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An overview of the property of Y(4260)

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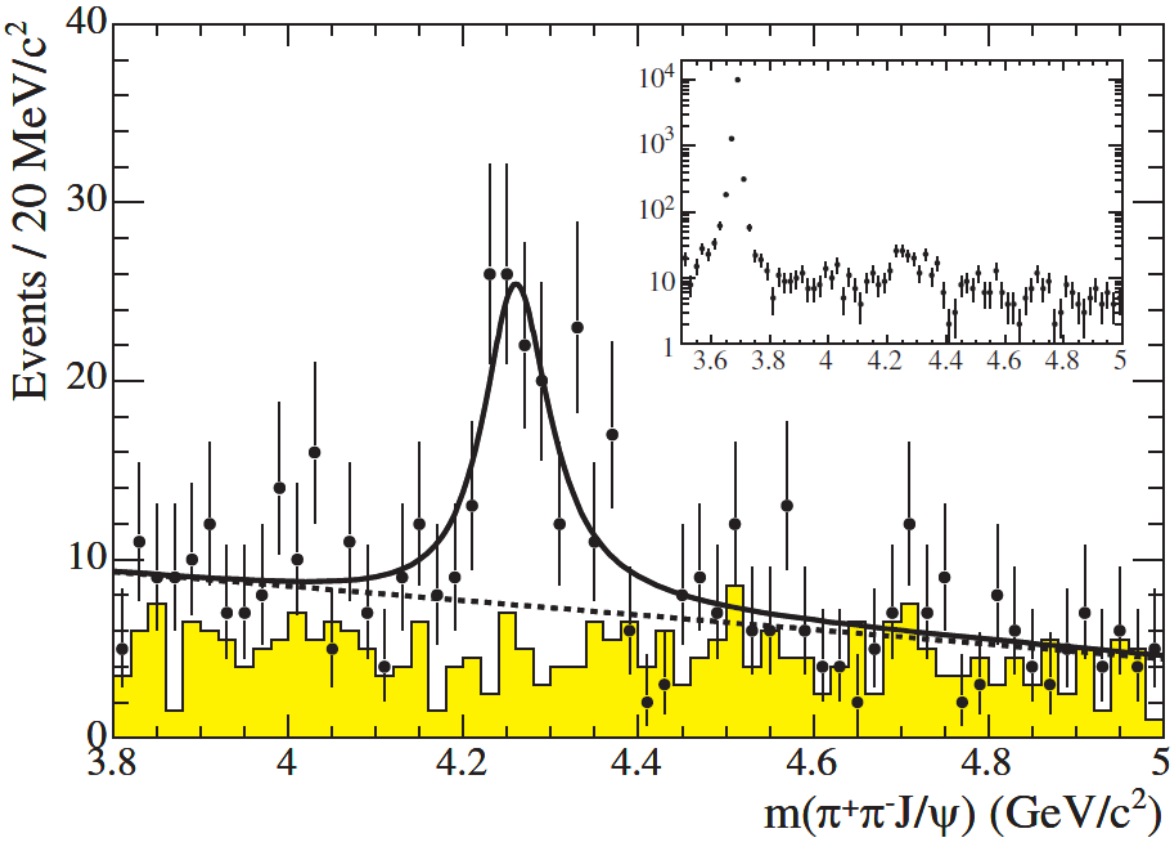
Outline

1. Observations of Y(4260)
2. Possible interpretations and reminder of some crucial issues

1. Observations of Y(4260)

First evidence from BaBar in $e^+e^- \to \gamma_{ISR}\, J/\psi\pi^+\pi^-$ and quickly confirmed by CLEO-c and Belle

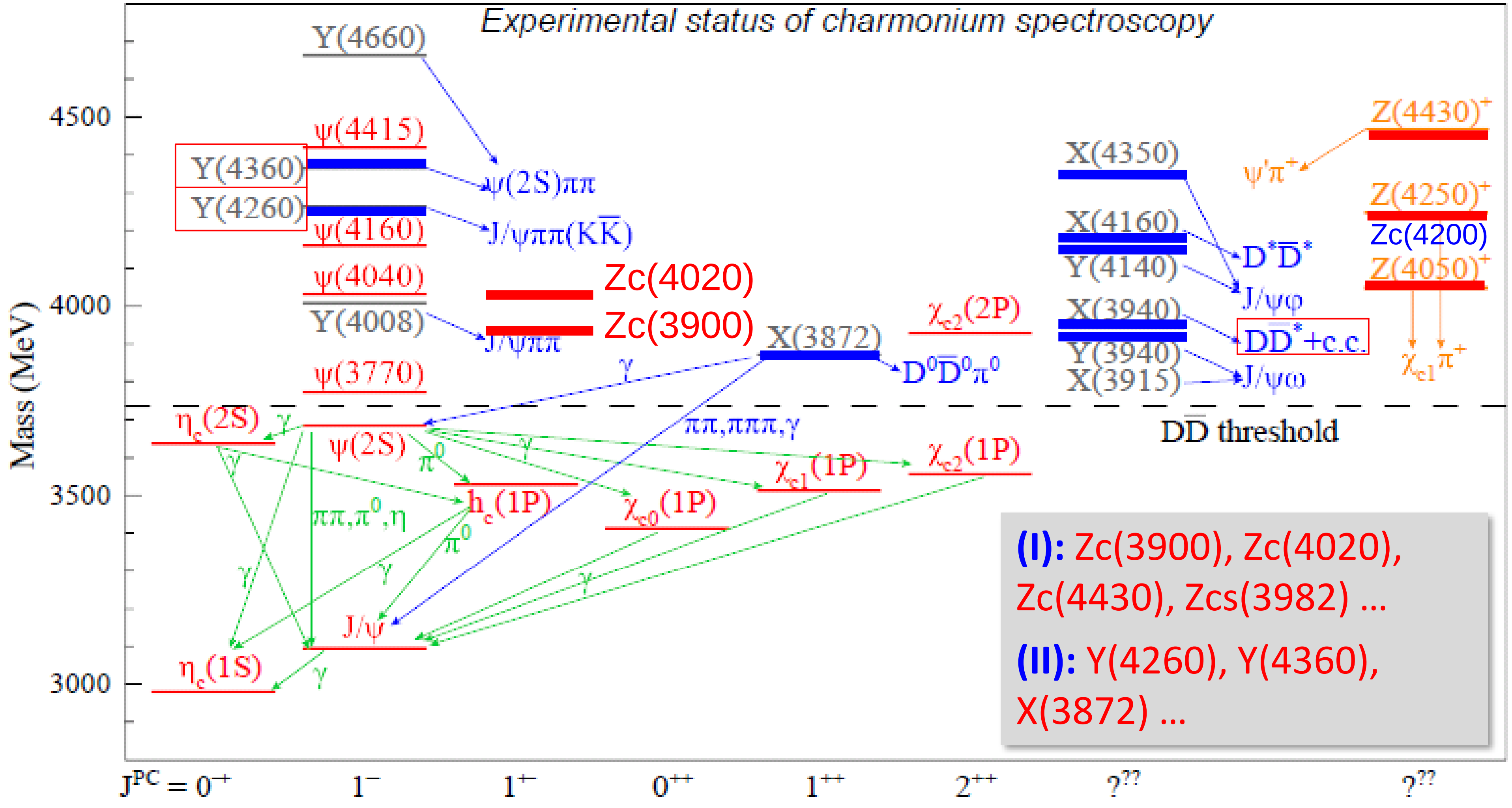


$$4259 \pm 8(\mathrm{stat})^{+2}_{-6}(\mathrm{syst})\ \mathrm{MeV}/c^2$$

$$88 \pm 23(\mathrm{stat})^{+6}_{-4}(\mathrm{syst})\ \mathrm{MeV}/c^2$$

BaBar, *Phys.Rev.Lett.* 95 (2005) 142001

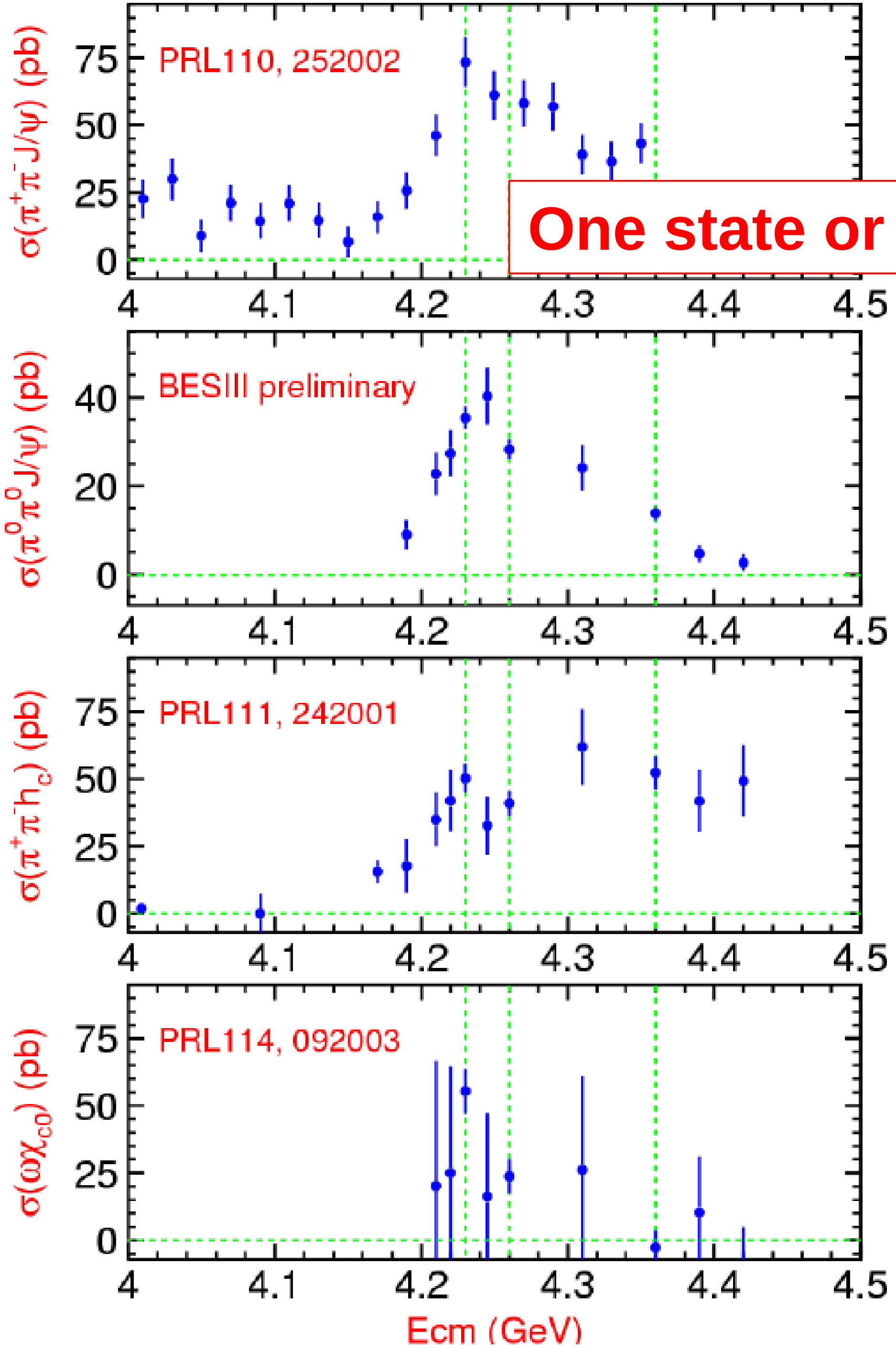
Heavy flavor states: Charmonia and charmonium-like states, i.e. X, Y, Z's.

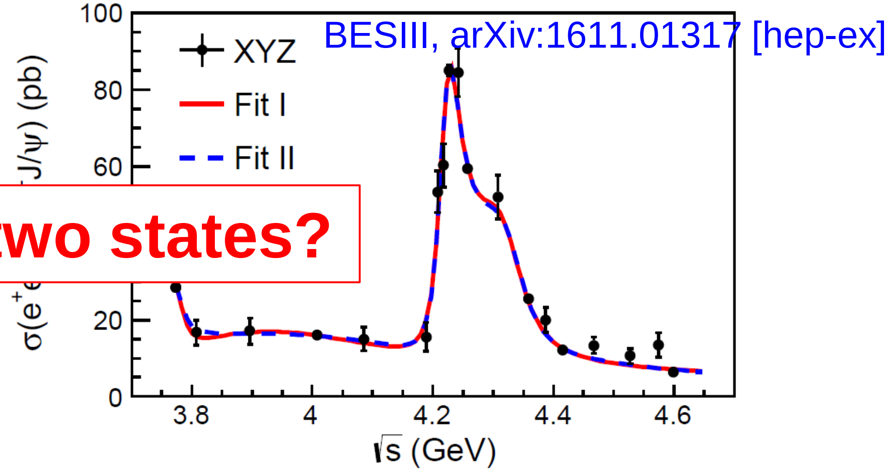


(I): Zc(3900), Zc(4020), Zc(4430), Zcs(3982) …

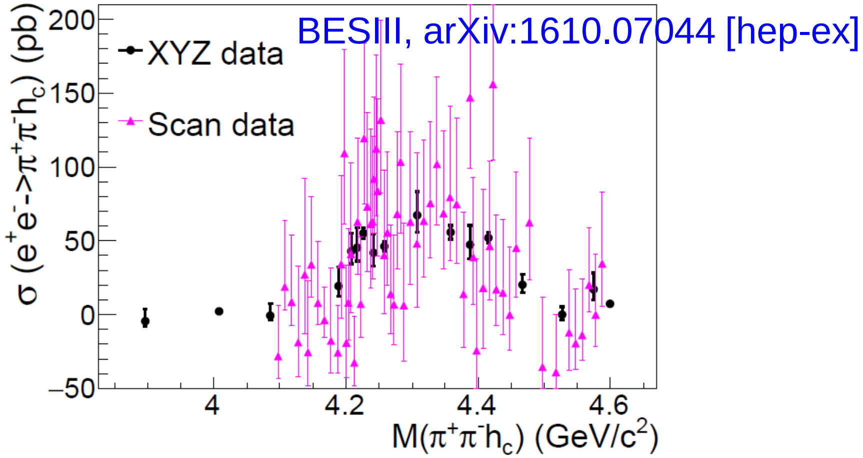
(II): Y(4260), Y(4360), X(3872) …

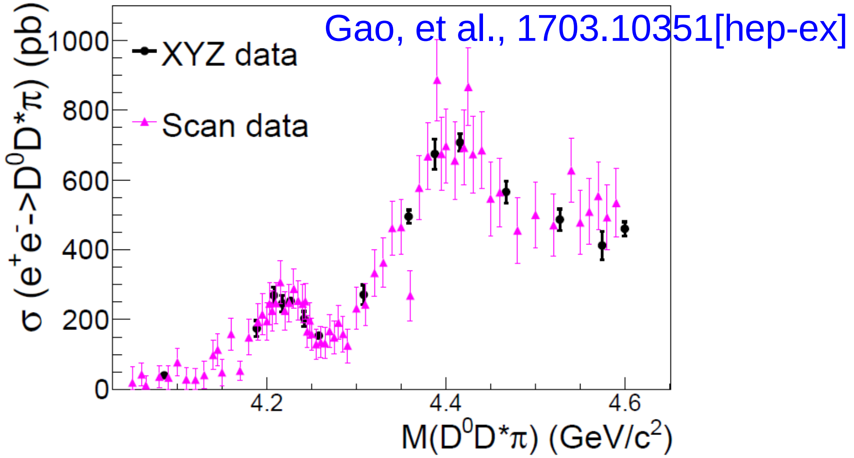
No place for Y(4260) in the potential quark model!



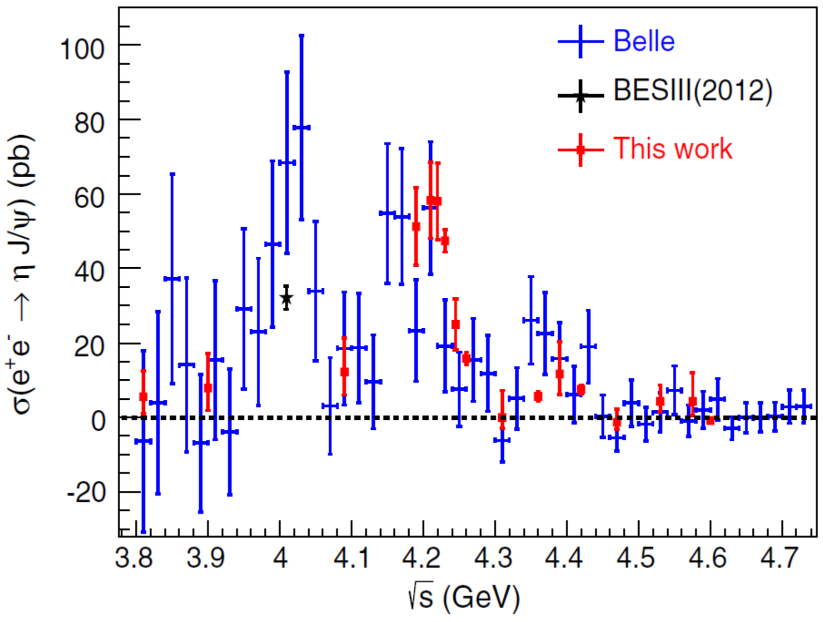


One state or two states?



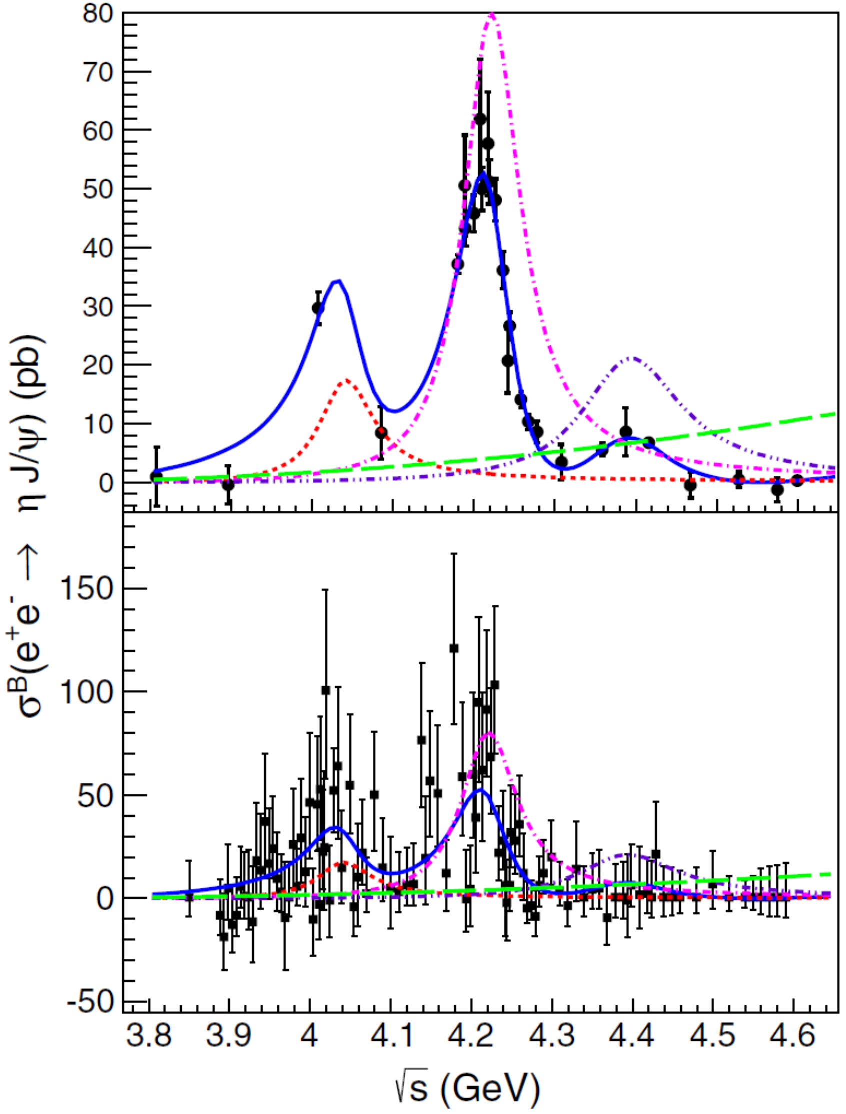


$e^+e^- \to \eta J/\psi$



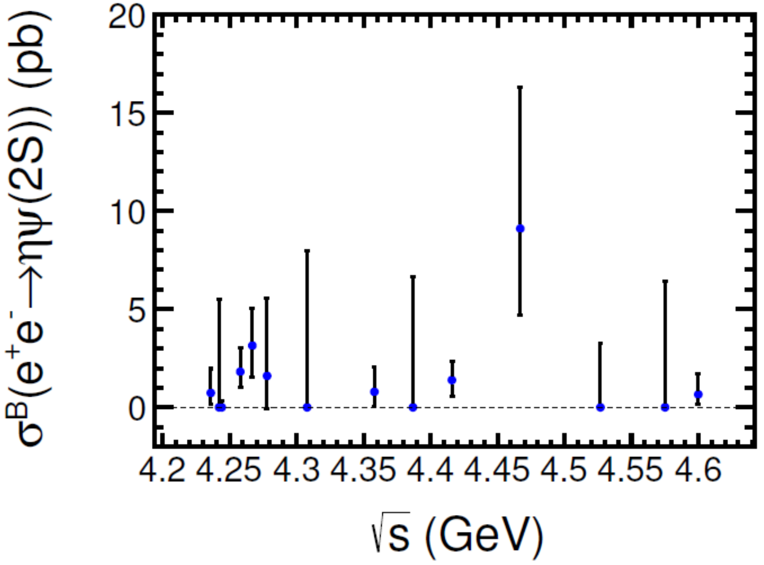
BESIII, PRD91, 112005 (2015)

