Investigating the structure of X(3872)

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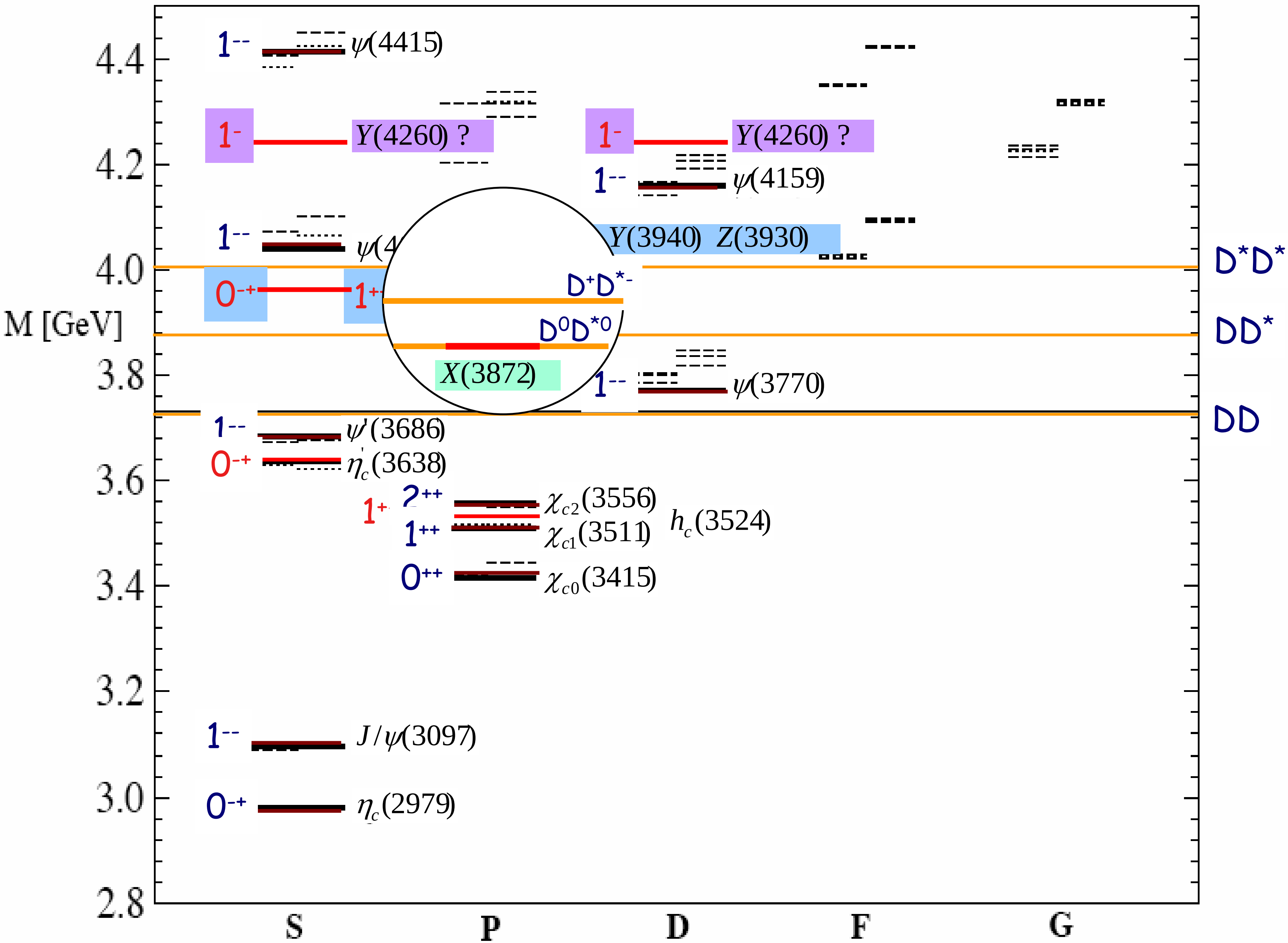
- brief summary of known X(3872) properties
- radiative X decays to charmed mesons:
  are they sensitive to a possible molecular structure?
- conclusions

