Finding XYZ states@BEPC3

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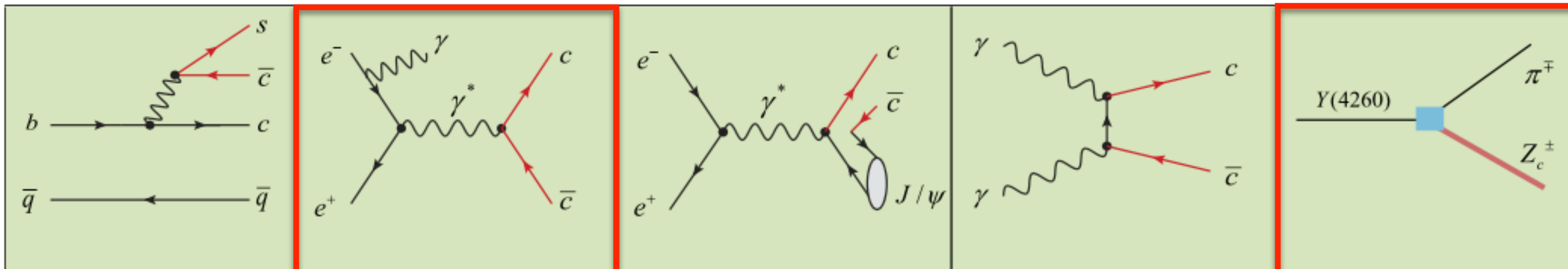
BEPCII物理联合研讨会
高能物理研究所 2021年4月15日

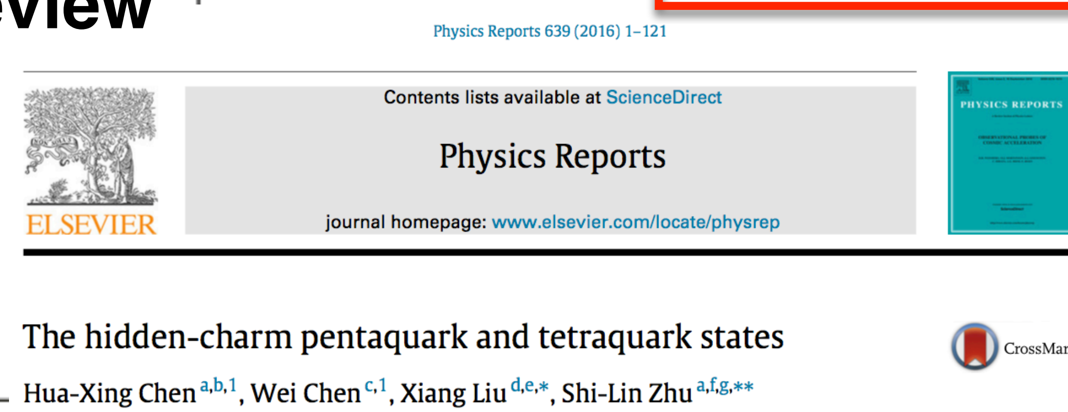
The observed XYZ states

According to the production mechanisms, we can categorize them into five groups



$X(3872)$	$Y(4260)$	$X(3940)$	$X(3915)$	$Z_c(3900)$
$Y(3940)$	$Y(4008)$	$X(4160)$	$X(4350)$	$Z_c(4025)$
$Z^+(4430)$	$Y(4360)$		$Z(3930)$	$Z_c(4020)$
$Z^+(4051)$	$Y(4630)$			$Z_c(3885)$
$Z^+(4248)$	$Y(4660)$			
$Y(4140)$				
$Y(4274)$				
$Z_c^+(4200)$				
$Z^+(4240)$				
$X(3823)$				

see review


Physics Reports 639 (2016) 1–121

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The hidden-charm pentaquark and tetraquark states

Hua-Xing Chen[a,b,1], Wei Chen[c,1], Xiang Liu[d,e,*], Shi-Lin Zhu[a,f,g,**]

Outline

- Z_c **and** Z_{cs} **structures**
- **Y Problems and higher charmonia**
- **Summary**

Z_c and Z_{cs} structures

PHYSICAL REVIEW D **84**, 034032 (2011)

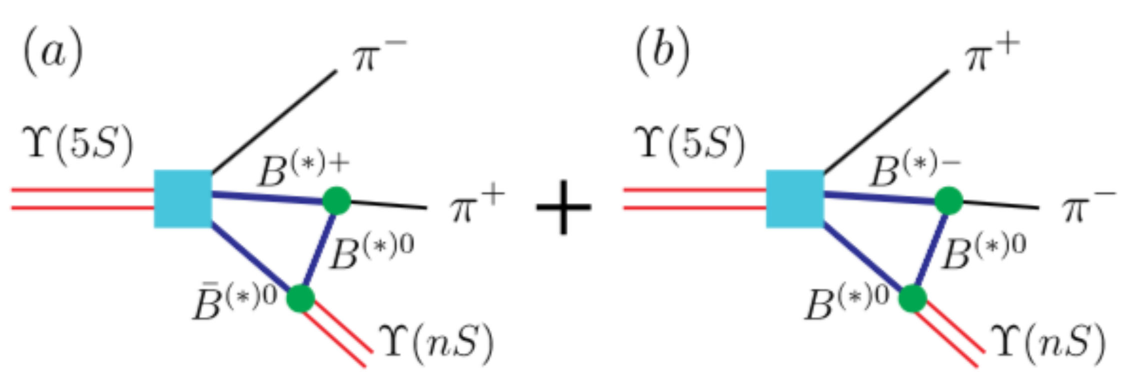
Predicted charged charmoniumlike structures in the hidden-charm dipion decay of higher charmonia

Dian-Yong Chen[1,3] and Xiang Liu[1,2,*,†]

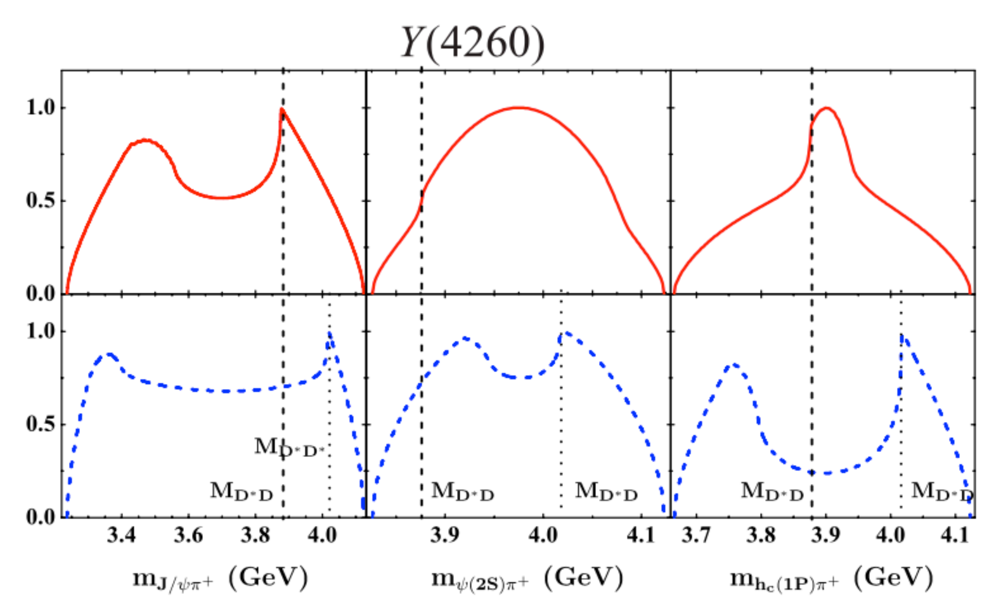
In this work, we predict two charged charmoniumlike enhancement structures close to the $D^*\bar{D}$ and $D^*\bar{D}^*$ thresholds, where the Initial Single Pion Emission mechanism is introduced in the hidden-charm dipion decays of higher charmonia $\psi(4040)$, $\psi(4160)$, $\psi(4415)$ and charmoniumlike state $Y(4260)$. We suggest BESIII to search for these structures in the $J/\psi\pi^+$, $\psi(2S)\pi^+$ and $h_b(1P)\pi^+$ invariant mass spectra of the $\psi(4040)$ decays into $J/\psi\pi^+\pi^-$, $\psi(2S)\pi^+\pi^-$ and $h_b(1P)\pi^+\pi^-$. In addition, the experimental search for these enhancement structures in the $J/\psi\pi^+$, $\psi(2S)\pi^+$ and $h_c(1P)\pi^+$ invariant mass spectra of the $\psi(4260)$ hidden-charm dipion decays will be accessible at Belle and *BABAR*.

Explicitly predict charged charmonium-like structures existing in hidden-charm dipion decays of Y(4260)

Initial Single Pioin Emission (ISPE) mechanism

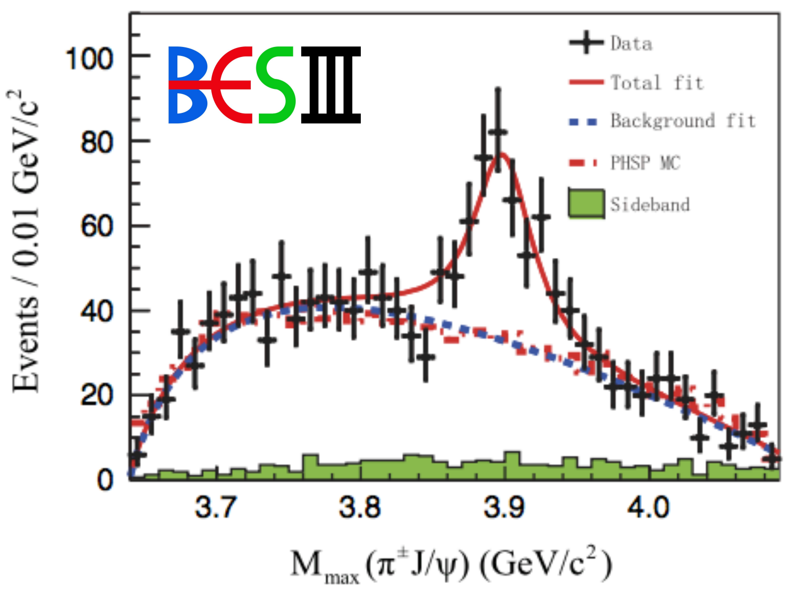


Chen, Liu, PRD84 (2011) 094003

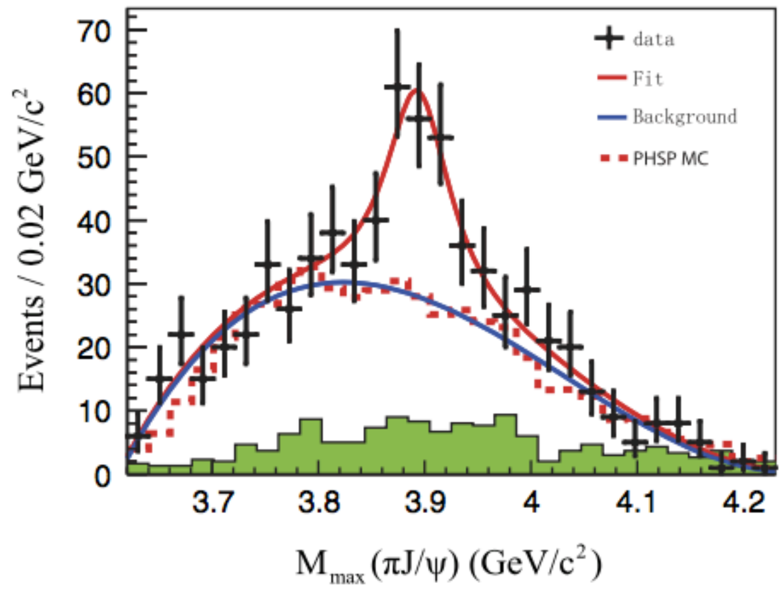


Discovery of Zc(3900)

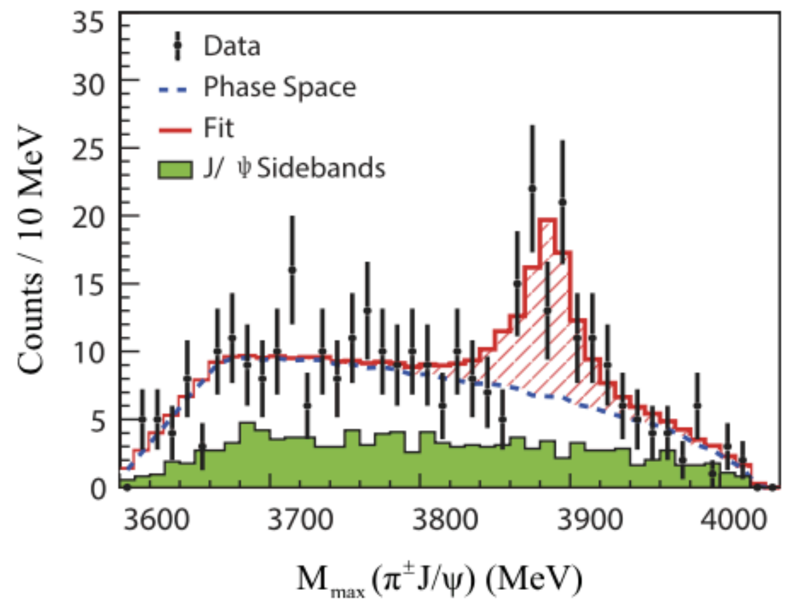
PRL110 (2013) 252001



PRL110 (2013) 252002

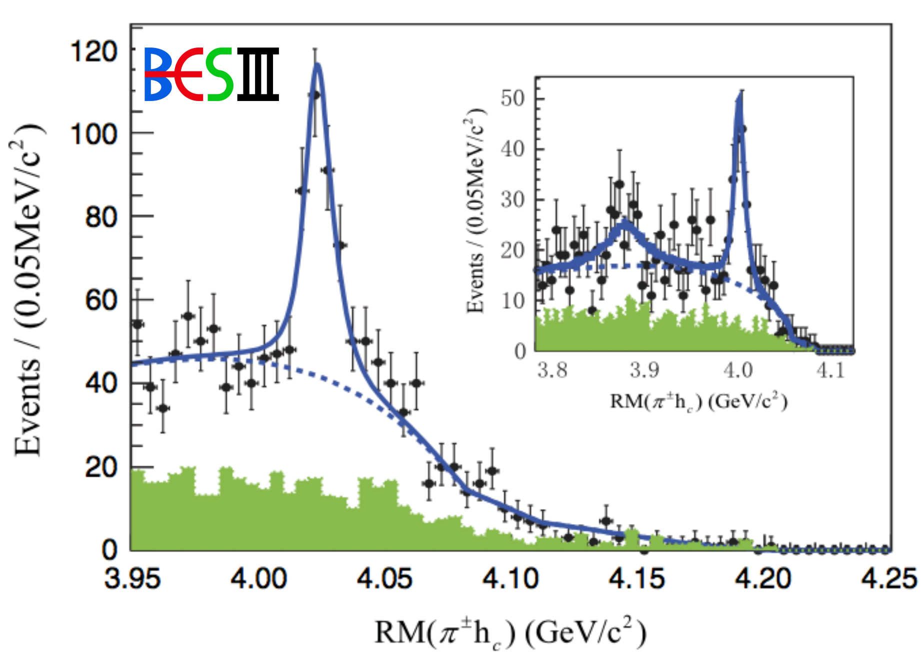


PLB773 (2013) 366



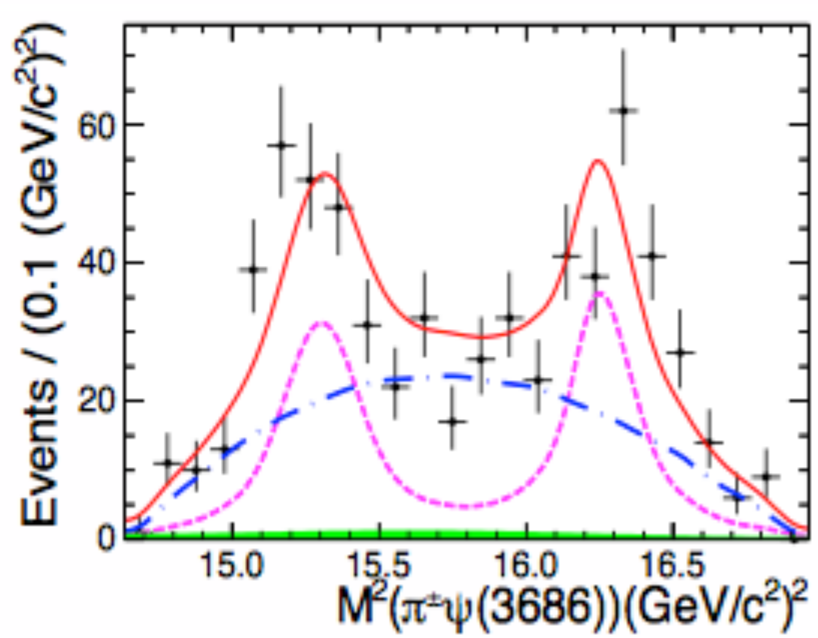
Discovery of Zc(4020)