$e^+e^- \to \eta J/\psi$



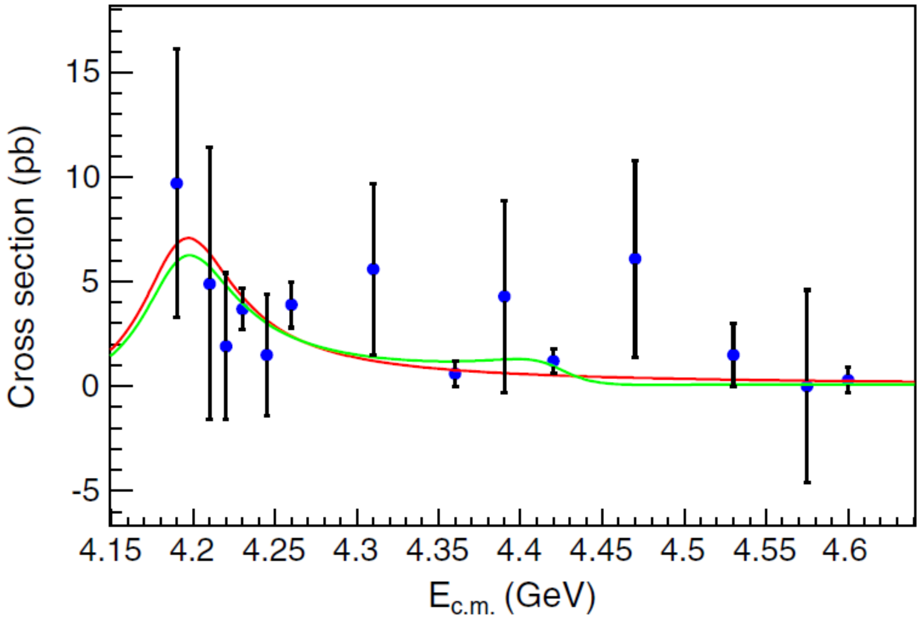
BESIII, PRD102, 031101 (2020)

$e^+e^- \to \eta\psi(2S)$



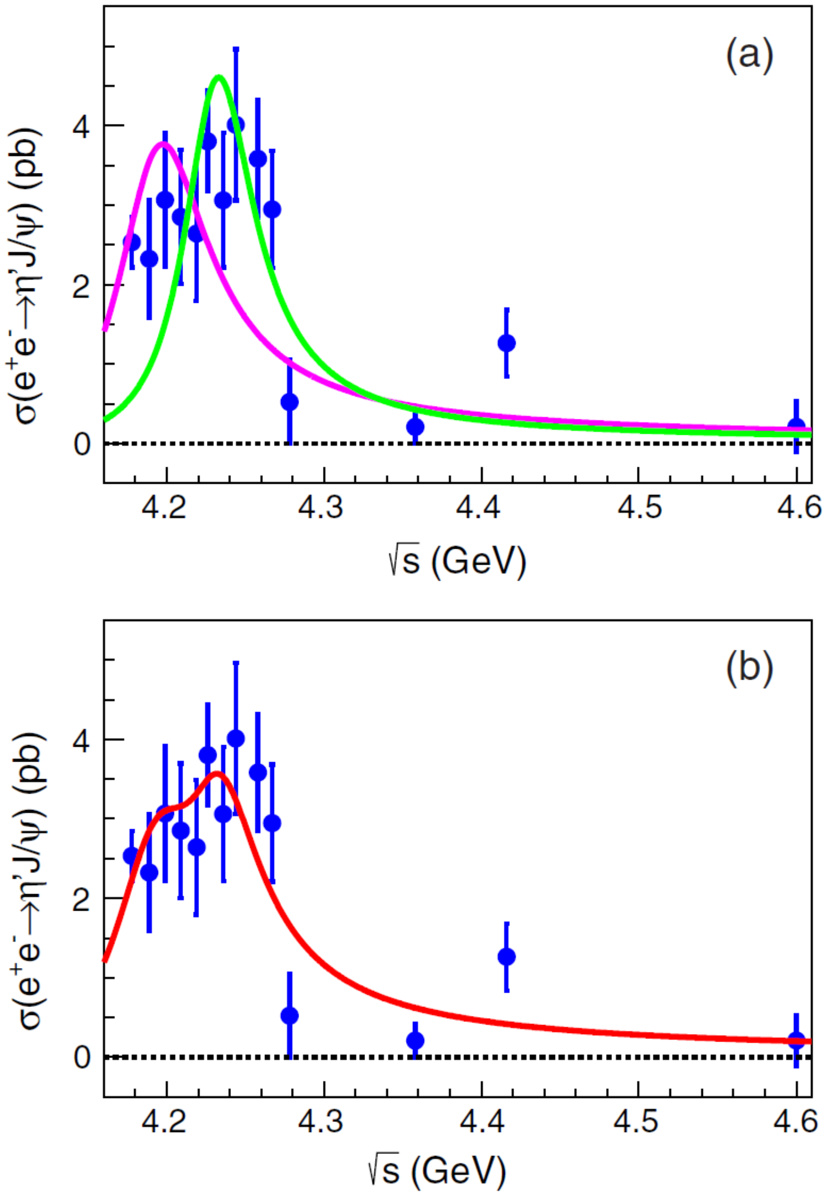
BESIII, *JHEP* 10 (2021) 177

$e^+e^- \to \eta' J/\psi$



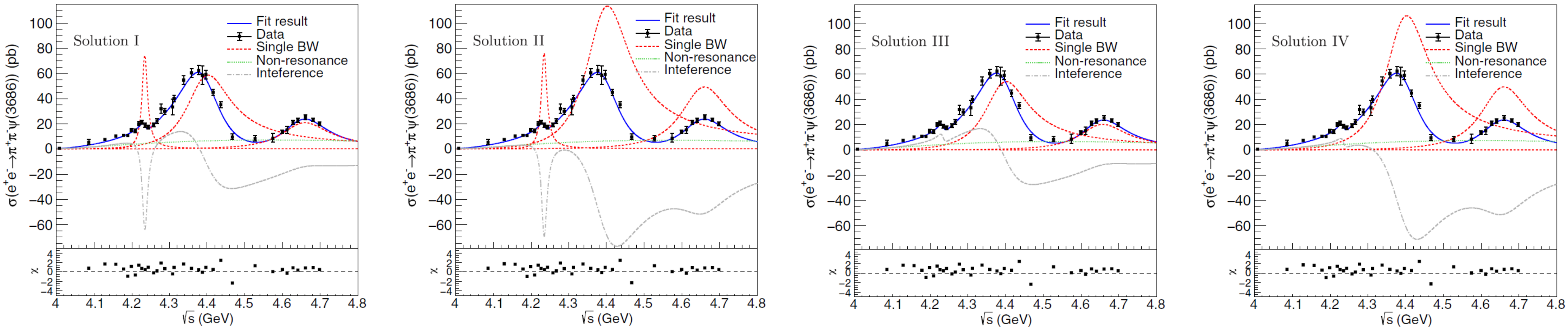
BESIII, PRD94, 032009 (2016)

$e^+e^- \to \eta' J/\psi$



BESIII, PRD101, 012008 (2020)

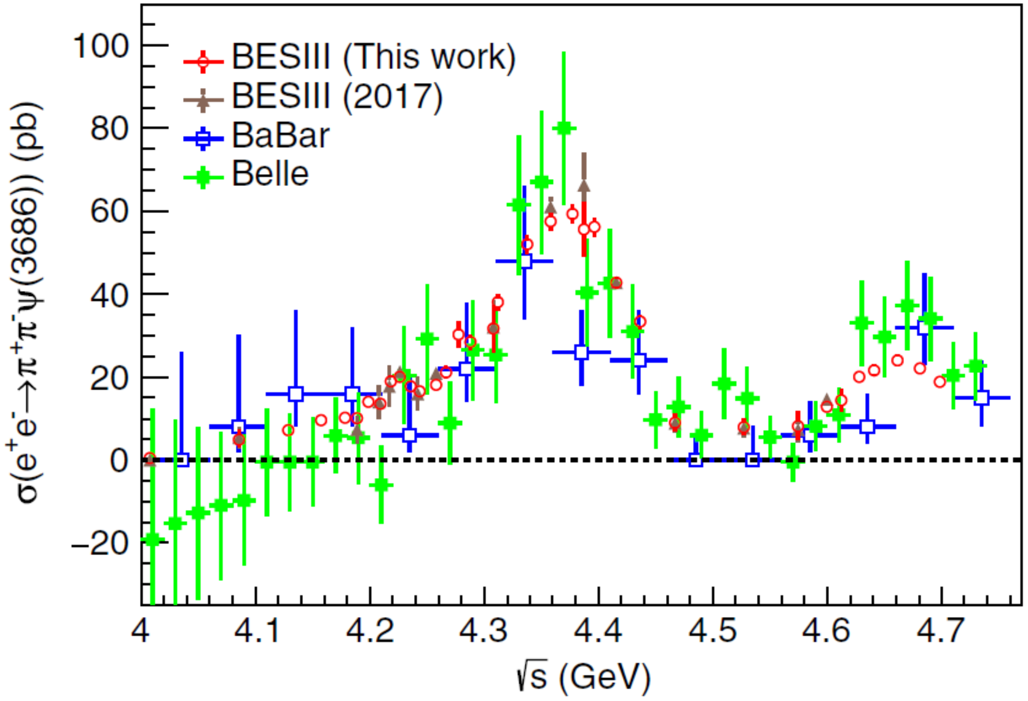
$e^+e^- \to \pi^+\pi^-\psi(3686)$

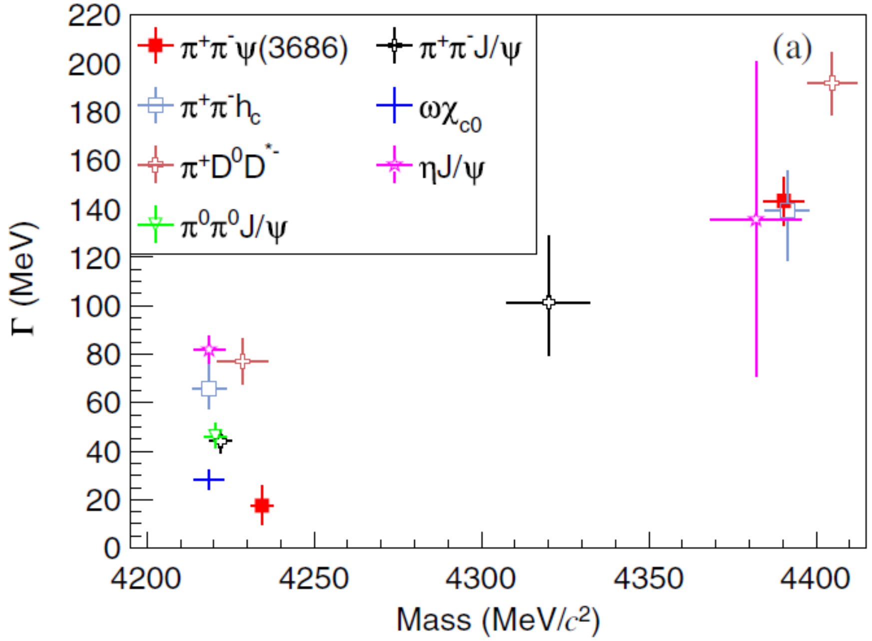


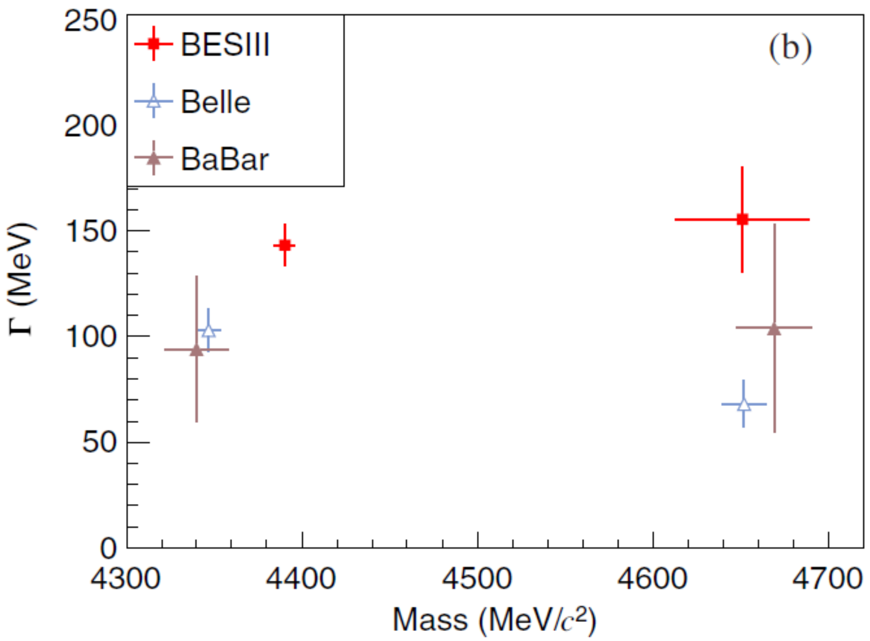
Parameters	Solution I	Solution II	Solution III	Solution IV
$\mathrm{M}(Y4220)$ (MeV/c^2)		4234.4 ± 3.2		
$\Gamma^{\mathrm{tot}}(Y4220)$ (MeV)		17.6 ± 8.1		
$\mathcal{B}\Gamma^{ee}(Y4220)$ (eV)	1.59 ± 0.75	1.63 ± 0.78	0.02 ± 0.01	0.02 ± 0.01
$\mathrm{M}(Y4390)$ (MeV/c^2)		4390.3 ± 6.0		
$\Gamma^{\mathrm{tot}}(Y4390)$ (MeV)		143.3 ± 10.0		
$\mathcal{B}\Gamma^{ee}(Y4390)$ (eV)	10.70 ± 4.13	20.72 ± 2.46	9.86 ± 4.11	19.44 ± 2.04

Phys.Rev.D 104 (2021) 5, 052012; arXiv:2107.09210[hep-ex]

Phys.Rev.D 104 (2021) 5, 052012; arXiv:2107.09210[hep-ex]







$e^+e^- \to \gamma\chi_{cJ}$

BESIII, *Phys.Rev.D* 104 (2021) 9, 092001

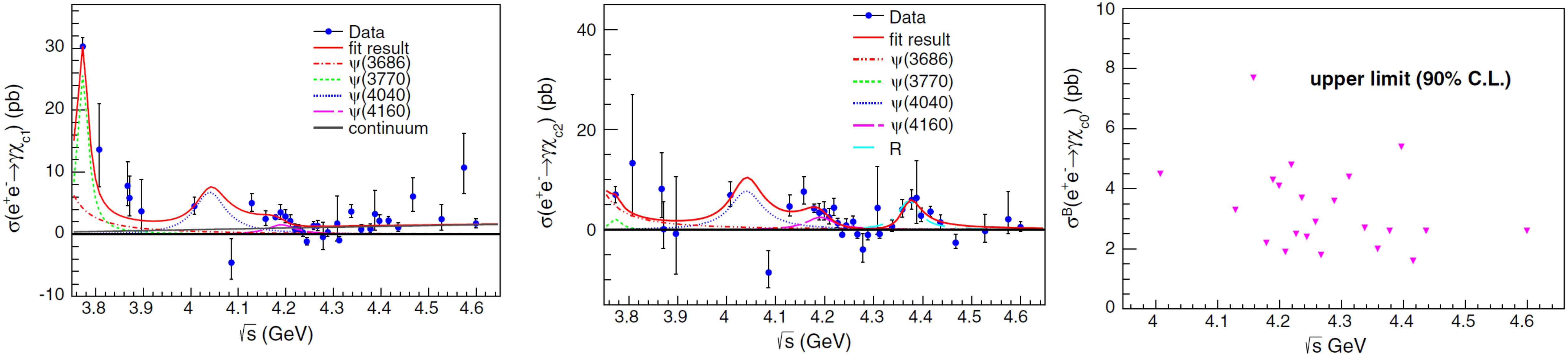
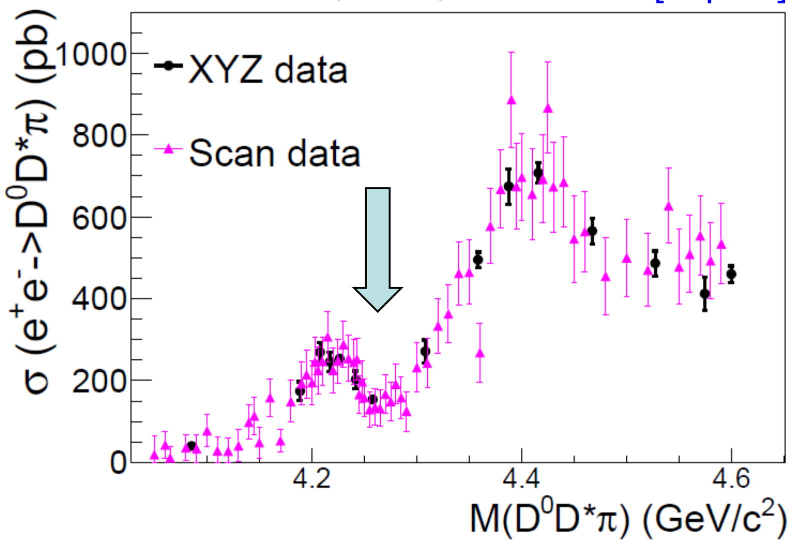


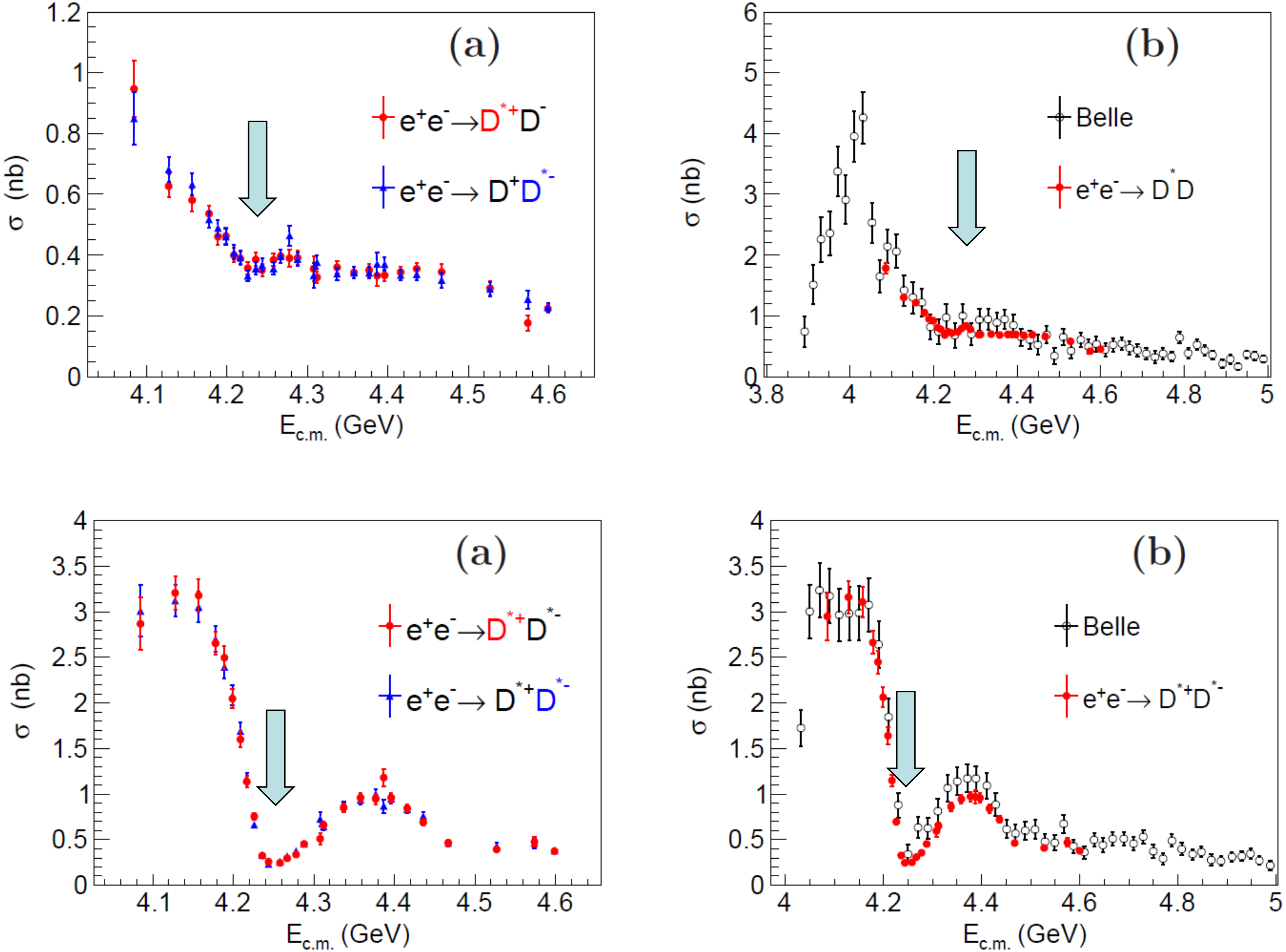
TABLE II. Results of the fit to the $e^+e^- \to \gamma\chi_{c2}$ cross sections. The unit of the e^+e^- partial width is eV/c^2. The errors are statistical only.