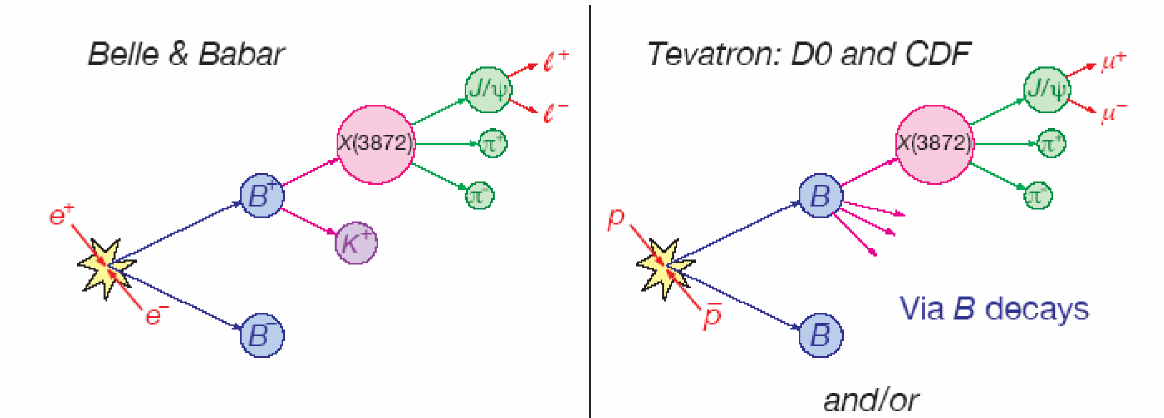
Based on work in collaboration with P. Colangelo and S. Nicotri
Phys. Lett. B650 (07) 166

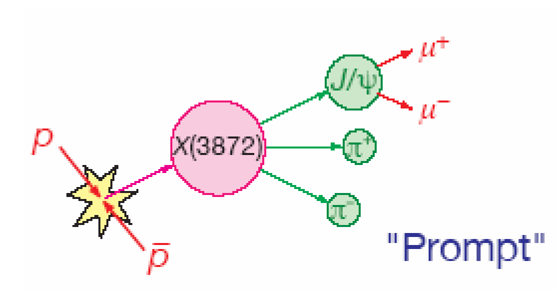


M [GeV]
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
S
P
D
F
G
1⁻⁻ ψ(4415)
1⁻ Y(4260) ?
1⁻ Y(4260) ?
1⁻⁻ ψ(4159)
1⁻⁻
Y(3940) Z(3930)
D*D*
0⁻⁺
D⁺D*⁻
DD*
D⁰D*⁰
X(3872)
1⁻⁻ ψ(3770)
DD
1⁻⁻ ψ'(3686)
0⁻⁺ η'c(3638)
2⁺⁺ χc2(3556)
1⁺⁺ χc1(3511)
hc(3524)
0⁺⁺ χc0(3415)
1⁻⁻ J/ψ(3097)
0⁻⁺ ηc(2979)