PRL111 (2013) 242001



Discovery of Zc(4032)

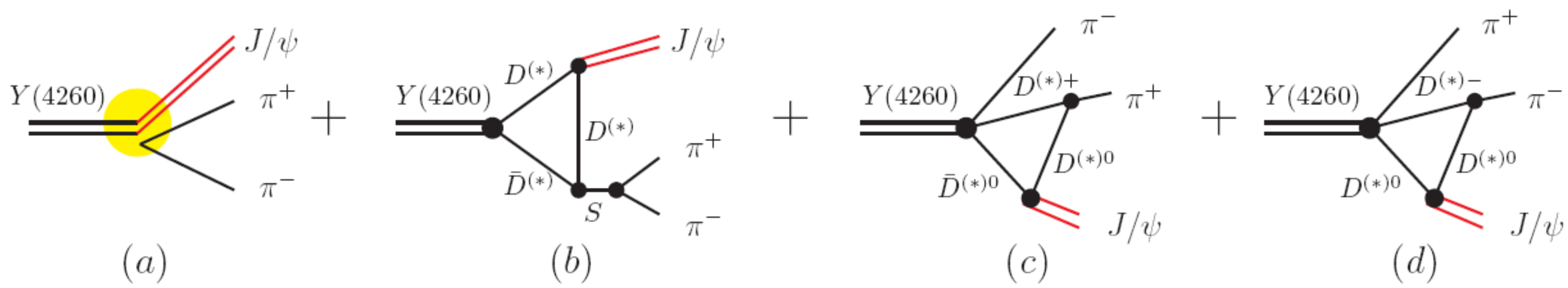
arXiv: 1703.08787



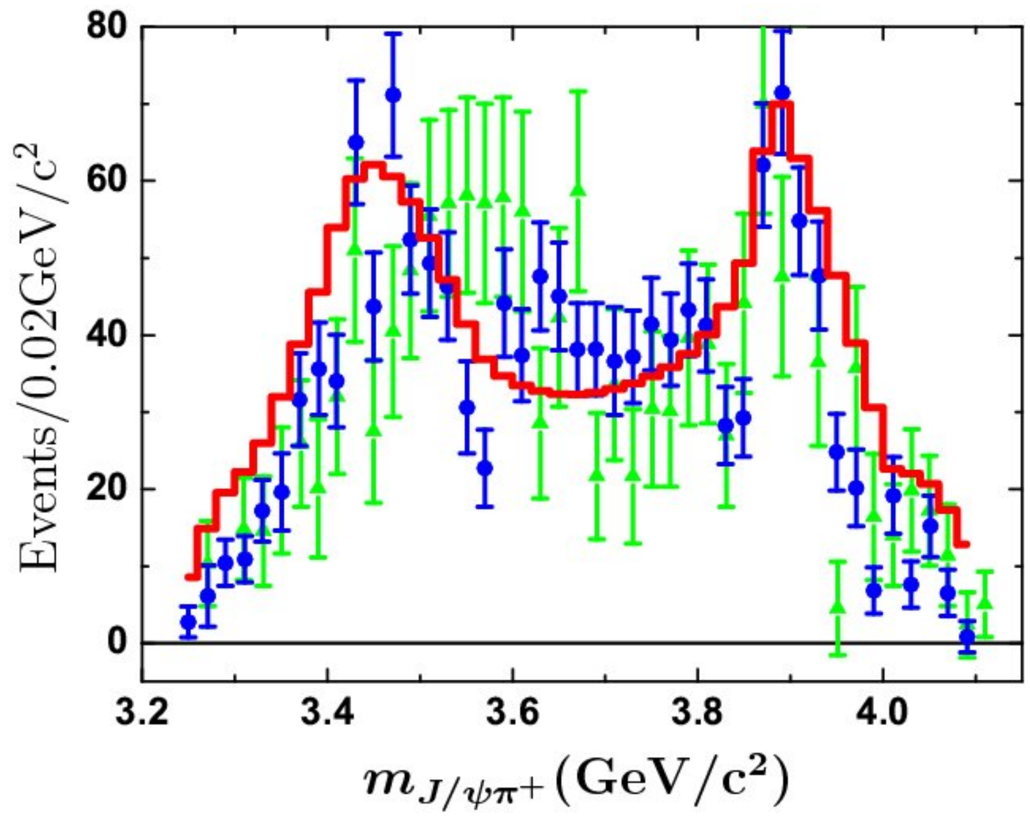
PHYSICAL REVIEW D **88**, 036008 (2013)

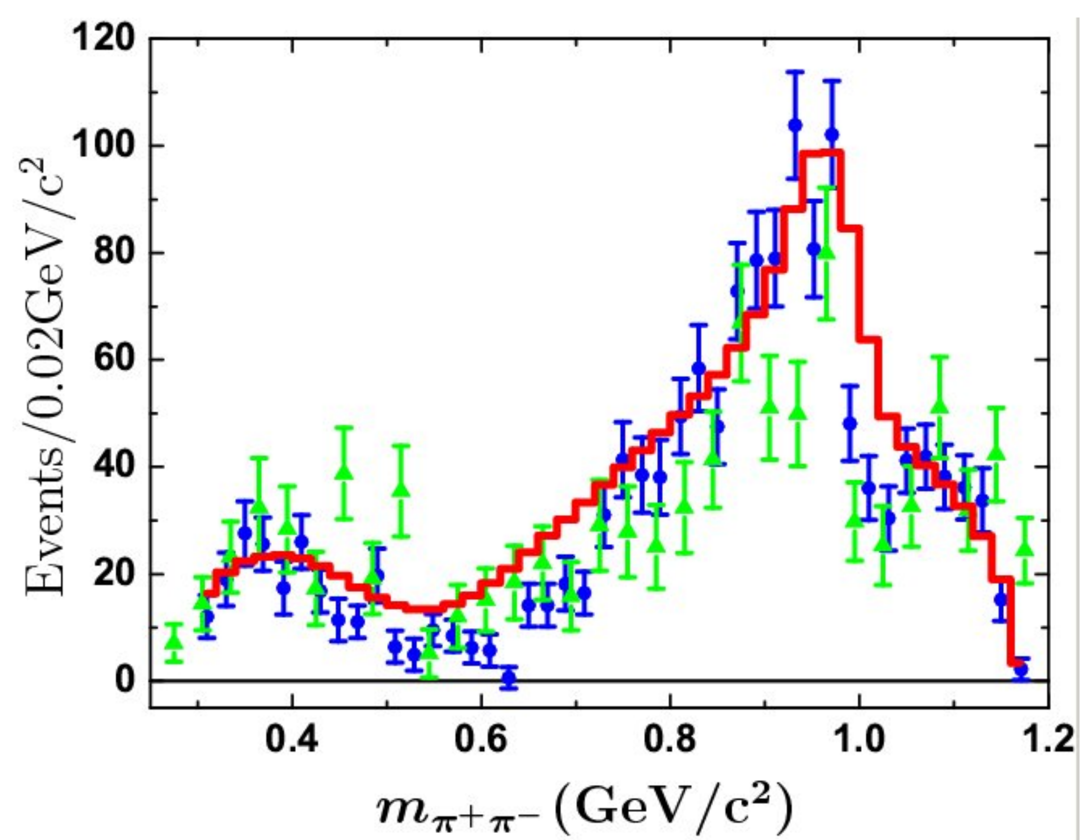
Reproducing the $Z_c(3900)$ structure through the initial-single-pion-emission mechanism

Dian-Yong Chen,[1,3,*] Xiang Liu,[1,2,†] and Takayuki Matsuki[4,‡]



Reproduce Zc(3900) via the ISPE mechanism





Predictions of Charged Charmoniumlike Structures with Hidden-Charm and Open-Strange Channels

Dian-Yong Chen,[1,3,†] Xiang Liu,[1,2,*,‡] and Takayuki Matsuki[4,§]

PRL **110,** 232001 (2013) PHYSICAL REVIEW LETTERS week ending 7 JUNE 2013

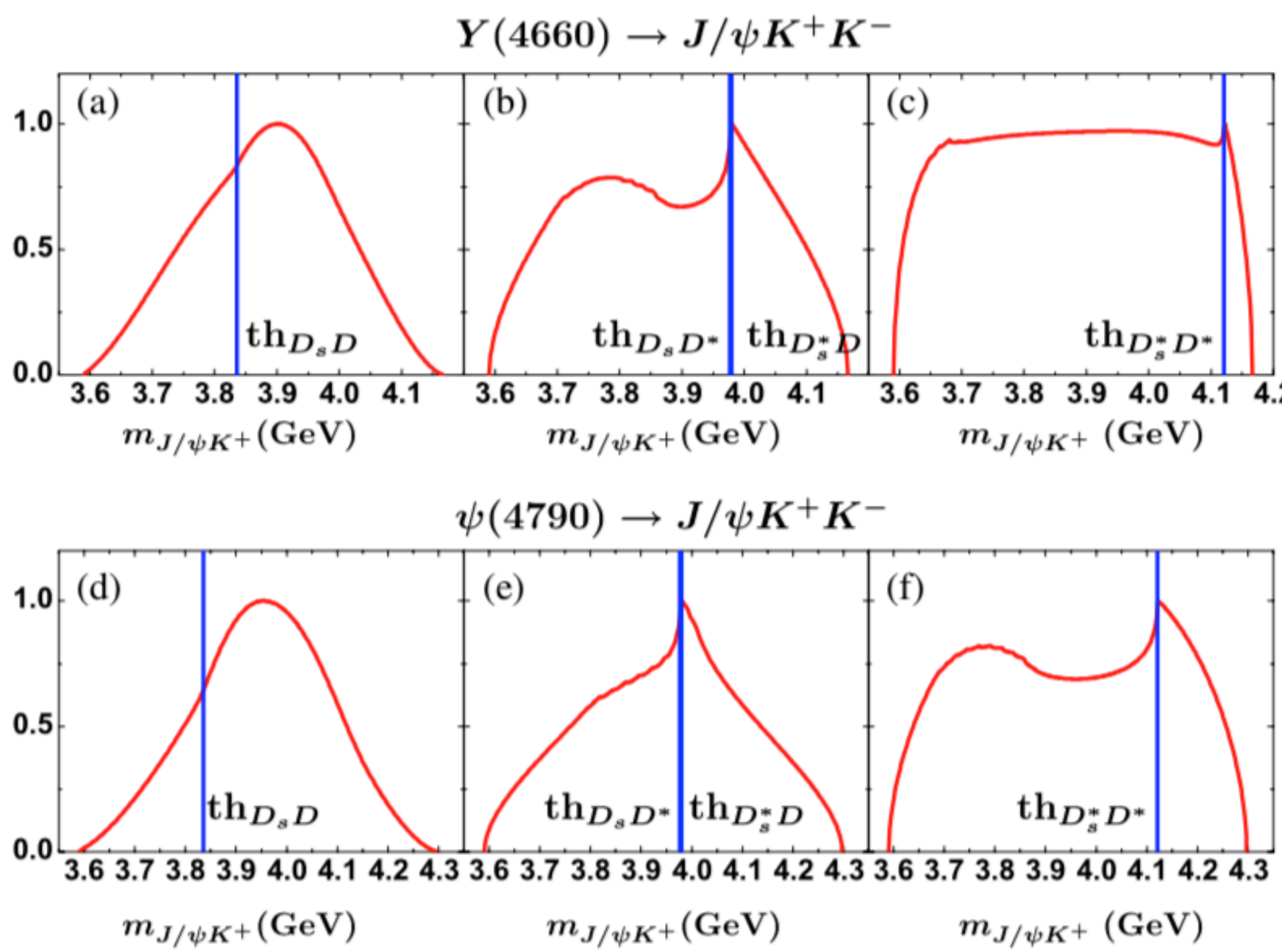


FIG. 3 (color online). Dependence of the distribution of $d\Gamma/dm_{J/\psi K^+}$ on the $J/\psi K^+$ invariant mass spectrum (red solid curves). The diagrams (a) and (d), the diagrams (b) and (e), and the diagrams (c) and (f), are the results considering the intermediate $D\bar{D}_s$ + H.c., $D^*\bar{D}_s + D\bar{D}_s^*$ + H.c., and $D^*\bar{D}_s^*$ + H.c. contributions, respectively. Here, the line shape of the distribution of $d\Gamma/dm_{J/\psi K^+}$ is normalized to 1.

Searching for Z_{cs} via $J/\psi K\bar{K}$ channel

Eur. Phys. J. C (2020) 80:1040
https://doi.org/10.1140/epjc/s10052-020-08621-4

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Theoretical Physics

Universal non-resonant explanation to charmoniumlike structures $Z_c(3885)$ and $Z_c(4025)$

Jun-Zhang Wang[1,2,a], **Dian-Yong Chen**[3,b], **Xiang Liu**[1,2,c], **Takayuki Matsuki**[4,d]

[1] School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China
[2] Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics o
[3] School of Physics, Southeast University, Nanjing 210094, China
[4] Tokyo Kasei University, 1-18-1 Kaga, Tokyo, Itabashi 173-8602, Japan

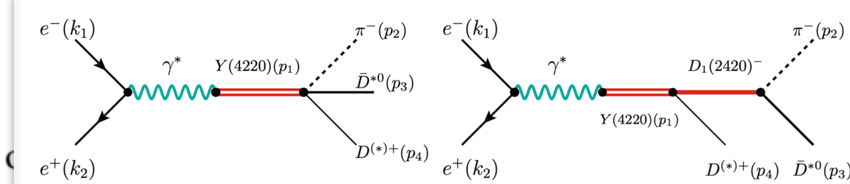

Fig. 1 The schematic diagrams of two main production contributions in the three-body open charm processes $e^+e^- \to D^{(*)+}\bar{D}^{*0}\pi^-$

