed and its properties not fully understood, so that the charmonium option for $X(3872)$ seems not excluded, yet. A warning comes from the $D^0\bar{D}^0\pi^0$ signal which, if due to $X(3872)$, can contribute to settle the question of the coincidence of the $X$ and $D^0\bar{D}^{*0}$ mass, a relevant issue since a $X(3872)$ above the $D^0\bar{D}^{*0}$ threshold is difficult to explain in a molecular picture.

In this note we address a particular aspect of $X(3872)$, namely the suggestion that the observation of the dominance of the process $X \to D^0\bar{D}^0\gamma$ with respect to $X \to D^+D^-\gamma$ could be interpreted as a signature of the molecular structure of $X(3872)$ [20]. Assuming that $X(3872)$ is an ordinary $J^{PC} = 1^{++}$ charmonium state, together with a standard mechanism for the radiative transition into charmed mesons, we obtain that the ratio $R = \frac{\Gamma(X\to D^+D^-\gamma)}{\Gamma(X\to D^0\bar{D}^0\gamma)}$ is small and in particular it is tiny in a wide range of the hadronic parameters governing the decays, so that the ratio $R \ll 1$ seems not peculiar of $X(3872)$ being a molecular quarkonium.

In order to study the transition $X(3872)(p,\epsilon) \to D(k_1) \times \bar{D}(k_2)\gamma(k,\tilde{\epsilon})$ ($p, k_1, k_2$ and $k$ are momenta, $\epsilon, \tilde{\epsilon}$ polarization vectors) we assume that the radiative decay amplitude is dominated by pole diagrams with intermediate particles nearest to their mass shell, as the ones depicted in Fig. 1 which involve $D^*$ and the $\psi(3770)$ mesons as intermediate states. These amplitudes can be expressed in terms of two unknown quantities: the coupling constant governing the $X\bar{D}D^*(D\bar{D}^*)$ matrix elements, and the coupling appearing in the $X\psi(3770)\gamma$ matrix element, since information about $D^*D\gamma$ and $\psi(3770)D\bar{D}$ couplings can be inferred from experimental data.

For the matrix element $X\bar{D}D^*(D\bar{D}^*)$ we use a formalism suitable to describe the interaction of the heavy charmonium with the doublet of heavy pseudoscalar and vector meson states [23]: the four states corresponding to the first radial excitation of $\ell = 1$ $\bar{c}c$ mesons, which are degenerate in the limit $m_c \to \infty$, can be described by the multiplet:

$$P^{(Q\bar{Q})\mu} = \left(\frac{1+\not{v}}{2}\right)\left(\chi_2^{\mu\alpha}\gamma_\alpha + \frac{1}{\sqrt{2}}\epsilon^{\mu\alpha\beta\gamma}v_\alpha\gamma_\beta\chi_{1\gamma} + \frac{1}{\sqrt{3}}(\gamma^\mu - v^\mu)\chi_0 + h_1^\mu\gamma_5\right)\left(\frac{1-\not{v}}{2}\right), \quad (2)$$

where $\chi_2$, $\chi_1$ and $\chi_0$ correspond to the spin triplet with $J^{PC} = 2^{++}$, $1^{++}$ and $0^{++}$, respectively, while the spin singlet $h_1$ has $J^{PC} = 1^{+-}$. In the $\bar{c}c$ interpretation $X(3872)$ is described by $\chi_1$. The expression of the multiplet is analogous to that describing the lowest radial states, $\chi_{c0,1,2}$ and $h_c$; the fields in Eq. (2) contain a factor $\sqrt{m}$, with $m$ the meson mass. The strong interaction with the $D$ and $D^*$ mesons can be described by the

[1] Other proposals based on a multiquark picture are described in Ref. [1].

[2] For example, it was argued [22] that the molecular binding mechanism cannot be a single $\pi^0$ exchange, since this would produce an attractive potential which is a delta function in space and therefore it would not give rise to a bound state. However, this argument is controversial: a detailed discussion can be found in the Appendix B of the first review in Ref. [1].