X(3872): discovery and properties

Observed in 2003 by four experiments in two production channels: **PDG07**





From R. Van Kooten, D0

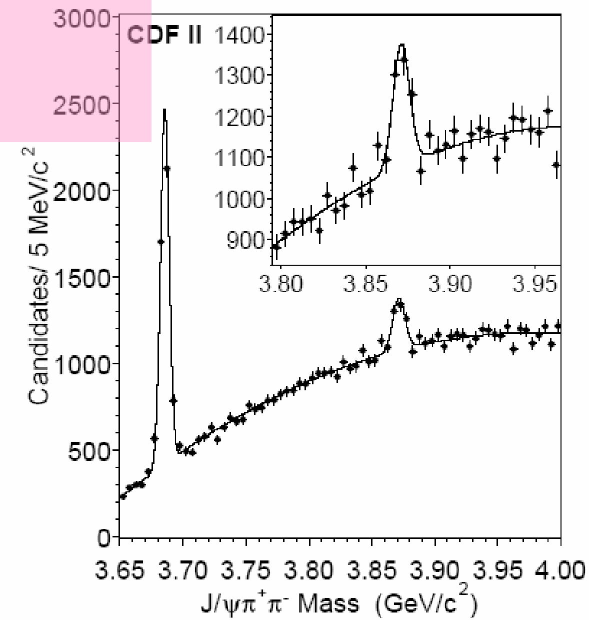
M(MeV)	mode	significance	experiment
$3872.0 \pm 0.6 \pm 0.5$	$B^{\pm} \to K^{\pm} X \to K^{\pm} J/\psi \pi^{+}\pi^{-}$	10σ	Belle
$3871.3 \pm 0.7 \pm 0.4$	$p\bar{p} \to X \to J/\psi \pi^{+}\pi^{-}$	11.6σ	CDFII
$M(J/\psi) + 774.9 \pm 3.1 \pm 3.0$	$p\bar{p} \to X \to J/\psi \pi^{+}\pi^{-}$	5.2σ	D0
3873.4 ± 1.4	$B^{\pm} \to K^{\pm} X \to K^{\pm} J/\psi \pi^{+}\pi^{-}$	3.5σ	BaBar

World average X mass:

$$M_X = 3871.9 \pm 0.5 \quad \text{MeV}$$

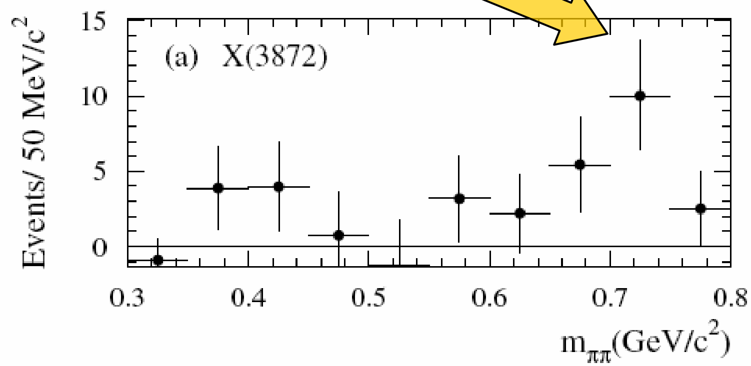
Width:

$$\Gamma < 2.3 \quad \text{MeV}$$



X(3872): resolving quantum numbers

BaBar



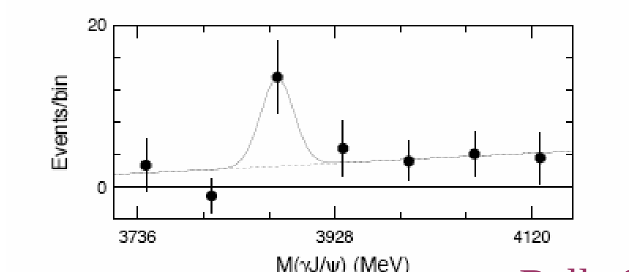
- $\pi^+\pi^-$ spectrum peaked at large mass
- Experimental search found no charged partners ⇒ **I=0**
- Two and three pion modes were found with:

$$\frac{B(X \to J/\psi\pi^+\pi^-\pi^0)}{B(X \to J/\psi\pi^+\pi^-)} = 1.0 \pm 0.4 \pm 0.3$$

⇒ Isospin violation

- Belle has measured:

$$B(B \to KX)B(X \to J/\psi\,\gamma) = (1.8 \pm 0.6 \pm 0.1) \times 10^{-6}$$



Belle 05

the observation of this mode allows to fix **C=+1**

- Angular distribution in the final state $J/\psi\pi^+\pi^-$ is compatible with the assignment **$J^P=1^+$**

⇒ **$J^{PC}=1^{++}$**

Even though 2^{++} is not excluded

X(3872): other experimental information

Belle, BaBar

Observation of $B \to XK$, $X \to D^0 \overline{D}^0 \pi^0$

Mass enhancement is observed at

$$M = 3875.2 \pm 0.7 \pm^{0.3}_{1.6} \pm 0.8 \quad \text{MeV}$$

Presumably the same state: approx. 4 MeV higher than the world average!