Parameter	Solution I	Solution II	Solution III	Solution IV
$\Gamma^{ee}\mathcal{B}(\psi(3770)\to\gamma\chi_{c2})$	$(0.6\pm0.4)\times10^{-1}$			
$\Gamma^{ee}\mathcal{B}(\psi(4040)\to\gamma\chi_{c2})$	$(13.4\pm4.7)\times10^{-1}$	$(6.9\pm3.5)\times10^{-1}$	$(13.3\pm4.7)\times10^{-1}$	$(6.9\pm3.5)\times10^{-1}$
$\Gamma^{ee}\mathcal{B}(\psi(4160)\to\gamma\chi_{c2})$	$(6.8\pm1.9)\times10^{-1}$	$(2.1\pm0.9)\times10^{-1}$	$(6.4\pm1.8)\times10^{-1}$	$(2.1\pm0.9)\times10^{-1}$
$M(\mathcal{R})$	4371.7 ± 7.5			
$\Gamma^{\mathrm{tot}}(\mathcal{R})$	51.1 ± 17.6			
$\Gamma^{ee}\mathcal{B}(\mathcal{R}\to\gamma\chi_{c2})$	$(4.7\pm1.6)\times10^{-1}$	$(3.9\pm1.3)\times10^{-1}$	$(4.4\pm1.5)\times10^{-1}$	$(4.1\pm1.4)\times10^{-1}$
ϕ_1	$241.5^\circ\pm15.0^\circ$	$105.6^\circ\pm33.7^\circ$	$238.9^\circ\pm14.8^\circ$	$107.3^\circ\pm34.2^\circ$
ϕ_2	$248.7^\circ\pm31.3^\circ$	$24.8^\circ\pm39.2^\circ$	$252.6^\circ\pm31.7^\circ$	$19.5^\circ\pm30.8^\circ$

Gao, et al., 1703.10351[hep-ex]



BESIII, 2112.06477[hep-ex]



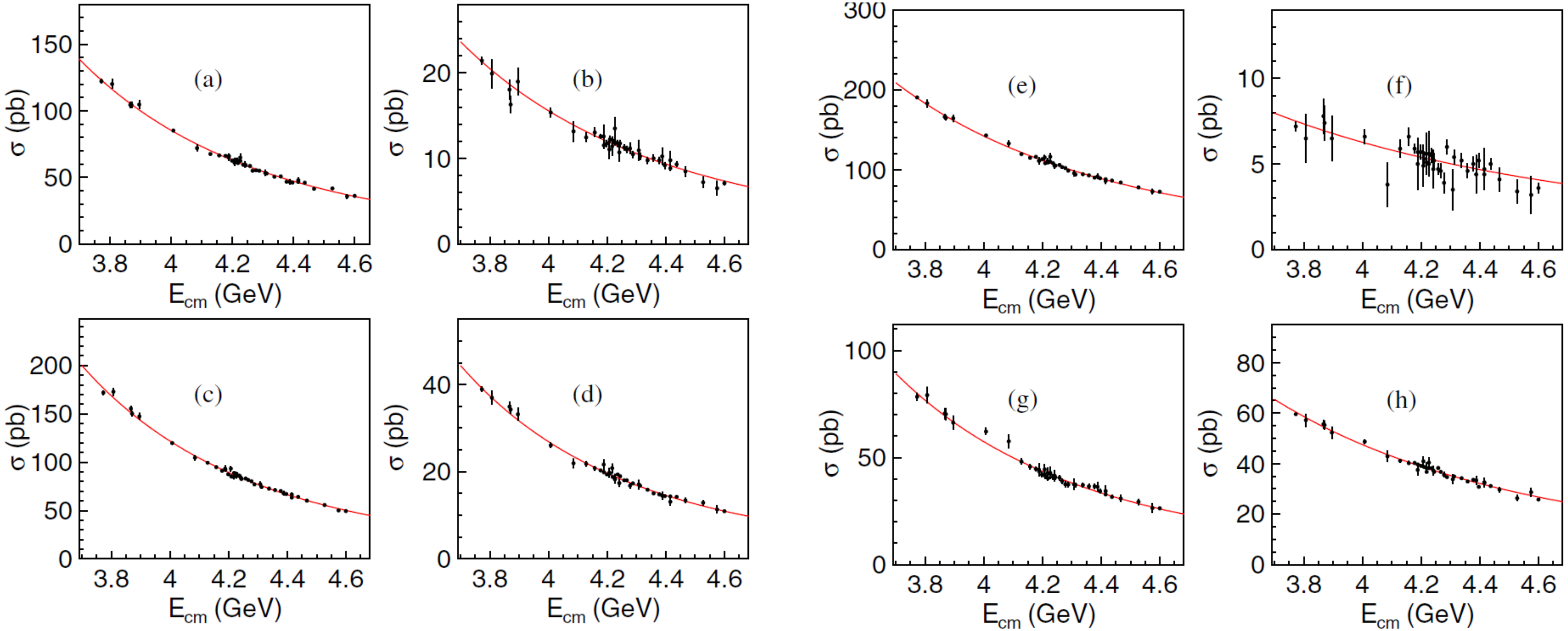
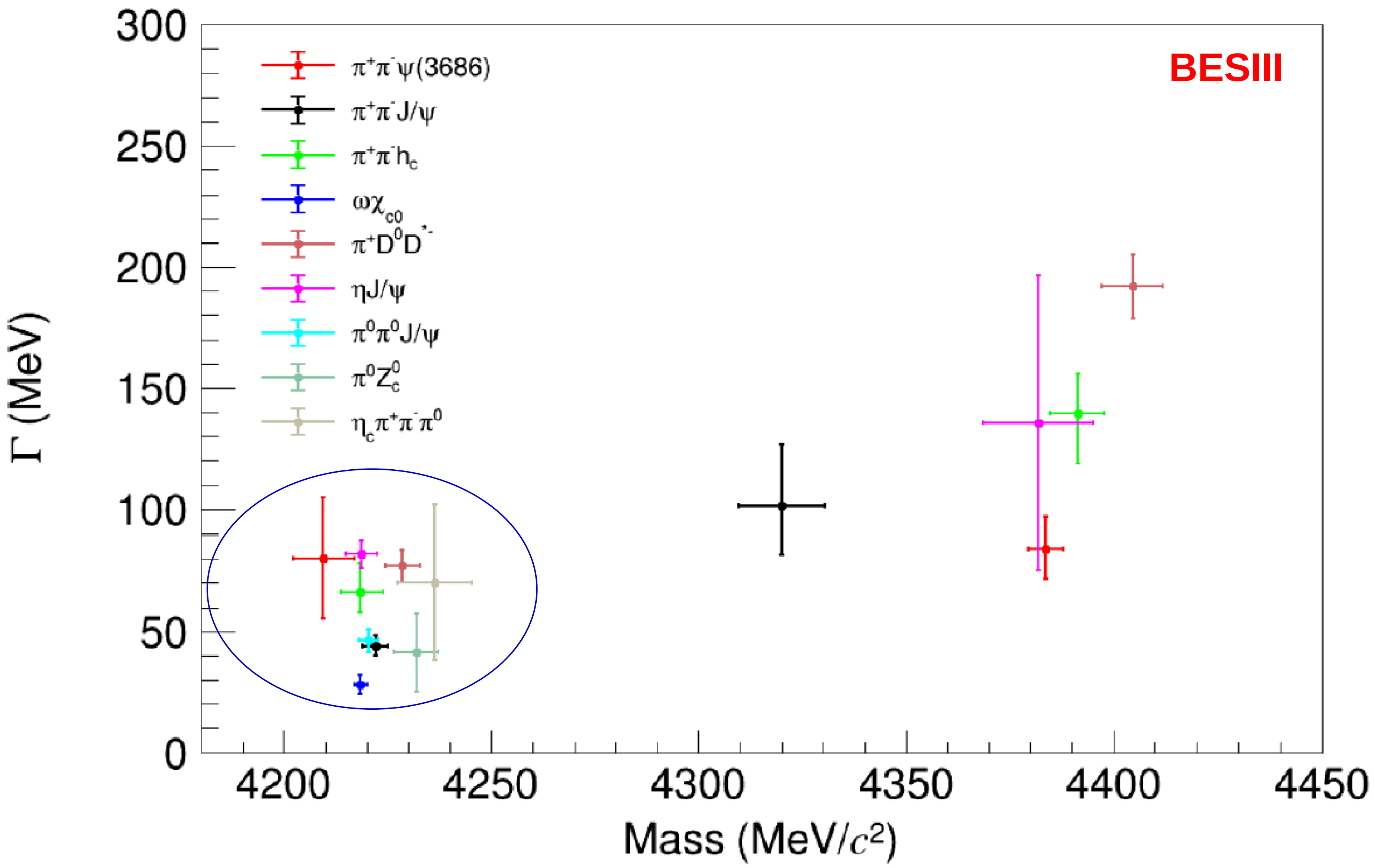


FIG. 3. Fits to dressed cross sections for (a) $e^+e^- \to K^+K^-\pi^+\pi^-$, (b) $e^+e^- \to K^+K^-K^+K^-$, (c) $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, (d) $e^+e^- \to p\bar{p}\pi^+\pi^-$, (e) $e^+e^- \to K^+K^-\pi^+\pi^-\pi^0$, (f) $e^+e^- \to K^+K^-K^+K^-\pi^0$, (g) $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$ and (h) $e^+e^- \to p\bar{p}\pi^+\pi^-\pi^0$ only considering contribution from continuum process. Points with error bars show the measured dressed cross sections. The red lines show the fit results.

Phys.Rev.D 104 (2021) 11, 112009; 2109.12751 [hep-ex]

Resonance parameters extracted around 4.26 GeV in different channels



PDG 2020

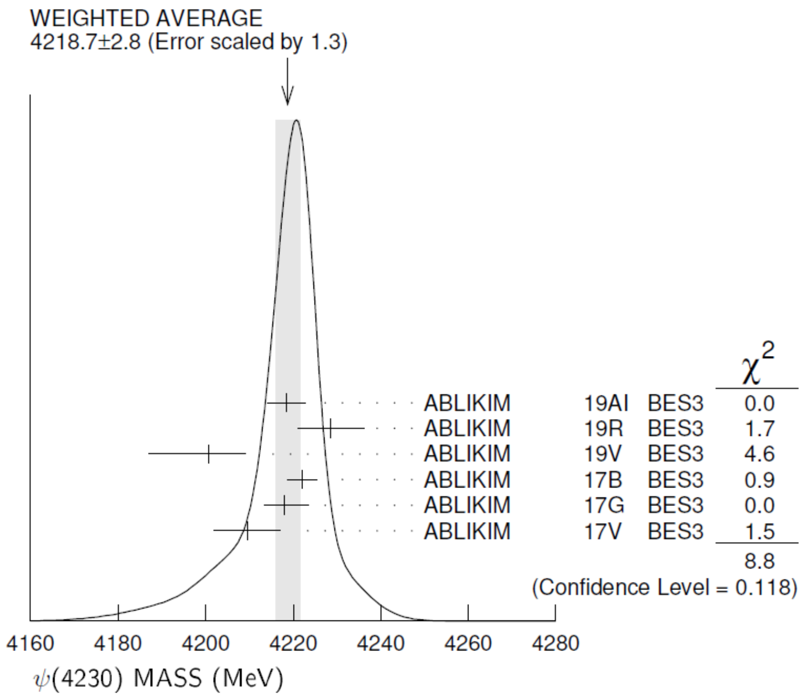
$\psi(4230)$

$I^G(J^{PC}) = 0^-(1^{--})$

also known as $Y(4230)$; was $X(4230)$

$\psi(4230)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	
Γ_2	$\omega\chi_{c0}$	seen
Γ_3	$\pi^+\pi^- h_c$	seen
Γ_4	$\pi^+\pi^- J/\psi$	seen
Γ_5	$\pi^+\pi^-\psi(2S)$	seen
Γ_6	$\pi^+ D^0 D^{*-}$ + c.c.	seen
Γ_7	$\Xi^-\overline{\Xi}^+$	
Γ_8	$\gamma\chi_{c1}(3872)$	seen



$\psi(4260)$

$I^G(J^{PC}) = 0^-(1^{--})$

OMITTED FROM SUMMARY TABLE

also known as $Y(4260)$; was $X(4260)$

$\psi(4260)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	
Γ_2	$J/\psi\pi^+\pi^-$	seen
Γ_3	$J/\psi f_0(980)$, $f_0(980) \to \pi^+\pi^-$	seen
Γ_4	$Z_c(3900)^\pm\pi^\mp$, $Z_c^\pm \to J/\psi\pi^\pm$	seen
Γ_5	$J/\psi\pi^0\pi^0$	seen
Γ_6	$J/\psi K^+K^-$	seen
Γ_7	$J/\psi K^0_S K^0_S$	not seen
Γ_8	$J/\psi\eta$	not seen
Γ_9	$J/\psi\pi^0$	not seen
Γ_{10}	$J/\psi\eta'$	not seen
Γ_{11}	$J/\psi\pi^+\pi^-\pi^0$	not seen
Γ_{12}	$J/\psi\eta\pi^0$	not seen

A brief summary of the experimental status and a list of concerns:

1) Complicated structures in the vicinity of 4.22~4.26 GeV.
2) Relatively narrow structure for the lower peak if fitted by Breit-Wigner.
3) The pion angular distribution recoiling $Z_c(3900)$ in $Y(4260) \to \bar{D}D^*\pi$ indicates non-S-wave contributions.
4) The open-charm cross section seems to be larger than those for the hidden charm channel.
5) The signal of Y(4260) in $e^+e^- \to D^*\bar{D}^*$ needs to be clarified.
6) The lepton decay width will depend on how the total width is saturated.
7) The Breit-Wigner width may not be the pole width.
8) ……

Status rating	Total cross section (pb)
$\bar{D}D^*\pi + c.c.$	200~300
$J/\psi\pi^+\pi^-$	~80
$h_c\pi^+\pi^-$	~50
$\omega\chi_{c0}$	~50
$J/\psi\eta$	50~60
$J/\psi\eta'$	2~4
$\psi(2S)\pi^+\pi^-$	~20
$J/\psi K^+K^-$	~4
$\gamma\chi_{c1,2}$	4~5

2. Possible interpretations and reminder of some crucial issues

Many papers on the properties of Y(4260), e.g. see recent reviews and reference therein:
H.-X. Chen, W. Chen, X. Liu and S.-L. Zhu, **Phys. Rept.** 639, 1 (2016)
F.K. Guo, C. Hanhart, U.-G. Meissner, Q. Wang, Q. Zhao, B.-S. Zou, **Rev. Mod. Phys.** 90, 015004 (2018)
A. Esposito, A. Pilloni and A.D. Polosa, **Phys. Rept.** 668, 1 (2017)

- **Why the DD*pi channel has the largest cross sections?**

  Hadronic molecule picture can explain.

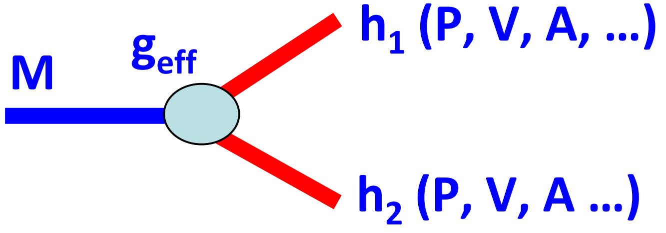
  Hybrid picture can possibly explain.

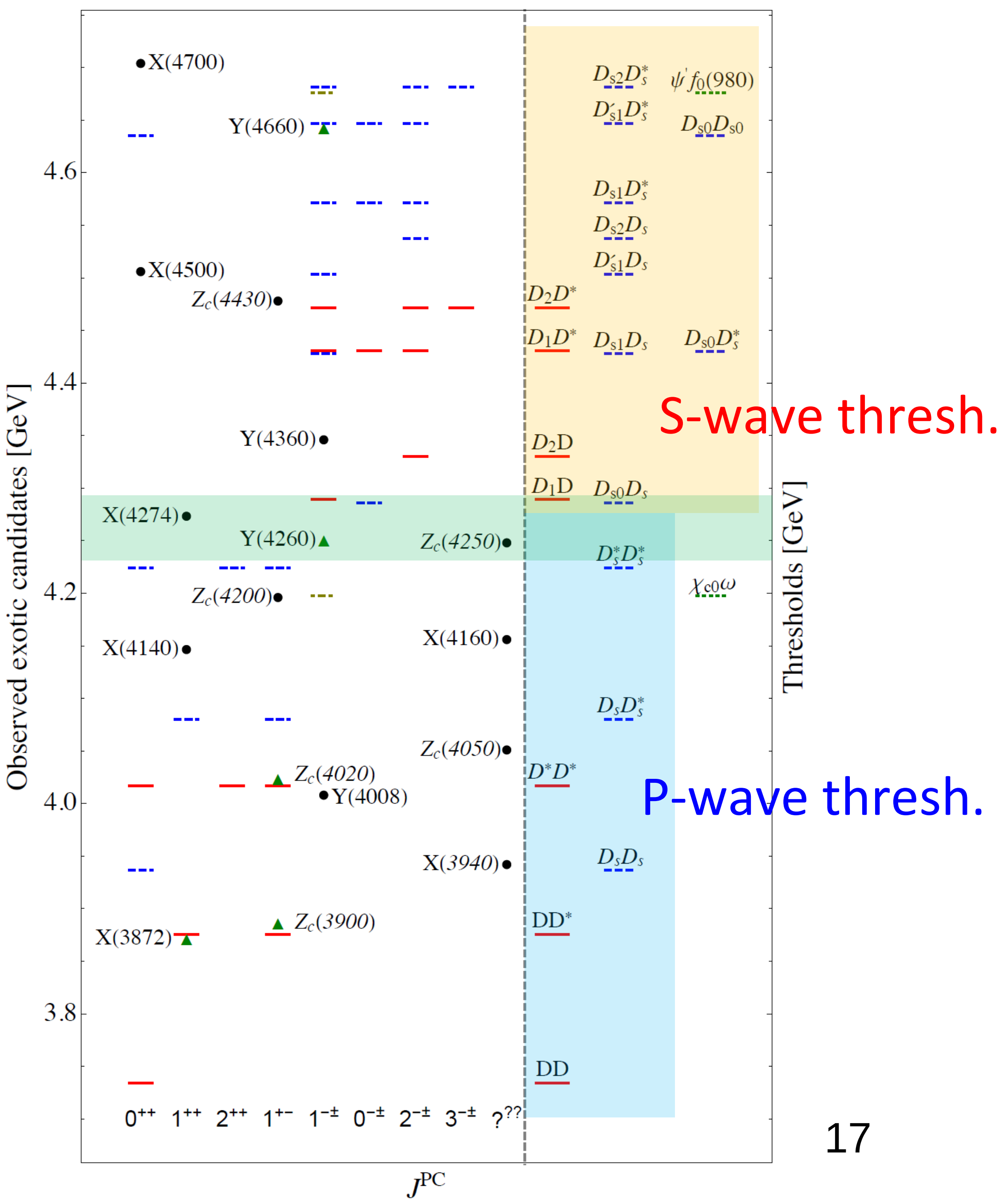
  Tetraquark picture seems to be failed.

The narrow two-body open thresholds:

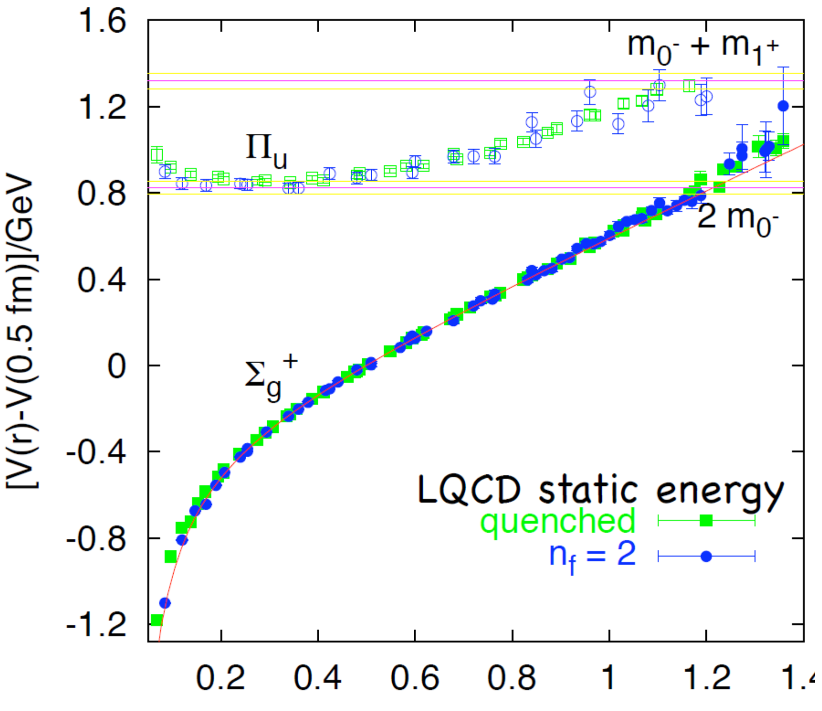
Their possible impact on the spectrum should be systematically investigated.