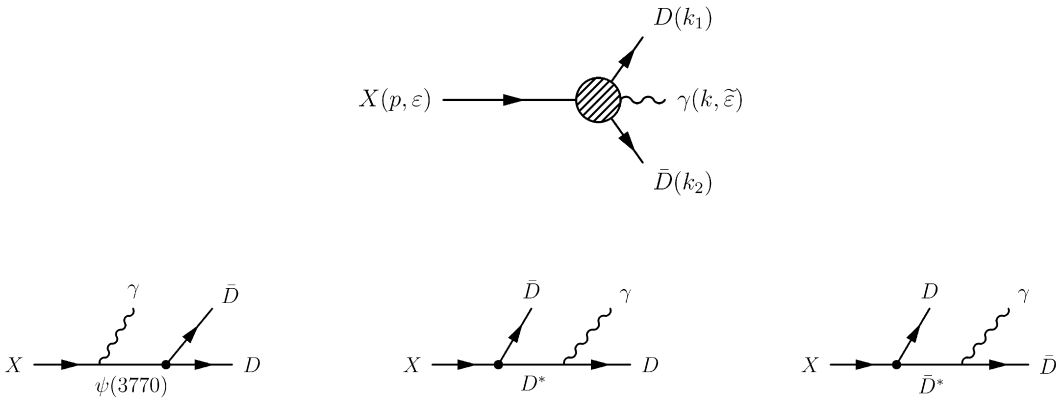


Fig. 1. Diagram describing the radiative modes $X \to D\bar{D}\gamma$ (top), and contributions corresponding to the intermediate states nearest to their mass shell (bottom).

effective Lagrangian [24]

$$\mathcal{L}_1 = ig_1 \,\mathrm{Tr}\big[P^{(Q\bar{Q})\mu}\bar{H}_{1a}\gamma_\mu \bar{H}_{2a}\big] + \text{h.c.}, \tag{3}$$

where the fields $H_{1,2}$ represent the spin doublets $(D, D^*)$ and $(\bar{D}, \bar{D}^*)$, respectively; $H_{1a}$ is the field describing the heavy–light mesons with quark content $Q\bar{q}_a$ and four-velocity $v$, $D^{(*)0}, D^{(*)+}, D_s^{(*)}$:

$$H_{1a} = \left(\frac{1+\not{v}}{2}\right)\big[M_a^\mu \gamma_\mu - M_a \gamma_5\big], \tag{4}$$

while $H_{2a}$ describes the heavy–light mesons with quark content $q_a\bar{Q}$, $\bar{D}^{(*)0}, D^{(*)-}, \bar{D}_s^{(*)}$:

$$H_{2a} = \big[M_a'^\mu \gamma_\mu - M_a' \gamma_5\big]\left(\frac{1-\not{v}}{2}\right), \tag{5}$$

with $\bar{H}_{1,2} = \gamma^0 H_{1,2}^\dagger \gamma^0$. The effective Lagrangian (3) accounts for the fact that the two heavy–light $D, D^*$ mesons are coupled to the charmonium state in $S$-wave. Moreover, this expression is invariant under independent rotations of the spin of the heavy quarks, since these spins are decoupled in the infinite heavy quark mass limit. Invariance under heavy quark (antiquark) spin rotations can be obtained considering that under independent heavy quark spin transformations: $S_1 \in SU(2)_Q$ and $S_2 \in SU(2)_{\bar{Q}}$, the following transformation properties hold for the various multiplets:

$$\begin{aligned}
&H_{1a} \to S_1 H_{1a}, \qquad \bar{H}_{1a} \to \bar{H}_{1a} S_1^\dagger,\\
&H_{2a} \to H_{2a} S_2^\dagger, \qquad \bar{H}_{2a} \to S_2 \bar{H}_{2a},\\
&P^{(Q\bar{Q})\mu} \to S_1 P^{(Q\bar{Q})\mu}, \qquad P^{(Q\bar{Q})\mu} \to P^{(Q\bar{Q})\mu} S_2^\dagger.
\end{aligned} \tag{6}$$

Using the effective Lagrangian (3) the couplings $XD^0\bar{D}^{*0}$ and $X\bar{D}^0 D^{*0}$ (or $XD^+D^{*-}$ and $XD^-D^{*+}$) which enter in the calculation of the second and the third diagrams in Fig. 1, respectively, can be expressed in terms of the constant $g_1$. For later convenience, we use the dimensionless coupling constant $\hat{g}_1 = g_1\sqrt{m_D}$. Due to isospin symmetry, the couplings of the meson $X$ to charged and neutral $D$ are equal, at odds with the molecular description where $X$ mainly couples to neutral $D$.

