Open Charm Effects on the E1 Transition of $\psi(3770)/\psi' \to \gamma\chi_{cJ}$

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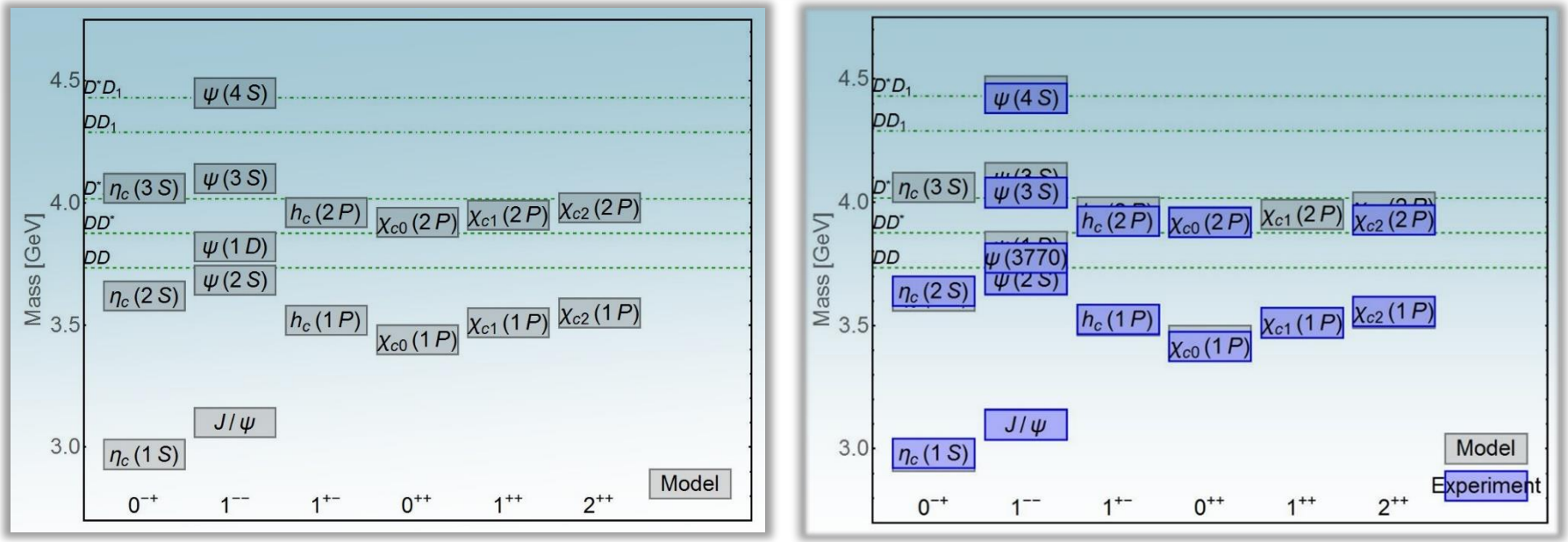
SPECTRUM



Charmonium Spectrum: QM Prediction[1] *V.S. Exp. Data*

- ***Quark model works quite good in producing the charmonium spectrum. Even with a "naive" color Coulomb plus linear scalar potential we get a relatively successful description of the spectrum***[2]**.**

[1]S. Godfrey and N. Isgur, Phys. Rev. D 32, 189 (1985)
[2]E. Eichten et al., Phys. Rev. D 21 (1980) 203

E1 TRANSITION IN QM

[1]E. Eichten *et al.*, Phys. Rev. D 21 (1980) 203 [2]N. Brambilla *et al.*[Quarkonium Working Group Collaboration], hep-ph/0412158
[3] T. Barnes, S. Godfrey and E. S. Swanson, Phys. Rev. D 72 (2005) 054026