X(3872): what is it?

In the **charmonium** interpretation, due to $J^{PC}=1^{++}$, it should be identified with χ'_{c1}

Possible explanation of isospin violation:

See Suzuki, PRD 72, 114013 (05)

phase space severely suppressed

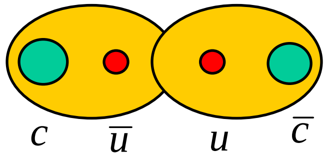
$$\frac{B(X \to J/\psi \pi^+ \pi^- \pi^0)}{B(X \to J/\psi \pi^+ \pi^-)} = 1.0 \pm 0.4 \pm 0.3 \quad \Rightarrow \quad \frac{A(X \to J/\psi \rho)}{A(X \to J/\psi \omega)} \cong 0.2$$

phace space not very suppressed

Some other possibilities:

- hybrid state $c\bar{c}g$
- tetraquark state
- DD^* molecule
- ....

X(3872): **molecule** vs charmonium



Swanson, Brateen, Voloshin

X proximity to $D^0\bar{D}^{*0}$ threshold:

$$M(X) = 3871.9 \pm 0.5 \quad \text{MeV}$$

$$M(D^0\bar{D}^{*0}) = 3871.2 \pm 1.0 \quad \text{MeV}$$

$$M(D^+D^{*-}) = 3879.3 \quad \text{MeV}$$

Suggests that a molecular state made of charmed mesons contributes to the structure of X

Voloshin

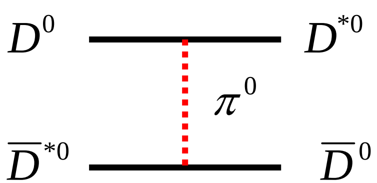
$$\psi_X = a_0\psi_0 + \sum_i a_i\psi_i$$

$$\psi_0 = \frac{D^0\bar{D}^{*0} + \bar{D}^0 D^{*0}}{\sqrt{2}}$$

Other hadronic states also $c\bar{c}$

Mixing of the molecule (dominant component) with other states such as pure charmonium → no definite isospin

Binding by light hadron exchange



X(3872): **molecule** vs charmonium- role of radiative decays

Voloshin

In the molecular scenario $X \to D^0 \overline{D}^0 \gamma$ & $X \to D^+ D^- \gamma$
arise from the radiative decays of the individual vector mesons

$D^{*0} \to D^0 \gamma, \quad \overline{D}^{*0} \to \overline{D}^0 \gamma$ & $D^{*\pm} \to D^{\pm} \gamma$

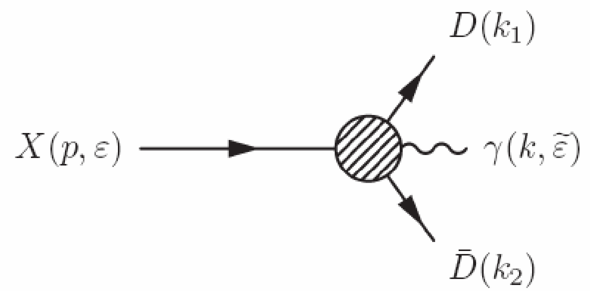
The decay $X \to D^+ D^- \gamma$ is strongly suppressed with respect to $X \to D^0 \overline{D}^0 \gamma$ because

- $\Gamma(D^{*\pm} \to D^{\pm}\gamma) = 1.5 \pm 0.5$ KeV $\Gamma(D^{*0} \to D^0\gamma) = 26 \pm 6$ KeV (PDG)
- Stronger distructive interference in the emission of γ by the charged meson pair in X
- Binding by pion exchange is repulsive for $D^{*+} D^-$ molecules (Tornqvist- Close & Godfrey)

