Three perspectives on decoding charmonium-like states

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Outline

- **An overview of experimental status**
- **Theory**
- **Selected topics**

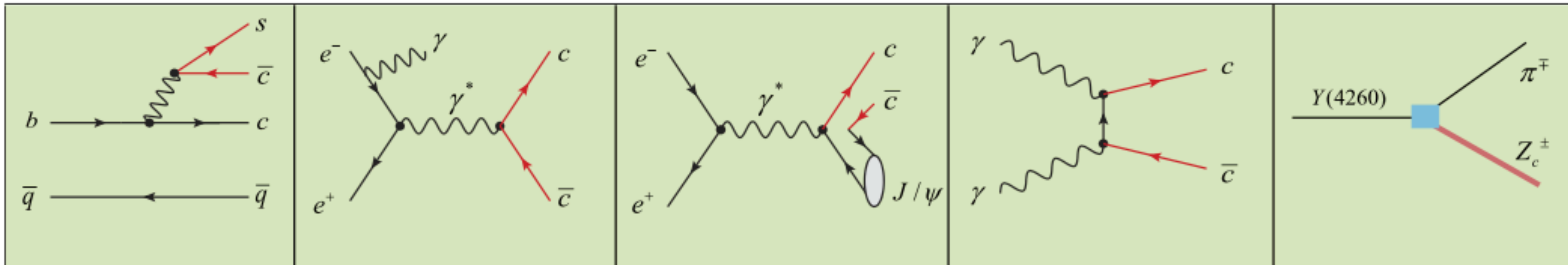
1. **What can we learn from X(3872)**
2. **From Y(4260) to Y(4220) narrow structure**
3. **Charged Zc states**

- **Summary**

An overview of experimental status

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

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The hidden-charm pentaquark and tetraquark states

CrossMark

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CESR CLEO · BABAR · BELLE · BESIII · CDF · DØ · LHCb · CMS

Abundant discovery modes—hidden-charm and open-charm decay channels

States	Status	Mass [MeV]	Width [MeV]	$I^G J^{PC}/IJ^P$	Observation	Note
$X(3872)$	$*\,*\,*\,*$	3871.69 ± 0.17 [1]	<1.2 [1]	0^+1^{++}	$B \to KX(3872) \to J/\psi\rho^0, J/\psi\pi^+\pi^-$	Belle [63], BaBar [84]
					$B \to KX(3872) \to J/\psi\omega(\to \pi^+\pi^-\pi^0)$	Belle [75], BaBar [90]
					$B \to KX(3872) \to D^0\bar{D}^{*0}, D^0\bar{D}^0\pi^0$	Belle [76], BaBar [87]
					$B \to KX(3872) \to \gamma J/\psi, \gamma\psi(3686)$	Belle [75], BaBar [86]
					$p\bar{p} \to \cdots + X(3872)(\to J/\psi\pi^+\pi^-)$	CDF [67], D0 [68]
					$pp \to \cdots + X(3872) \to J/\psi\pi^+\pi^-$	LHCb [91], CMS [73]
					$pp \to \cdots + X(3872) \to \gamma J/\psi, \gamma\psi(3686)$	LHCb [92]
					$e^+e^-[\to Y(4260)] \to \gamma X(3872)(\to J/\psi\pi^+\pi^-)$	BESIII [93]
$Y(4260)$	$*\,*\,*\,*$	4251 ± 9 [1]	120 ± 12 [1]	0^-1^{--}	$e^+e^- \to \gamma_{\rm ISR}Y(4260) \to J/\psi\pi^+\pi^-$	BaBar [62], CLEO [60], Belle [119]
					$e^+e^- \to \gamma_{\rm ISR}Y(4260) \to J/\psi f_0(980)$	BaBar [123]
					$e^+e^- \to \gamma_{\rm ISR}Y(4260) \to J/\psi\pi^0\pi^0$	CLEO [120]
					$e^+e^- \to Y(4260) \to \pi^- Z_c(3900)^+(\to J/\psi\pi^+)$	BESIII [64], Belle [124]
					$e^+e^- \to Y(4260) \to \pi^- Z_c(3885)^+(\to (D\bar{D}^*)^+)$	BESIII [159]
					$e^+e^- \to Y(4260) \to \pi^- Z_c(4020)^+(\to h_c\pi^+)$	BESIII [160]
					$e^+e^- \to Y(4260) \to \pi^- Z_c(4025)^+(\to (D^*\bar{D}^*)^+)$	BESIII [161]
					$e^+e^-[\to Y(4260)] \to \gamma X(3872)(\to J/\psi\pi^+\pi^-)$	BESIII [93]