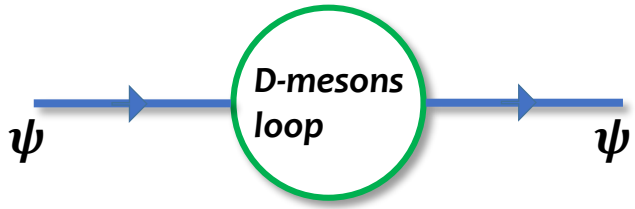
Channel	Ref. [1]/keV	Ref. [2]/keV	Ref. [3] /keV	Ref. [3]/keV	Exp. data/keV
$\psi(3770) \to \gamma\chi_{c0}$	null	299	403	213	198.56 ± 25.54
$\psi(3770) \to \gamma\chi_{c1}$	null	99	125	77	67.46 ± 7.85
$\psi(3770) \to \gamma\chi_{c2}$	null	3.88	4.9	3.3	<17.4
$\psi' \to \gamma\chi_{c0}$	43.2	47	63	26	29.87 ± 1.14
$\psi' \to \gamma\chi_{c1}$	34	42.8	54	29	28.55 ± 1.20
$\psi' \to \gamma\chi_{c2}$	23.7	30.1	38	24	27.24 ± 1.18

Table of the E1 decay width of $\psi(3770)/\psi' \to \gamma\chi_{cJ}$ predicted by various QM model comparing with exp. data

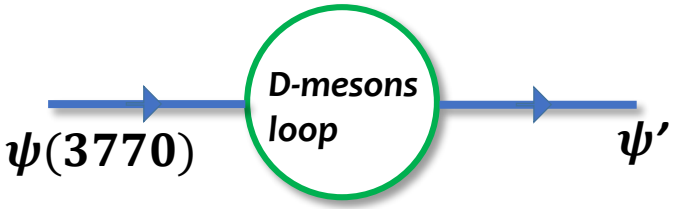
- ***Significant discrepancies between various QM predictions and experimental data.***

OPEN CHARM EFFECTS

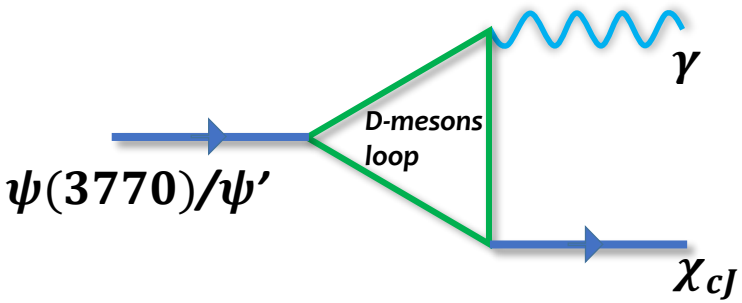
The coupling of $\psi(3770)/\psi'$ and two D mesons(pseudoscalar or vector) allows these kinds of diagrams which derive our study of the open charm effects.