If observed, the suppression of $X \to D^+ D^- \gamma$ **with respect to** $X \to D^0 \overline{D}^0 \gamma$ **would support the molecular interpretation** **(Voloshin)**

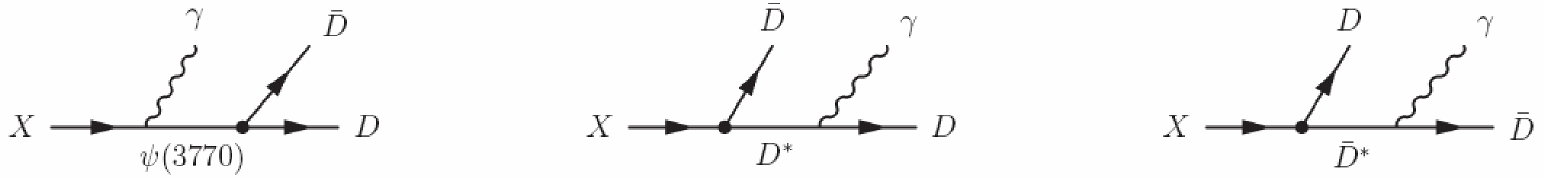
True?

X(3872) as the first radial excitation of χ_{c1} : radiative decays

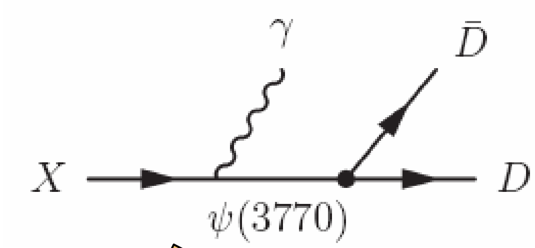


Standard mechanism for radiative X transitions into charmed states

Pole diagrams



Intermediate $\psi(3770)$



c

$g_{\psi DD}$

- $$< \psi_{(3770)}(q,\eta)\gamma(k,\tilde{\epsilon})|X(p,\epsilon) >= i\, e\, c\, \epsilon^{\alpha\beta\mu\nu}\, \tilde{\epsilon}^*_\alpha\, \epsilon_\beta\, \eta^*_\mu\, k_\nu$$

Unknown coupling **c**

- Defining $$< D(k_1)\bar{D}(k_2)|\psi(q,\eta) >= g_{\psi D\bar{D}}\, \eta\cdot k_1$$

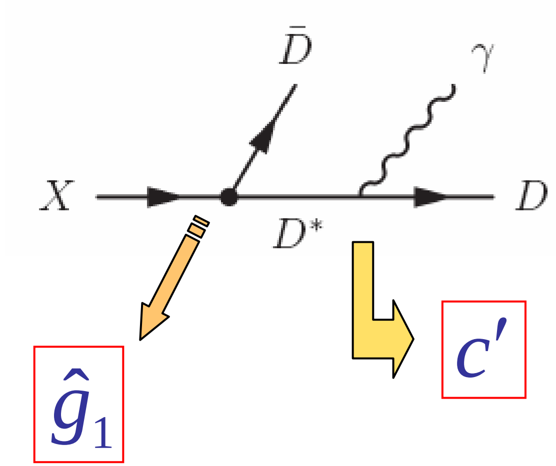
and using: $\Gamma(\psi(3770)) = 23.0 \pm 2.7$ MeV (PDG)

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

Coupling $g_{\psi DD}$ known from exp data

The analysis of this diagram does not rely on any interpretation for ψ (3770)

Intermediate D*



$$< D(k_1)\gamma(k,\tilde{\epsilon})|D^*(p_1,\xi) >= i\, e\, c'\, \epsilon^{\alpha\beta\tau\theta}\, \tilde{\epsilon}^*_\alpha\, \xi_\beta\, p_{1\tau}\, k_\theta$$

Coupling of γ to *c* and *q*:

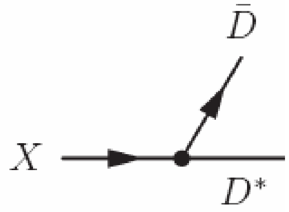
$$c' = \frac{e_c}{m_c} + \frac{e_q}{\Lambda_q}$$