States	Status	Mass [MeV]	Width [MeV]	$I^G J^{PC}/IJ^P$	Observation	Note
$Y(3940)$	$*\,*\,*$	$3919.1^{+3.8}_{-3.5} \pm 2.0$ [90]	$31^{+10}_{-8} \pm 5$ [90]	$0^+\,?^{?+}$	$B \to KY(3940)(\to J/\psi\omega)$	Belle [96], BaBar [97]
$Y(4140)$	$*\,*\,*$	$4148.0 \pm 2.4 \pm 6.3$ [74]	$28^{+15}_{-11} \pm 19$ [74]	$0^+\,?^{?+}$	$B \to KY(4140)(\to J/\psi\phi)$	CDF [69], D0 [102], CMS [74]
$Y(4274)$	$*\,*\,*$	$4274.4^{+8.4}_{-6.7} \pm 1.9$ [100]	$32.3^{+21.9}_{-15.3} \pm 7.6$ [100]	$0^+\,?^{?+}$	$B \to KY(4274)(\to J/\psi\phi)$	CDF [100], CMS [74]
$X(3823)$	$*\,*\,*\,*$	$3821.7 \pm 1.3 \pm 0.7$ [118]	<16 [118]	0^-2^{--}	$\psi' \to J/\psi\pi^+\pi^-$	E705 [111],
					$B \to KX(3823)(\to \gamma\chi_{c1})$	Belle [112],
					$e^+e^- \to \pi^+\pi^- X(3823)(\to \gamma\chi_{c1})$	BESIII [118]
$Y(4360)$	$*\,*\,*$	4354 ± 10 [1]	78 ± 16 [1]	0^-1^{--}	$e^+e^- \to \gamma_{\rm ISR}Y(4360)(\to \psi(3686)\pi^+\pi^-)$	BaBar [144],Belle [145]
$Y(4660)$	$*\,*\,*\,*$	4665 ± 10 [1]	53 ± 16 [1]	0^-1^{--}	$e^+e^- \to \gamma_{\rm ISR}Y(4660)(\to \psi(3686)\pi^+\pi^-)$	Belle [145], BaBar [146]
$Y(4630)$		4634^{+8+5}_{-7-8} [147]	92^{+40+10}_{-24-21} [147]		$e^+e^- \to \gamma_{\rm ISR}Y(4630)(\to \Lambda_c\bar{\Lambda}_c)$	Belle [147]
$X(3915)$	$*\,*\,*$	$3915\pm3\pm2$ [152]	$17\pm10\pm3$ [152]	0^+0^{++}	$\gamma\gamma \to X(3915)(\to J/\psi\omega)$	Belle [152], BaBar [155]
$Z(3930)$	$*\,*\,*$	$3929\pm5\pm2$ [151]	$29\pm10\pm2$ [151]	0^+2^{++}	$\gamma\gamma \to Z(3930)(\to D\bar{D})$	Belle [151], BaBar [154]
$Z^+(4430)$	$*\,*\,*$	4478^{+15}_{-18} [1]	181 ± 31 [1]	1^+1^{+-}	$B \to KZ^+(4430)(\to \psi(3686)\pi^+)$	Belle [103],LHCb [108]
$Z_c(3900)$	$*\,*\,*\,*$	3888.7 ± 3.4 [1]	35 ± 7 [1]	1^+1^{+-}	$e^+e^- \to Y(4260) \to \pi^- Z_c(3900)^+(\to J/\psi\pi^+)$	BESIII [64], Belle [124],
					$e^+e^- \to \psi(4160) \to \pi^- Z_c(3900)^+(\to J/\psi\pi^+)$	Xiao et al. [61]
$Z_c(3885)$		$3883.9 \pm 1.5 \pm 4.2$ [159]	$24.8 \pm 3.3 \pm 11.0$ [159]		$e^+e^- \to Y(4260) \to \pi^- Z_c(3885)^+(\to (D\bar{D}^*)^+)$	BESIII [159]
$Z_c(4020)$	$*\,*\,*\,*$	$4022.9 \pm 0.8 \pm 2.7$ [160]	$7.9 \pm 2.7 \pm 2.6$ [160]	1^+1^{+-}	$e^+e^- \to Y(4260) \to \pi^- Z_c(4020)^+(\to h_c\pi^+)$	BESIII [160]
$Z_c(4025)$		$4026.3 \pm 2.6 \pm 3.7$ [161]	$24.8 \pm 5.6 \pm 7.7$ [161]		$e^+e^- \to Y(4260) \to \pi^- Z_c(4025)^+(\to (D^*\bar{D}^*)^+)$	BESIII [161]