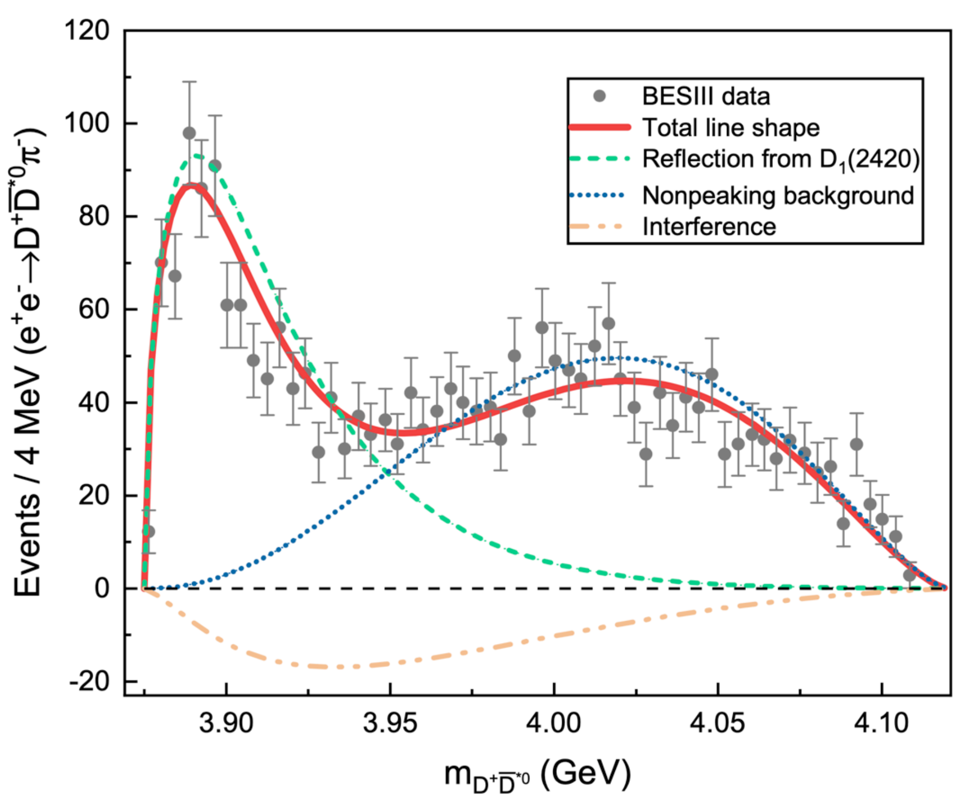

Fig. 2 The fit to the experimental data of $e^+e^- \to D^+\bar{D}^{*0}\pi^-$ by line shapes on the spectrum of $m_{D^+\bar{D}^{*0}}$ [11], where the structure near the threshold of $D^+\bar{D}^{*0}$ corresponds to the reported $Z_c(3885)^+$. Here, included are only the reflection from charmed meson $D_1(2420)$ and normal nonpeaking contributions together with their interference

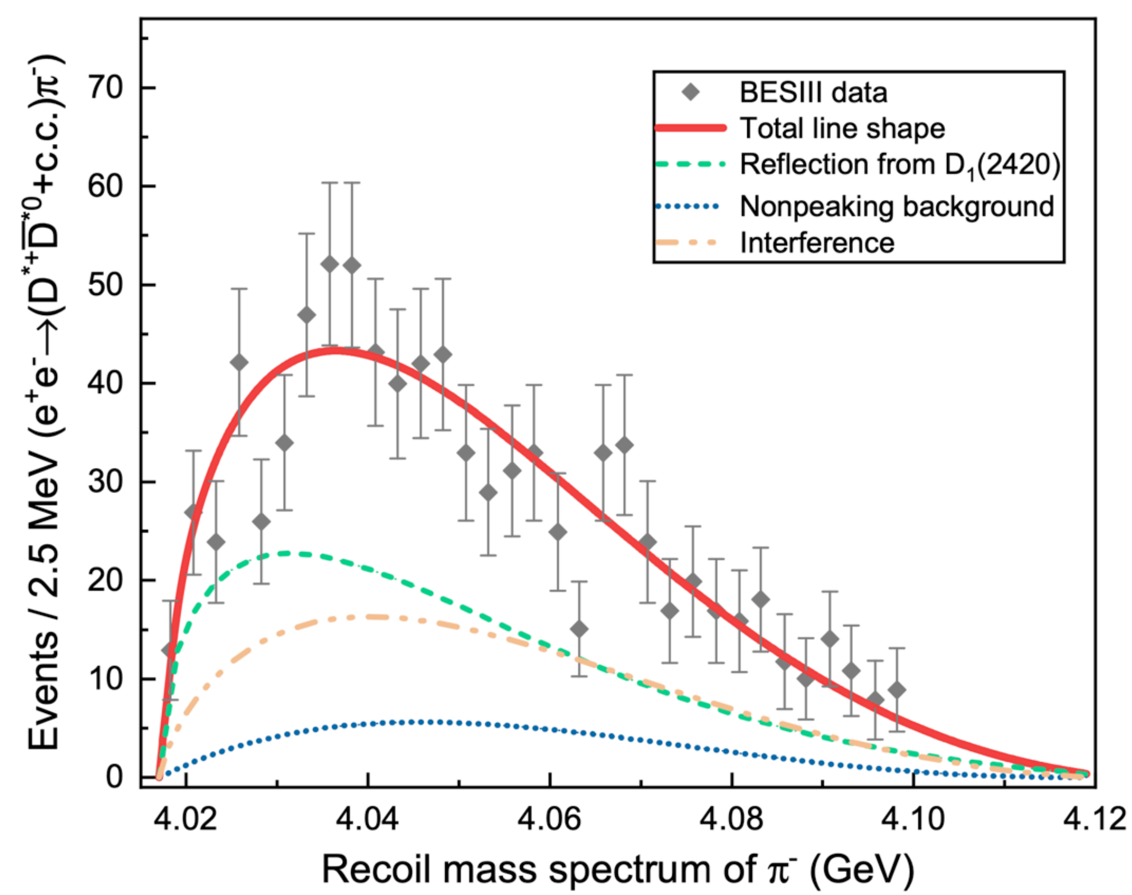

Fig. 3 The same as Fig. 2 but for recoil mass spectrum of π^- of $e^+e^- \to D^{*+}\bar{D}^{*0}\pi^-$. The broad peak corresponds to $Z_c(4025)$

Eur. Phys. J. C (2021) 81:51
https://doi.org/10.1140/epjc/s10052-021-08877-4

THE EUROPEAN PHYSICAL JOURNAL C

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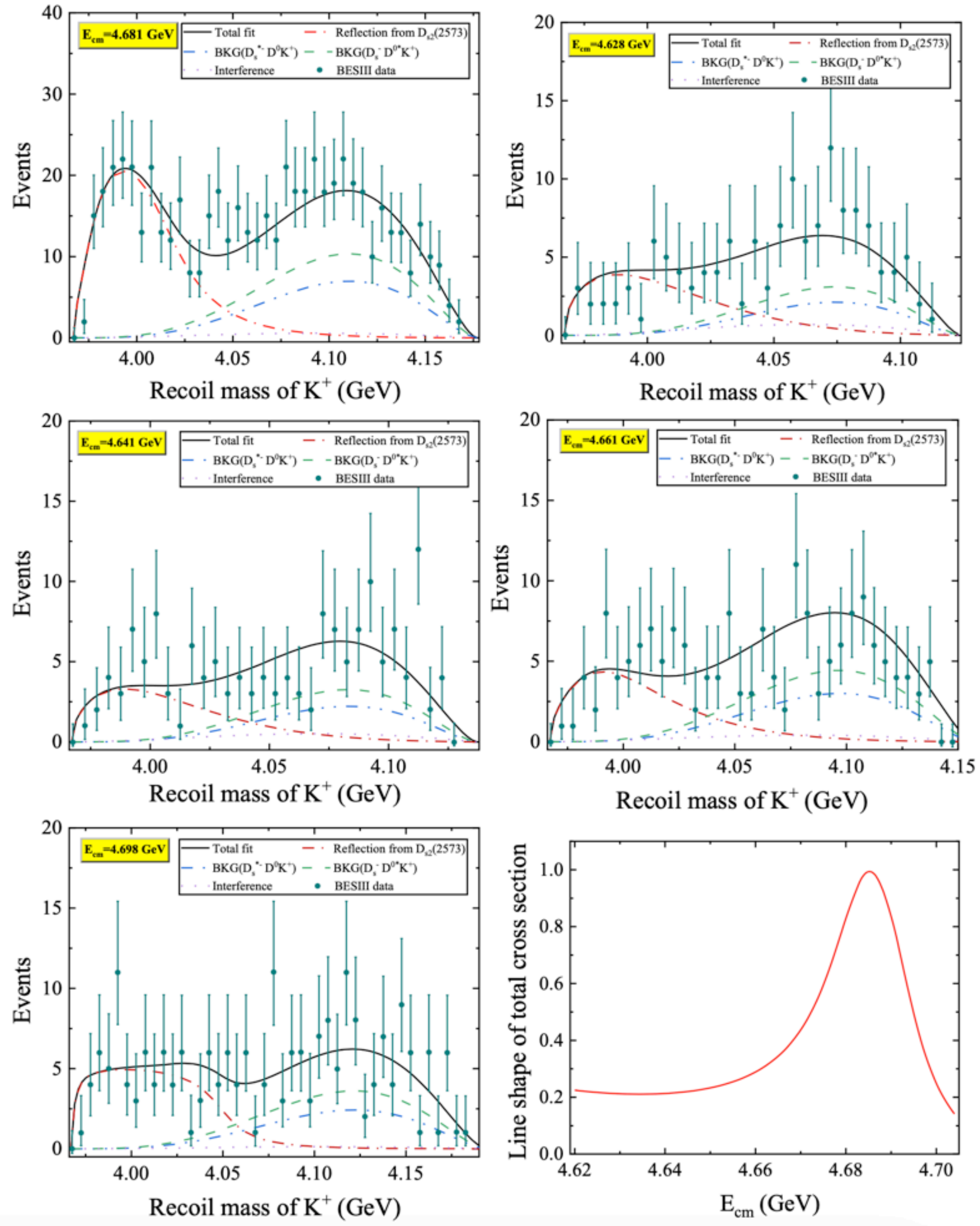
Regular Article - Theoretical Physics

Toward charged $Z_{cs}(3985)$ structure under a reflection mechanism

Jun-Zhang Wang[1,2,a], **Qin-Song Zhou**[1,2,b], **Xiang Liu**[1,2,c], **Takayuki Matsuki**[3,d]



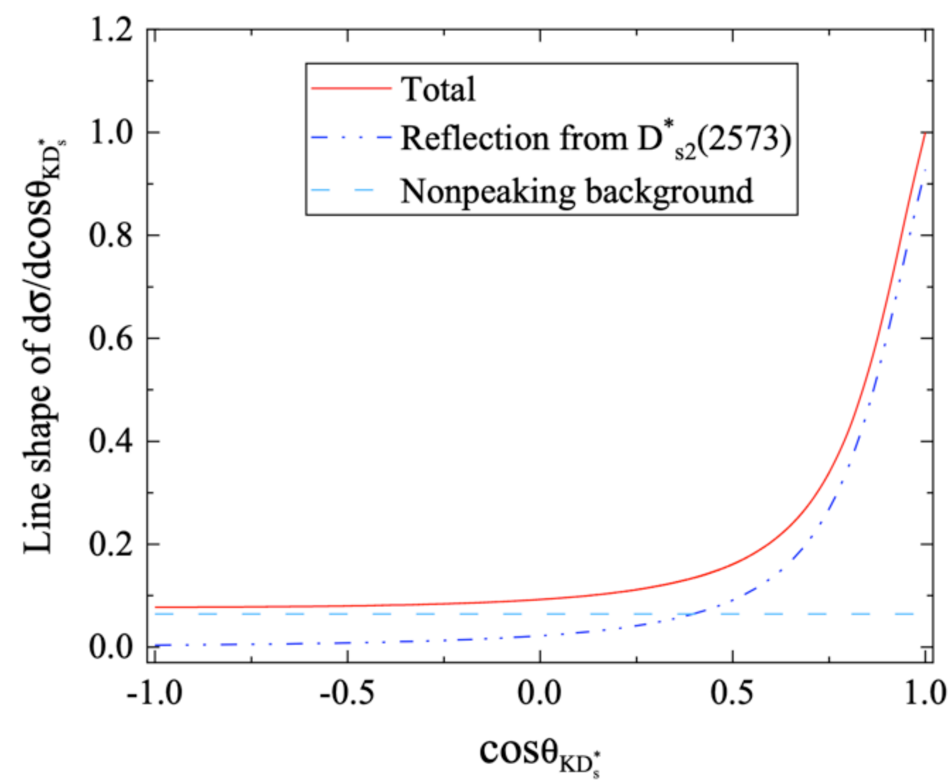
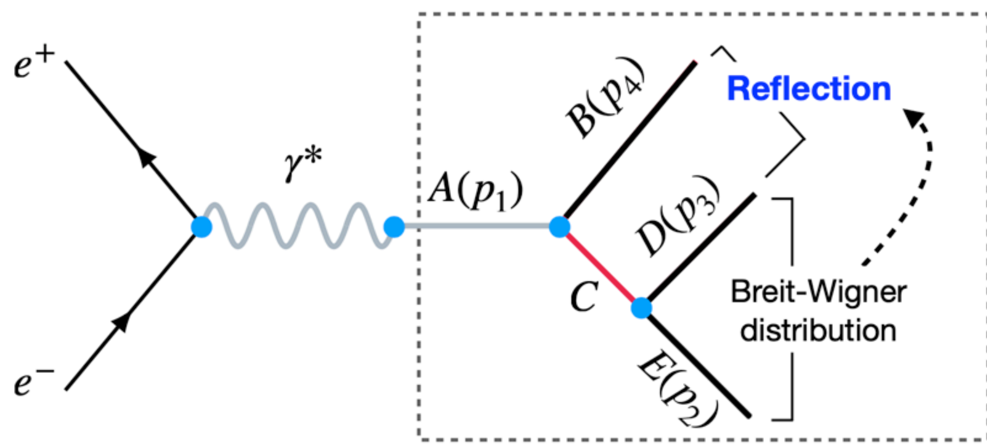


Fig. 3 The predicted line shape of differential cross section of $e^+e^- \to D^0K^+D_s^{*-}$ vs. $\cos\theta_{KD_s^*}$

Mapping a new cluster of charmoniumlike structures at e^+e^- collisions

Jun-Zhang Wang[1,2,*], Dian-Yong Chen[3,†], Xiang Liu[1,2,4‡,§] and Takayuki Matsuki[5¶]

arXiv:2011.08501



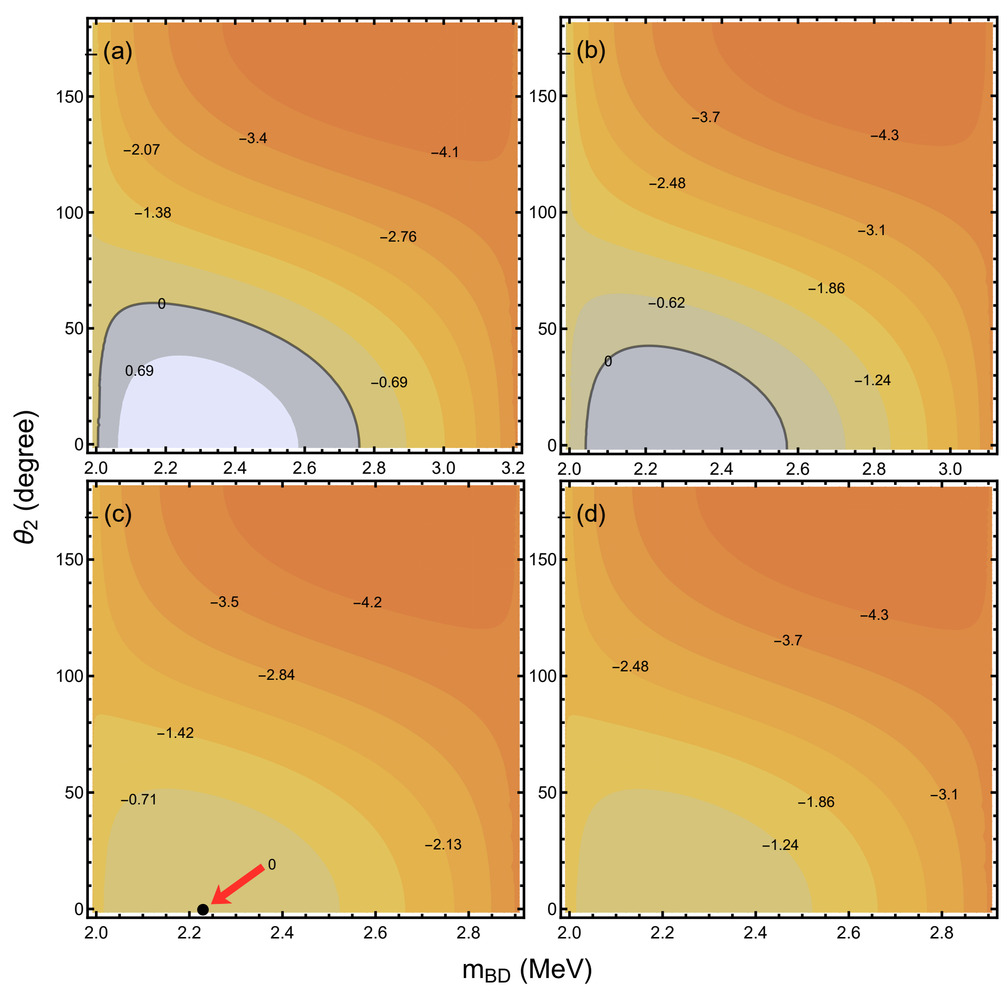


TABLE I: The proposal for inducing charmoniumlike structures through our proposed CEE mechanism. The last column shows the corresponding pole position of a reflective charmoniumlike peak in the invariant mass of $D^{(*)}_{(s)}D^{(*)}_{(s)}$.