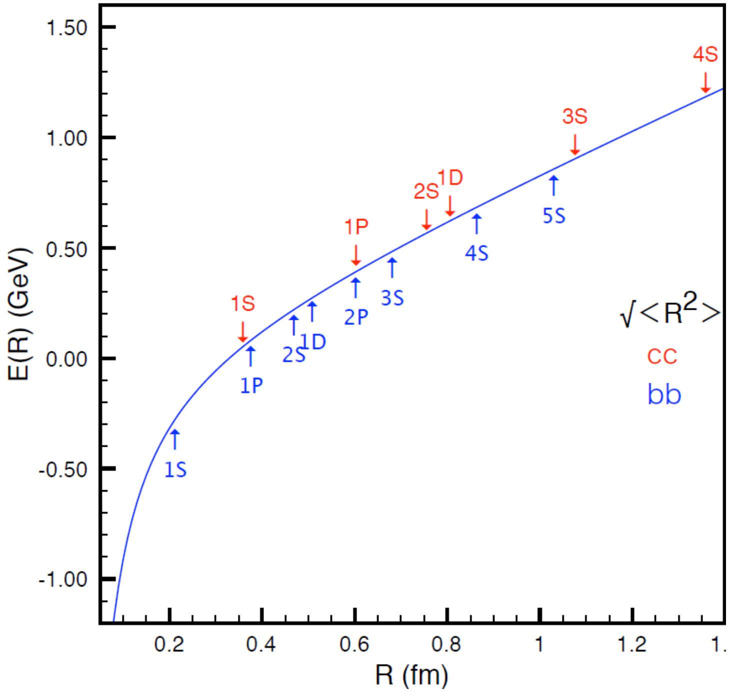
	$S-wave(L=0)$	$P-wave(L=1)$
PP	$0^{+(\pm)}$	$1^{-(\pm)}$
PV	$1^{+(\pm)}$	$0^{-(\pm)},\ 1^{-(\mp)},\ 2^{-(\pm)}$
VV	$0^{+(+)},\ 1^{+(-)},\ 2^{+(+)}$	$1^{-(+)};$ $0^{-(-)},\ 1^{-(-)},\ 2^{-(-)};$ $1^{-(+)},\ 2^{-(+)},\ 3^{-(+)}$
PA	$1^{-(-)}$	$\cdots\cdots$
VA	$0^{-(\pm)},\ 1^{-(\mp)},\ 2^{-(\pm)}$	$\cdots\cdots$

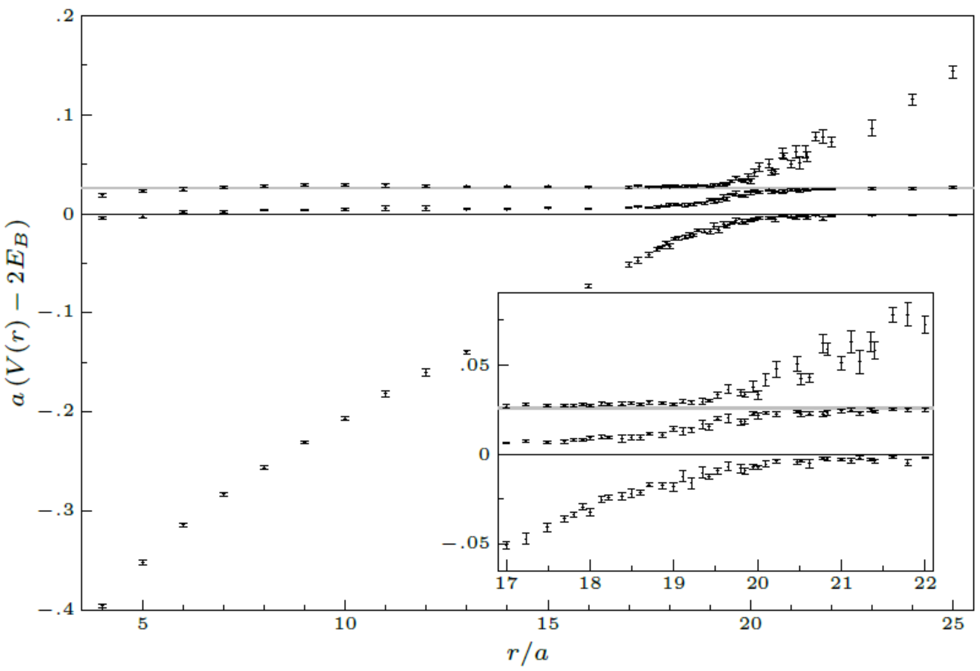




The connection between the quark model and QCD **ONLY** becomes clear in certain circumstances: in the heavy quark limit the soft QCD for quark-antiquark or quark-quark interactions can become much simpler.





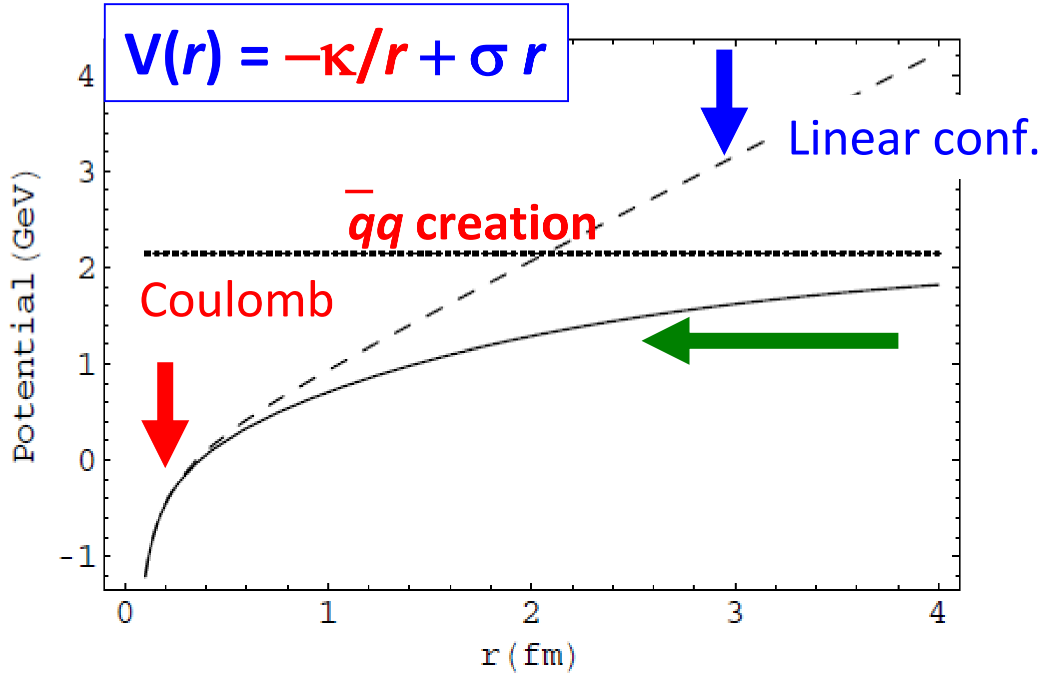


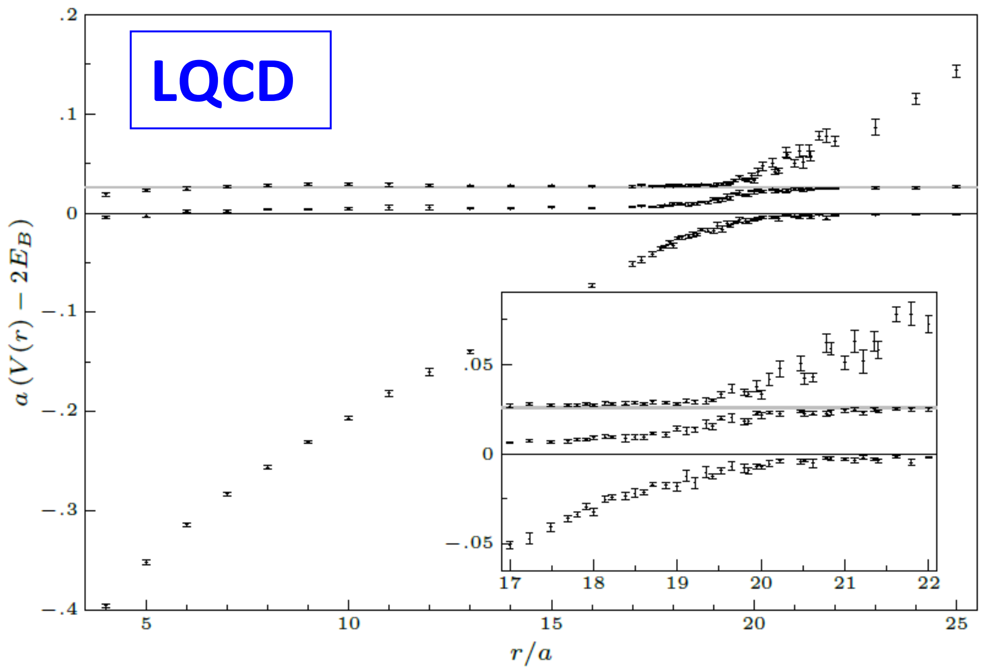
However, the effects of the open channels on the soft QCD potential is also evident!

G. S. Bali, et al., Phys. Rev. D62, 054503 (2000)
J. Bulava, et al., Phys. Lett. B793, 493 (2019),
M. Foster and C. Michael (UKQCD), Phys. Rev. D59, 094509 (1999)

2. Threshold phenomena and dynamics

- Color screening effects? String breaking effects?

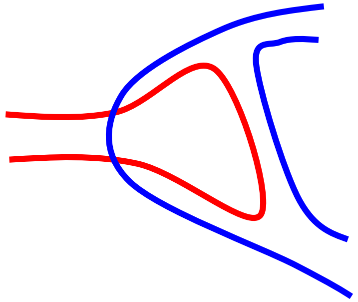




- The effect of vacuum polarization due to dynamical quark pair creation may be manifested by the strong coupling to open thresholds and compensated by that of the hadron loops, i.e. coupled-channel effects.

E. Eichten et al., PRD17, 3090 (1987)
E. J. Eichten, K. Lane, and C. Quigg, Phys. Rev. D 69, 094019 (2004)
B.-Q. Li and K.-T. Chao, Phys. Rev. D79, 094004 (2009);
T. Barnes and E. Swanson, Phys.Rev. C77, 055206 (2008)

Typical processes where the open threshold coupled channels can play a role



$\psi(3770) \to non D\bar{D}$

"ρπ puzzle"

Y.J. Zhang, G. Li, Q. Zhao, PRL(2009);
X. Liu, B. Zhang, X.Q. Li, PLB(2009)
Q. Wang et al. PRD(2012), PLB(2012)

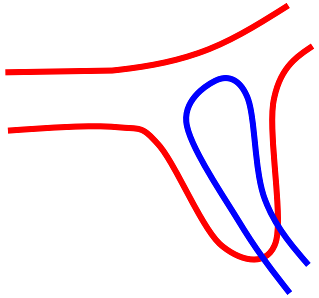
$\chi_{c1} \to VV, \ \chi_{c2} \to VP$

X.-H. Liu et al, PRD81, 014017(2010);
X. Liu et al, PRD81, 074006(2010)

$\eta_c(\eta_c') \to VV$

Q. Wang et al, PRD2012

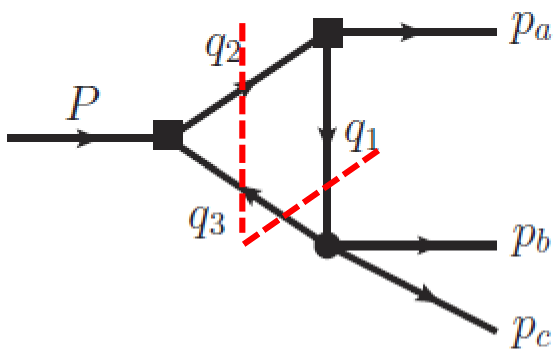
The open channel couplings introduce NOT ONLY additional dynamics (add. effective DOF) into the hadron structures, BUT ALSO novel kinematic effects, i.e. triangle singularity …

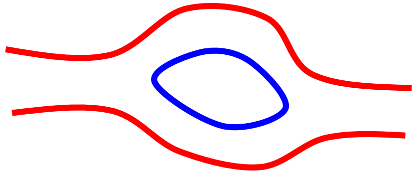


$\psi' \to J/\psi\pi^0, \psi' \to J/\psi\eta$

$\psi' \to \gamma\eta_c, J/\psi \to \gamma\eta_c$

G. Li and Q. Zhao, PRD(2011)074005
F.K. Guo, C. Hanhart, G. Li, U.-G. Meiβner and Q. Zhao, PRD82, 034025 (2010); PRD83, 034013 (2011)
F.K. Guo and Ulf-G Meiβner, PRL108(2012)112002

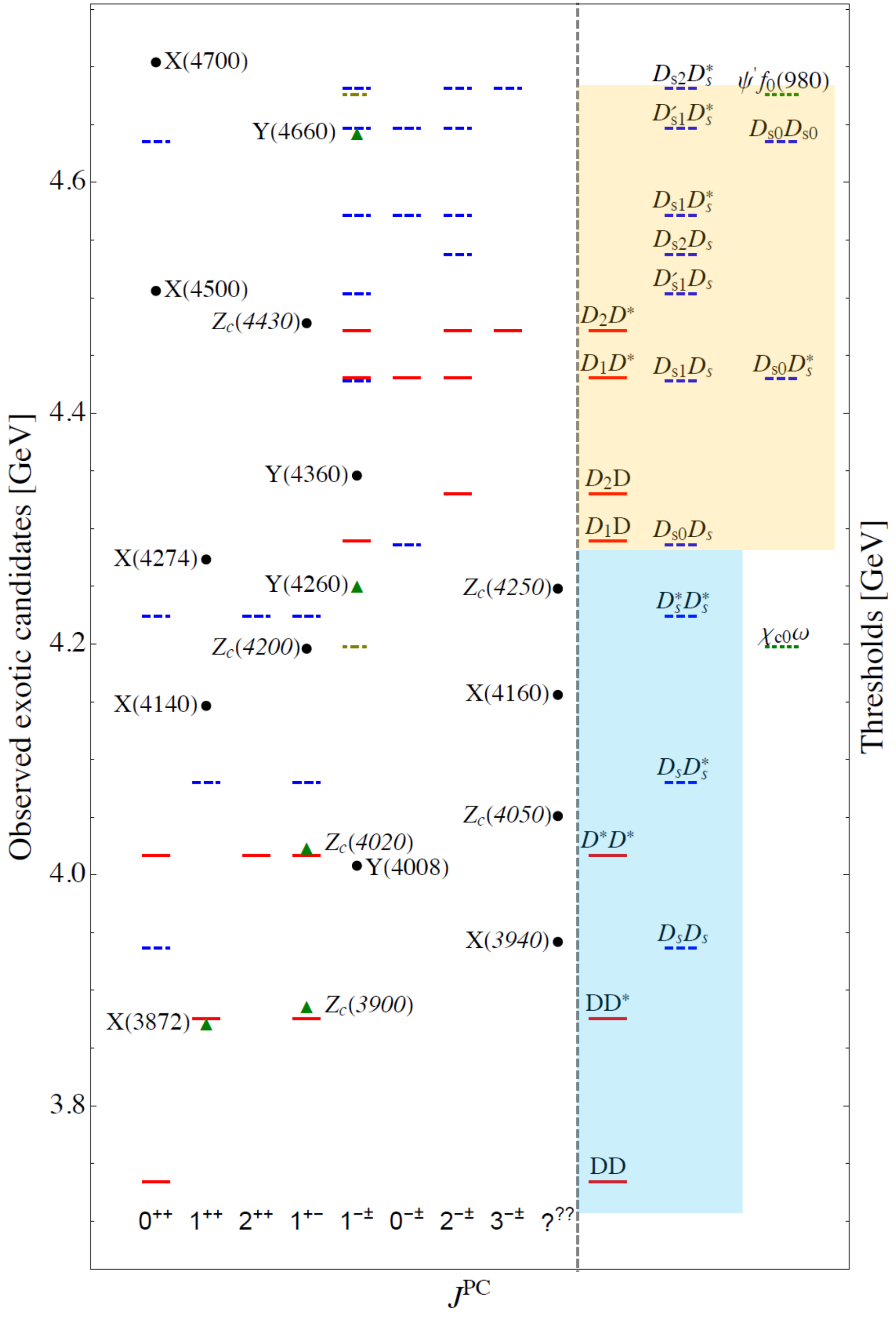




$D_{s1}(2460) - D_{s1}(2536)$

The mass shift in charmonia and charmed mesons, E.Eichten et al., PRD17(1987)3090
X.-G. Wu and Q. Zhao, PRD85, 034040 (2012)

S wave thresholds and effects on the lineshapes



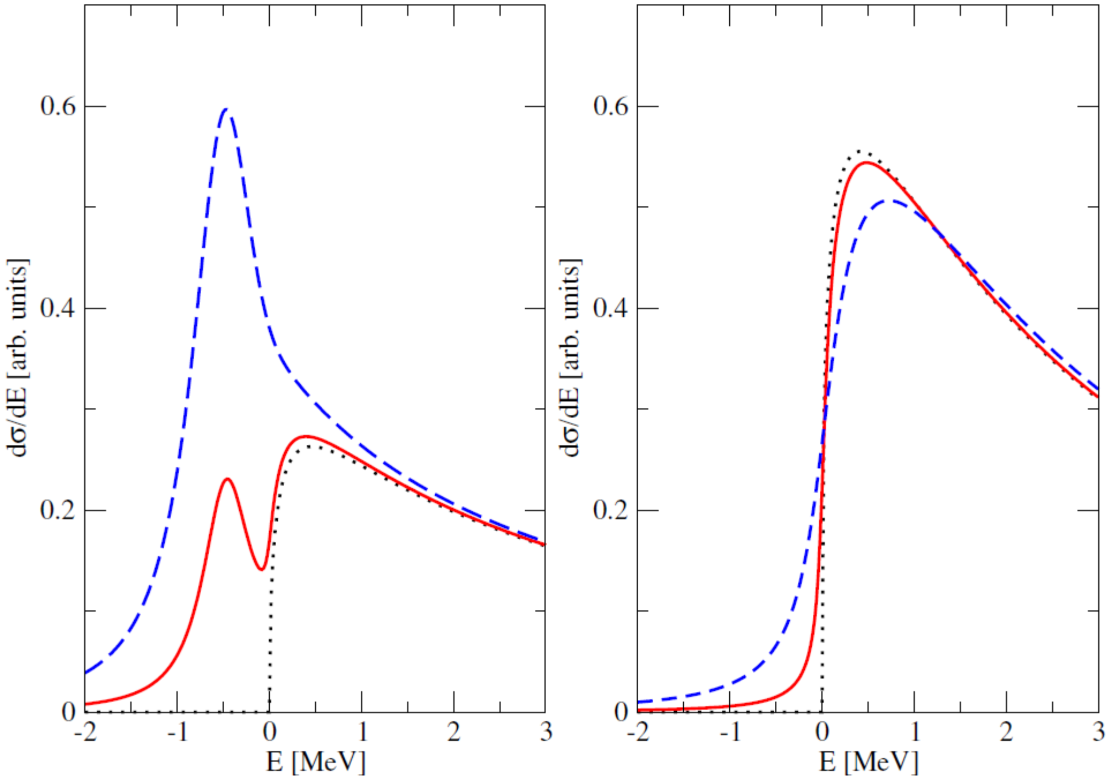
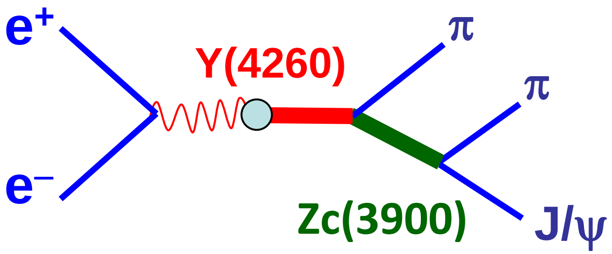
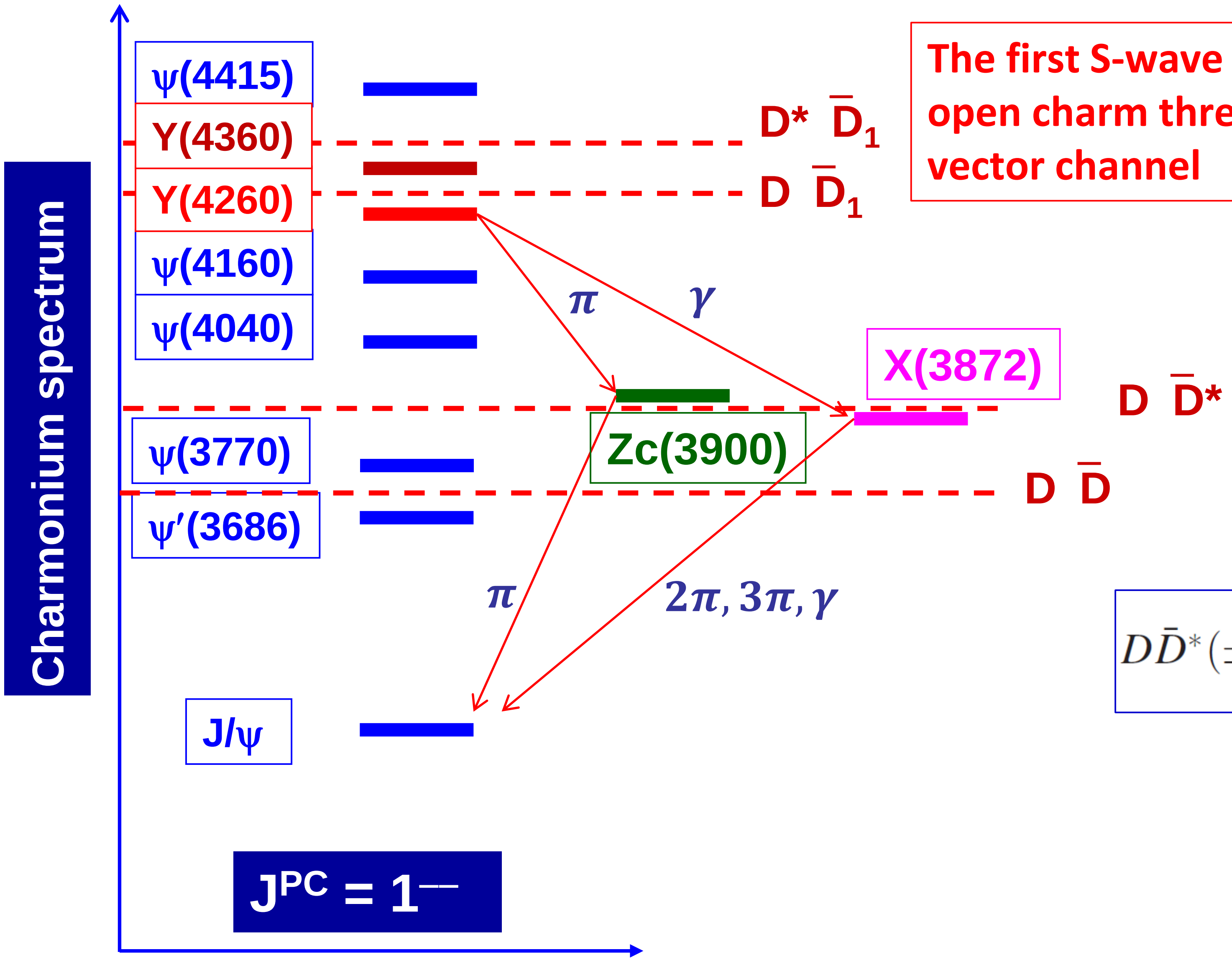


FIG. 10 Line shapes that emerge for a bound state (left panel) and for a virtual state (right panel) once one of the constituents is unstable. The dotted, solid and dashed line show the results for $\Gamma = 0, 0.1$ and 1 MeV, respectively. The other parameters of the calculation are given in Eq. (36).