Λ_q can be fixed using: $\Gamma(D^{*+}) = 96 \pm 22$ keV

and $\mathcal{B}(D^{*+} \to D^+\gamma) = (1.6 \pm 0.4)\%$

$\longrightarrow$ $\Lambda_q = 335 \pm 29$ MeV

$\hat{g}_1$



Effective Lagrangian approach

- Multiplet of radial excitations of $\chi_{c2},\ \chi_{c1},\ \chi_{c0},\ h_c$

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

to be identified with X(3872)

- Doublet of $Q\bar{q}$ mesons $D^*,\ D$: $H_{1a} = \left(\frac{1+\not{v}}{2}\right)[M_a^\mu\gamma_\mu - M_a\gamma_5]$

- Doublet of $\bar{Q}q$ mesons $\bar{D}^*,\ \bar{D}$: $H_{2a} = [M_a'^\mu\gamma_\mu - M_a'\gamma_5]\left(\frac{1-\not{v}}{2}\right)$

Effective Lagrangian:

$$\mathcal{L}_1 = ig_1 Tr\left[P^{(Q\bar{Q})\mu}\bar{H}_{1a}\gamma_\mu\bar{H}_{2a}\right] + h.c.$$

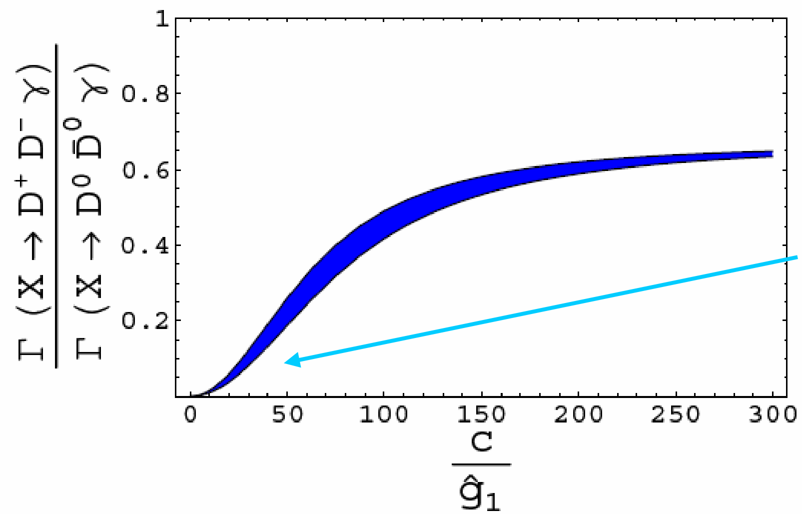
→ Isospin conserving vertex

$$\hat{g}_1 = g_1\sqrt{m_D}$$

→ unknown

$$R = \frac{\Gamma(X \to D^+ D^- \gamma)}{\Gamma(X \to D^0 \overline{D}^0 \gamma)}$$

Can be evaluated as a function of the ratio of the two unknown couplings $\frac{c}{\hat{g}_1}$



Very small values of R

- R<0.7
- in the $c\bar{c}$ description R is very small for small values of $\frac{c}{\hat{g}_1}$ (when the ψ pole contribution is negligible)

the suppression of R is not peculiar of the molecular scenario

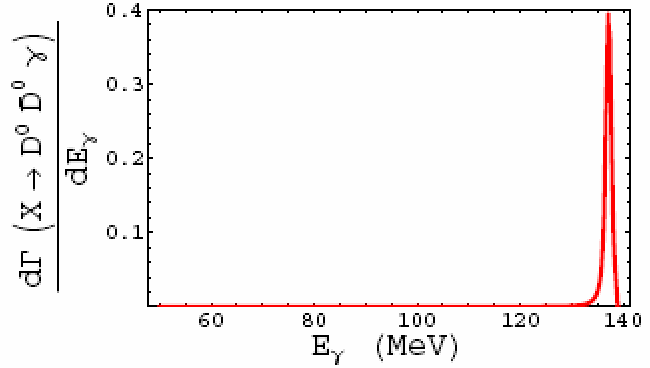
Photon spectrum

Can be computed for representative values of $\frac{c}{\hat{g}_1}$

1st scenario: small values of $\frac{c}{\hat{g}_1}$ ⟹ intermediate D* dominates the amplitude