$\sqrt{s_{\text{critical}}}$ [a]	Recommended process	Involved state	$m^{pole}_{D^{(*)}_{(s)}D^{(*)}_{(s)}}$
4286	$e^+e^- \to DD^*\pi$	$D_1(2420)$ (1^+)	3890
4429	$e^+e^- \to D_sD_s^*\pi$	$D_{s1}(2460)$ (1^+)	4091
4430	$e^+e^- \to D_s^*D_s\pi$	$D_{s0}(2317)$ (0^+)	4092
4431	$e^+e^- \to D^*D^*\pi$	$D_1(2420)$ (1^+)	4035
4471	$e^+e^- \to D^*D\pi$	$D_2^*(2460)$ (2^+)	3910
4474	$e^+e^- \to DD^*\pi$	$D^*(2600)$ (1^-)	3906
4504	$e^+e^- \to D_sD^*K$	$D_{s1}(2536)$ (1^+)	3982
4572	$e^+e^- \to D_s^*D_s^*\pi$	$D_{s1}(2460)$ (1^+)	4234
4615	$e^+e^- \to D_sD^*K$	$D_s(2646)$ $(0^-)^b$	3994
4617	$e^+e^- \to DD^*\pi$	$D(2750)$ (2^-)	3921
4619	$e^+e^- \to D^*D^*\pi$	$D^*(2600)$ (1^-)	4052
4647	$e^+e^- \to D_s^*D^*K$	$D_{s1}(2536)$ (1^+)	4125
4677	$e^+e^- \to D_sDK$	$D_{s1}^*(2700)$ (1^-)	3878
4750	$e^+e^- \to DD^*\rho$	$D(2885)$ $(1^+)^b$	3889
4758	$e^+e^- \to D_s^*D^*K$	$D_s(2646)$ $(0^-)^b$	4138
4762	$e^+e^- \to D^*D^*\pi$	$D(2750)$ (2^-)	4068
4820	$e^+e^- \to D_s^*DK$	$D_{s1}^*(2700)$ (1^-)	4023
4894	$e^+e^- \to D^*D\rho$	$D(2884)$ $(2^+)^b$	3914
4895	$e^+e^- \to D^*D^*\rho$	$D(2885)$ $(1^+)^b$	4034
5013	$e^+e^- \to DD\rho$	$D(3148)$ $(2^-)^b$	3812
5116	$e^+e^- \to D_s^*D^*K^*$	$D_s(3004)$ $(2^+)^b$	4138
5158	$e^+e^- \to D^*D\rho$	$D(3148)$ $(2^-)^b$	3960
5229	$e^+e^- \to D_sDK^*$	$D_s(3260)$ $(2^-)^b$	3924
5372	$e^+e^- \to D_s^*DK^*$	$D_s(3260)$ $(2^-)^b$	4070

Y Problems and higher charmonia

Chen, He, Liu, PRD83 (2011) 05402
Chen, He, Liu, PRD83 (2011) 074012
Chen, Liu, Matsuki, PRD93 (2016) 014011

Chen, Liu, Matsuki, EPJC 78:136 (2018)

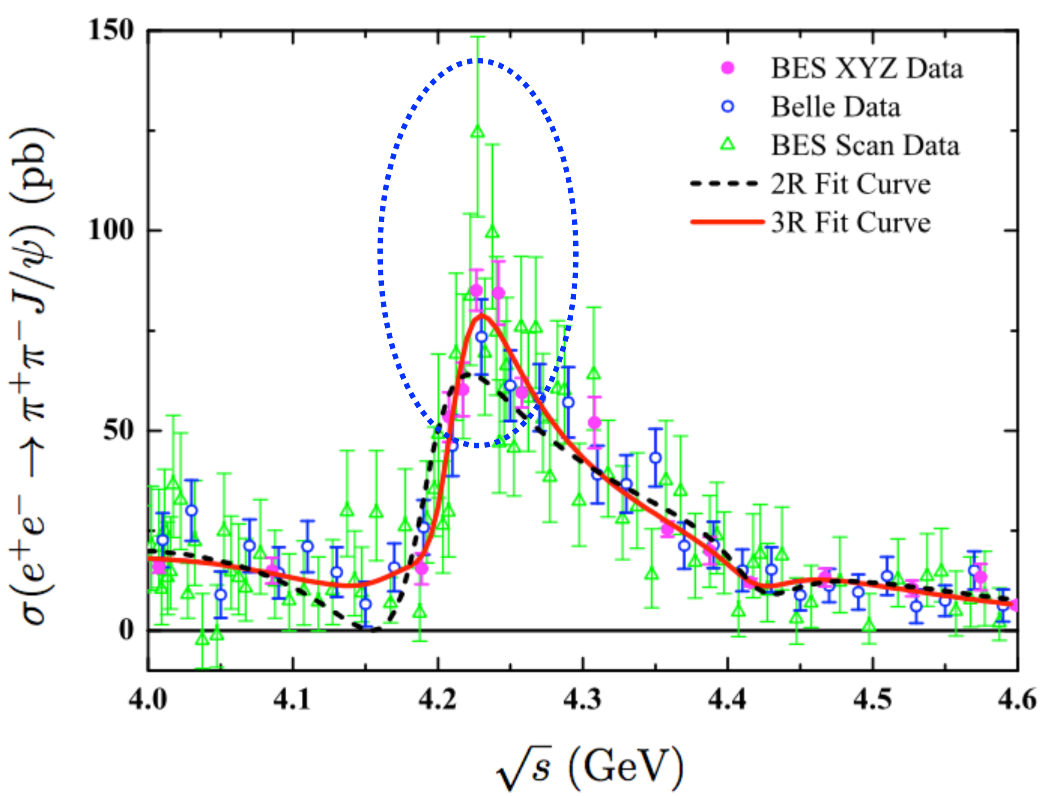
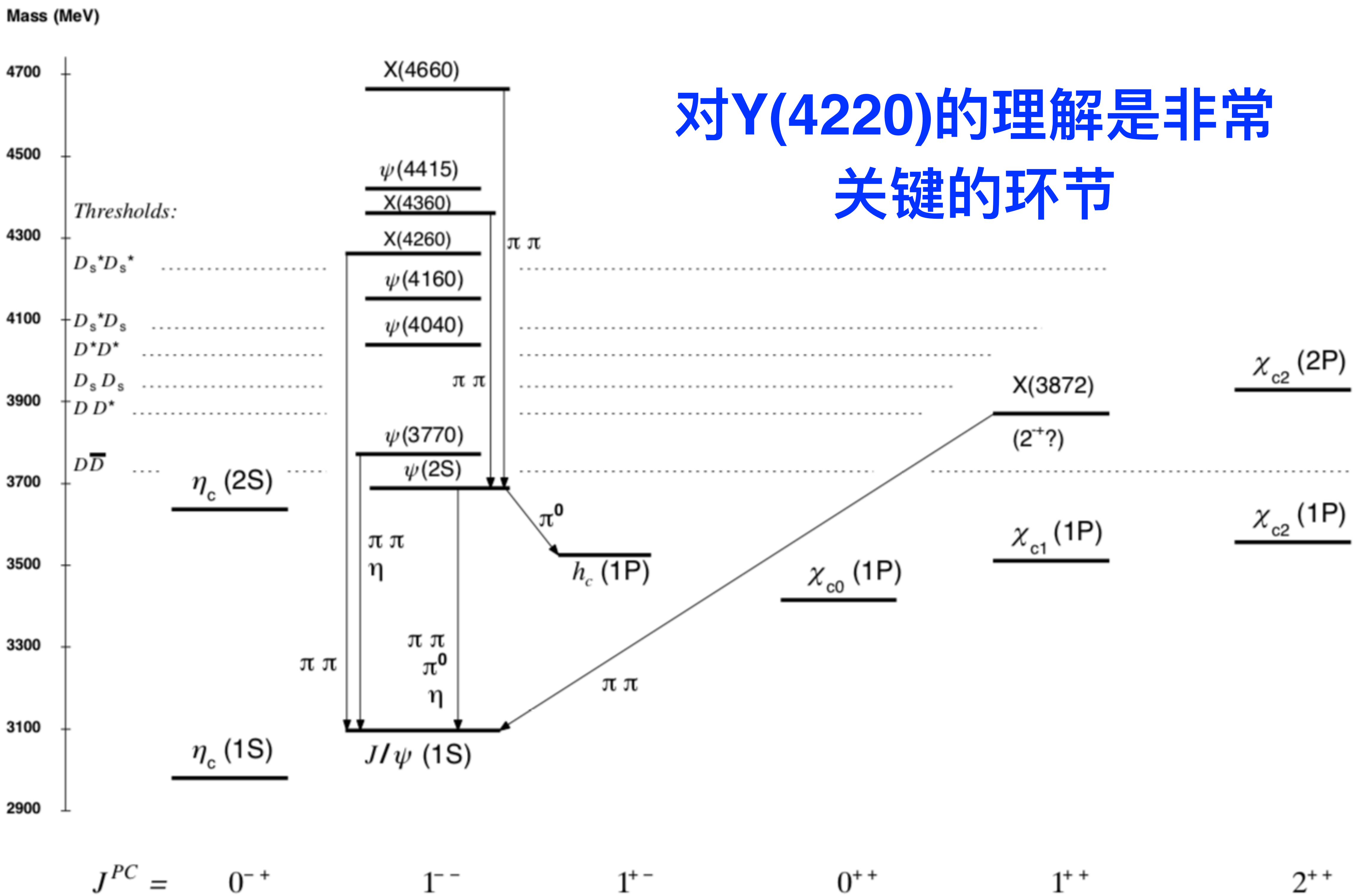


FIG. 2: (color online). Our fit to the cross sections for the $e^+e^- \to \pi^+\pi^- J/\psi$ process measured by the Belle [8] and BESIII collaborations [11] under the 2R and 3R fit schemes. Here, the BES scan data [11] are also listed for comparison.

Past	Now
Y(4008)	Y(4008) BaBar PRD86:051102
$e^+e^- \to J/\psi\pi^+\pi^-$	Y(4220)
Y(4260)	Y(4320) Inference effect
Y(4360)	Y(4390)
$e^+e^- \to \psi(3686)\pi^+\pi^-$	
Y(4660) Y(4630)	Y(4660) Y(4630)
$e^+e^- \to \Lambda_c^+\Lambda_c^-$	

对于粲偶素的理解也折射出我们对QCD的了解还是多么的贫乏



对Y(4220)的理解是非常关键的环节

PHYSICAL REVIEW D VOLUME 21, NUMBER 1 1 JANUARY 1980

Charmonium: Comparison with experiment

E. Eichten,* K. Gottfried, T. Kinoshita, K. D. Lane,* and T. M. Yan
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14853
(Received 25 June 1979)

TABLE II. $c\bar{c}$ bound states in naive model, and their properties. Parameters used are $m_c = 1.84$ GeV, $a = 2.34$ GeV^{-1}, and $\kappa = 0.52$.

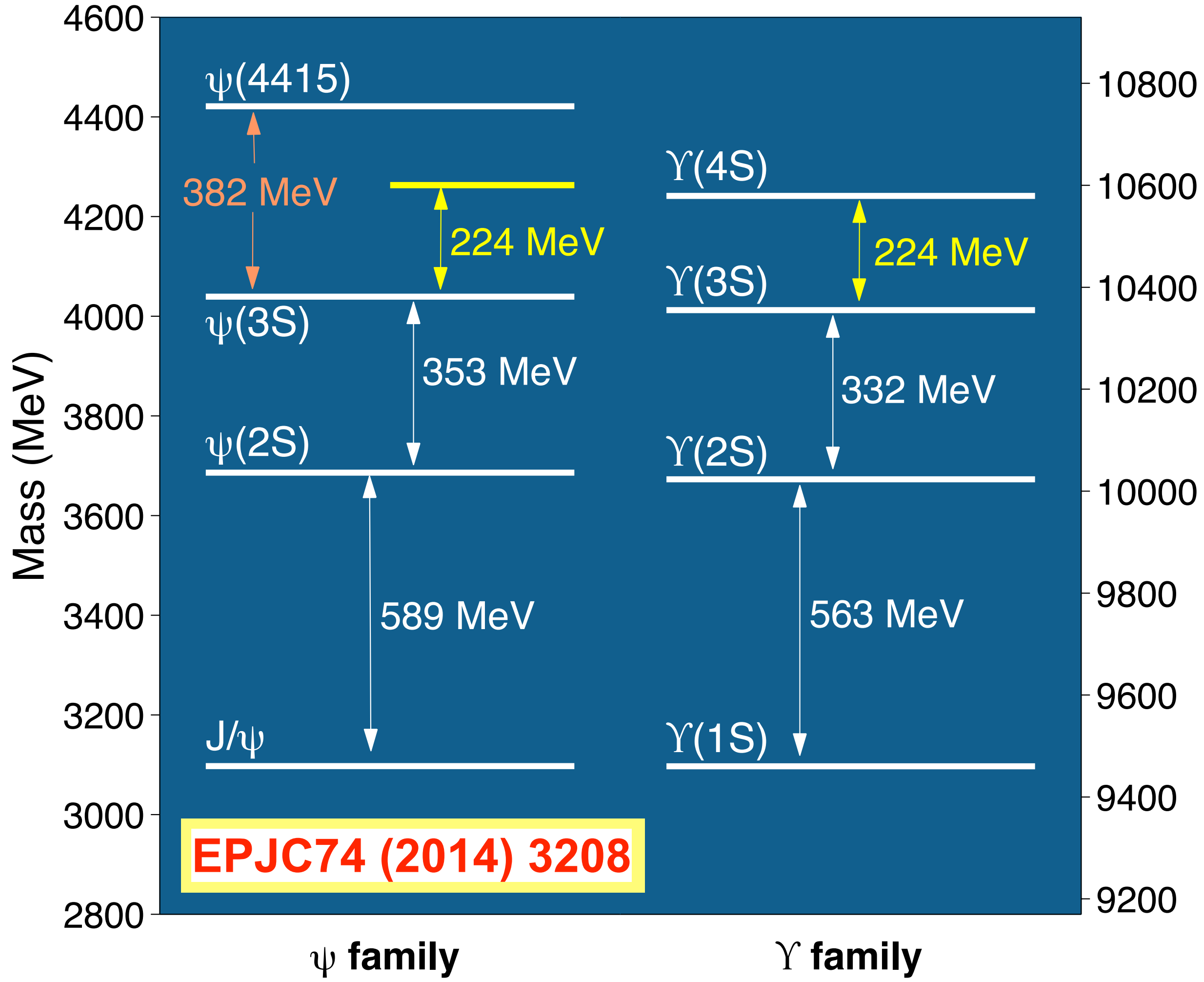
State	Mass (GeV)	Γ_{ee} (keV) [b]	$\left\langle \frac{v^2}{c^2} \right\rangle$	$\langle r^2 \rangle^{1/2}$ (fm)	Candidate
1S	3.095 [a]	4.8	0.20	0.47	$\psi(3095)$
1P	3.522 [a]		0.20	0.74	$\chi_{0,1,2}(3522 \pm 5)$
2S	3.684 [a]	2.1	0.24	0.96	$\psi'(3684)$
1D	3.81		0.23	1.0	$\psi'(3772)$ [c]
3S	4.11	1.5	0.30	1.3	$\psi(4028)$
2D	4.19		0.29	1.35	$\psi(4160)$ [d]
4S	4.46	1.1	0.35	1.7	$\psi(4414)$
5S	4.79	0.8	0.40	2.0	

$\psi(4415)$被安排为粲偶素$\psi(4S)$

这一安排对吗?