The second and third diagrams in Fig. 1 also require the knowledge of the electromagnetic vertex $D^*D\gamma$. We use the parametrization:

$$\big\langle D(k_1)\gamma(k,\tilde{\epsilon})\big|D^*(p_1,\xi)\big\rangle = ic'\epsilon^{\alpha\beta\tau\theta}\tilde{\epsilon}_\alpha^*\xi_\beta p_{1\tau}k_\theta, \tag{7}$$

where the parameter $c'$ accounts for the contributions of the photon coupling to both the charm and the light quark [25]:

$$c' = \frac{e_c}{m_c} + \frac{e_q}{\Lambda_q}, \tag{8}$$

with $e_c$ and $e_q$ the charm and the light quark charges in units of $e$, therefore $e_q = 2/3(-1/3)$ for neutral (charged) charmed mesons. We use the value $m_c = 1.35$ GeV for the charm quark mass [7]; $\Lambda_q$ can be fixed from $D^*$ data since, using $\Gamma(D^{*+}) = 96 \pm 22$ keV and $\mathcal{B}(D^{*+} \to D^+\gamma) = (1.6 \pm 0.4)\%$ [7], we obtain $\Lambda_q = 335 \pm 29$ MeV. This also implies, from $\mathcal{B}(D^{*0} \to D^0\gamma) = (38.1 \pm 2.9)\%$ [7], that the $D^{*0}$ width can be estimated as $\Gamma(D^{*0}) = 102 \pm 16$ keV (the present upper bound is $\Gamma(D^{*0}) < 2.1$ MeV [7]).

Coming to the hadronic parameter $c$ governing the radiative $X\psi(3770)\gamma$ matrix element and entering in the first diagram in Fig. 1:

$$\big\langle \psi(3770)(q,\eta)\gamma(k,\tilde{\epsilon})\big|X(p,\epsilon)\big\rangle = iec\epsilon^{\alpha\beta\mu\nu}\tilde{\epsilon}_\alpha^*\epsilon_\beta\eta_\mu^* k_\nu, \tag{9}$$

this parameter is also unknown. On the other hand, the coupling between $\psi(3770)D\bar{D}$, which appears in the expression of the first diagram in Fig. 1, is known from the experiment. Using the definition:

$$\big\langle D(k_1)\bar{D}(k_2)\big|\psi(q,\eta)\big\rangle = g_{\psi D\bar{D}}\,\eta\cdot k_1 \tag{10}$$

and the value $\Gamma(\psi(3770)) = 23.0 \pm 2.7$ MeV [7], together with the observation that the $\psi(3770)$ width is saturated by $D\bar{D}$ modes, we obtain

$$g_{\psi D\bar{D}} = 25.7 \pm 1.5, \tag{11}$$

both for charged and neutral $D$ meson pairs. Notice that in this determination we do not need to adopt any interpretation for the $J^{PC} = 1^{--}$ $\psi(3770)$ state, a meson the properties of which are still under scrutiny [26]. Another point to be stressed is that we determine the coupling constants $g_{\psi D\bar{D}}$ and $c'$ from on-shell processes and use them in the vertices in Fig. 1 neglecting possible form-factor effects. Inclusion of form factors would represent an additional source of theoretical uncertainty;

however, in our case the intermediate states are nearly on-shell, therefore form factor effects are expected to be small.

We can now evaluate the ratio $R = \frac{\Gamma(X\to D^+D^-\gamma)}{\Gamma(X\to D^0\bar{D}^0\gamma)}$ as a function of the ratio of the two couplings $\frac{c}{\hat{g}_1}$ and including the uncertainties on $\Gamma(D^{*+})$, $\Gamma(\psi(3770))$, $\Lambda_q$ and $g_{\psi D\bar{D}}$. The result is plotted in Fig. 2, where it is shown that in any case $R < 0.7$. For large vales of $\frac{c}{\hat{g}_1}$ the error on $R$ is small, since in this case only $\psi(3770)$ contributes to the amplitudes.