- *Mass of charmonium states*

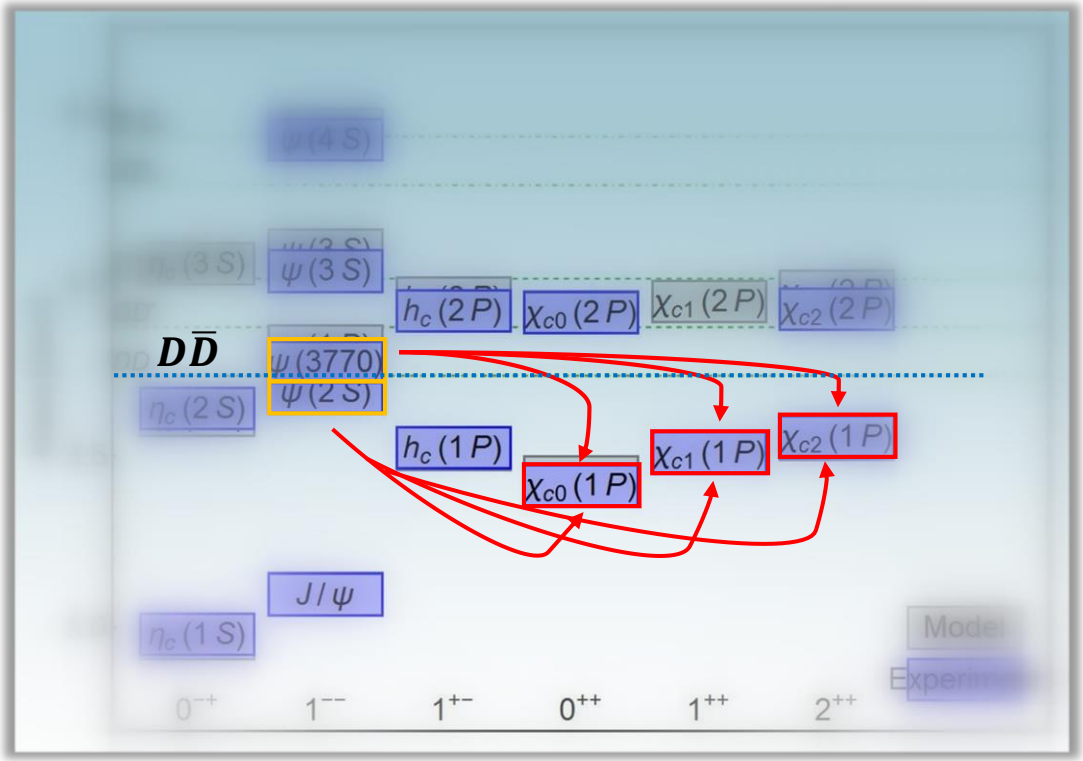


- *S-D mixing*



- *Charmonium decays, e.g. E1 decay transition of $\psi(3770)$ and ψ'*

MOTIVATION



- *We focus on the E1 transitions* $\psi(3770)/\psi' \to \gamma\chi_{cJ}$ *and study the open charm effects as final state Interactions for these processes for both* $\psi(3770)$ *and* ψ' *are close to the* $D\bar{D}$ *threshold.*

- *Studying these effects help us better understand the long-standing* $\rho\pi$ *puzzle and the non-*$D\bar{D}$ *decay of* $\psi(3770)$.
- *Similar mechanism has been studied in the M1 transition of* J/ψ *and* ψ'[1]*comparing to the previous studies in quark model* and lattice QCD.

[1]G. Li and Q. Zhao, Phys. Lett. B 670 (2008) 55

NONRELATIVISTIC EFFECTIVE FIELD THEORY

Heavy mesons:

$$H = P + \vec{\sigma}\cdot\vec{V}$$

D-mesons:

$$P_D = (D^0, D^+, D_s)\,; \quad V_D = (D^{*0}, D^{*+}, D_s^*)$$

Interaction Lagrangians with heavy mesons:

S-wave charmonia:

$$J = \vec{\sigma}\cdot\vec{\psi} + \eta_c' \quad \cdots\cdots \quad \mathcal{L}_{HH\psi_S} = i\frac{g_2}{2}\left\langle \bar{H}_a^\dagger \sigma^i \overleftrightarrow{\partial}^i H_a^\dagger J\right\rangle + H.c.$$

P-wave charmonia:

$$\chi^i = \sigma^j\left(-\chi_{c2}^{ij} - \frac{1}{\sqrt{2}}\epsilon^{ijk}\chi_{c1}^k + \frac{1}{\sqrt{3}}\delta^{ij}\chi_{c0}\right) + h_c^i \quad \cdots\cdots \quad \mathcal{L}_{HH\chi} = i\frac{g_1}{2}\left\langle \chi^{\dagger i} H_a \sigma^i \bar{H}_a\right\rangle + H.c.$$