Discovery modes (continued)

States	Status	Mass [MeV]	Width [MeV]	$I^G J^{PC}/IJ^P$	Observation	Note
$Y(4008)$	$*$	$4008 \pm 40^{+114}_{-28}$ [119]	$226 \pm 44 \pm 87$ [119]	$0^- 1^{--}$	$e^+e^- \to \gamma_{\rm ISR} Y(4008)(\to J/\psi \pi^+\pi^-)$	Belle [119]
$X(3940)$	$*$	$3942^{+7}_{-6} \pm 6$ [148]	$37^{+26}_{-15} \pm 8$ [148]	$?^? ?^{?+}$	$e^+e^- \to J/\psi X(3940)(\to \bar{D}D^*)$	Belle [148]
$X(4160)$	$*$	$4156^{+25}_{-20} \pm 15$ [148]	$139^{+111}_{-61} \pm 21$ [148]	$?^? ?^{?+}$	$e^+e^- \to J/\psi X(4160)(\to \bar{D}^*D^*)$	Belle [148]
$X(4350)$	$*$	$4350.6^{+4.6}_{-5.1} \pm 0.7$ [99]	$13^{+18}_{-9} \pm 4$ [99]	$?^? 0^{?+}/2^{?+}$	$\gamma\gamma \to X(4350)(\to J/\psi \phi)$	Belle [99]
$Z^+(4051)$	$*$	$4051 \pm 14^{+20}_{-41}$ [109]	82^{+21+47}_{-17-22} [109]	$? ?^?$	$B \to KZ^+(4051)(\to \chi_{c1}\pi^+)$	Belle [109]
$Z^+(4248)$	$*$	$4248^{+44+180}_{-29-35}$ [109]	$177^{+54+316}_{-39-61}$ [109]	$? ?^?$	$B \to KZ^+(4248)(\to \chi_{c1}\pi^+)$	Belle [109]
$Z^+(4200)$	$*$	4196^{+31+17}_{-29-13} [107]	$370^{+70+70}_{-70-132}$ [107]	1^+1^{+-}	$B \to KZ^+(4200)(\to J/\psi \pi^+)$	Belle [107]
$Z^+(4240)$	$*$	$4239 \pm 18^{+45}_{-10}$ [108]	$220 \pm 47^{+108}_{-74}$ [108]	$?0^-/?1^+$	$B \to KZ^+(4240)(\to \psi(3686)\pi^+)$	LHCb [108]
$Z_b(10610)$	$**$	10607.2 ± 2.0 [172]	18.4 ± 2.4 [172]	1^+1^{+-}	$\Upsilon(5S) \to \pi^\mp Z_b^\pm(10610) \begin{cases} \to \pi^\pm \Upsilon(nS)(n=1,2,3) \\ \to \pi^\pm h_b(mP)(m=1,2) \end{cases}$ $\Upsilon(10860) \to \pi^\mp Z_b^\pm(10610)(\to [B\bar{B}^* + \text{c.c.}]^\pm)$	Belle [172], Belle [177]
$Z_b(10650)$	$**$	10652.2 ± 1.5 [172]	11.5 ± 2.2 [172]	1^+1^{+-}	$\Upsilon(5S) \to \pi^\mp Z_b^\pm(10610) \begin{cases} \to \pi^\pm \Upsilon(nS)(n=1,2,3) \\ \to \pi^\pm h_b(mP)(m=1,2) \end{cases}$ $\Upsilon(10860) \to \pi^\mp Z_b^\pm(10650)(\to [B^*\bar{B}^*]^\pm)$	Belle [172], Belle [177]
$P_c(4380)^+$	$*$	$4380 \pm 8 \pm 29$ [2]	$205 \pm 18 \pm 86$ [2]	$\frac{1}{2}\ ?^?$	$\Lambda_b^0 \to K^- P_c(4380)^+(\to J/\psi p)$	LHCb [2]
$P_c(4450)^+$	$*$	$4449.8 \pm 1.7 \pm 2.5$ [2]	$39 \pm 5 \pm 19$ [2]	$\frac{1}{2}\ ?^?$	$\Lambda_b^0 \to K^- P_c(4450)^+(\to J/\psi p)$	LHCb [2]

Theory

- **Studying** **hadron spectrum** **is helpful to enlarge our knowledge of color confinement and χSB**

The exotic muliquark states were predicted at the birth of Quark Model

Phys.Lett. 8 (1964) 214-215

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

...