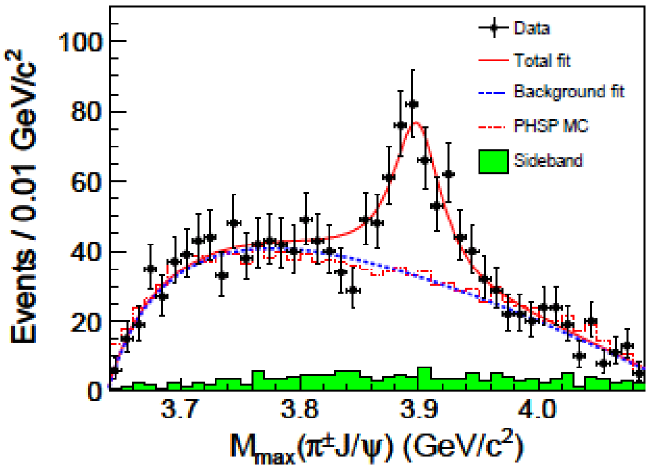
F.-K. Guo, C. Hanhart, U.-G. Meissner, Q. Wang, Q. Zhao, B.-S. Zou, Rev. Mod. Phys. 90, 015004 (2018)

Correlations between Y(4260) and Zc(3900)/X(3872)





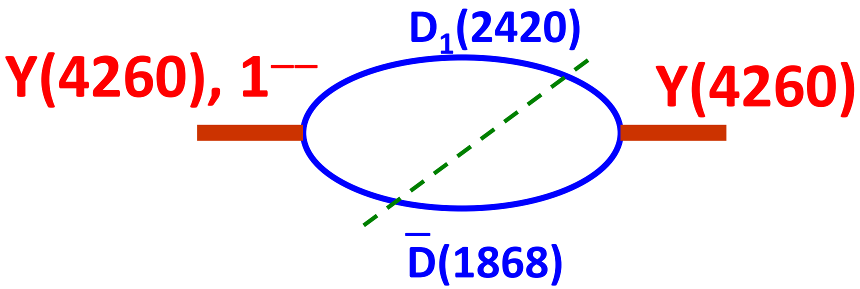
The first S-wave narrow open charm threshold in vector channel

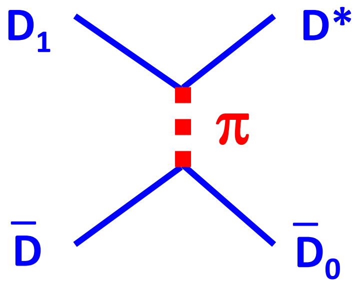


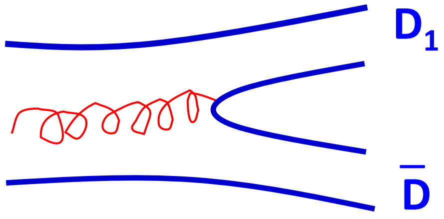
$$D\bar{D}^*(\pm) = \frac{1}{\sqrt{2}}(D\bar{D}^* \pm D^*\bar{D})$$

- **Y(4260) could be a hadronic molecule made of DD_1(2420) with coupled channel effects.**

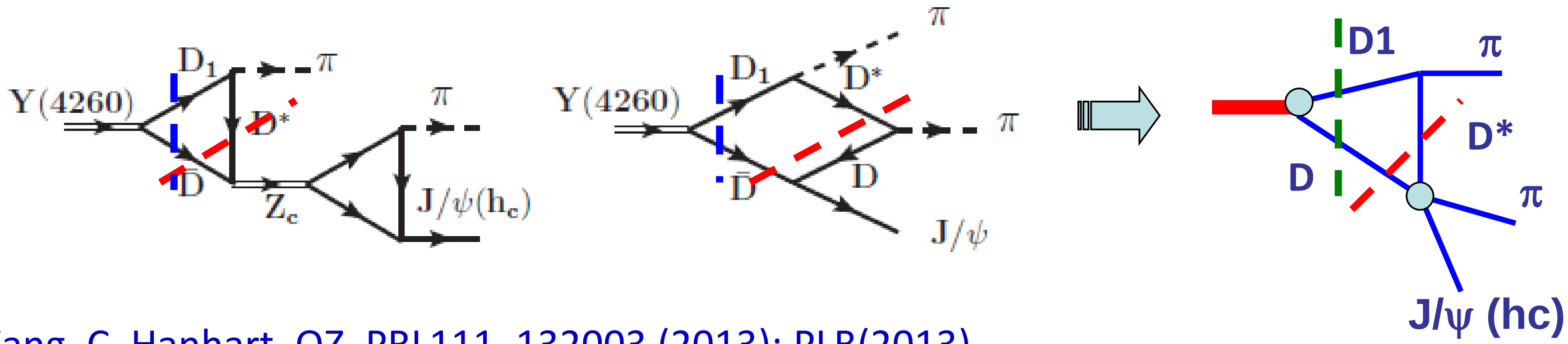
Y(4260) may have sizeable couplings to DD_1(2420) if it is a hybrid. Then, how to distinguish them?







- **The production of Zc(3900) is strongly correlated with Y(4260) and enhanced by the triangle singularity kinematics.**



Q. Wang, C. Hanhart, QZ, PRL111, 132003 (2013); PLB(2013)
Q. Wang et al., PRD89, 034001 (2014); M. Cleven et al., PRD90, 074039 (2014);
W. Qin, S.R. Xue, QZ, PRD94, 054035 (2016)

Lagrangians in the NREFT

- **$Y(4260)D_1D$ coupling:**

$$\mathcal{L}_Y = i\frac{y}{\sqrt{2}}\left(\bar{D}_a^\dagger Y^i D_{1a}^{i\dagger} - \bar{D}_{1a}^{i\dagger} Y^i D_a^\dagger\right) + \text{H.c.},$$

$$|y| = \left(3.28^{+0.25}_{-0.28} \pm 1.39\right) \ \text{GeV}^{-1/2}$$

- **$Z_c(3900)DD^*$ coupling:**

$$\mathcal{L}_Z = \frac{z}{\sqrt{2}}\left[\bar{V}^{\dagger i} Z^i P^\dagger - \bar{P}^\dagger Z^i V^{\dagger i}\right] + \text{H.c.} \ ,$$

$$Z_{ba}^i = \begin{pmatrix} \frac{1}{\sqrt{2}} Z^{0i} & Z^{+i} \\ Z^{-i} & -\frac{1}{\sqrt{2}} Z^{0i} \end{pmatrix}_{ba} \qquad P(V) = \left(D^{(*)0}, D^{(*)+}\right)$$

- **$D_1D^*\pi$ coupling:**

$$\mathcal{L}_{D_1} = i\frac{h'}{f_\pi}\left[3D_{1a}^i(\partial^i\partial^j\phi_{ab})D_b^{*\dagger j} - D_{1a}^i(\partial^j\partial^j\phi_{ab})D_b^{*\dagger i}\right.$$
$$\left. -3\bar{D}_a^{*\dagger i}(\partial^i\partial^j\phi_{ab})\bar{D}_{1b}^j + \bar{D}_a^{*\dagger i}(\partial^j\partial^j\phi_{ab})\bar{D}_{1b}^i\right] + \text{H.c.}, (2)$$

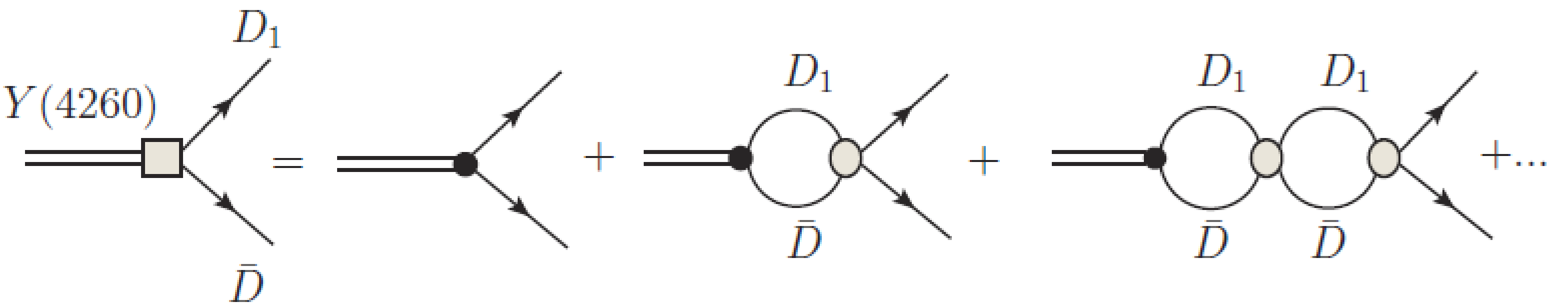
Q. Wang, C. Hanhart, QZ, PRL111, 132003 (2013); PLB(2013)
Q. Wang et al., PRD89, 034001 (2014); M. Cleven et al., PRD90, 074039 (2014);
W. Qin et al., PRD94, 054035 (2016)

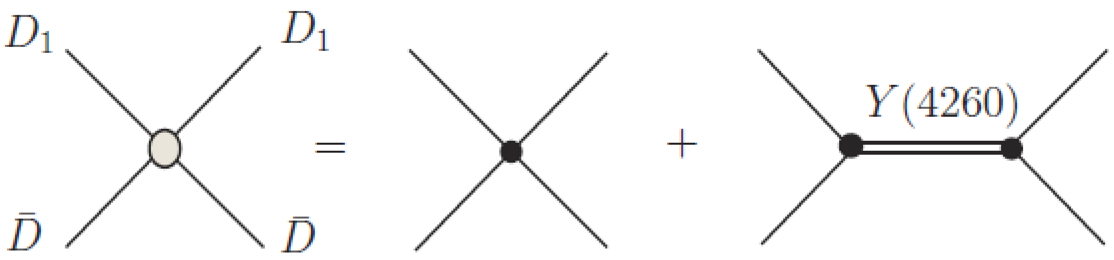
Defining the molecular component of Y(4260)

$$|Y(4260)\rangle = \alpha|c\bar{c}\rangle + \beta|D_1\bar{D} + c.c.\rangle$$

HQSS breaking is implicated

$$\mathcal{L}_Y = \frac{y^{\text{bare}}}{\sqrt{2}}(\bar{D}_a^\dagger Y^i D_{1a}^{i\dagger} - \bar{D}_{1a}^{i\dagger} Y^i D_a^\dagger) + g_1\{(D^i_{1a}\bar{D}_a)^\dagger(D^i_{1a}\bar{D}_a) + (D_a\bar{D}^i_{1a})^\dagger(D_a\bar{D}^i_{1a})\} + H.c.$$





The propagator of Y(4260)

$$\mathcal{G}_Y(E) = \frac{1}{2}\frac{i}{E - m_0 + \Sigma_{D_1\bar{D}}(E) \times [i(y^{\rm bare})^2 - 4i(E-m_0)g_1]}$$
$$\equiv \frac{1}{2}\frac{i}{E - m_0 - \Sigma_1(E)},$$

$$\Sigma_{D_1\bar{D}}(E) = \frac{-1}{4}\int \frac{d^D l}{(2\pi)^D}\frac{1}{(l^0 - \vec{l}^{\,2}/(2m_D) + i\epsilon)(E - l^0 - \vec{l}^{\,2}/(2m_{D_1}) + i\Gamma_{D_1}/2)}.$$

$$\Sigma^{\overline{\rm MS}}_{D_1\bar{D}}(E) = \frac{\mu}{8\pi}\sqrt{2\mu(E - m_D - m_{D_1}) + i\mu\Gamma_{D_1}},$$

$$m_Y = m_0 + {\rm Re}\Sigma_1(m_Y)$$

$$\tilde{\Sigma}_1(E) \equiv \Sigma_1(E) - {\rm Re}(\Sigma_1(m_Y)) - (E - m_Y){\rm Re}(\partial_E\Sigma_1(m_Y))$$

$$\boxed{\mathcal{G}_Y(E) = \frac{1}{2}\frac{iZ}{E - m_Y - Z\tilde{\Sigma}_1(E)}}$$

$$\boxed{Z \equiv 1/[1 - {\rm Re}(\partial_E\Sigma_1(m_Y))]}$$

$$|Y(4260)\rangle = \alpha|c\bar{c}\rangle + \beta|D_1\bar{D} + c.c.\rangle$$

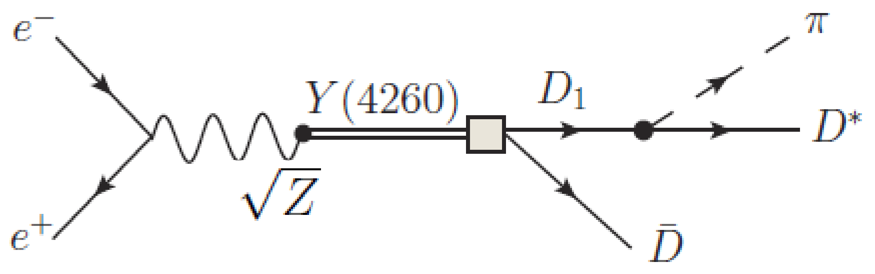
$$|Y(4260)\rangle = 0.359|c\bar{c}\rangle + 0.933|D_1\bar{D} + c.c.\rangle$$

Short-range component

Long-range component

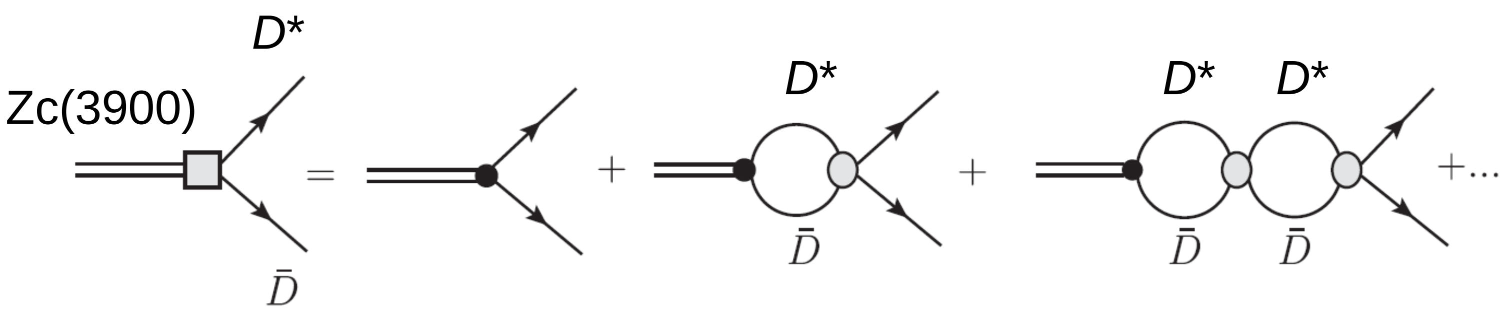
$$\begin{cases} |\alpha| \simeq \sqrt{Z} \\ |\beta| = \sqrt{1-Z} \end{cases} \qquad \begin{cases} Z = \alpha^2 = 0.129 \\ 1 - Z = \beta^2 = 0.871 \end{cases}$$

$$\mathcal{G}_Y(E) = \frac{1}{2}\frac{iZ}{E - m_Y - Z\tilde{\Sigma}_1(E) + i\Gamma^{\mathrm{non}-D_1\bar{D}}/2}$$



Y(4260) is dominated by molecular component but also contains a component (charmonium? Or something else?) as a compact structure.

Similar treatment for Zc(3900) as a DD* molecular state

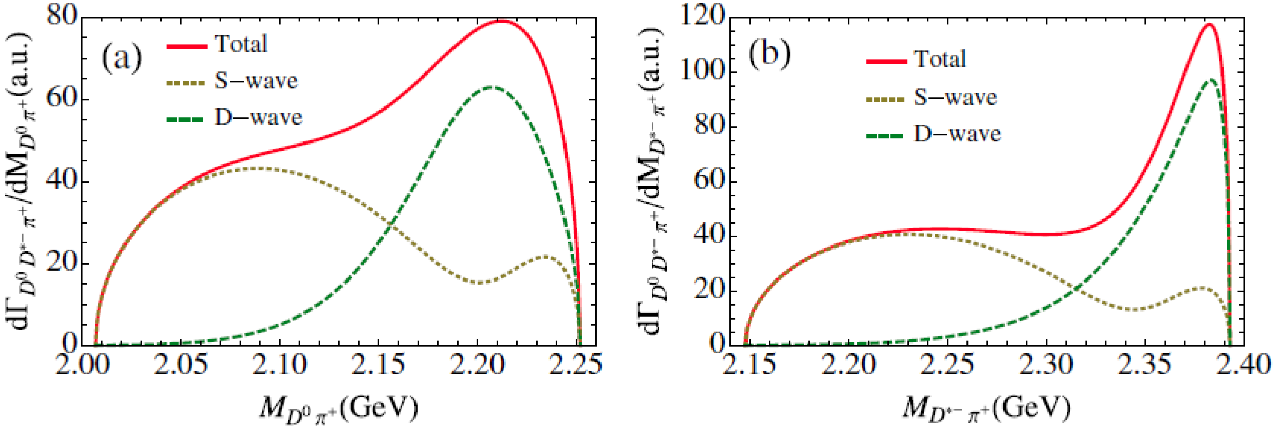


$$\mathcal{G}_{Z_c}(E) = \frac{1}{2}\frac{i}{E - m_Z + \Sigma_{\bar{D}D^*}(E) \times [iz^2 - 2i(E - m_Z)g_2] + i\Gamma^{\text{non}-\bar{D}D^*}/2}$$

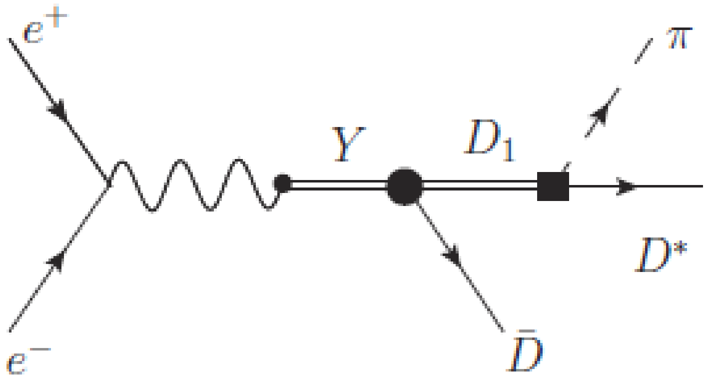
$$\Sigma_{\bar{D}D^*}(E) \equiv \frac{\mu'}{8\pi}\left(\sqrt{2\mu'\epsilon}\,\theta(\epsilon) + i\sqrt{-2\mu'\epsilon}\,\theta(-\epsilon)\right)$$

where $\mu' = m_D m_{D^*}/(m_D + m_{D^*})$, $\epsilon = E - m_D - m_{D^*}$, and $|z| \approx 0.77\ \text{GeV}^{-1/2}$ is the coupling constant of $Z_c(3900)$ to $\bar{D}D^*$ [26]. The contact interaction of $\bar{D}D^* \to \bar{D}D^*$ is introduced by the term with coupling g_2 in Eq. (8). However, by fitting the $\bar{D}D^*$ + c.c. invariant mass spectrum it shows that the value of g_2 is negligibly small and so we take $g_2 = 0$ in the following analysis.

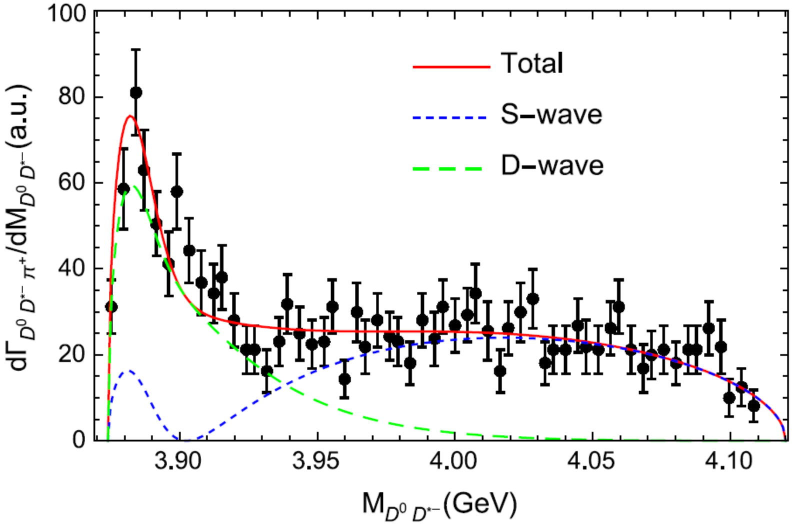
Invariant mass spectra for Dπ, D*π, and $\bar{D}D^*$



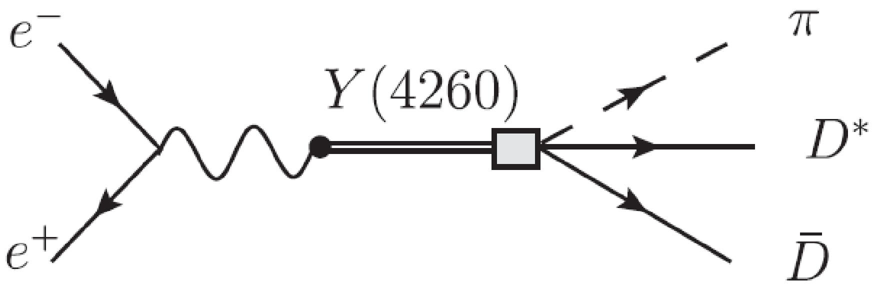
Signature for $D_1(2420)$ via the tree diagram.