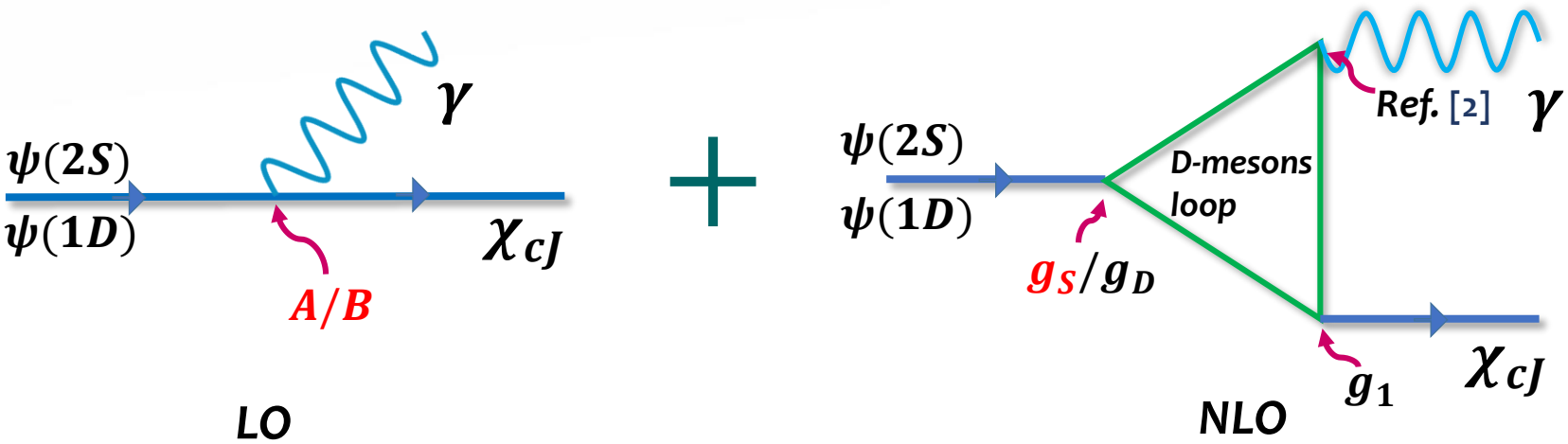
D-wave charmonia:

$$J^{ij} = \frac{1}{2}\sqrt{\frac{3}{5}}\left(\sigma^i\psi^j + \sigma^j\psi^i\right) - \frac{1}{\sqrt{15}}\delta^{ij}\vec{\sigma}\cdot\vec{\psi} \quad \cdots\cdots \quad \mathcal{L}_{HH\psi_D} = i\frac{g_3}{2}\left\langle \bar{H}_a^\dagger \sigma^i \overleftrightarrow{\partial}^j H_a^\dagger J^{ij}\right\rangle + H.c.$$

Photons γ $\cdots\cdots$ $\mathcal{L}_{HH\gamma} = \frac{e\beta}{2}\left\langle H_a^\dagger H_b \vec{\sigma}\cdot\vec{B} Q_{ab}\right\rangle + \frac{eQ'}{2m_Q}\left\langle H_a^\dagger \vec{\sigma}\cdot\vec{B} H_a\right\rangle + c.c.$

Not ***all the couplings here are clearly known***

POWER COUNTING AND COUPLINGS



- *For the leading order terms, we use the Lagrangians*

$$\mathcal{L}_{SP\gamma} = A\langle\chi^{\dagger i}J\rangle E^i + h.c. \qquad \mathcal{L}_{DP\gamma} = B\langle\chi^{\dagger i}J^{ij}\rangle E^j + h.c.$$