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while

8419/TH.412
21 February 1964

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING II *)

G. Zweig
CERN---Geneva

*) Version I is CERN preprint 8182/TH.401, Jan. 17, 1964.

...

6) In general, we would expect that baryons are built not only from the product of three aces, AAA, but also from $\bar{A}AAAA$, $\bar{A}\bar{A}AAAAA$, etc., where $\bar{A}$ denotes an anti-ace. Similarly, mesons could be formed from $\bar{A}A$, $\bar{A}\bar{A}AA$ etc. For the low mass mesons and baryons we will assume the simplest possibilities, $\bar{A}A$ and AAA, that is, "deuces and treys".

Types of hadrons in nature

$$
\text{Hadron}\begin{cases}
\text{Conventional QM states} & \begin{cases}\text{Meson}: & q\bar{q},\quad Q\bar{q},\quad Q\bar{Q}\\ \text{Baryon}: & qqq,\quad Qqq,\quad QQq,\quad \ldots\end{cases}\\
\text{Exotic states} & \begin{cases}\text{Molecular state}\\ \text{Hybrid meson}\\ \text{Glueball}\\ \text{Tetraquark}\\ \text{Pentaquark}\\ \ldots\end{cases}
\end{cases}
$$

- **Identifying exotic states is one of the most important research issues of particle physics**
- **The observed XYZ states provide us good platform to identify exotic state**

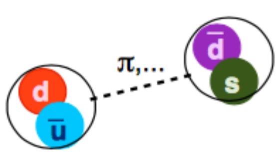
Theoretical explanations

Resonant *vs* Non-resonant

Conventional hadrons

charmonium

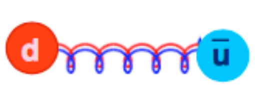
Exotic states



- **Molecular states**: loosely bound states composed of a pair of mesons, probably bound by the pion exchange

diquark-diantiquark

- **Tetraquarks**: bound states of four quarks, bound by colored-force between quarks, some are charged or carry strangeness, there are many states within the same multiplet



- **Hybrid charmonium**: bound states composed of a pair of quarks and one excited gluon

Many XYZ states lie very close to open-charm threshold

It's quite possible some threshold enhancements are not ***real*** resonances.

- Kinematical effect
- Opening of new threshold
- Cusp effect
- Final state interaction
- Interference between continuum and well-known charmonium states
- Triangle singularity due to the special kinematics

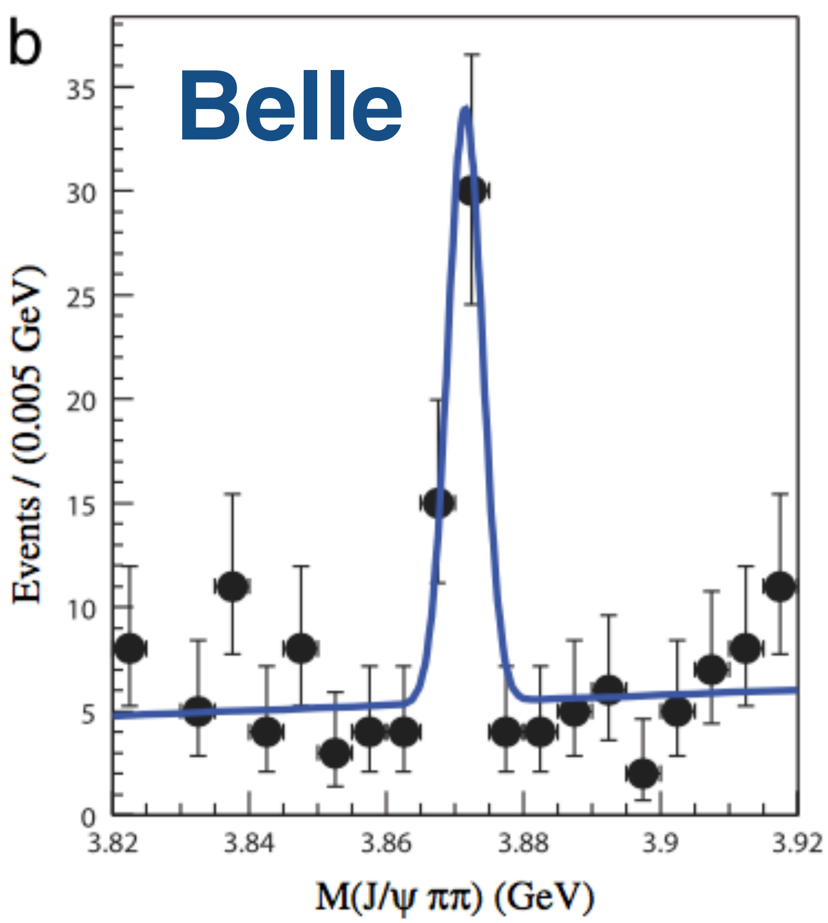
Selected topic I

What can we learn from X(3872)?