The predicted ψ(4S) and its property

The similarity between J/ψ and Υ families



The predicted mass of ψ(4S) should be located at 4263 MeV

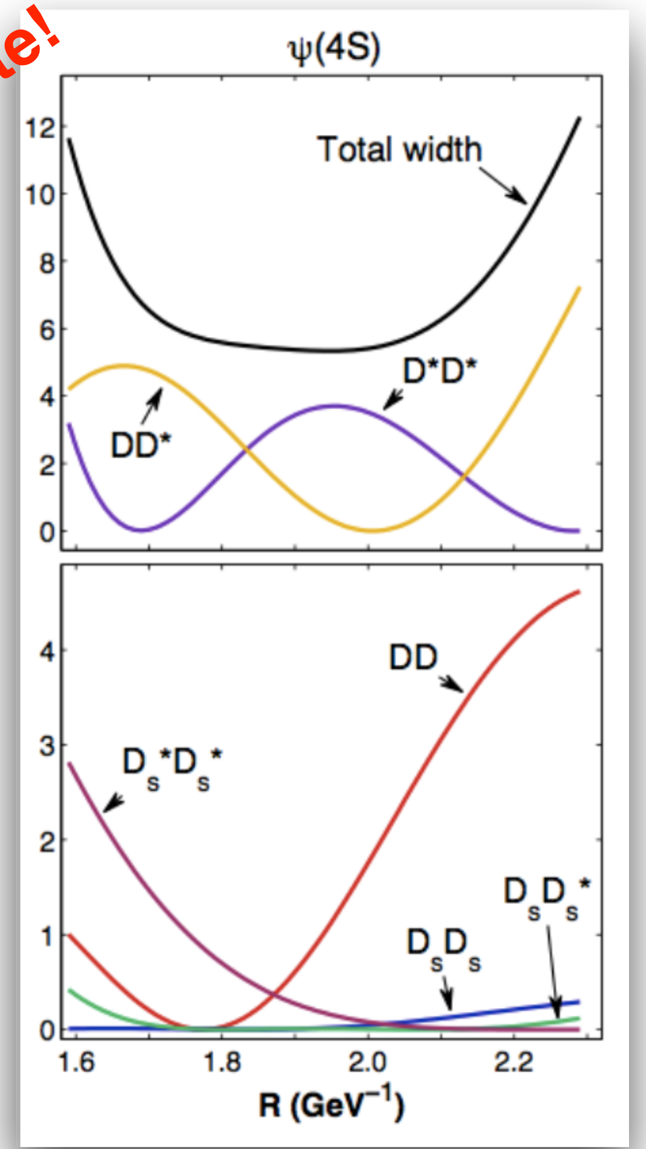
Consistent

The screening potential prediction of ψ(4*S*) mass:

- **4273 MeV Li&Chao PRD79, 094004 (2009)**
- **4247 MeV Dong et al., PRD49, 1642**

Open-charm decay behavior

A narrow state!



Due to node effect!

The predicted charmonium ψ(4*S*) has very narrow width around 6 MeV

Y(4220)= ψ(4S)?

Constructing J/ψ family with updated data of charmoniumlike Y states

Jun-Zhang Wang,[1,2,*] Dian-Yong Chen,[3,†] Xiang Liu,[1,2,‡] and Takayuki Matsuki[4,5,§]

[1]*School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China*
[2]*Research Center for Hadron and CSR Physics, Lanzhou University & Institute of Modern Physics of CAS, Lanzhou 730000, China*
[3]*School of Physics, Southeast University, Nanjing 211189, China*
[4]*Tokyo Kasei University, 1-18-1 Kaga, Itabashi, Tokyo 173-8602, Japan*
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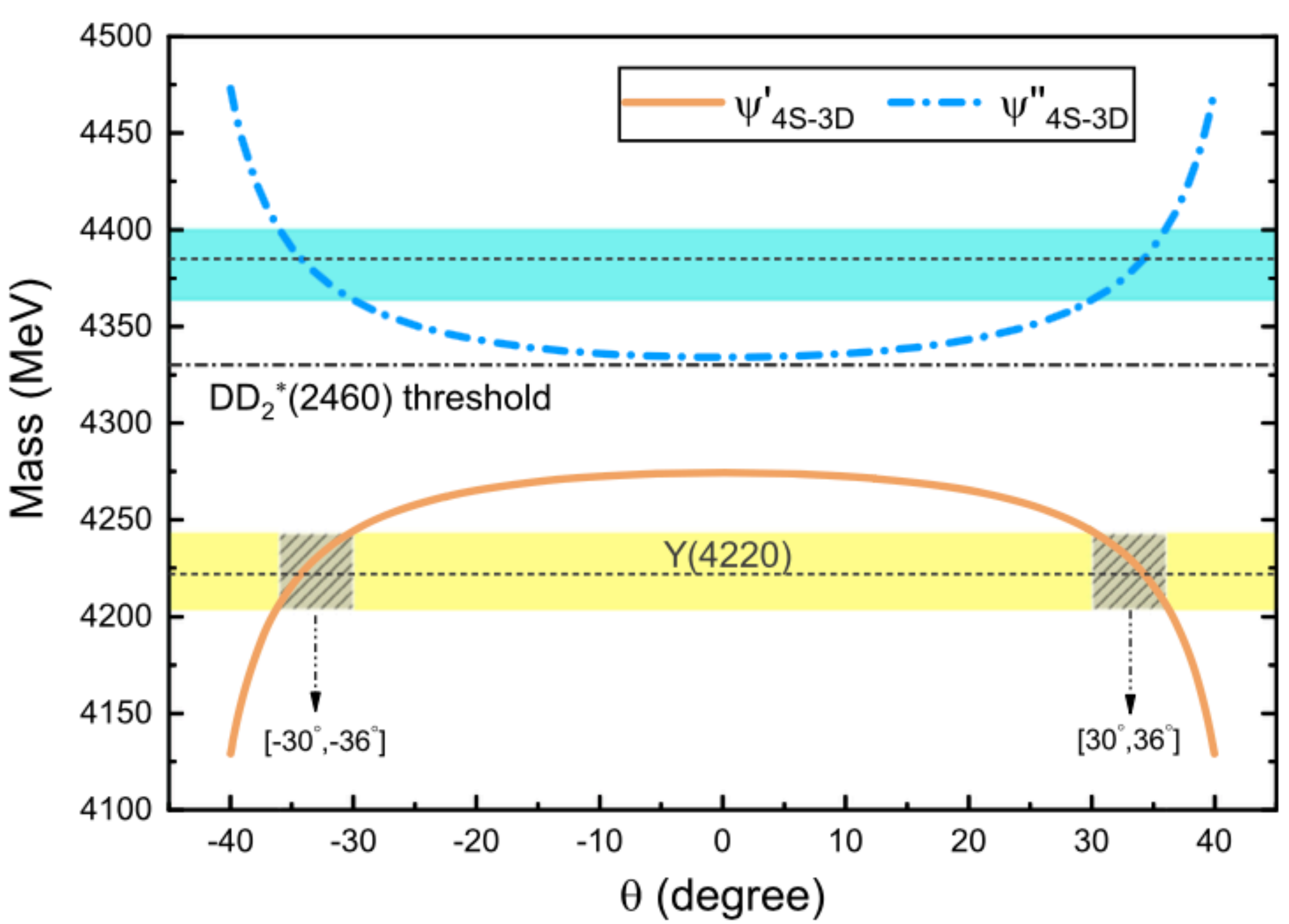
(Received 20 March 2019; published 5 June 2019)

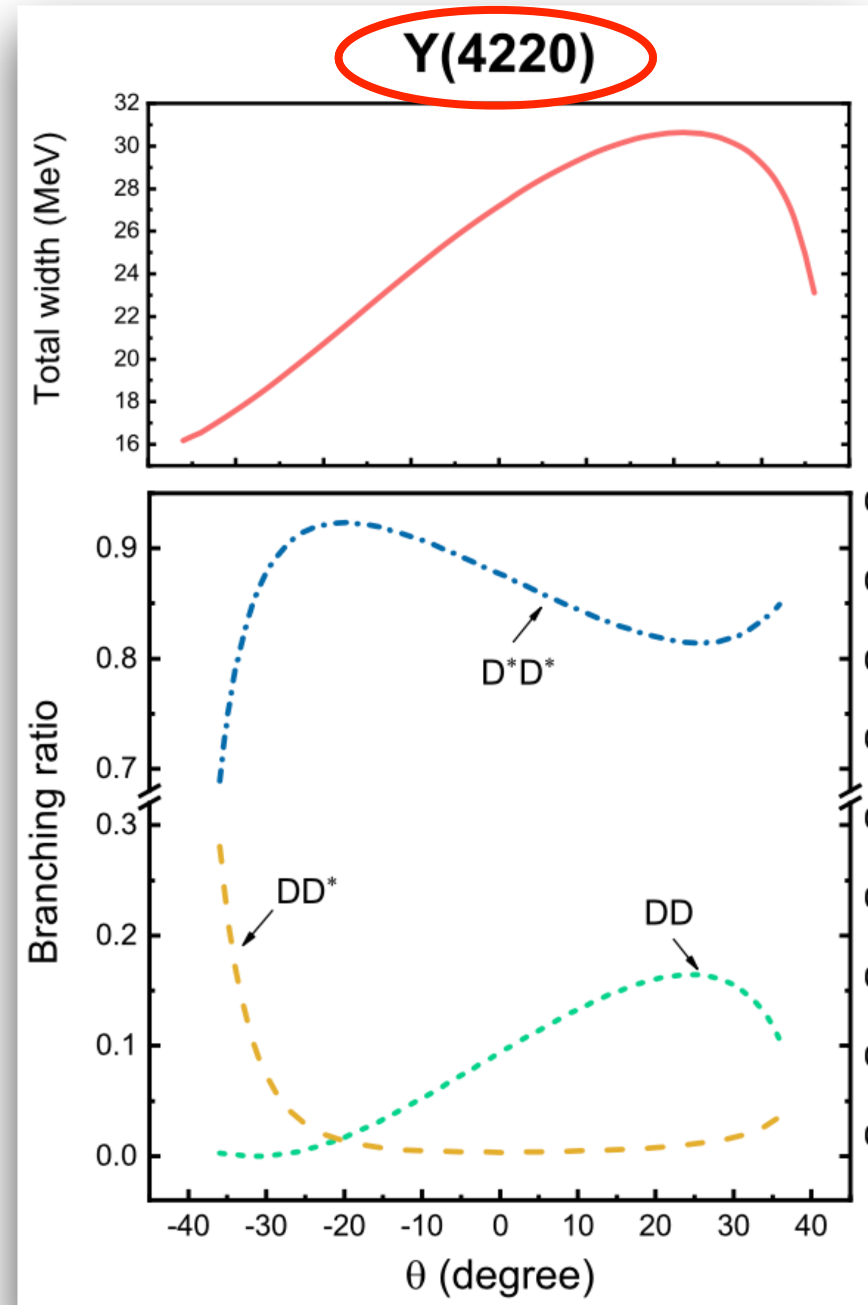
Based on the updated data of charmoniumlike state $Y(4220)$ reported in the hidden-charm channels of the e^+e^- annihilation, we propose a $4S$-$3D$ mixing scheme to categorize $Y(4220)$ into the J/ψ family. We find that the present experimental data can support this charmonium assignment to $Y(4220)$. Thus, $Y(4220)$ plays a role of a scaling point in constructing higher charmonia above 4 GeV. To further test this scenario, we provide more abundant information on the decay properties of $Y(4220)$, and predict its charmonium partner $\psi(4380)$, whose evidence is found by analyzing the $e^+e^- \to \psi(3686)\pi^+\pi^-$ data from BESIII. If $Y(4220)$ is indeed a charmonium, we must face how to settle the established charmonium $\psi(4415)$ in the J/ψ family. In this work, we may introduce a $5S$-$4D$ mixing scheme, and obtain the information of the resonance parameters and partial open-charm decay widths of $\psi(4415)$, which do not contradict the present experimental data. Additionally, we predict a charmonium partner $\psi(4500)$ of $\psi(4415)$, which can be accessible at future experiments, especially, BESIII and BelleII. The studies presented in this work provide new insights to establish the higher charmonium spectrum.

DOI: 10.1103/PhysRevD.99.114003

Introducing 4S-3D mixing scheme

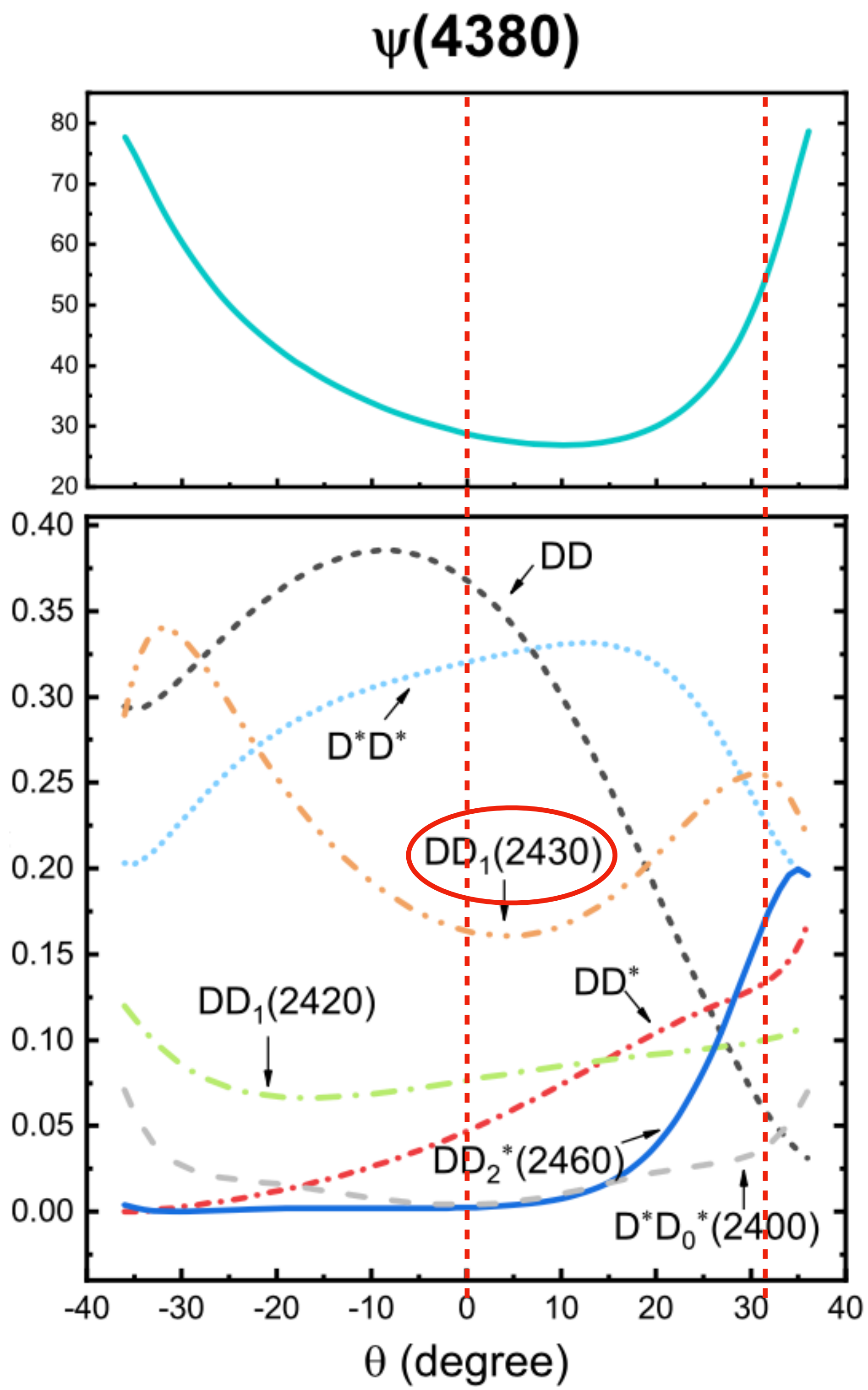
$$\begin{pmatrix} |\psi'_{4S-3D}\rangle \\ |\psi''_{4S-3D}\rangle \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} |4^3S_1\rangle \\ |3^3D_1\rangle \end{pmatrix}$$