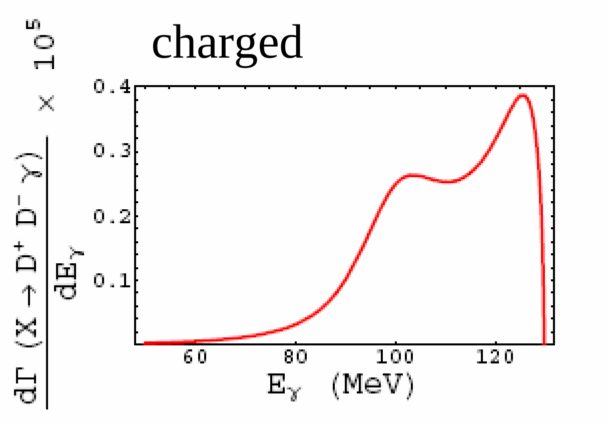
$\frac{c}{\hat{g}_1}=1$

neutral



⟹ Essentially coincides with the line in D* decay: $E_\gamma \cong 139$ MeV

charged



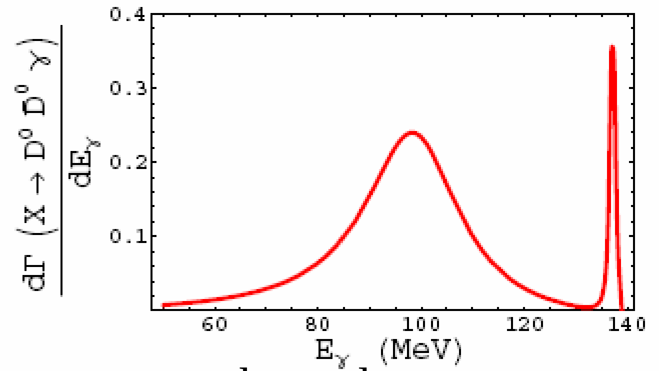
⟹ Broader spectrum, peaked at $E_\gamma \cong 125$ MeV

Photon spectrum

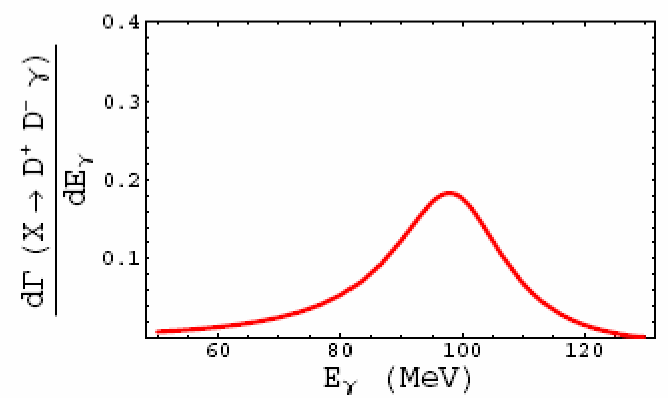
- 2nd scenario: large values of $\frac{c}{\hat{g}_1}$ ⇨ intermediate ψ dominates the amplitude