X(3872)

Abundant experimental information

PRL 91 (2003) 262001



	Decay modes								
	$J/\psi\pi^+\pi^-$	$J/\psi\pi^+\pi^-\pi^0$ ($J/\psi\omega$)	$J/\psi\eta$	$D^0\bar{D}^0\pi^0$	$D^{*0}\bar{D}^0$	$\gamma J/\psi$	$\gamma\psi'$	Mass (MeV)	J^{PC}
Belle-1	■							$3872.0 \pm 0.6 \pm 0.5$	
Belle-2		■				■		–	
Belle-3				■				$3875.2 \pm 0.7^{+0.3}_{-1.6} \pm 0.8$	
Belle-4	■							$3871.46 \pm 0.37 \pm 0.07$	
Belle-5					■			$3872.9^{+0.3+0.5}_{-0.6-0.5}$	
Belle-6						■	■	–	
BaBar-1	■							3873.4 ± 1.4	
BaBar-2			□					–	
BaBar-3	■							–	
BaBar-4	■							$3871.3 \pm 0.6 \pm 0.1$ (B^-) $3868.6 \pm 1.2 \pm 0.2$ (B^0)	
BaBar-5				■				–	
BaBar-6						■		–	
BaBar-7					■			$3875.1^{+0.5}_{-0.7} \pm 0.5$	
BaBar-8	■							$3871.4 \pm 0.6 \pm 0.1$ (B^+) $3868.7 \pm 1.5 \pm 0.4$ (B^0)	
BaBar-9						■	■	–	
BaBar-10		■						$3873.0^{+1.8}_{-1.6} \pm 1.3$	2^{-+}
CDF-1	■							$3871.3 \pm 0.7 \pm 0.4$	
CDF-2	■							–	
CDF-3	■							–	$1^{++}/2^{-+}$
CDF-4	■							$3871.61 \pm 0.16 \pm 0.19$	
D0	■							$3871.8 \pm 3.1 \pm 3.0$	
LHCb-1	■							–	1^{++}
LHCb-2	■							$3871.95 \pm 0.48 \pm 0.12$	
CMS	■							–	
BESIII						■		$3891.9 \pm 0.7 \pm 0.2$	

$m(D^0D^{*0}) = (3871.81 \pm 0.36)$ MeV | PDG average mass of $X(3872)$: (3871.68 ± 0.17) MeV

Low mass puzzle:

The mass of X(3872) is 50-200 MeV lower than the prediction from potential model

X(3872)=molecular state?