The result depicted in Fig. 2 shows that there is always a suppression of the radiative $X$ decay mode into charged $D$ mesons with respect to the mode with neutral $D$. Moreover, for small values of $\frac{c}{\hat{g}_1}$ the ratio $R$ is tiny, so that this is not peculiar of a molecular structure of $X(3872)$. The suppression of the contribution of the two last diagrams in Fig. 1 in case of charged $D$ is mainly due to the higher mass of $D^{*\pm}$ with respect to $D^{*0}$, an important effect in the kinematic conditions of the process.

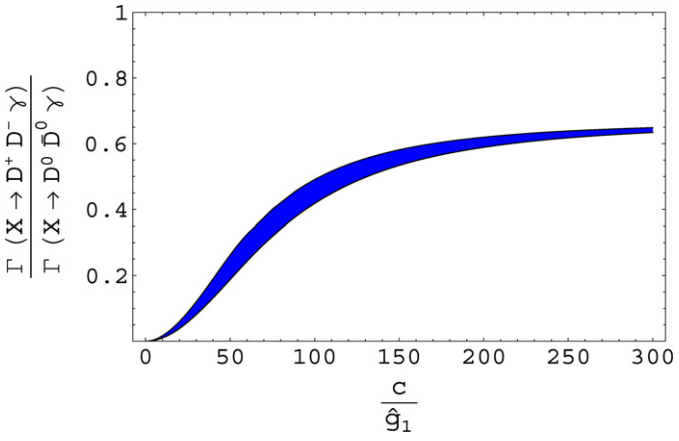


Fig. 2. Ratio of charged $X \to D^+D^-\gamma$ to neutral $X \to D^0\bar{D}^0\gamma$ decay widths versus the ratio of hadronic parameters $c/\hat{g}_1$.

The photon spectrum in radiative $X$ decays to both neutral and charged $D$ meson pairs for two representative values of $\frac{c}{\hat{g}_1}$, namely $\frac{c}{\hat{g}_1} = 1$ and $\frac{c}{\hat{g}_1} = 300$, is depicted in Fig. 3. For low value of the parameter $\frac{c}{\hat{g}_1}$, i.e., in the condition where the intermediate $D^*$ dominates the decay amplitude, the photon spectrum in the $D^0\bar{D}^0\gamma$ mode essentially coincides with the line corresponding to the $D^*$ decay at $E_\gamma \simeq 139$ MeV and width determined by the $D^*$ width. The narrow peak is different from the line shape expected in a molecular description, which is related to the wave function of the two heavy mesons bound in the $X(3872)$, in particular to the binding energy of the system, being broader for larger binding energy. On the other hand, the photon spectrum in the charged $D^+D^-\gamma$ mode is broader, with a peak at $E_\gamma \simeq 125$ MeV, the total $X \to D^+D^-\gamma$ rate being severely suppressed with respect to the $X \to D^0\bar{D}^0\gamma$ one.

At the opposite side of the $\frac{c}{\hat{g}_1}$ range, where $\psi(3770)$ gives a large contribution to the radiative amplitude, a peak at $E_\gamma \simeq 100$ MeV appears both in neutral and charged $D$ meson modes, in the first case together with the structure at $E_\gamma \simeq 139$ MeV. This spectrum was described also in [20], where in this case the radiative decay was interpreted as deriving from the $\bar{c}c$ core of $X(3872)$. In this range of parameters the ratio of the $X \to D^+D^-\gamma$ to $X \to D^0\bar{D}^0\gamma$ rates reaches the largest value.