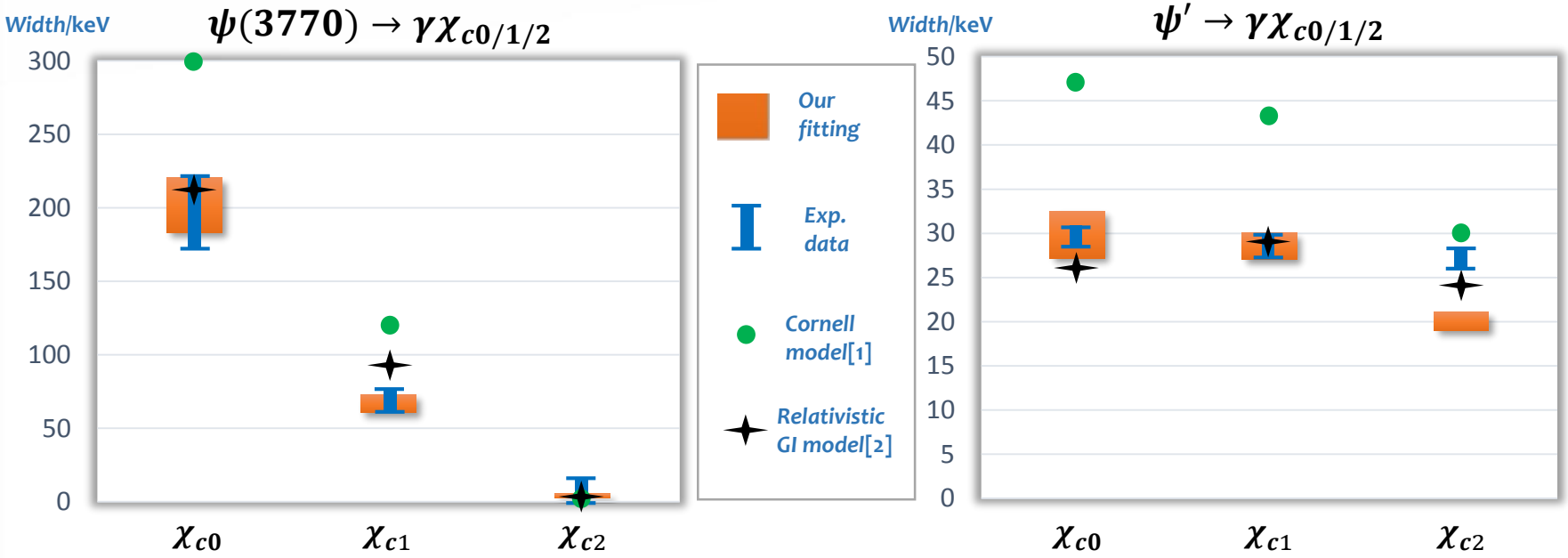
- g_1 *is taken from Ref.* [1] *and the photon coupling is introduced from Ref.* [2].
- g_D *is fitted through the tree process* $\psi(3770) \to D\bar{D}$.
- g_S *is taken as a free parameter.*
- *We are still working on including S-D mixing.*

[1] P. Colangelo, F. De Fazio, and T. N. Pham, Phys. Lett. B542, 71 (2002) [2]J. Hu and T. Mehen, Phys. Rev. D 73 (2006) 054003

RESULTS& CONCLUSION

[1]N. Brambilla et al.[QWG Collaboration], hep-ph/0412158

[2] T. Barnes, S. Godfrey and E. S. Swanson, Phys. Rev. D 72 (2005) 054026



Fitting results in decay width comparing with exp. data and predictions in QM

- ***Fitting results for most channels work well.***
- ***Fitting results for $\psi' \to \gamma\chi_{c2}$ can not match the data at all. We finally elimate this channel when fitting.***

RESULTS& CONCLUSION

Channel	Without loops/keV	Fitted width/keV
$\psi(3770) \to \gamma\chi_{c0}$	167.1	201.8
$\psi(3770) \to \gamma\chi_{c1}$	66.7	52.7
$\psi(3770) \to \gamma\chi_{c2}$	2.74	2.05
$\psi' \to \gamma\chi_{c0}$	29.9	33.6
$\psi' \to \gamma\chi_{c1}$	28.6	29.1
$\psi' \to \gamma\chi_{c2}$	20.1	20.0

- *Obviously the open charm effects play a important role in these E1 transition.*
- $g_s = (0.93 \pm 0.54)\mathrm{GeV}^{-3/2}$ *in our fitting which is close to the number in Ref.* [1].

This work shows the importance of including the open charm effects on these E1 transitions. We will try to include the S-D mixing properly in the future.

Thank you for your attention !

[1]G. Y. Chen and Q. Zhao, Phys. Lett. B 718 (2013) 1369