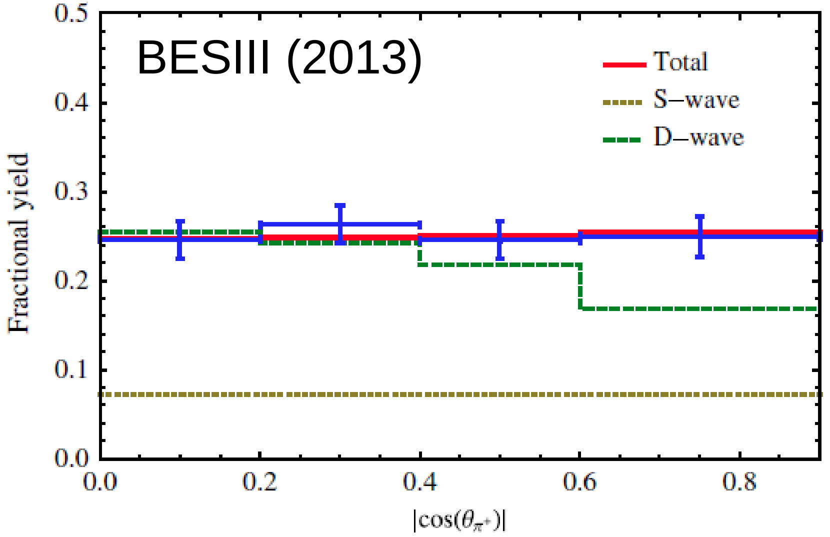
The Zc(3900) could have a pole below the DD* threshold.

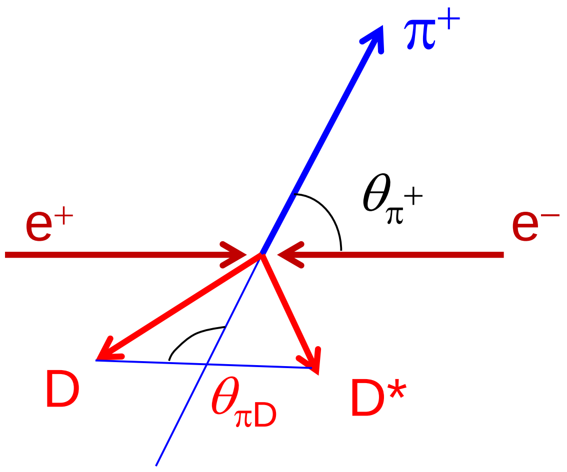


Dominant S-wave only contributes to different kinematics:

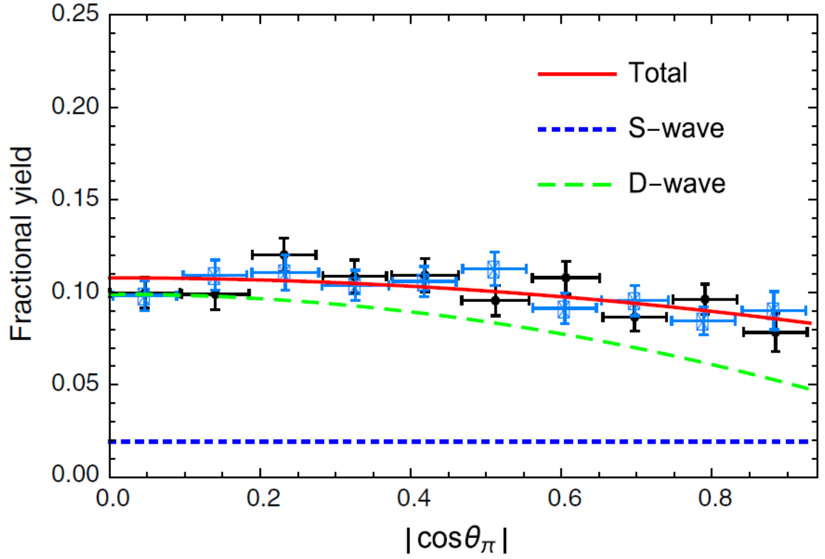


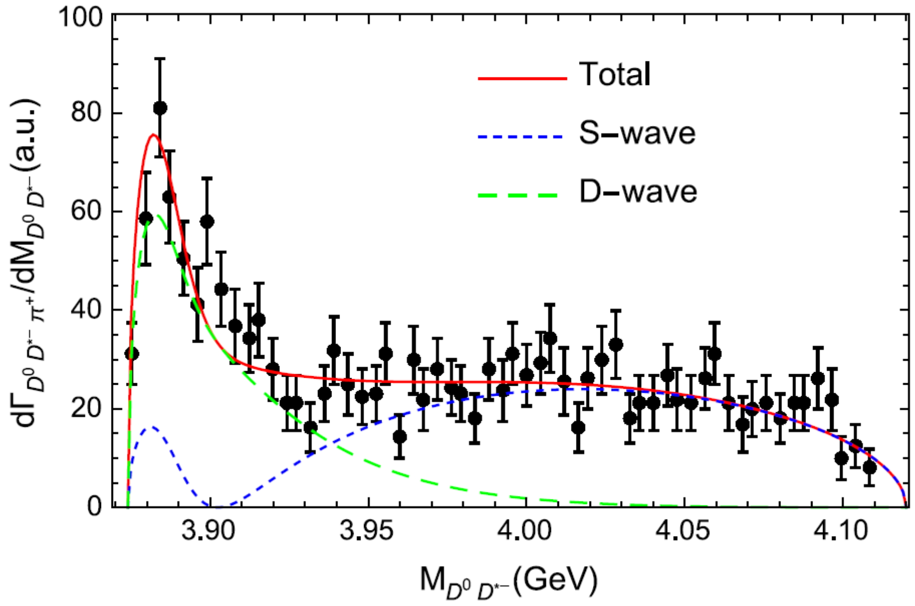
Angular distribution analysis





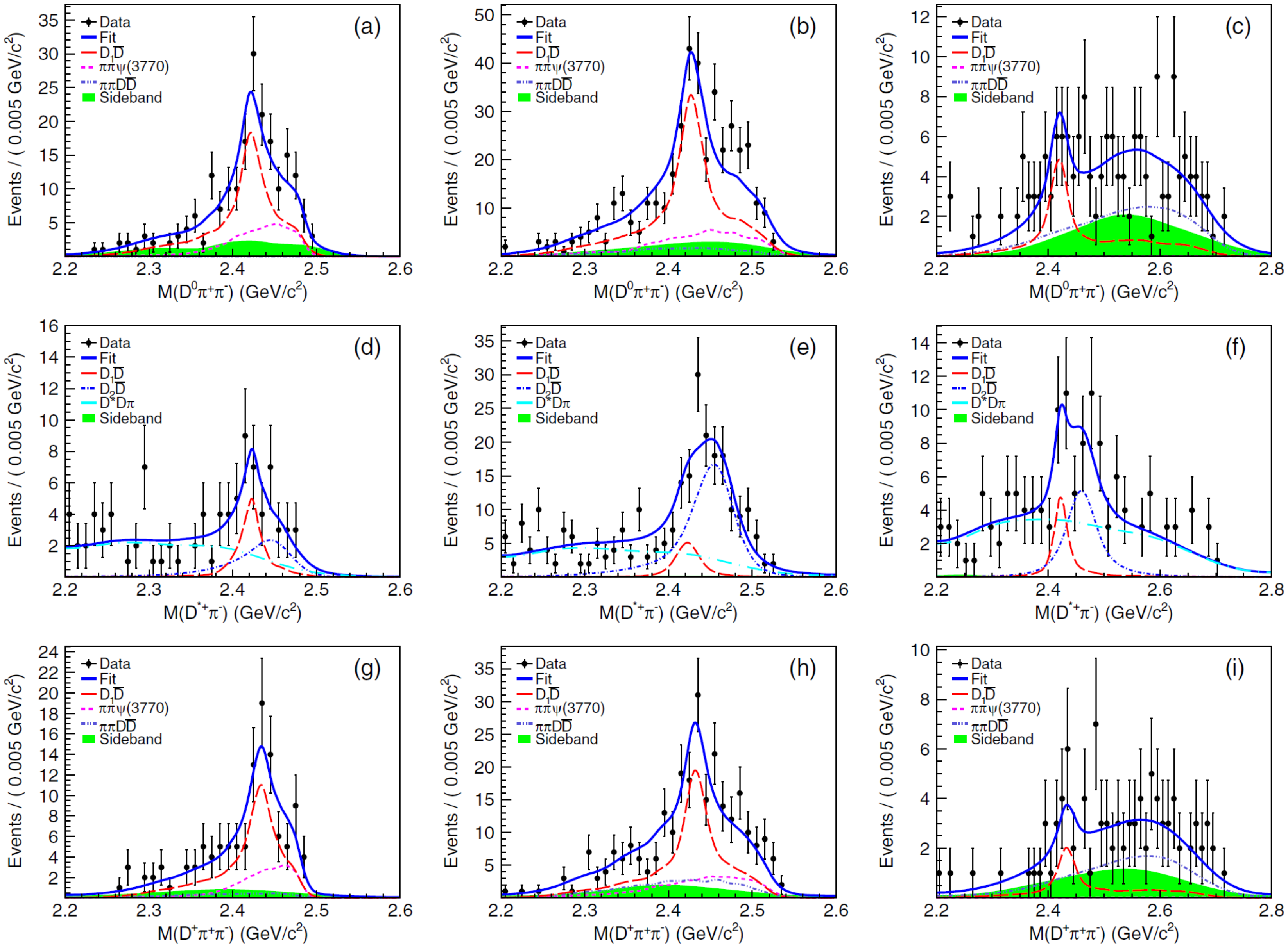
The dominance of D wave at the Zc peak can compromise with the angular distribution.





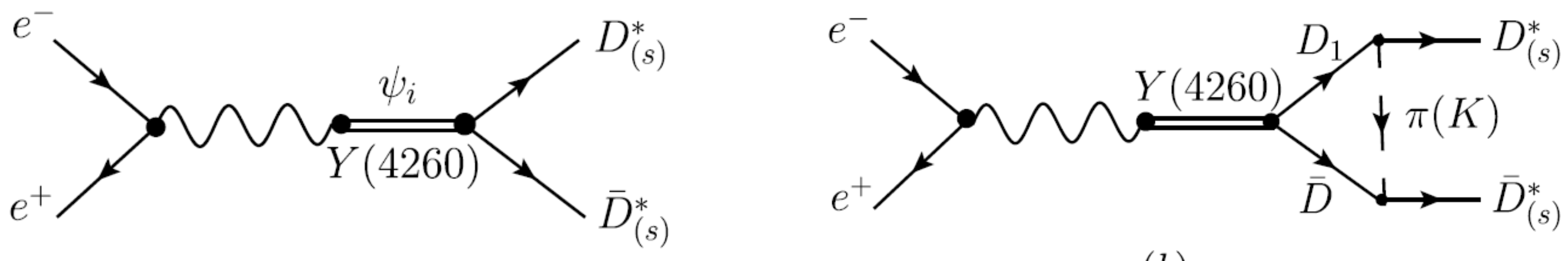
M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. D **92**, 092006 (2015).

$e^+e^- \to D_1(2420)\bar{D} + c.c.$



BESIII, *Phys.Rev.D* 100 (2019) 3, 032005

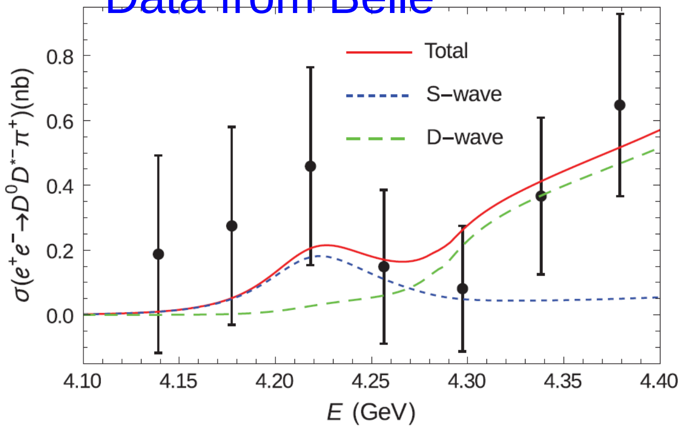
Observables sensitive to the presence of the $D_1(2420)\bar{D}$ + c.c. Threshold:



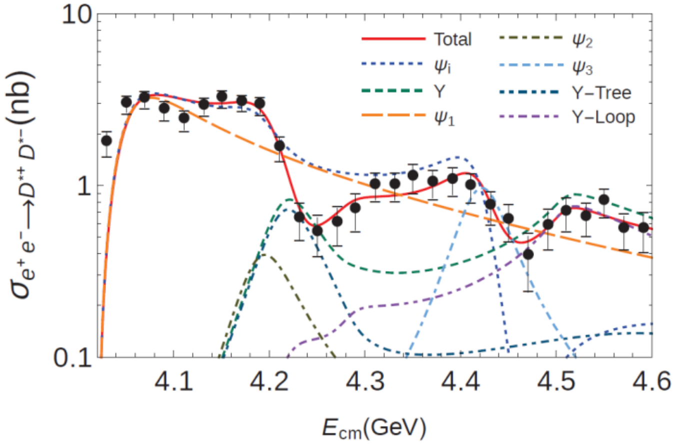
(a) (b)

$\boxed{e^+e^- \to \bar{D}D^*\pi + \text{c.c.}}$

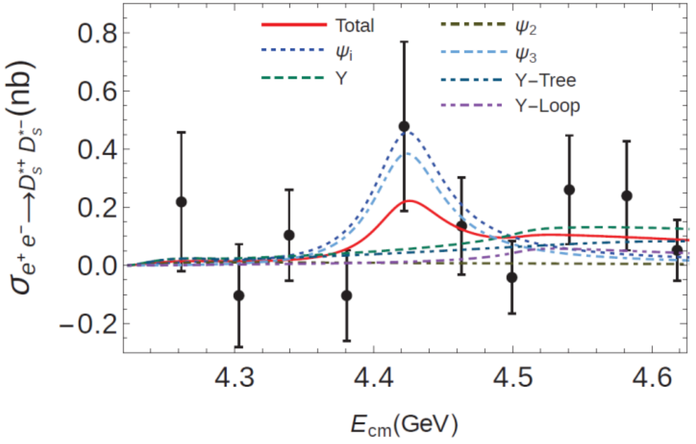
Data from Belle



$\boxed{e^+e^- \to D^{*+}D^{*-}}$



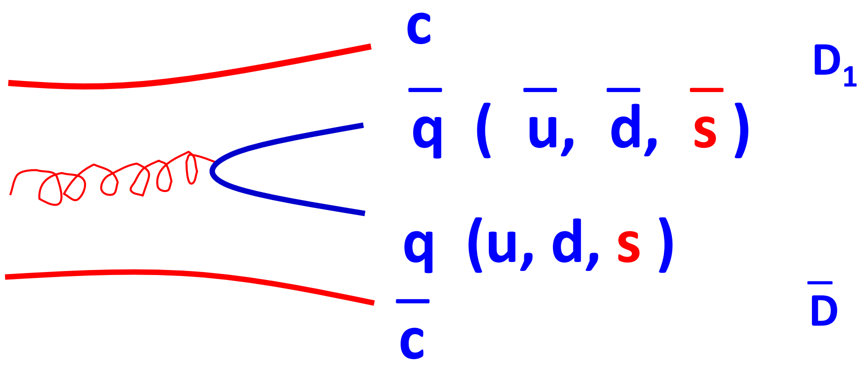
$\boxed{e^+e^- \to D_s^{*+}D_s^{*-}}$



W. Qin, S.-R. Xue, and Q. Zhao, PRD94, 054035 (2016)
S.R. Xue, H.J. Jing, F.K. Guo and Q. Zhao, Phys. Lett. B 779 (2018) 402-408

- **What are we expecting from a hybrid scenario?**

Y(4260) may have sizeable couplings to **$DD_1(2420)$** if it is a hybrid.
Then, how to distinguish them?

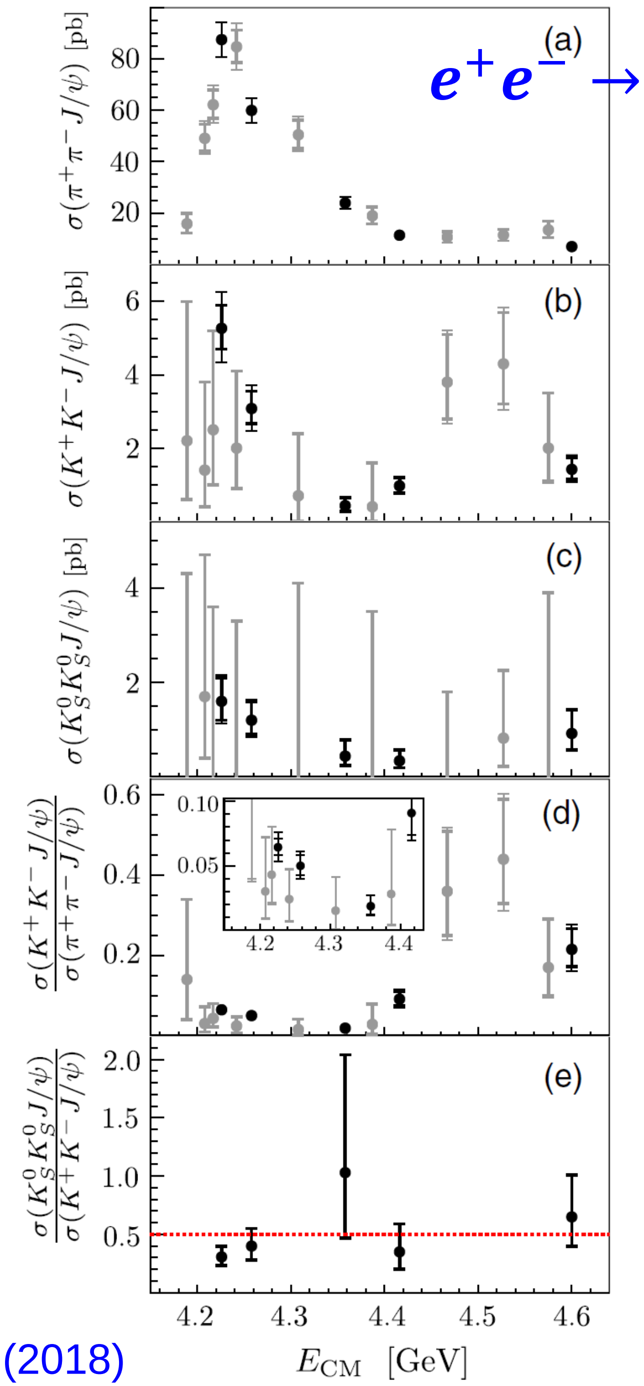


A hybrid mode will have access to $J/\psi\, K\, \bar{K}$ by quark rearrangement?

Y(4260) as a hybrid:

$\sigma(e^+e^- \to K\bar{K}\,J/\psi) \cong \sigma(e^+e^- \to \pi\pi\,J/\psi)$

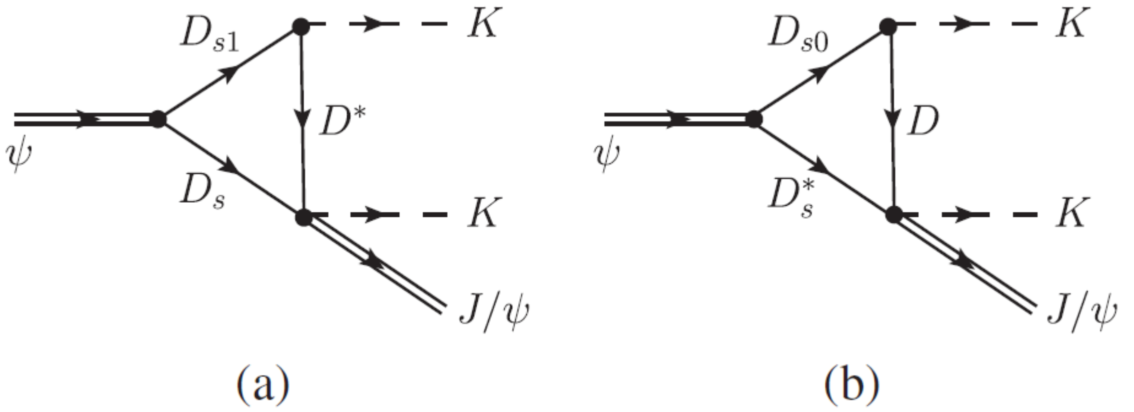
$e^+e^- \to K\bar{K}\,J/\psi$



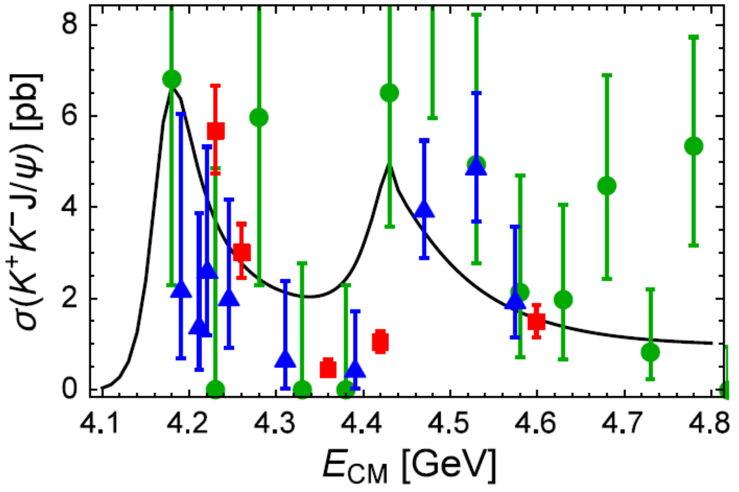
BESIII, PRD 97, 071101(R) (2018)

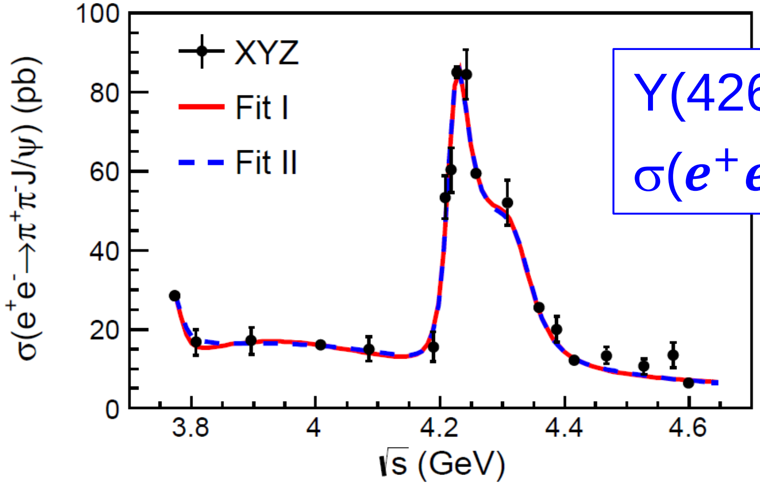
What kind of observables are sensitive to the internal structure of Y(4260)?