The experimental determination of the photon spectrum of the type depicted in Fig. 3, together with the measurement

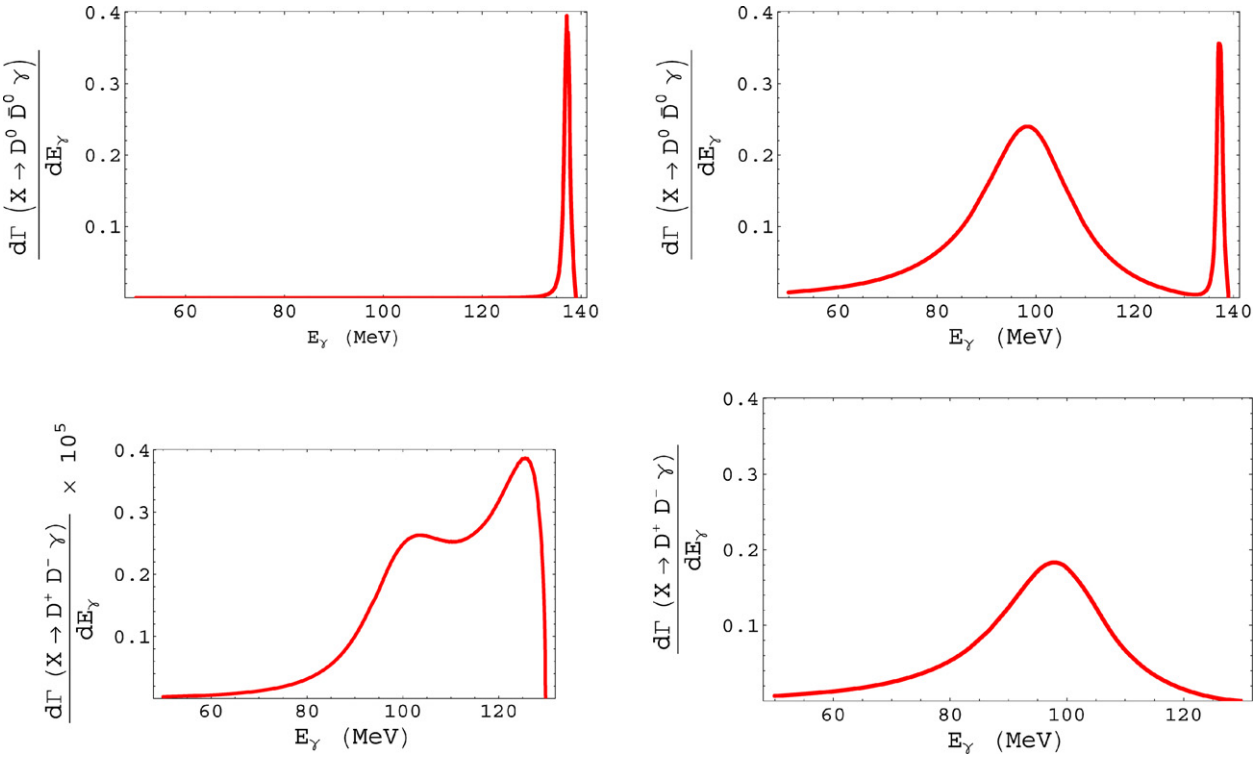


Fig. 3. Photon spectrum (in arbitrary units) in $X \to D^0\bar{D}^0\gamma$ (top) and $X \to D^+D^-\gamma$ (bottom) decays for values of the hadronic parameter $c/\hat{g}_1 = 1$ (left) and $c/\hat{g}_1 = 300$ (right).

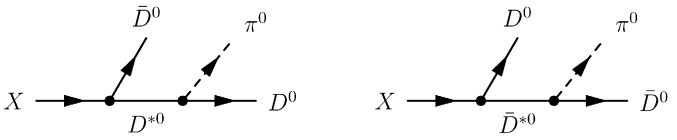


Fig. 4. Diagrams contributing to the mode $X \to D^0\bar{D}^0\pi^0$.

of the $X \to D\bar{D}\gamma$ widths is a challenging task. Nevertheless, this measurement is important to shed light on the structure of $X(3872)$.