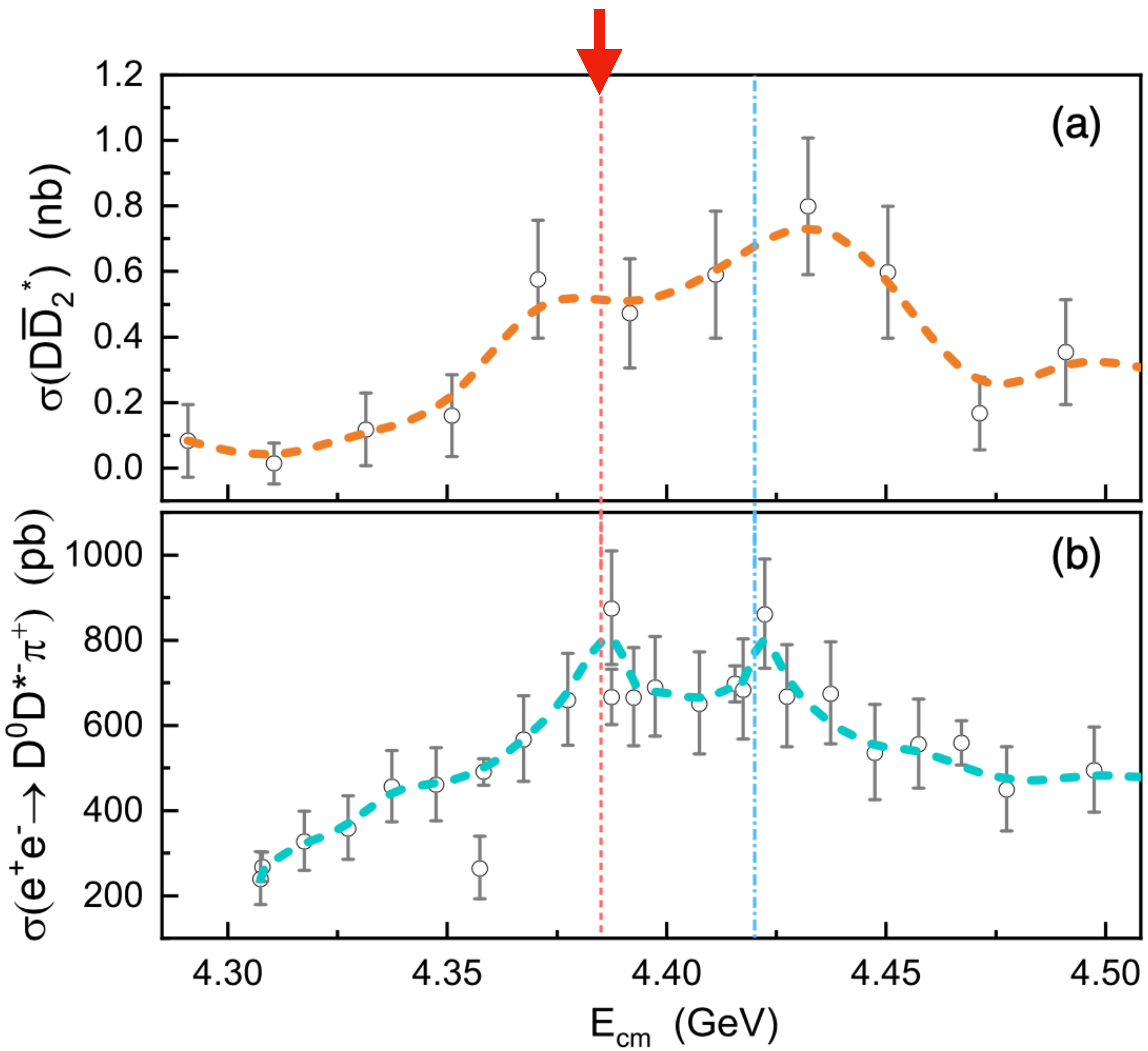


Our calculation supports this scenario

Predicting $\psi(4380)$ as the partner of $Y(4220)$

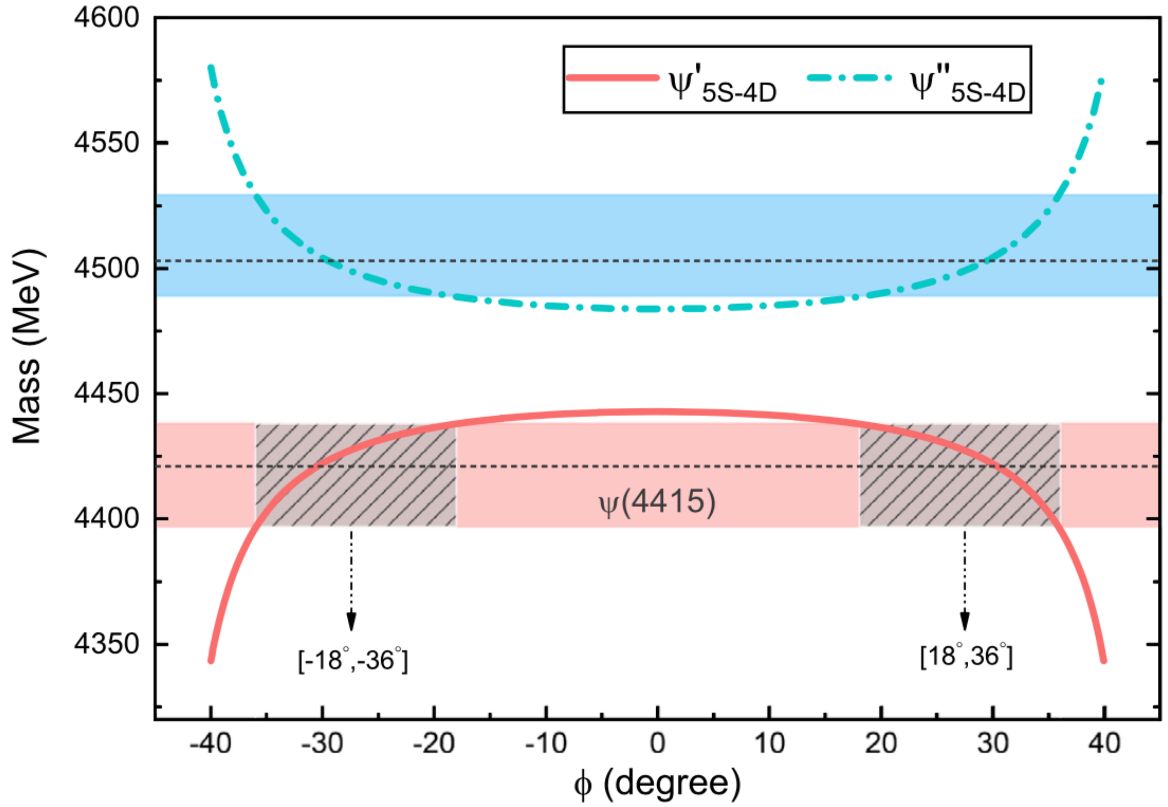


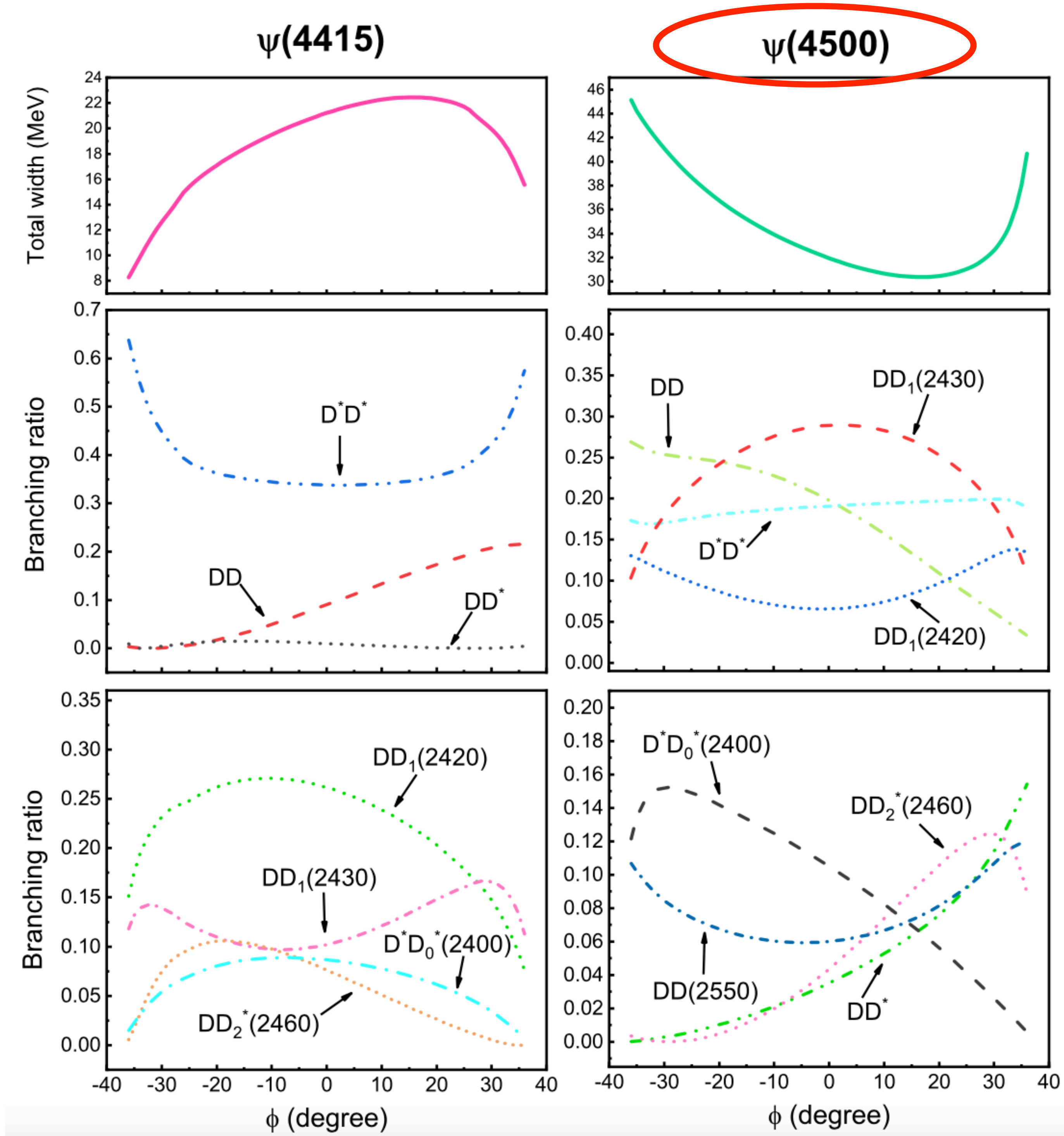
- The total width of $\psi(4380)$ has a significant enhancement
- There exists sizable enhancement of $\psi(4380) \to DD_2(2460)$



Proposing 5S-4D mixing scheme

$$\begin{pmatrix} |\psi'_{5S-4D}\rangle \\ |\psi''_{5S-4D}\rangle \end{pmatrix} = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix}\begin{pmatrix} |5^3S_1\rangle \\ |4^3D_1\rangle \end{pmatrix},$$





PHYSICAL REVIEW D **101,** 034001 (2020)

Are the Y states around 4.6 GeV from e^+e^- annihilation higher charmonia?

Jun-Zhang Wang,[1,2,†] Ri-Qing Qian,[1,2,‡] Xiang Liu,[1,2,*] and Takayuki Matsuki[3,4,§]

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In this work, we present the mass spectrum of higher charmonia around and above 4.6 GeV by adopting the unquenched potential model. We perform a combined fit to the updated experimental data of $e^+e^- \to \psi(2S)\pi^+\pi^-$ and $e^+e^- \to \Lambda_c\bar{\Lambda}_c$. To understand the “platform” structure observed in the range of 4.57–4.60 GeV existing in the $\Lambda_c\bar{\Lambda}_c$ invariant mass spectrum of $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ of BESIII, we introduce two resonances in this combined fit to $e^+e^- \to \psi(2S)\pi^+\pi^-$ and $e^+e^- \to \Lambda_c\bar{\Lambda}_c$, which have resonance parameters, $m_{Y_1} = 4585 \pm 2$ MeV, $\Gamma_{Y_1} = 29.8 \pm 8.0$ MeV, $m_{Y_2} = 4676 \pm 7$ MeV, and $\Gamma_{Y_2} = 85.7 \pm 15.0$ MeV. Furthermore, combining with our theoretical results, we indicate that the two charmoniumlike Y states can be due to two higher charmonia, which are mixtures of $6S$ and $5D$ $c\bar{c}$ states. Their two-body open-charm decay behaviors are given. Under the same framework, our analysis of the data of $e^+e^- \to D_s^+D_{s1}(2536)^-$ recently released by Belle supports the introduction of these two higher charmonia around 4.6 GeV. Additionally, we predict the masses and two-body open-charm decays of six higher charmonia $\psi(nS)$ and $\psi(mD)$ with $n = 7, 8, 9$ and $m = 6, 7, 8$ above 4.6 GeV. The search for these higher charmonia will be an interesting issue for the running BESIII and BelleII, and even the possible Super Tau-Charm Factory discussed in China.

An unquenched calculation of mass spectrum of charmonium

TABLE I: The charmonium mass spectrum with different μ values. Here, we take μ = 0.11, 0.12, 0.13, 0.14, 0.15 to show our results. The results in Ref. [15] are also presented for comparison. All results are in units of MeV.