D_1D: 2420+1868=4288 MeV
$D_{s1}D_s$: 2460+1968=4428 MeV
2536+1968=4504 MeV
$D_{s1}D_s^*$: 2536+2112=4648 MeV
$D_{s2}D_s^*$: 2573+2112=4685 MeV



$e^+e^- \to K\bar{K}\,J/\psi$

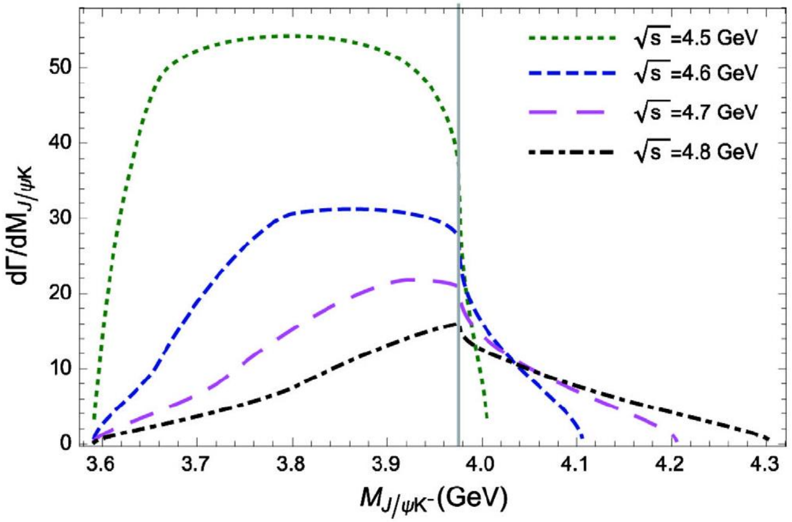




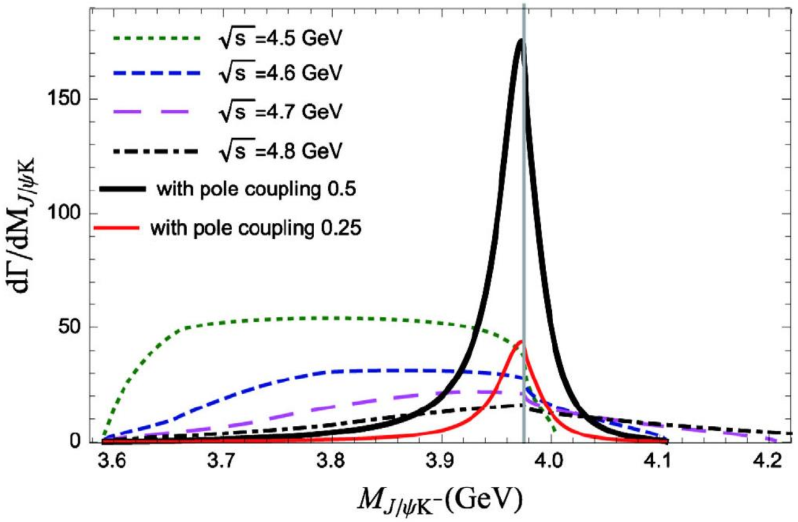
Y(4260) as a hadronic molecule:
$\sigma(e^+e^- \to K\bar{K}\,J/\psi) \ll \sigma(e^+e^- \to \pi\pi\,J/\psi)$

Z. Cao and Q.Z., Phys. Rev. D99, 014016 (2019)

Lineshapes of the J/ψK invariant mass spectrum at different energies
-- sensitive to the nearby triangle singularity condition!

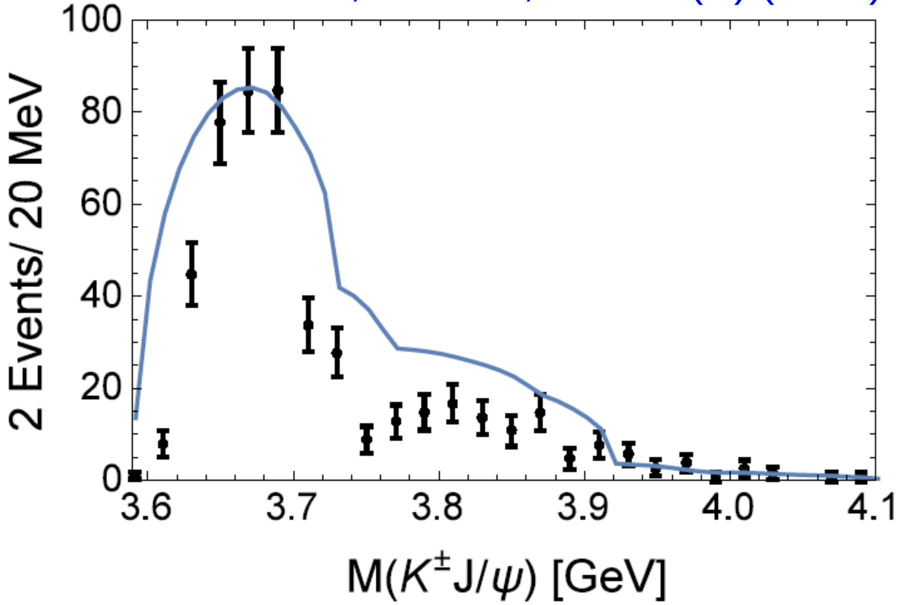


(a)

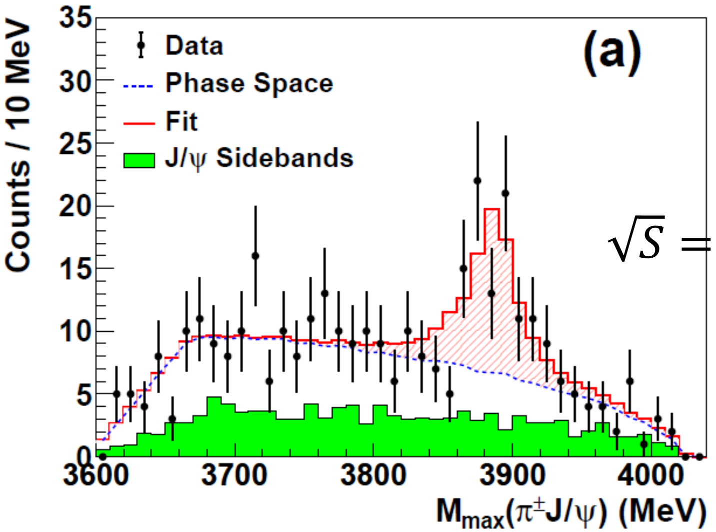


(b)

BESIII, PRD 97, 071101(R) (2018)



- **Why Zcs(3985) does not appear in the threshold region?**

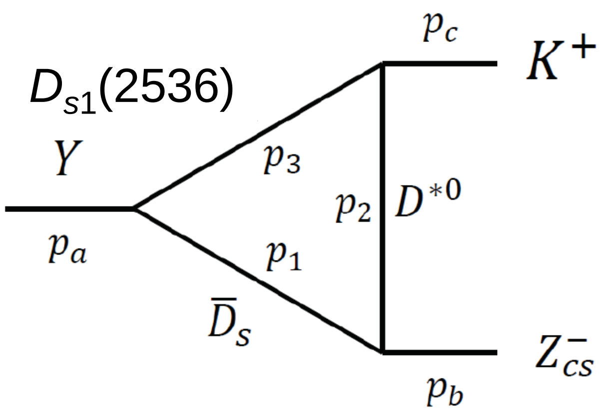


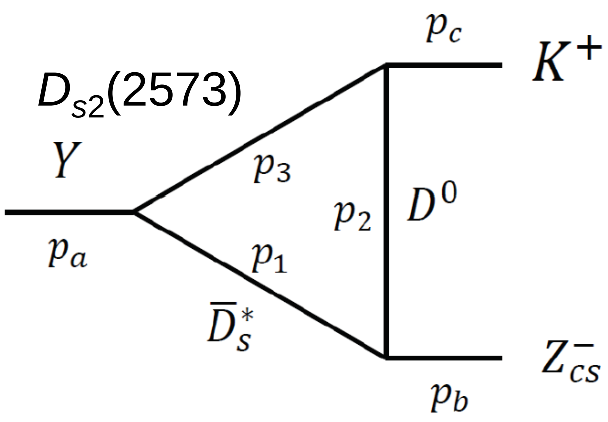
$\sqrt{S} = 4.17$ GeV

T. Xiao et al., *Phys.Lett.B* 727 (2013) 366-370

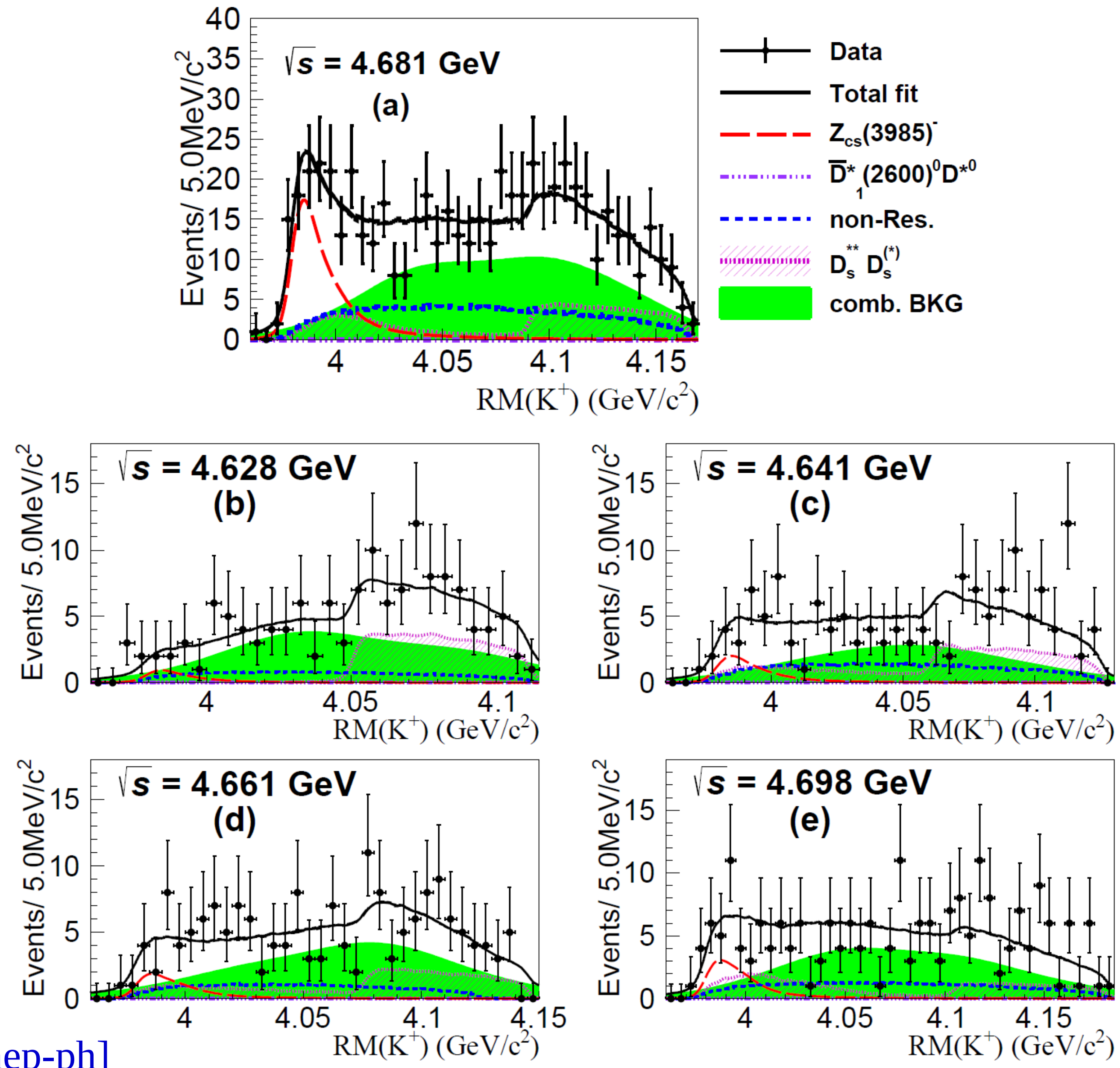
Experimental evidence for $Z_{cs}(3985)$

$$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$$





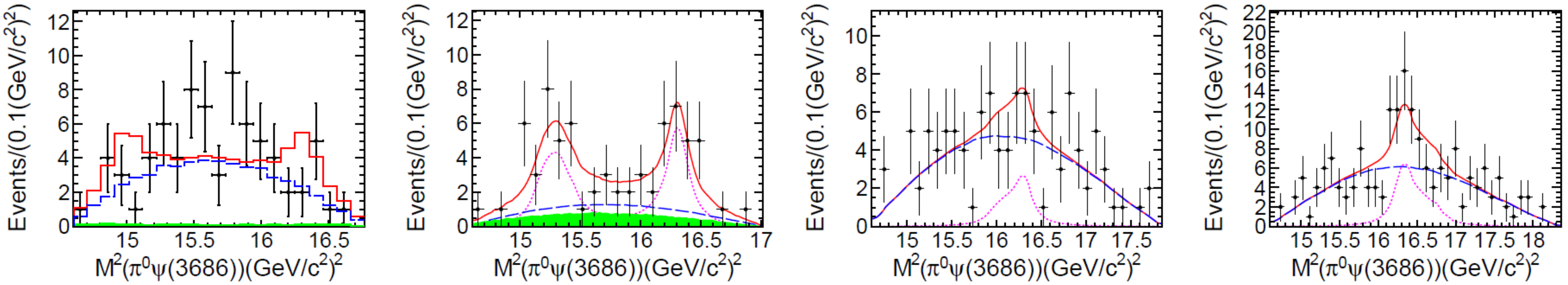
BESIII, arXiv:2011.07855v1 [hep-ex]

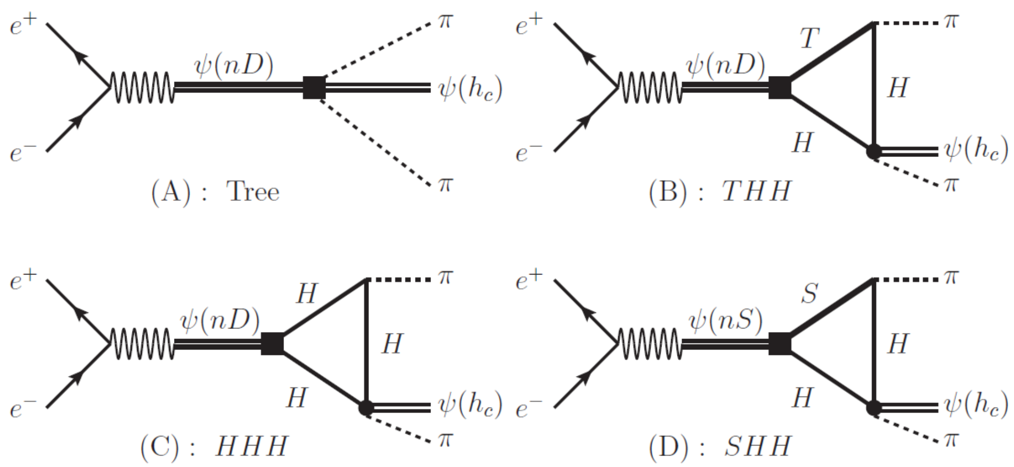


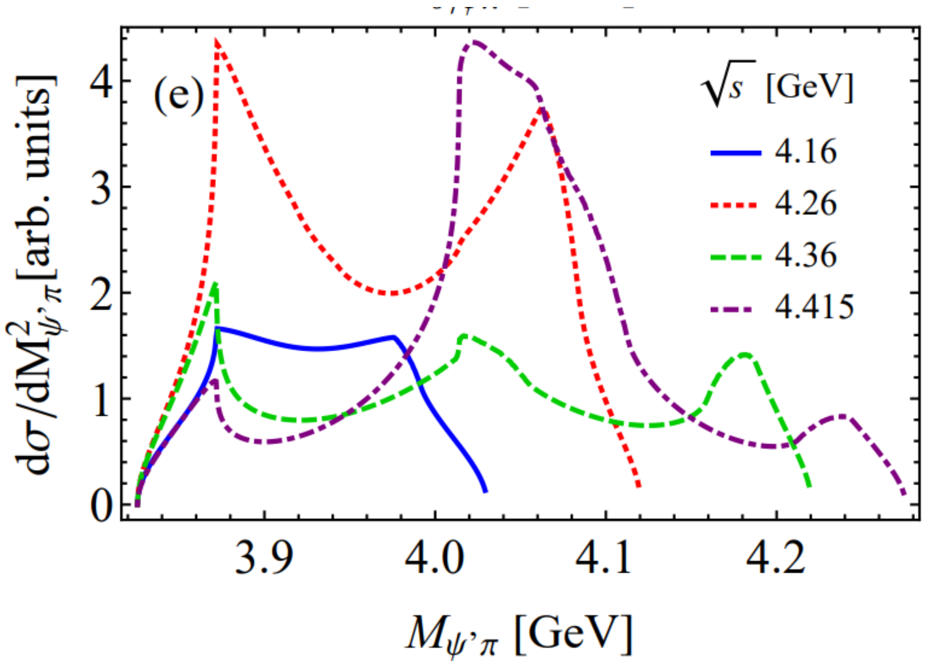
M.C. Du, Q. Wang and Q. Zhao, arXiv:2011.09225v1 [hep-ph]

$e^+e^- \to \psi(3686)\pi^0\,\pi^0$

BESIII, Phys.Rev. D97 (2018) no.5, 052001







X.-H. Liu, PRD90 (2014) 074004

FERMILAB-PUB-18-303-E

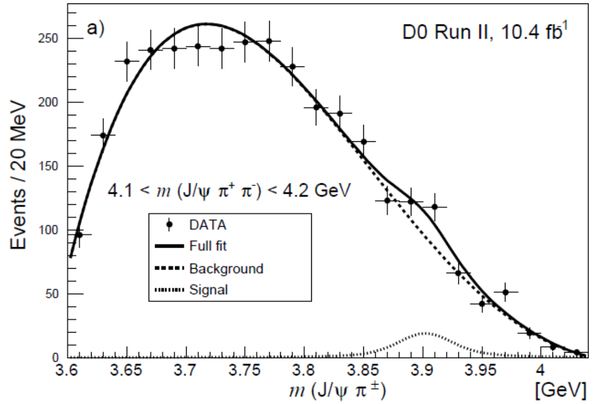
Production correlation?