$\frac{c}{\hat{g}_1} = 300$

neutral



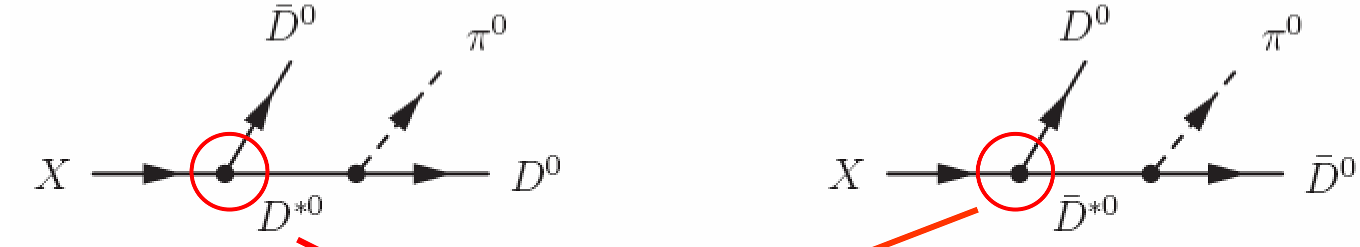
charged



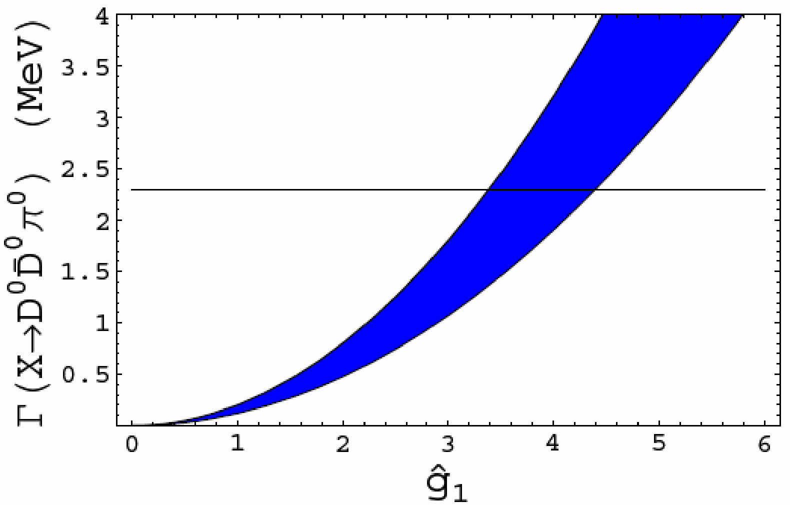
Both peaked at ≈ 100 MeV
A second peak being present
in the neutral channel

The spectra would be different
in the molecular scenario depending on
the parameters of the WF
of D D^* bounded in X

$X \to D^0 \bar{D}^0 \pi^0$



Could be useful to obtain information on $\hat{g}_1$



Exp bound

Values of $\hat{g}_1$ typical of hadronic couplings can reproduce the small width of X(3872)

Charmonium vs molecule/four quark scenarios: analysis of the modes $X \to \chi_{cJ}\pi(\pi)$

Voloshin, 0709.4474

charmonium

- among $X \to \chi_{cJ}$ transitions the dominant one should be $X \to \chi_{c1}\pi\pi$
- $X \to \chi_{c2}$ is strongly suppressed
- $X \to \chi_{c0}$ is forbidden
- they are anyway very small: $\Gamma(X \to \chi_{c1}\pi\pi) \approx 1$ KeV
- isospin breaking 1π transitions are still weaker

molecule

- no suppression of 1π transitions:
  expected to be due to the I=1 part of the X wave function
  should be dominant over the kinematically suppressed 2π emissions
- all the χ_{cJ} states are allowed in the final state
- no reliable estimate of such rates in the composite scenarios,
  an approximate estimate (Voloshin) predicts no suppression of the modes
  $X \to \chi_{cJ}\pi^0$ with respect to $X \to J/\psi\pi^+\pi^-$

Conclusions

• Since its discovery in 2003, X(3872) is still a puzzling meson

• Main goal: distinguishing among the different interpretations

• Radiative decays: useful tool however
the suppression of the mode $X \to D^+ D^- \gamma$ with respect to $X \to D^0 \overline{D}^0 \gamma$
is not peculiar of the molecular scenario

• some other tools: analysis of the photon spectrum

other modes, such as $X \to \chi_{cJ} \pi(\pi)$

X line shapes ⟶ see talk by Brateen