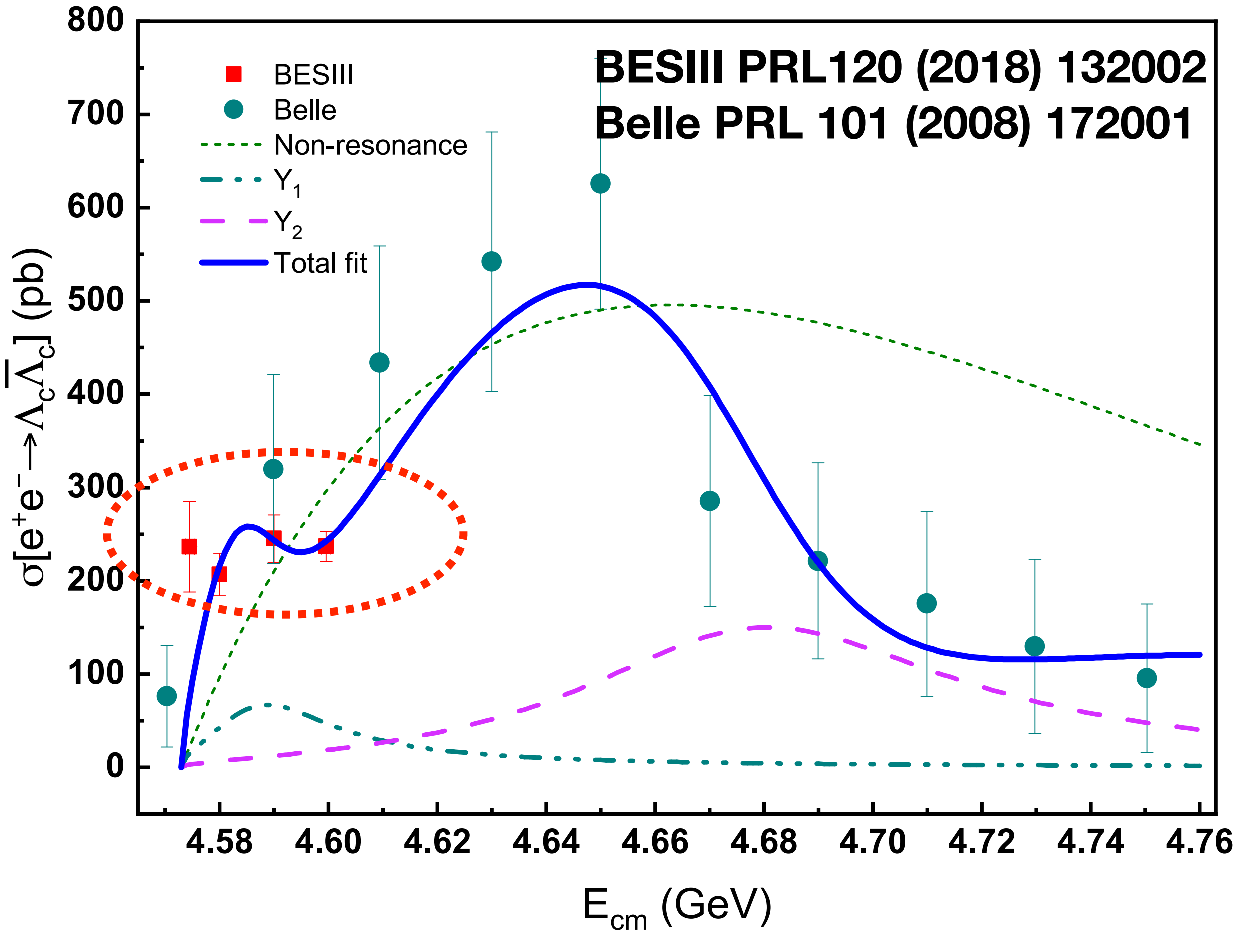
	μ=0.11	μ=0.12	μ=0.13	μ=0.14	μ=0.15	Ref. [15]	Expt. [32]
$\eta_c(1^1S_0)$	2984	2984	2984	2984	2984	2981	2983.9 ± 0.5
$\psi(1^3S_1)$	3096	3096	3096	3097	3098	3096	3096.9 ± 0.5
$\chi_{c0}(1^3P_0)$	3449	3452	3455	3457	3462	3464	3414.71 ± 0.30
$\chi_{c1}(1^3P_1)$	3515	3517	3520	3523	3528	3530	3510.67 ± 0.05
$h_{c1}(1^1P_1)$	3523	3526	3528	3531	3536	3538	3525.38 ± 0.11
$\chi_{c2}(1^3P_2)$	3555	3557	3560	3563	3568	3571	3556.17 ± 0.07
$\eta_c(2^1S_0)$	3626	3669	3631	3634	3638	3642	3637.6 ± 1.2
$\psi(2^3S_1)$	3667	3669	3672	3674	3679	3683	3686.097 ± 0.006
$\psi(1^3D_1)$	3808	3811	3818	3818	3824	3830	3778.1 ± 1.2
$\psi_2(1^3D_2)$	3827	3830	3833	3836	3842	3848	3822.2 ± 1.2
$\psi_3(1^3D_3)$	3838	3841	3844	3847	3853	3859	$3842.71 \pm 0.16 \pm 0.12$ [33]
$\chi_{c2}(1^3P_2)$	3937	3938	3939	3940	3944	3952	3927.2 ± 2.6
$\psi(3^3S_1)$	4026	4025	4025	4024	4027	4035	4039 ± 1
$\psi(2^3D_1)$	4115	4114	4113	4112	4115	4125	4159 ± 20
$\psi(4^3S_1)$	4286	4279	4272	4264	4262	4274	4230 ± 8
$\psi(3^3D_1)$	4348	4340	4333	4324	4321	4334	···
$\psi(5^3S_1)$	4484	4470	4454	4437	4428	4443	4421 ± 4
$\psi(4^3D_1)$	4530	4514	4497	4479	4468	4484	···
$\psi(6^3S_1)$	4640	4615	4589	4562	4542	···	···
$\psi(5^3D_1)$	4674	4648	4620	4591	4570	···	···
$\psi(7^3S_1)$	4762	4726	4688	4649	4618		
$\psi(6^3D_1)$	4788	4750	4711	4669	4636		
χ^2/n	30.1	25.2	21.8	24.4	22.0		

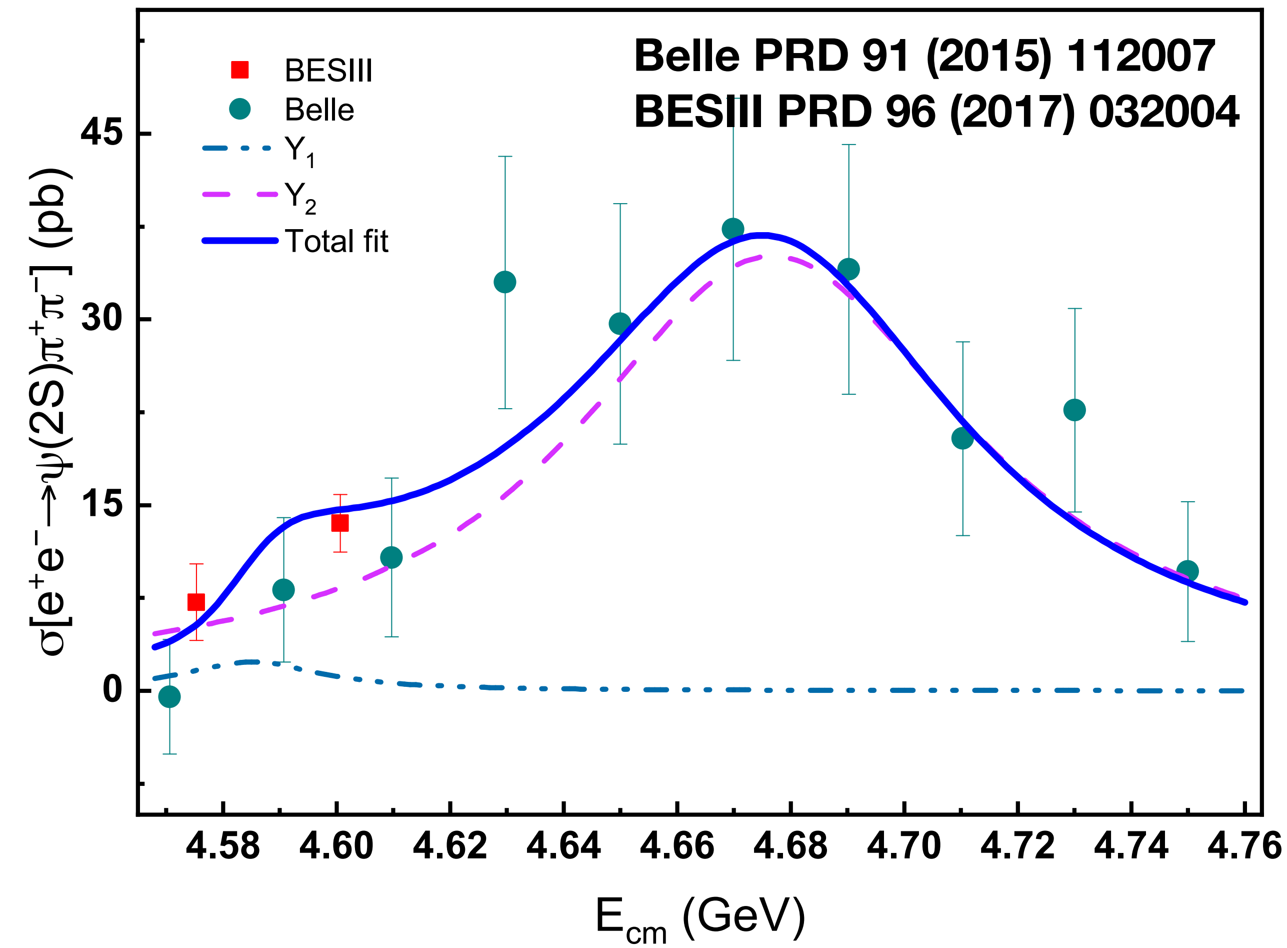
The screened confining potential

$$S(r) = \frac{b(1 - e^{-\mu r})}{\mu} + c$$

Hints from experimental data

Wang, Qian, X. Liu, Matsuki, Phys.Rev.D101(2020) 034001





Two structures?

$$\mathcal{M}^{\text{Total}}_{\psi(2S)\pi^+\pi^-} = \mathcal{M}_R(Y_1) + e^{i\theta}\mathcal{M}_R(Y_2),$$
$$\mathcal{M}^{\text{Total}}_{\Lambda_c\bar{\Lambda}_c} = \mathcal{M}_{NoR} + e^{i\phi_1}\mathcal{M}'_R(Y_1) + e^{i\phi_2}\mathcal{M}'_R(Y_2),$$

In our scheme, the resonance parameters of two charmoniumlike structures Y_1 and Y_2 are fitted to be

$$m_{Y_1} = 4585 \pm 2\,\text{MeV}, \qquad \Gamma_{Y_1} = 29.8 \pm 8.0\,\text{MeV},$$
$$m_{Y_2} = 4676 \pm 7\,\text{MeV}, \qquad \Gamma_{Y_2} = 85.7 \pm 15.0\,\text{MeV}, \quad (18)$$

6S and 5D mixing scheme for these Y states around 4.6 GeV

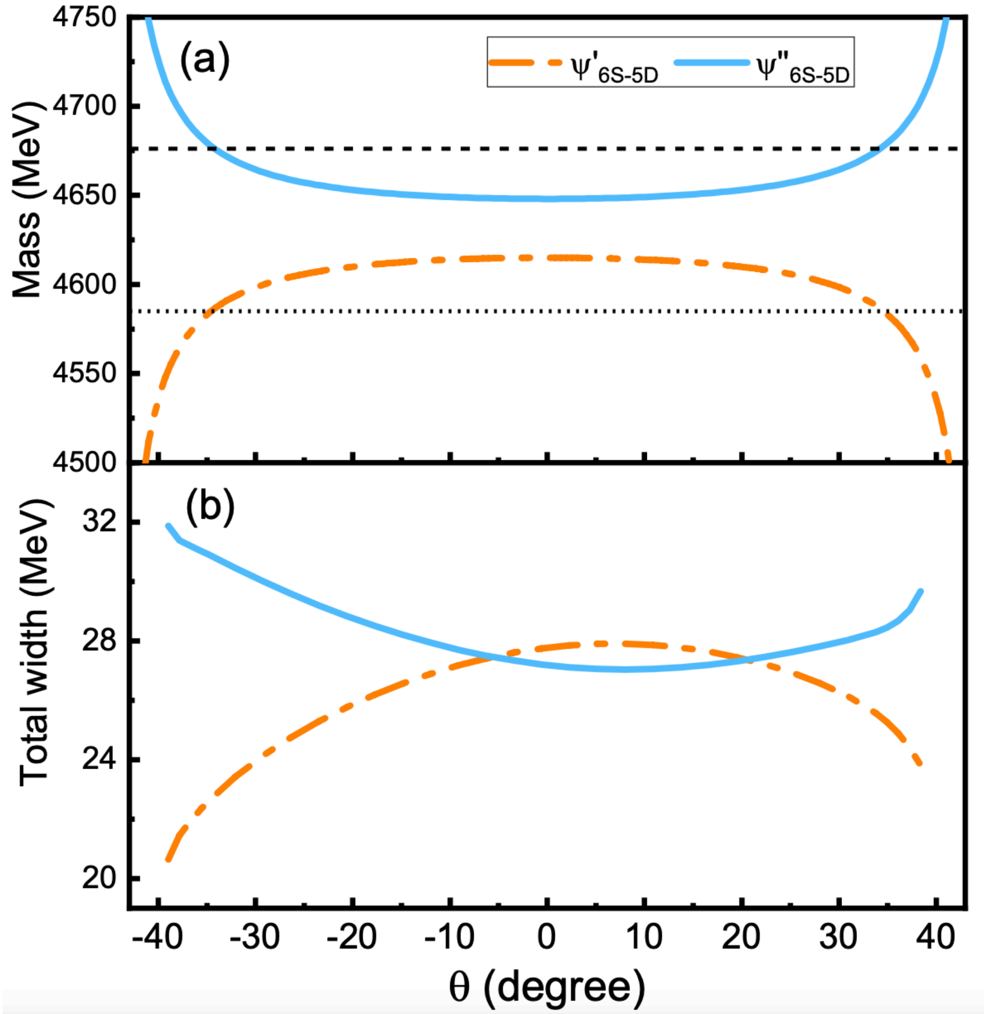
we introduce

$$\begin{pmatrix} |\psi'_{6S-5D}\rangle \\ |\psi''_{6S-5D}\rangle \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} |6^3S_1\rangle \\ |5^3D_1\rangle \end{pmatrix}. \quad (19)$$

Here, θ denotes the mixing angle, and the mass eigenvalues of ψ'_{6S-5D} and ψ''_{6S-5D} are determined by the masses of two basis vectors m_{6S}, m_{5D}, and the mixing angle θ, i.e.,

$$m^2_{\psi'_{6S-5D}} = \frac{1}{2}\left(m^2_{6S} + m^2_{5D} - \sqrt{(m^2_{5D} - m^2_{6S})^2 \sec^2 2\theta}\right), \quad (20)$$

$$m^2_{\psi''_{6S-5D}} = \frac{1}{2}\left(m^2_{6S} + m^2_{5D} + \sqrt{(m^2_{5D} - m^2_{6S})^2 \sec^2 2\theta}\right), \quad (21)$$



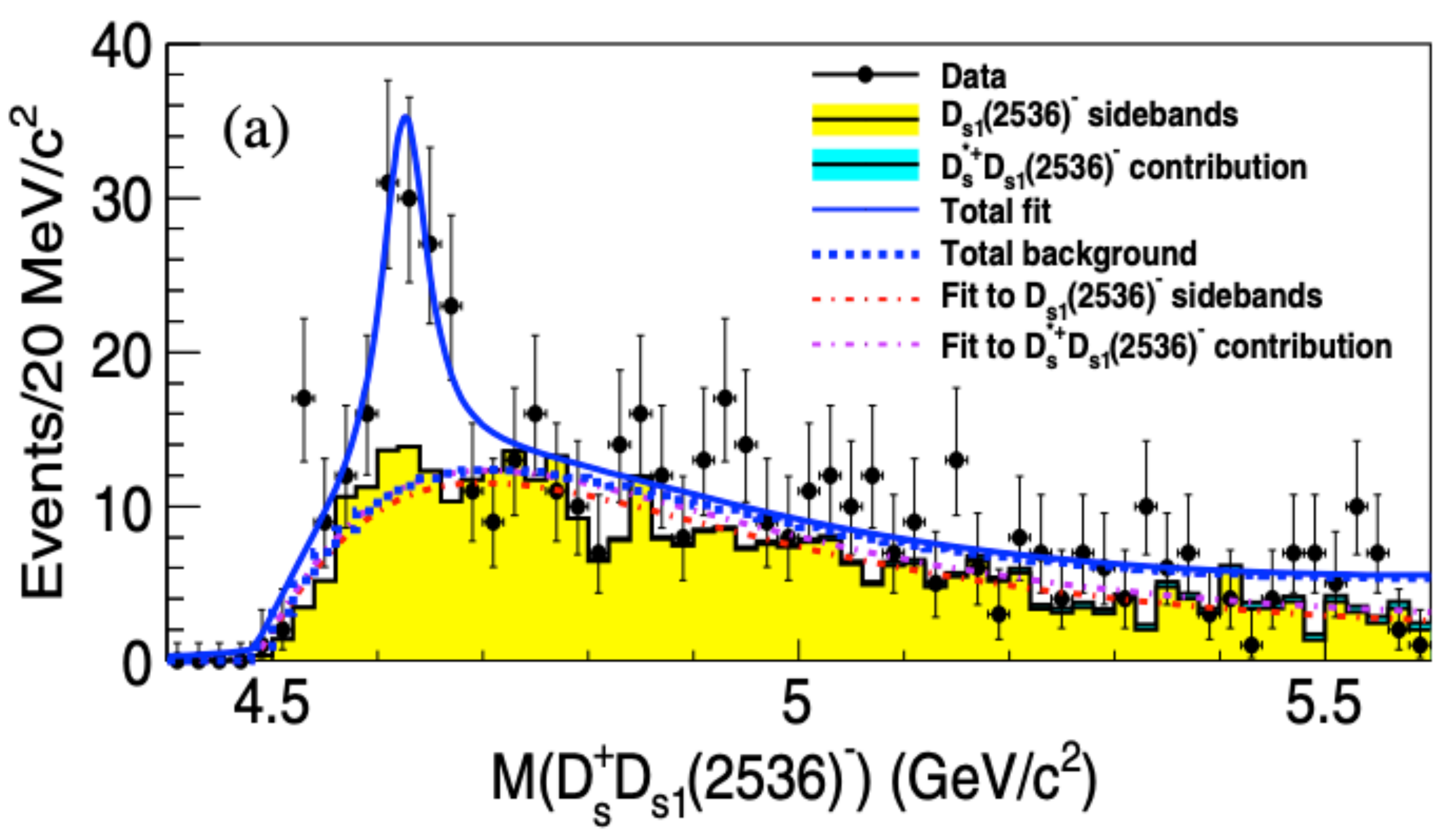
	$\theta = -34^\circ(34^\circ)$		Fit	
	M(MeV)	Γ(MeV)	M(MeV)	Γ(MeV)
ψ'_{6S-5D}	4587(4587)	23(25)	4585±2	29.8±8
ψ''_{6S-5D}	4675(4675)	31(28)	4676±7	85.7±15