$D\bar{D}^*$

interaction

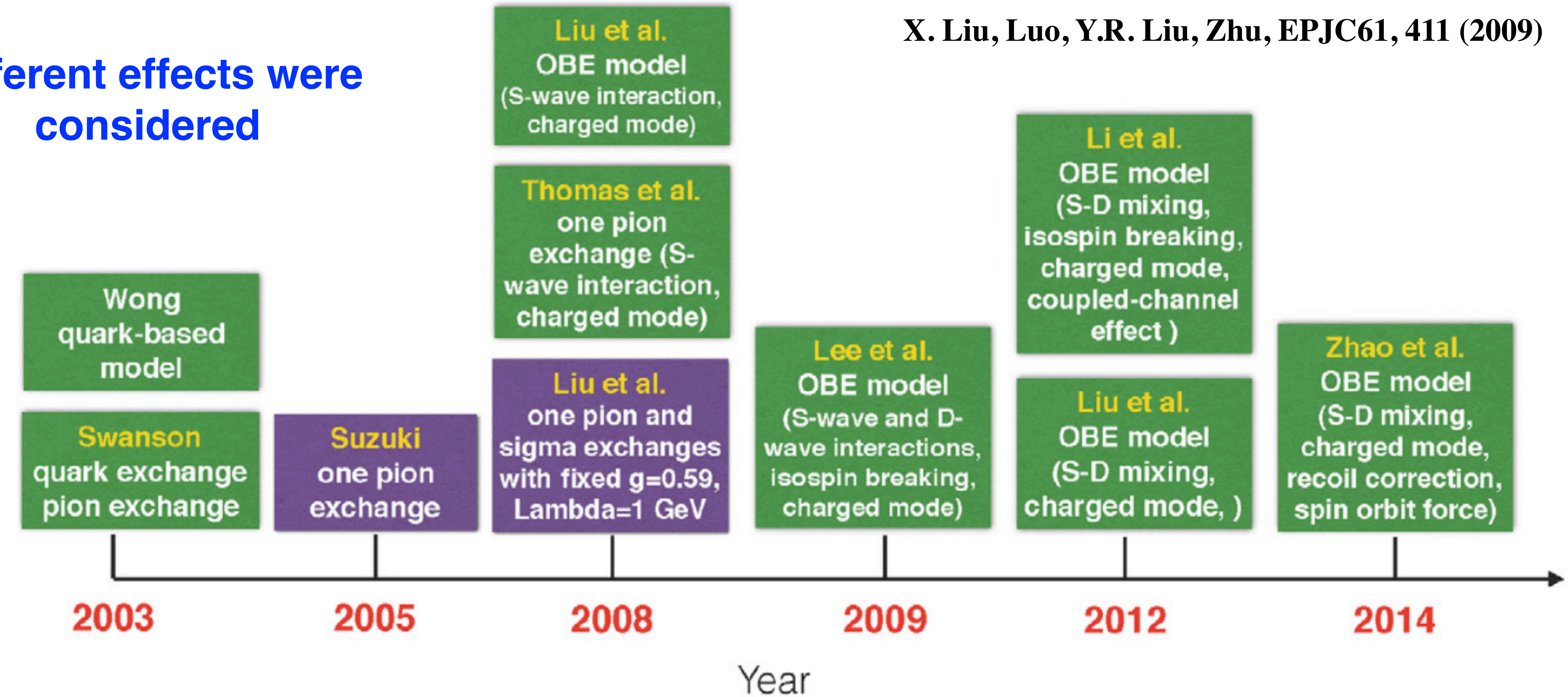
N. Li, S.L. Zhu, PRD86(2012)

L.Zhao, L.Ma, S.L.Zhu, PRD 89 (2014)

Y. Liu, X. Liu, Deng, Zhu, EPJC56, 63 (2008)

X. Liu, Luo, Y.R. Liu, Zhu, EPJC61, 411 (2009)

Different effects were considered



- **Reproduce the mass of X(3872)**
- **Explain isospin violating $J/\psi\rho$ decay mode of X(3872)**

The radiative decays of X(3872)

	BaBar	LHCb
	PRL102:132001	arXiv: 1404.0275
$\frac{BR(X(3872)\to\psi'\gamma)}{BR(X(3872)\to J/\psi\gamma)}$	$= 3.4 \pm 1.4$	$(2.46 \pm 0.64 \pm 0.29)$

- The E1 decay pattern suggests that X(3872) is a good candidate of the axial vector charmonium.
- If X(3872) is $\chi_{c1}(2P)$, both the radial WFs of $\chi_{c1}(2P)$ and $\psi(2S)$ contain one node. Their overlapping is large. $\chi_{c1}(2P)$ will decay into $\psi(2S)+\gamma$ more easily.
- In fact, this rate is consistent with the quark model prediction for the $\chi_{c1}(2P)$.

X(3872) as mixture of charmonium and molecule

Firstly proposed by Suzuki (PRD72:114013) and Meng&Gao&Chao (hep-ph/0506222)

- Moreover, the production cross section of X(3872) is comparable with that of $\psi(2S)$, which requires significant $(c\bar{c})$ component!
- On the other hand, the isospin violating dipion decay of X(3872) requires the molecular component!

Coupled-channel effect

Kalashnikova PRD72: 034010

Danilkin&Simonov PRL105:102002

The coupling of the bare 2^3P_1 state to $D\bar{D}^*$ channel can generate a near-threshold virtual state, which can correspond to X(3872).

Dynamical lattice QCD simulation

Padmanath, Lang, Prelovsek PRD92:034501

They found a lattice candidate for the X(3872) with $J^{PC} = 1^{++}$ and $I = 0$ only if both $c\bar{c}$ and $D\bar{D}^*$ operators are included

Supports X(3872) as a mixture of $c\bar{c}$ and $D\bar{D}^*$ molecule

Common Feature:
Couple-channel effects important

Λ(1405)

- Lower than quark model prediction for P-wave uds state
- Very close to KN threshold
- Dynamically generated resonance or genuine quark model state?
- Or mixture of uds and KN?
- Two poles with JP=1/2- near Λ(1405)?

D_{s0} (2317)

- Lower than quark model prediction for P-wave cs state
- Very close to DK threshold
- Dynamically generated resonance or genuine quark model state?
- Or mixture of cs and DK?