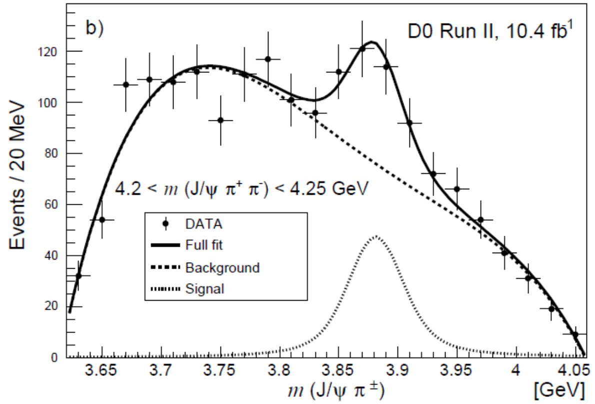
Evidence for $Z_c^{\pm}(3900)$ in semi-inclusive decays of b-flavored hadrons

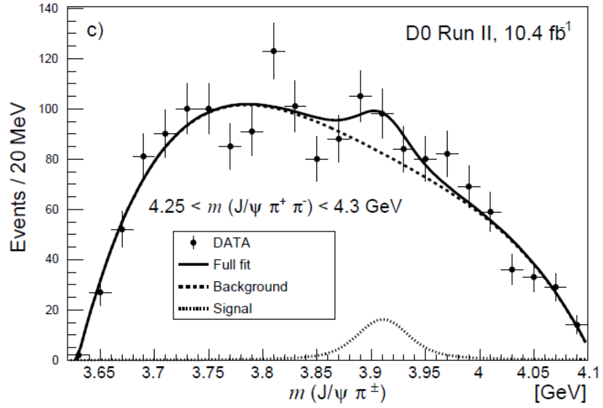
(The D0 Collaboration*)

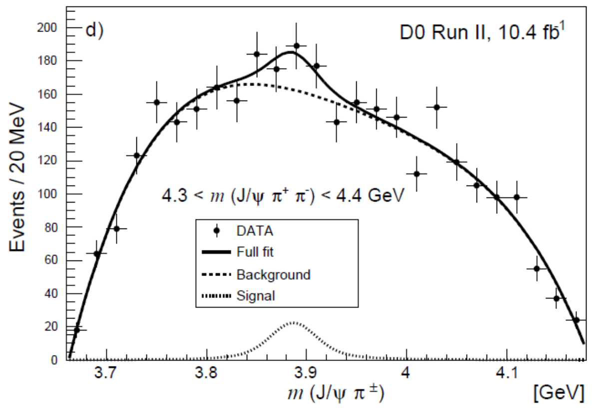
arXiv:1807.00183v1 [hep-ex]

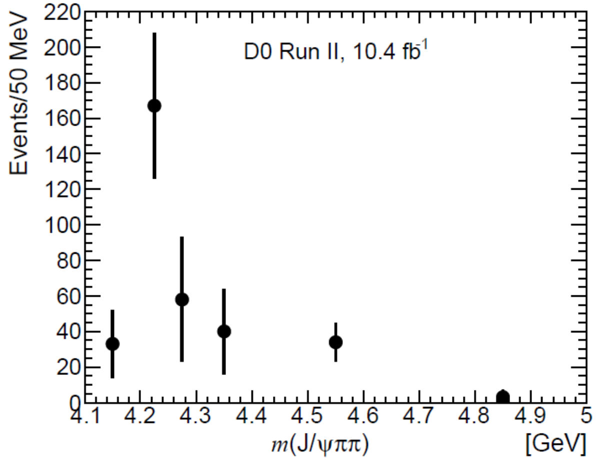
$$\boxed{H_b \to J/\psi\pi^+\pi^- + \text{anything}}$$

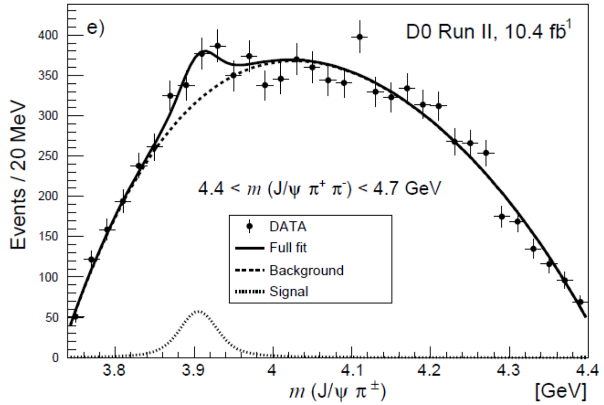


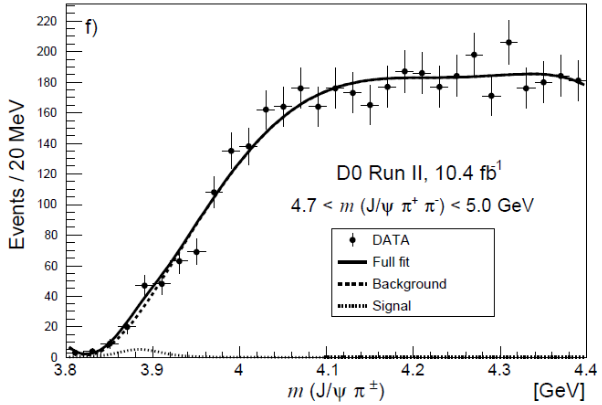


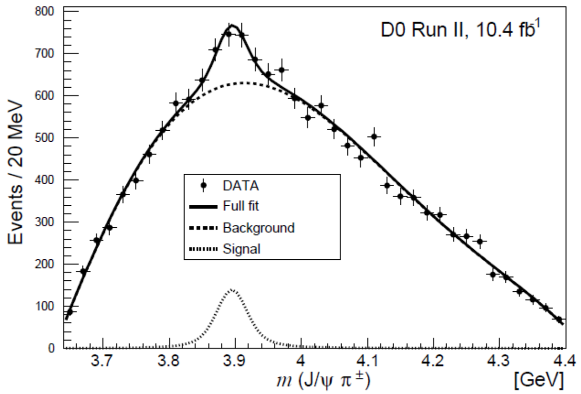




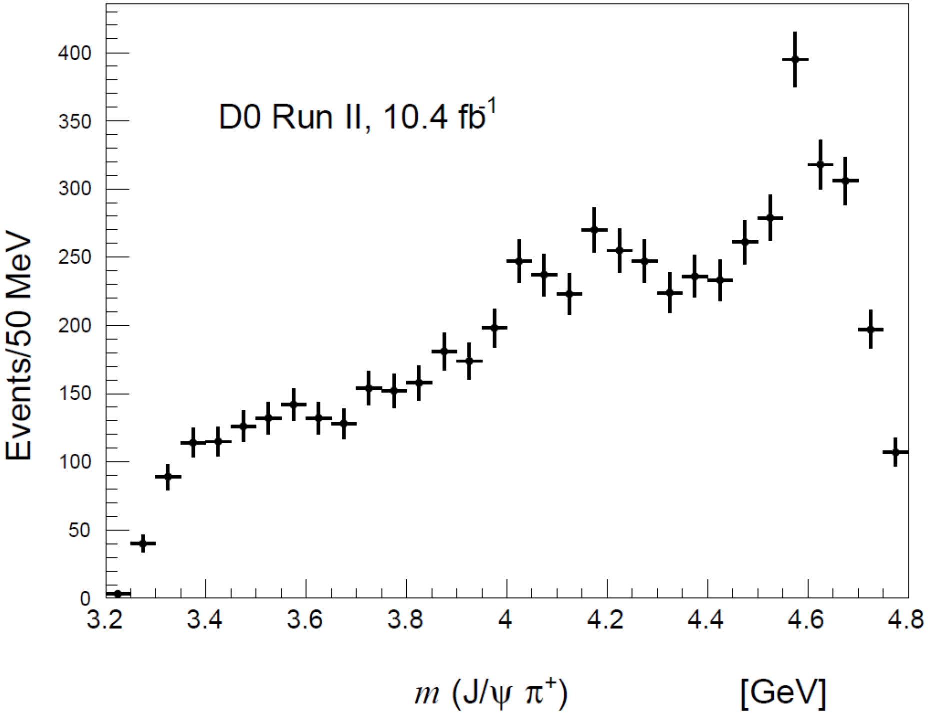




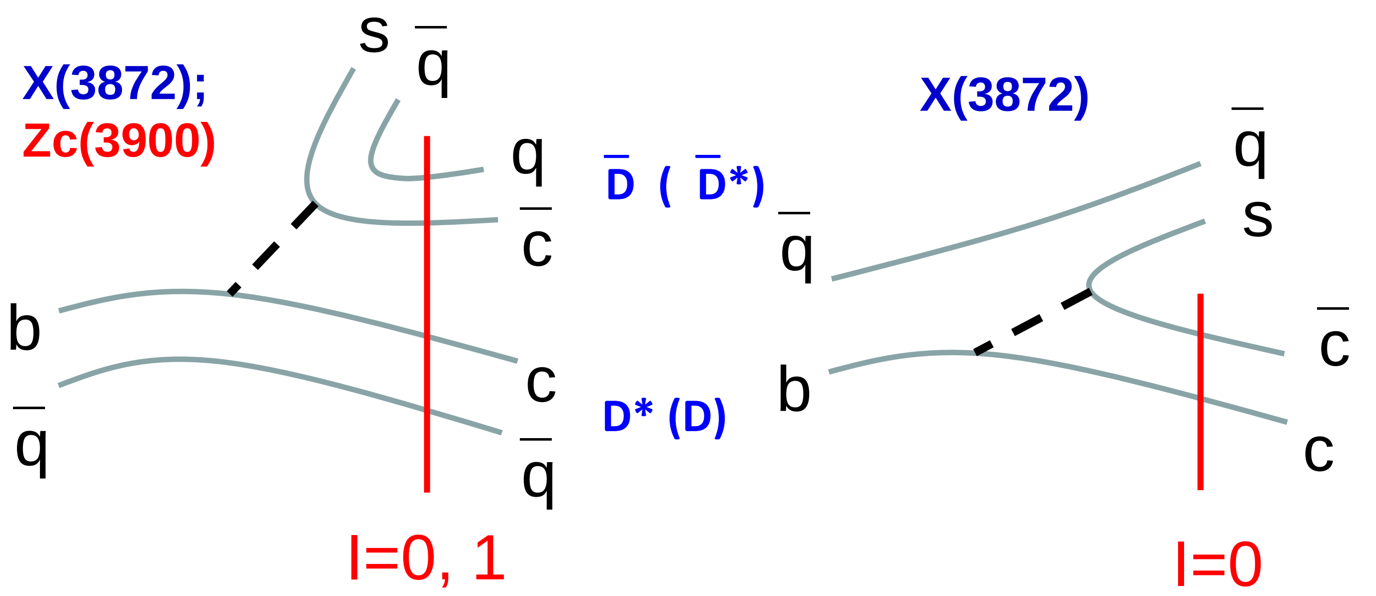




Search for the $Z_c^+(3900)$ in the decay $\bar{B}_d^0 \to J/\psi \pi^+ K^-$



- K* has been removed from the π K spectrum.
- No Zc(3900) signals seem to be present.
- Negative results from Belle and LHCb in similar processes.
- In contrast, X(3872) can be produced in both B decays and heavy ion collisions.
- This, however, may be understandable.

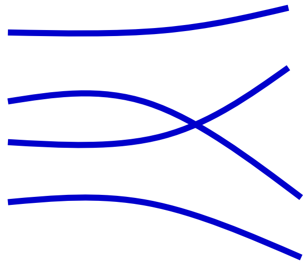


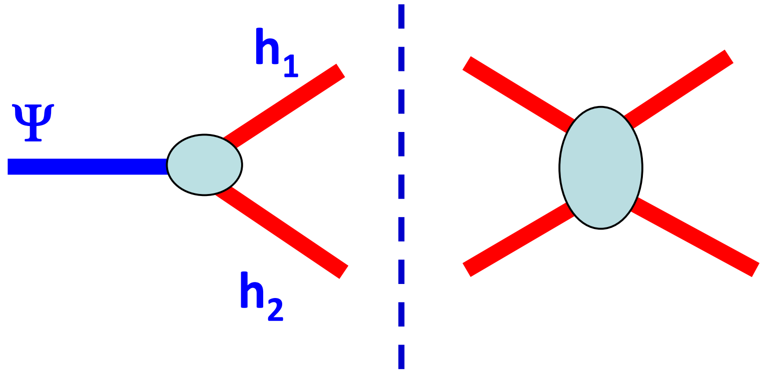
Short-distance component is responsible for the large production rate of X(3872) in both B decays and heavy ion collisions [G. Y. Chen, W. S. Huo and Q. Zhao, Chin. Phys. C **39**, no. 9, 093101 (2015)].

The general features with the tetraquark or hadronic molecule scenarios:

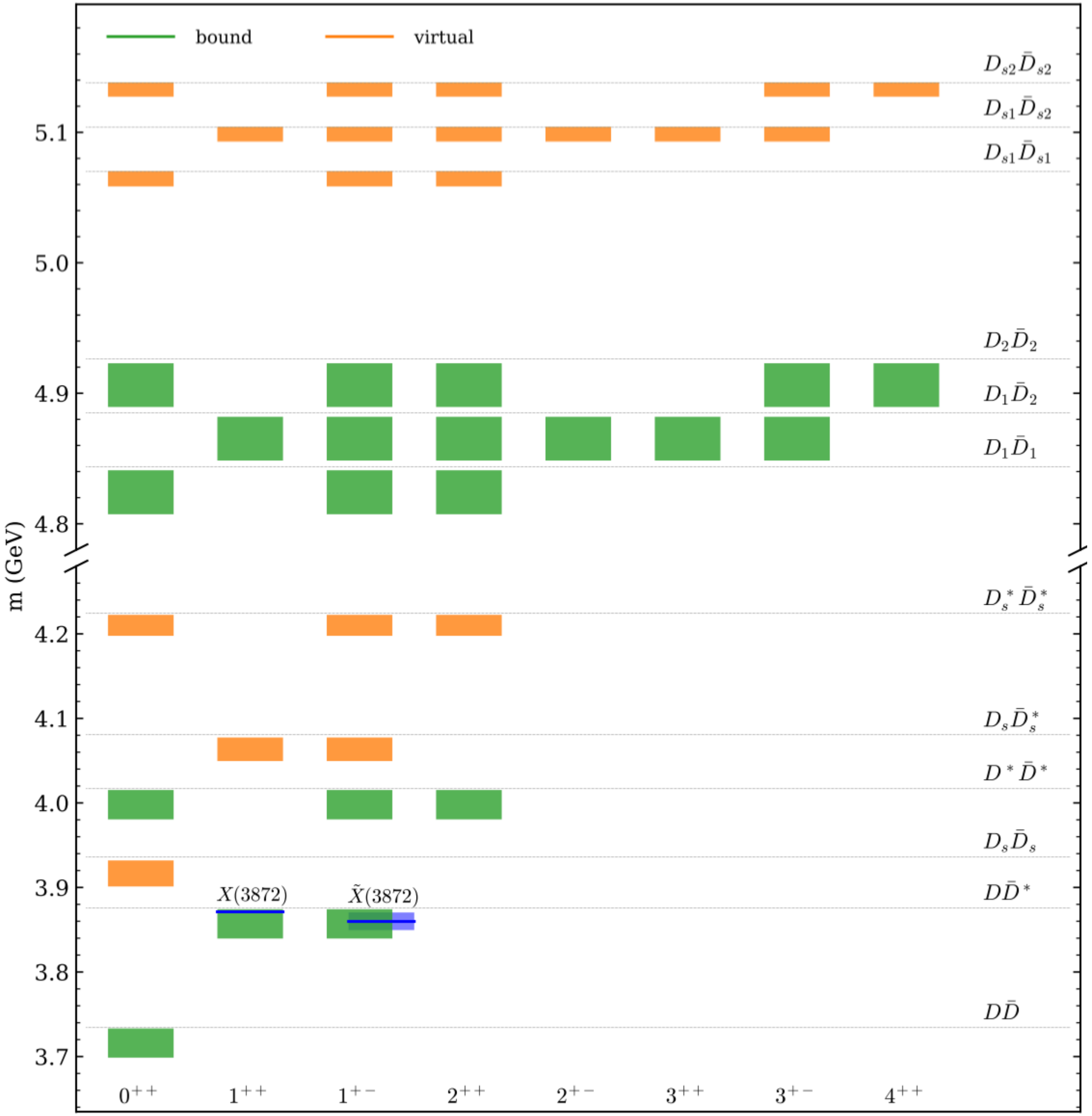
- Very rich spectra are expected.
- The form of diquark DoF can lead to very different results for the tetraquark production and decay.
- A strong coupling for a tetraquark state into a nearby S-wave threshold may need unitarization which will still introduce a molecular component into the wavefunction.

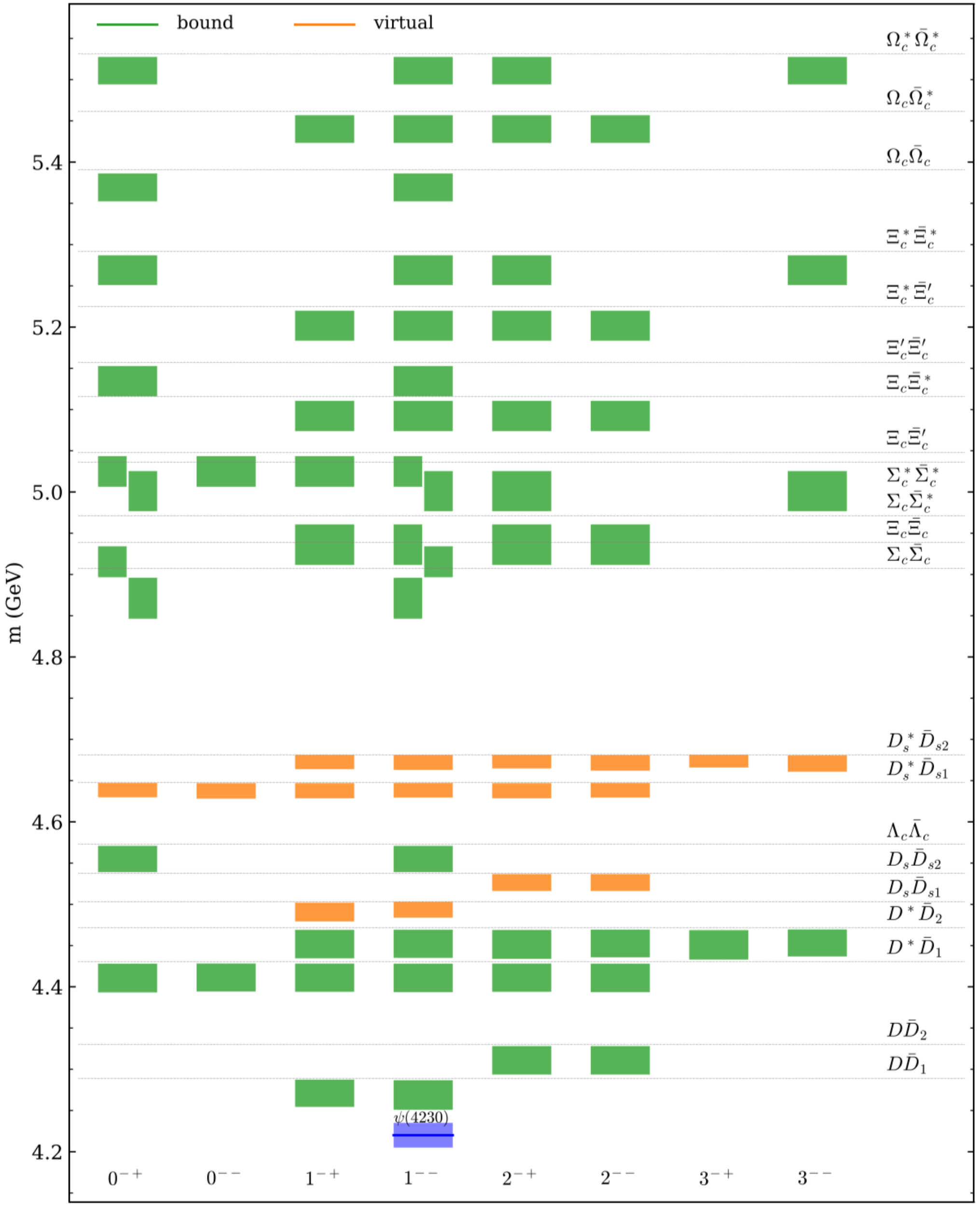
- Limited number of states close to threshold.
- Possible mixing with the kinematic singularity, but can be clarified by energy dependence of the lineshape measurement.
- Unitarization is crucial and EFT can be implemented. However, whether or not a molecular state can be formed would depend on the detailed dynamics.



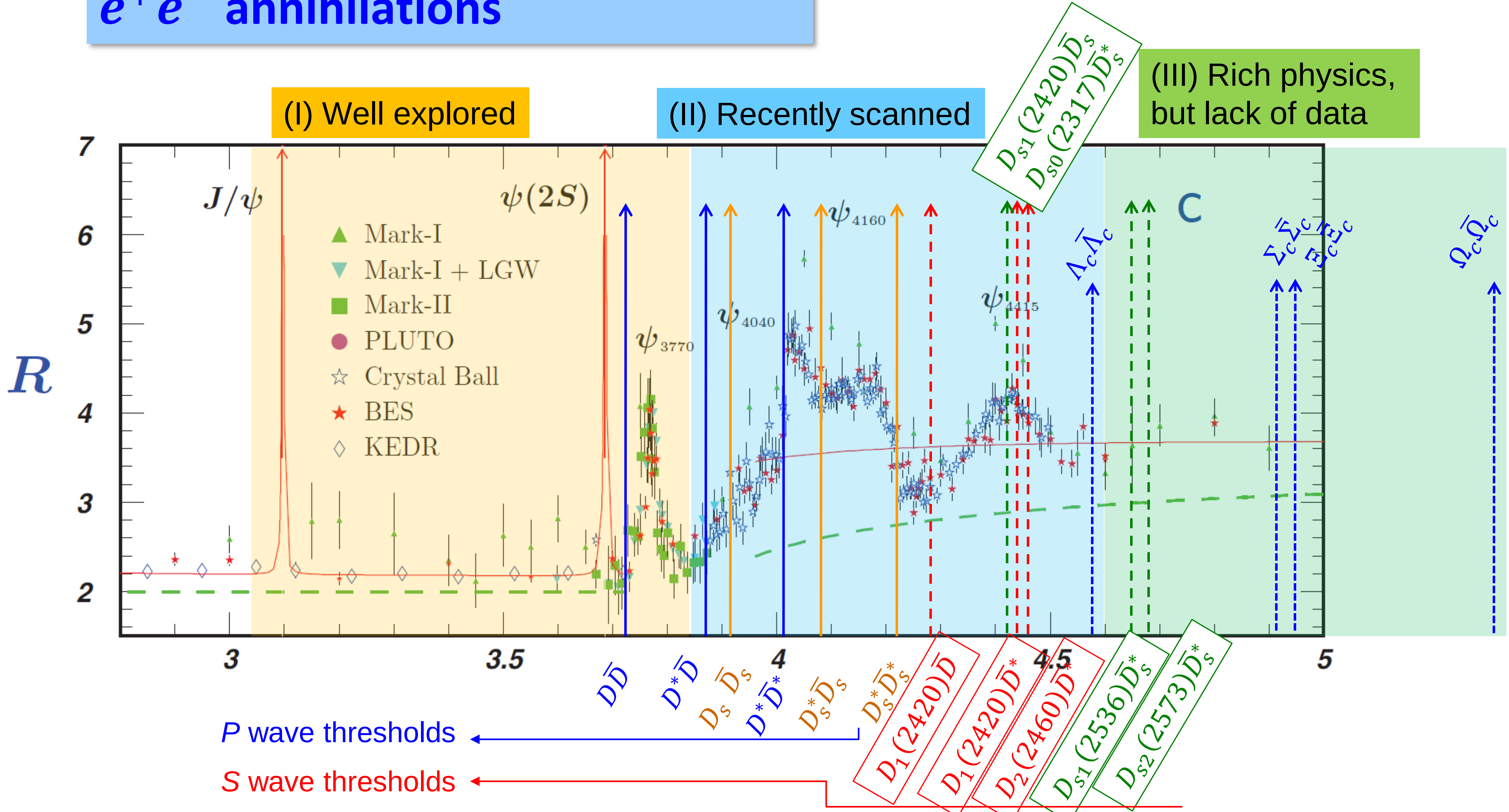


X.-K. Dong, F.-K. Guo, B.-S. Zou, Progr. Phys. 41 (2021) 65 [arXiv:2101.01021]





e^+e^- annihilations



Some crucial issues

- What are the proper effective degrees of freedom for hadron internal structures?
- What are the possible color-singlet hadrons apart from the simplest conventional mesons ($q\bar{q}$) and baryons (qqq)? (e.g. multiquarks, hadronic molecules, hadroquarkonia …)
- What are the proper observables for determining the internal structures for hadrons ?
- How to distinguish genuine states from kinematic enhancements due to TS?
- What’s happening in between “perturbative” and “non-perturbative”?
- … …

Thanks for your attention!