PHYSICAL REVIEW D **100**, 111103(R) (2019)

Rapid Communications

Observation of a vector charmoniumlike state in $e^+e^- \to D_s^+ D_{s1}(2536)^- + \text{c.c.}$

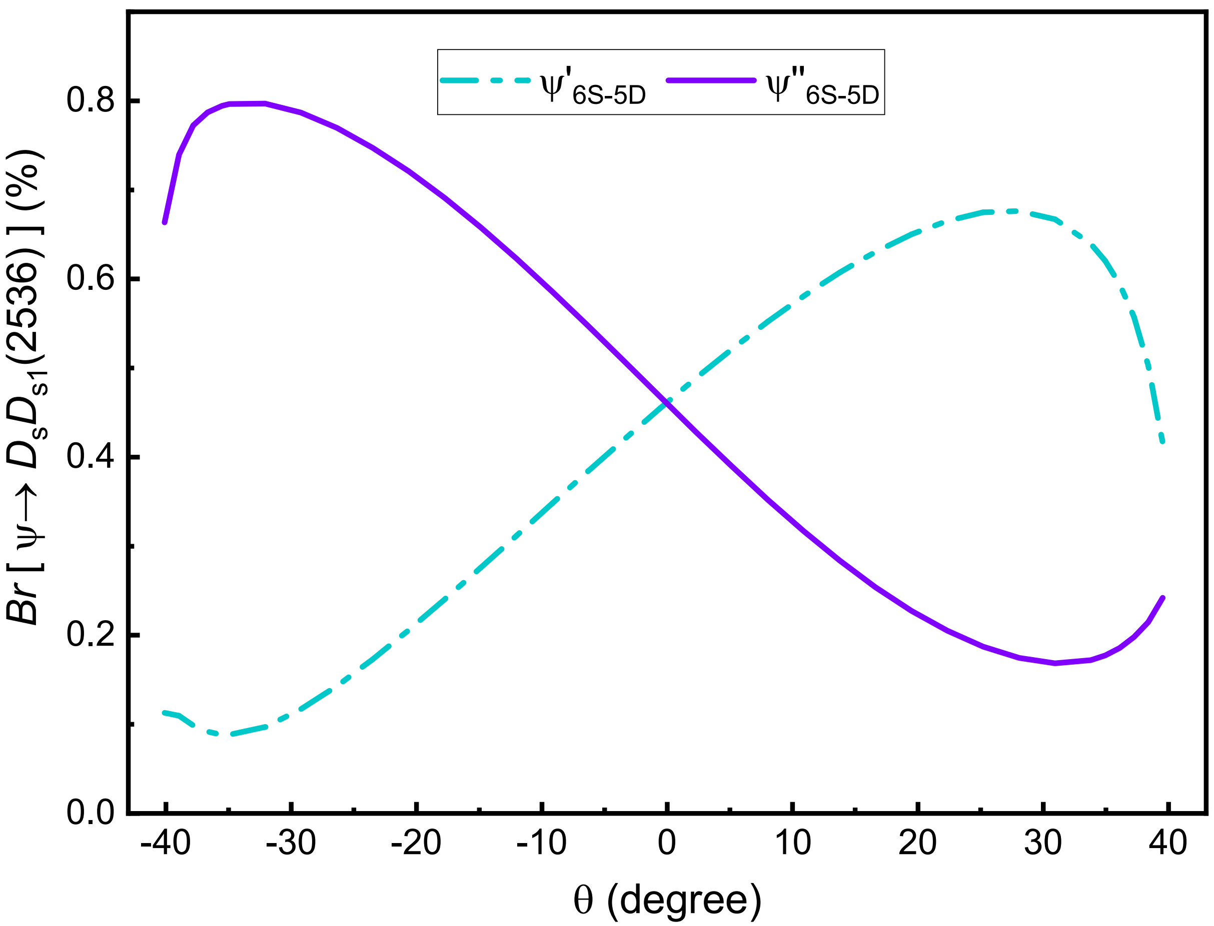
Using a data sample of 921.9 fb^{-1} collected with the Belle detector, we study the process of $e^+e^- \to D_s^+ D_{s1}(2536)^- + \text{c.c.}$ via initial-state radiation. We report the first observation of a vector charmoniumlike state decaying to $D_s^+ D_{s1}(2536)^- + \text{c.c.}$ with a significance of 5.9σ, including systematic uncertainties. The measured mass and width are $(4625.9^{+6.2}_{-6.0}(\text{stat}) \pm 0.4(\text{syst}))\ \text{MeV}/c^2$ and $(49.8^{+13.9}_{-11.5}(\text{stat}) \pm 4.0(\text{syst}))\ \text{MeV}$, respectively. The product of the $e^+e^- \to D_s^+ D_{s1}(2536)^- + \text{c.c.}$ cross section and the branching fraction of $D_{s1}(2536)^- \to \bar{D}^{*0} K^-$ is measured from the $D_s \bar{D}_{s1}(2536)$ threshold to 5.59 GeV.

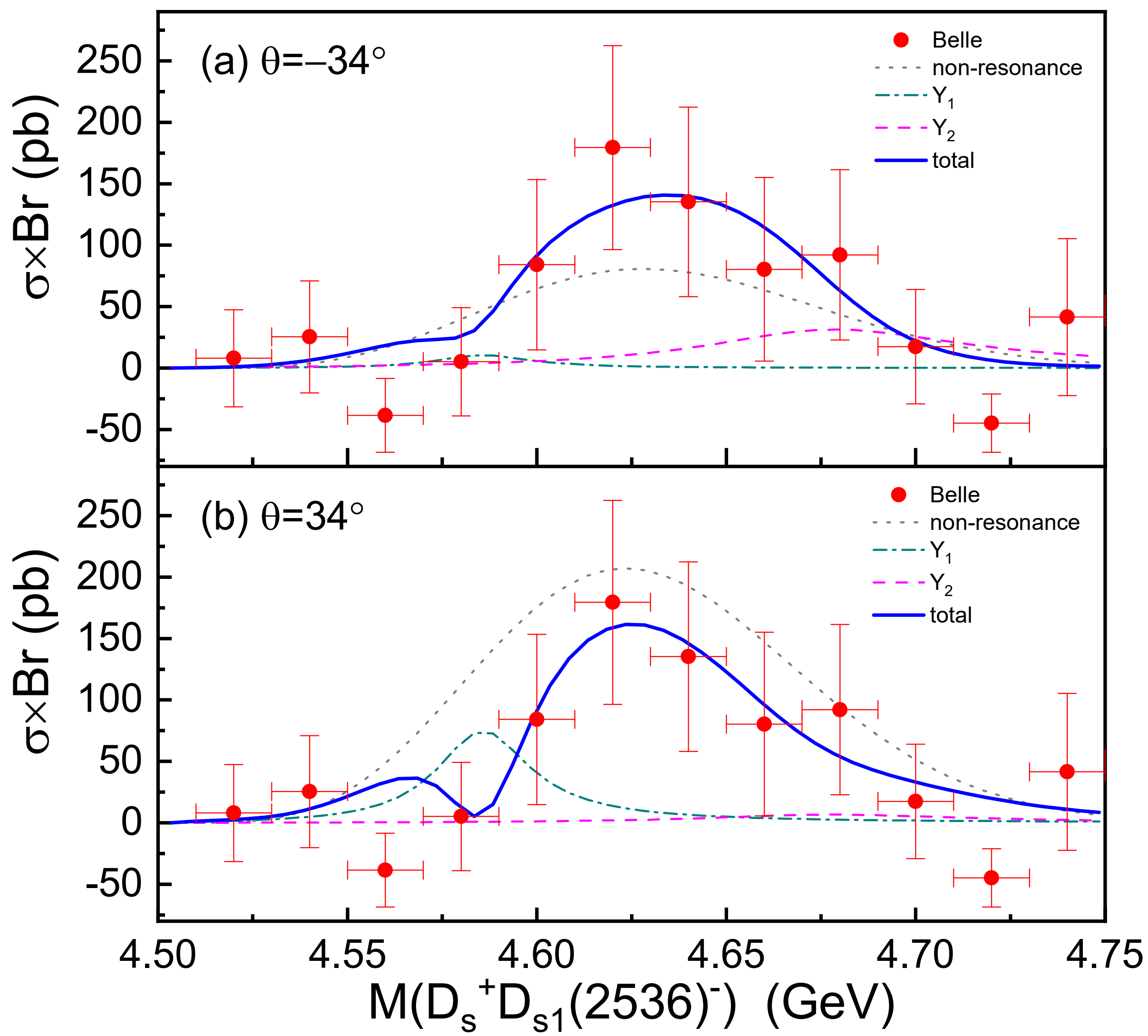


We can depict the Belle data in our framework

Wang, Qian, X. Liu, Matsuki, Phys.Rev.D101(2020) 034001

$$e^+e^- \to D_s^+ D_{s1}(2536)^-$$





Predicting the open-charm decays of vector charmonia around and above 4.6 GeV

Wang, Qian, X. Liu, Matsuki, Phys.Rev.D101(2020) 034001

	$\psi(6S)$	$\psi(7S)$	$\psi(8S)$	$\psi(9S)$	$\psi(5D)$	$\psi(6D)$	$\psi(7D)$	$\psi(8D)$
Mass	4615	4726	4808	4867	4648	4750	4826	4880
Total width	28.50	27.60	23.11	17.07	27.35	19.77	14.71	10.19
Channel								
DD	1.49	1.13	0.81	0.55	4.33	2.98	2.04	1.31
DD^*	0.40	0.49	0.45	0.35	0.76	0.58	0.44	0.28
D^*D^*	3.06	1.29	0.60	0.29	4.22	3.17	2.32	1.52
$DD_0^*(2400)$	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
$DD_1(2420)$	7.09	5.41	3.80	2.51	2.04	1.09	0.62	0.36
$DD_1(2430)$	1.85	0.92	0.53	0.32	2.76	1.04	0.50	0.29
$DD_2^*(2460)$	2.23	1.10	0.51	0.23	0.53	0.14	0.03	0.01
$D^*D_0^*(2400)$	5.89	5.27	3.94	2.69	1.66	1.01	0.63	0.38
$DD(2550)$	1.33	0.42	0.10	0.02	1.18	0.11	10^{-3}	0.02
$DD^*(2600)$	1.44	2.05	1.29	0.69	1.75	1.03	0.49	0.23
$D^*D_1(2420)$	1.14	3.34	3.60	2.92	1.72	2.01	1.66	1.18
$D^*D_1(2430)$	1.09	2.19	1.90	1.32	3.82	3.33	2.19	1.31
$D^*D_2^*(2460)$	0.02	2.01	2.70	2.23	1.50	1.35	0.86	0.50
$D^*D(2550)$	0.05	0.58	0.89	0.70	0.22	0.78	0.62	0.38
$D^*D^*(2600)$	⋯	0.02	0.44	0.95	0.08	0.36	0.88	0.74
$DD(^3D_1)$	⋯	10^{-5}	0.02	0.03	10^{-4}	0.02	0.06	0.06
$DD(^1D_2)$	⋯	10^{-3}	0.03	0.07	0.01	0.04	0.34	0.38
$DD(^3D_2)$	⋯	10^{-3}	0.02	0.06	10^{-3}	0.01	0.09	0.11
$DD^*(2760)$	⋯	10^{-3}	0.05	0.08	10^{-3}	0.02	0.06	0.05
$D_0^*(2400)D_0^*(2400)$	⋯	10^{-6}	0.01	0.02	10^{-3}	0.03	0.11	0.13
$DD(2^3P_0)$	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
$DD(2^1P_1)$	⋯	10^{-4}	0.02	0.09	⋯	0.03	0.22	0.45
$DD(2^3P_1)$	⋯	⋯	0.04	0.11	⋯	0.01	0.06	0.14
$DD(2^3P_2)$	⋯	⋯	10^{-4}	10^{-3}	⋯	⋯	10^{-3}	0.02
D_sD_s	10^{-3}	10^{-3}	10^{-3}	10^{-3}	0.01	0.01	0.01	0.01
$D_sD_s^*$	0.12	0.06	0.03	0.01	0.07	0.04	0.02	0.01
$D_s^*D_s^*$	0.31	0.22	0.14	0.09	0.09	0.05	0.03	0.02
$D_sD_{s0}^*(2317)$	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
$D_s^*D_{s0}^*(2317)$	0.8	0.77	0.84	0.41	0.23	0.15	0.09	0.06
$D_sD_{s1}(2460)$	0.01	0.03	0.03	0.02	0.21	0.18	0.13	0.08
$D_s^*D_{s1}(2460)$	0.01	0.01	0.01	0.05	10^{-3}	0.01	0.02	0.02
$D_sD_{s2}^*(2573)$	10^{-4}	10^{-3}	0.01	0.01	10^{-3}	0.01	0.01	0.01
$D_s^*D_{s2}^*(2573)$	⋯	10^{-5}	10^{-4}	10^{-6}	⋯	10^{-4}	10^{-4}	10^{-3}
$D_sD_{s1}(2536)$	0.17	0.23	0.21	0.16	0.16	0.13	0.10	0.06
$D_s^*D_{s1}(2536)$	⋯	0.06	0.08	0.07	10^{-4}	0.01	0.02	0.02

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018)

$\psi(4160)$

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

$\psi(4160)$ MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
4191 ± 5 OUR AVERAGE				
4191^{+9}_{-8}	AAIJ	13BC	LHCB	$B^+ \to K^+ \mu^+ \mu^-$
4191.7 ± 6.5	[1] ABLIKIM	08D	BES2	$e^+ e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4193 ± 7	[2] MO	10	RVUE	$e^+ e^- \to$ hadrons
4151 ± 4	[3] SETH	05A	RVUE	$e^+ e^- \to$ hadrons
4155 ± 5	[4] SETH	05A	RVUE	$e^+ e^- \to$ hadrons
4159 ± 20	BRANDELIK	78C	DASP	$e^+ e^-$

$\psi(4415)$

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

$\psi(4415)$ MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
4421 ± 4 OUR ESTIMATE				
4415.1± 7.9	[1] ABLIKIM	08D	BES2	$e^+e^- \rightarrow$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
4412 ±15	[2] MO	10	RVUE	$e^+e^- \rightarrow$ hadrons

$\psi(4415)$ WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
62 ±20 OUR ESTIMATE				
71.5±19.0	[6] ABLIKIM	08D	BES2	$e^+e^- \rightarrow$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •				
118 ±32	[7] MO	10	RVUE	$e^+e^- \rightarrow$ hadrons
77 ±20	[8] PAKHLOVA	08A	BELL	10.6 $e^+e^- \rightarrow D^0 D^- \pi^+ \gamma$
119 ±16	[9] SETH	05A	RVUE	$e^+e^- \rightarrow$ hadrons
118 ±35	[10] SETH	05A	RVUE	$e^+e^- \rightarrow$ hadrons
66 ±15	BRANDELIK	78C	DASP	e^+e^-
33 ±10	SIEGRIST	76	MRK1	e^+e^-

Summary

Possible topics accessible at BEPCIII

- Searching for Z_{cs} via $J/\psi K\bar{K}$ channel

  Measuring $J/\psi\pi^+$ and $h_c(1P)\pi^+$ invariant mass

  spectrum at different energy points

- Finding Z_c and Z_{cs} structures via open-charm channels

- Establishing higher charmonia

Thank you for your attention!