Information on the hadronic parameter $\hat{g}_1$ can be gained through the mode $X(3872) \to D^0\bar{D}^0\pi^0$ described by pole diagrams such as those in Fig. 4. The needed new quantity with respect to the radiative decay is the coupling constant $D^*D\pi$, which can be extracted from experimental data. We define:

$$\left\langle D^0(k_1)\pi^0(k)\middle|D^{*0}(p_1,\xi)\right\rangle = \frac{\sqrt{2m_{D^0}m_{D^{*0}}}}{f_\pi}g \tag{12}$$

with $f_\pi$ the pion leptonic constant and the coupling $g$ identified with the universal constant governing the interaction of $J^P = (0^-, 1^-)$ heavy–light mesons with light pseudoscalar mesons in the heavy quark and chiral limit [23]. Using the present determination of $\Gamma(D^{*+})$ together with the branching fractions $\mathcal{B}(D^{*+} \to D^0\pi^+) = (67.7 \pm 0.5)\%$ and $\mathcal{B}(D^{*+} \to D^+\pi^0) = (30.7 \pm 0.5)\%$ [7] we obtain $g = 0.64 \pm 0.07$ and $g = 0.60 \pm 0.07$, respectively.[3] This information would allow us to constrain $\hat{g}_1$ from the upper bound on $\Gamma(X \to D^0\bar{D}^0\pi^0)$, since $\Gamma(X \to D^0\bar{D}^0\pi^0) < \Gamma(X(3872)) < 2.3$ MeV. Using the central values of the masses of $X(3872)$ and $D^0$ we obtain $\hat{g}_1 < 4.5$, as shown in Fig. 5: therefore, a value of $\hat{g}_1$ of the typical size of the hadronic couplings can reproduce the small width of $X(3872)$, thus explaining one of the puzzling aspects of the meson which are difficult to understand, for instance, in a multiquark picture. However, the numerical result for $\hat{g}_1$ critically depends on the meson masses, since the phase space available for the process $X \to D^0\bar{D}^0\pi^0$ is tiny and the mass effects are essential. Reducing the available phase space by considering the present uncertainties on $M(X(3872))$ and $M(D^0)$ the upper bound for $\hat{g}_1$ is larger by about an order of magnitude, but still it has a size that could be expected for a typical hadronic coupling.

To conclude, our study is based on a particular interpretation of $X(3872)$ and not on a determination of various hadronic parameters that can be done, e.g., in versions of the quark model. Since at present the charmonium option for $X(3872)$ cannot be simply excluded, the analysis of the photon spectrum of radiative $X \to D\bar{D}\gamma$ decays can be useful in clarifying the situation. The confirmation of the existence and of the properties of the resonance $Y(3930)$ reported by Belle Collaboration, and a measurement with high precision of the $X(3872)$ mass from the $D^0\bar{D}^0\pi^0$ decay mode would provide us with new important information, while, from the theory view point, further studies of mechanisms for molecular binding are required. Due to the

[3] This value for the $D^*D\pi$ coupling is larger than obtained by various methods, for example in Ref. [27]; it comes from the $D^{*+}$ width currently quoted by PDG [7] and determined by a single measurement in [28].

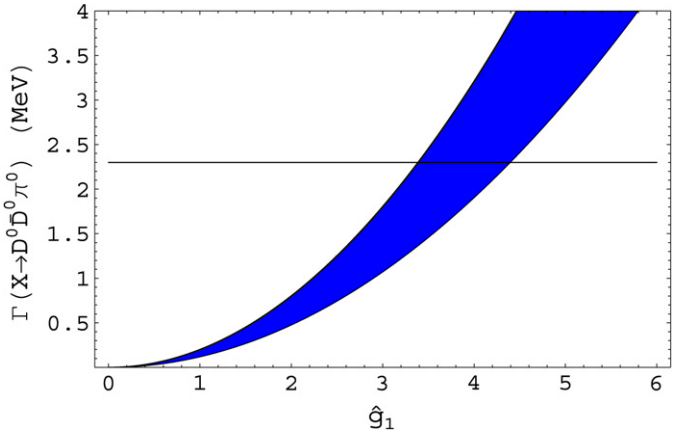


Fig. 5. The width $\Gamma(X(3872) \to D^0\bar{D}^0\pi^0)$ versus the coupling constant $\hat{g}_1$ obtained assuming that the decay proceeds as in Fig. 4 and using the central values of $M(X(3872))$ and $M(D^0)$. The horizontal line corresponds to the present bound on $\Gamma(X(3872))$.

importance of demonstrating the existence of a hadronic configuration comprising two bounded heavy mesons, such new investigations are worth carrying out.

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## References

[1] For recent reviews see: E.S. Swanson, Phys. Rep. 429 (2006) 243; P. Colangelo, F. De Fazio, R. Ferrandes, S. Nicotri, hep-ph/0609240; J.L. Rosner, hep-ph/0609195.
[2] S.K. Choi, et al., Belle Collaboration, Phys. Rev. Lett. 91 (2003) 262001.
[3] B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 71 (2005) 071103.
[4] D. Acosta, et al., CDF II Collaboration, Phys. Rev. Lett. 93 (2004) 072001.
[5] V.M. Abazov, et al., DØ Collaboration, Phys. Rev. Lett. 93 (2004) 162002.
[6] A. Abulencia, et al., CDF Collaboration, Phys. Rev. Lett. 96 (2006) 102002.
[7] W.M. Yao, et al., Particle Data Group, J. Phys. G 33 (2006) 1.
[8] B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 71 (2005) 031501.
[9] B. Aubert, et al., BaBar Collaboration, Phys. Rev. Lett. 93 (2004) 041801.
[10] S. Dobbs, et al., CLEO Collaboration, Phys. Rev. Lett. 94 (2005) 032004.
[11] B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 73 (2006) 011101.
[12] K. Abe, et al., Belle Collaboration, hep-ex/0505037; B. Aubert, et al., BaBar Collaboration, Phys. Rev. D 74 (2006) 071101.
[13] K. Abe, et al., Belle Collaboration, hep-ex/0505038; A. Abulencia, et al., CDF Collaboration, hep-ex/0612053.
[14] G. Gokhroo, et al., Phys. Rev. Lett. 97 (2006) 162002.
[15] G. Gokhroo et al., Belle Collaboration, BELLE-CONF-0568, 2005; P. Pakhlov, talk at ICHEP 2006, 26/7-2/8 2006, Moscow, Russia.
[16] K. Abe, et al., Belle Collaboration, Phys. Rev. Lett. 94 (2005) 182002.
[17] M.B. Voloshin, L.B. Okun, JETP Lett. 23 (1976) 333.
[18] N.A. Tornqvist, Phys. Lett. B 590 (2004) 209.
[19] F.E. Close, P.R. Page, Phys. Lett. B 578 (2004) 119; M.B. Voloshin, Phys. Lett. B 579 (2004) 316; C.Y. Wong, Phys. Rev. C 69 (2004) 055202; E. Braaten, M. Kusunoki, Phys. Rev. D 69 (2004) 074005; E.S. Swanson, Phys. Lett. B 588 (2004) 189; E.S. Swanson, Phys. Lett. B 598 (2004) 197; M.T. AlFiky, F. Gabbiani, A.A. Petrov, Phys. Lett. B 640 (2006) 238.
[20] M.B. Voloshin, Int. J. Mod. Phys. A 21 (2006) 1239.
[21] T. Barnes, S. Godfrey, Phys. Rev. D 69 (2004) 054008;

T. Barnes, S. Godfrey, E.S. Swanson, Phys. Rev. D 72 (2005) 054026;
E.J. Eichten, K. Lane, C. Quigg, Phys. Rev. D 69 (2004) 094019;
E.J. Eichten, K. Lane, C. Quigg, Phys. Rev. D 73 (2006) 014014;
E.J. Eichten, K. Lane, C. Quigg, Phys. Rev. D 73 (2006) 079903, Erratum.
[22] M. Suzuki, Phys. Rev. D 72 (2005) 114013.
[23] For a review see: R. Casalbuoni, A. Deandrea, N. Di Bartolomeo, R. Gatto, F. Feruglio, G. Nardulli, Phys. Rep. 281 (1997) 145.
[24] P. Colangelo, F. De Fazio, T.N. Pham, Phys. Rev. D 69 (2004) 054023.
[25] J.F. Amundson, et al., Phys. Lett. B 296 (1992) 415.
[26] M.B. Voloshin, Phys. Rev. D 71 (2005) 114003, and references therein.
[27] V.M. Belyaev, V.M. Braun, A. Khodjamirian, R. Ruckl, Phys. Rev. D 51 (1995) 6177;
P. Colangelo, F. De Fazio, Eur. Phys. J. C 4 (1998) 503.
[28] A. Anastassov, et al., CLEO Collaboration, Phys. Rev. D 65 (2002) 032003.