X(3872)

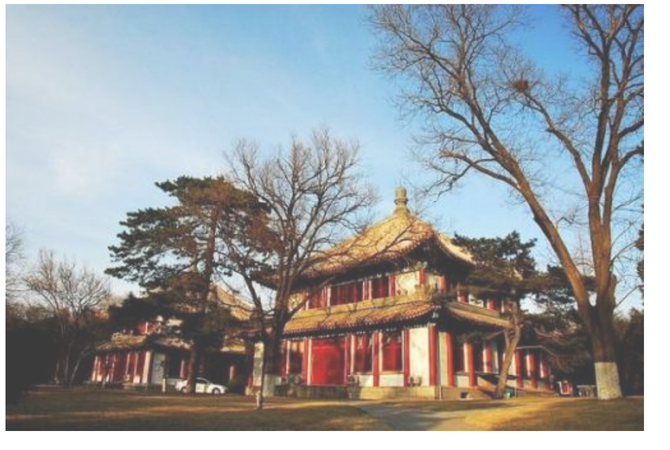
- Lower than quark model prediction for P-wave state χ'_{c1}
- Very close to DD* threshold
- Mixture of DD* and χ'_{c1} ?

Couple channel effects lower bare quark model level
S-wave continuum distorts QM spectrum

Its bottomonium analogue X_b not found since χ'_{b1} not close to BB* threshold

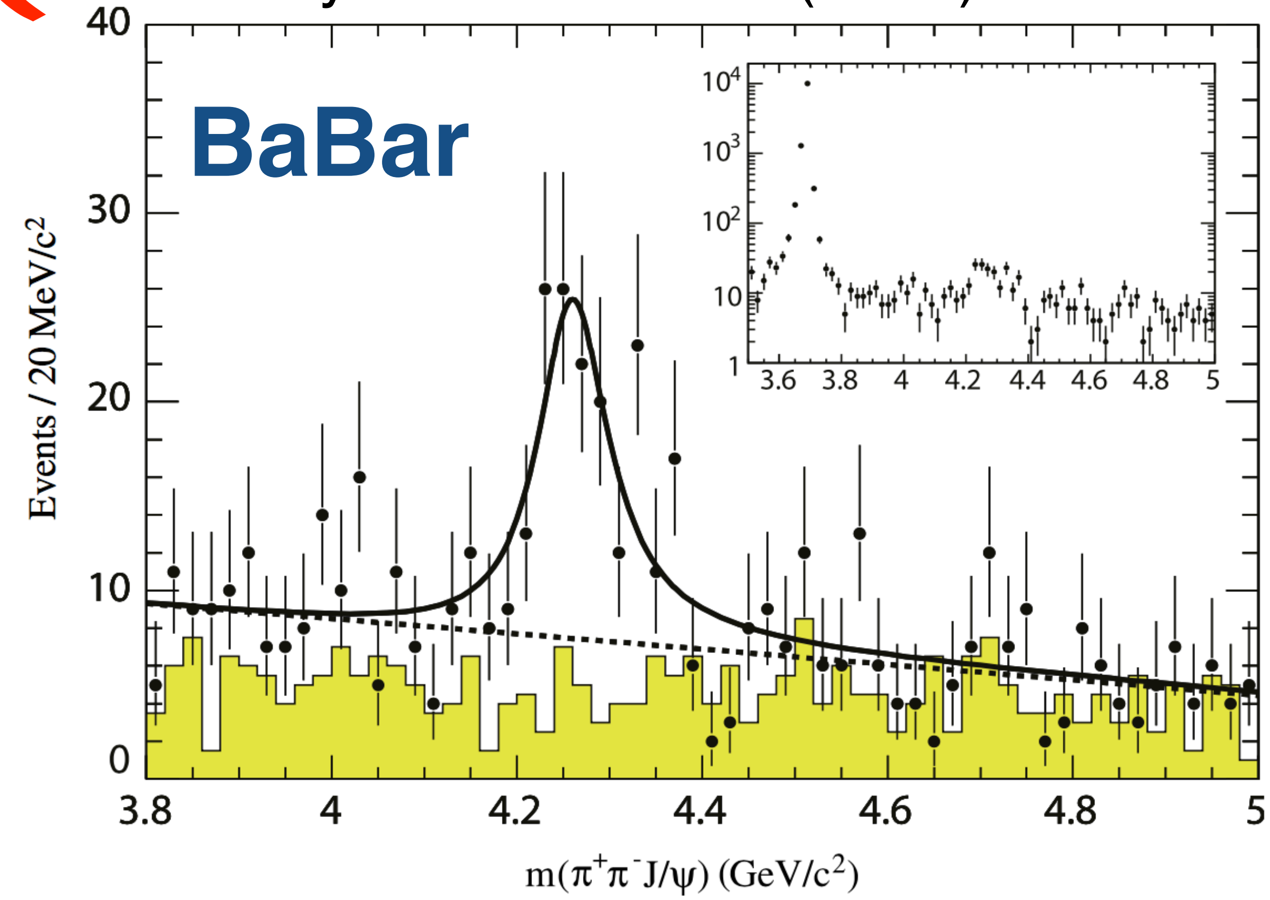
Selected topic II

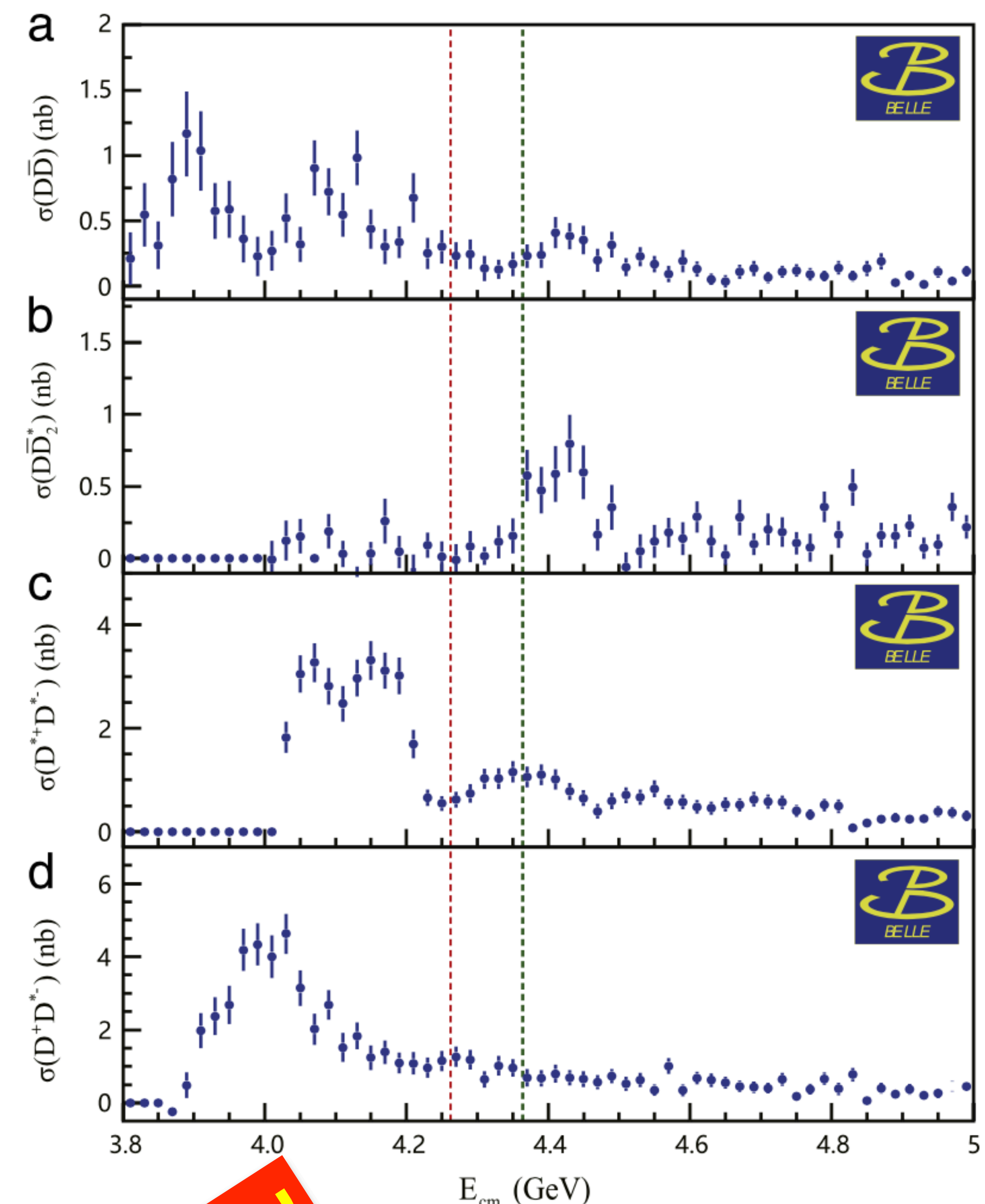
From Y(4260) to Y(4220) narrow structure

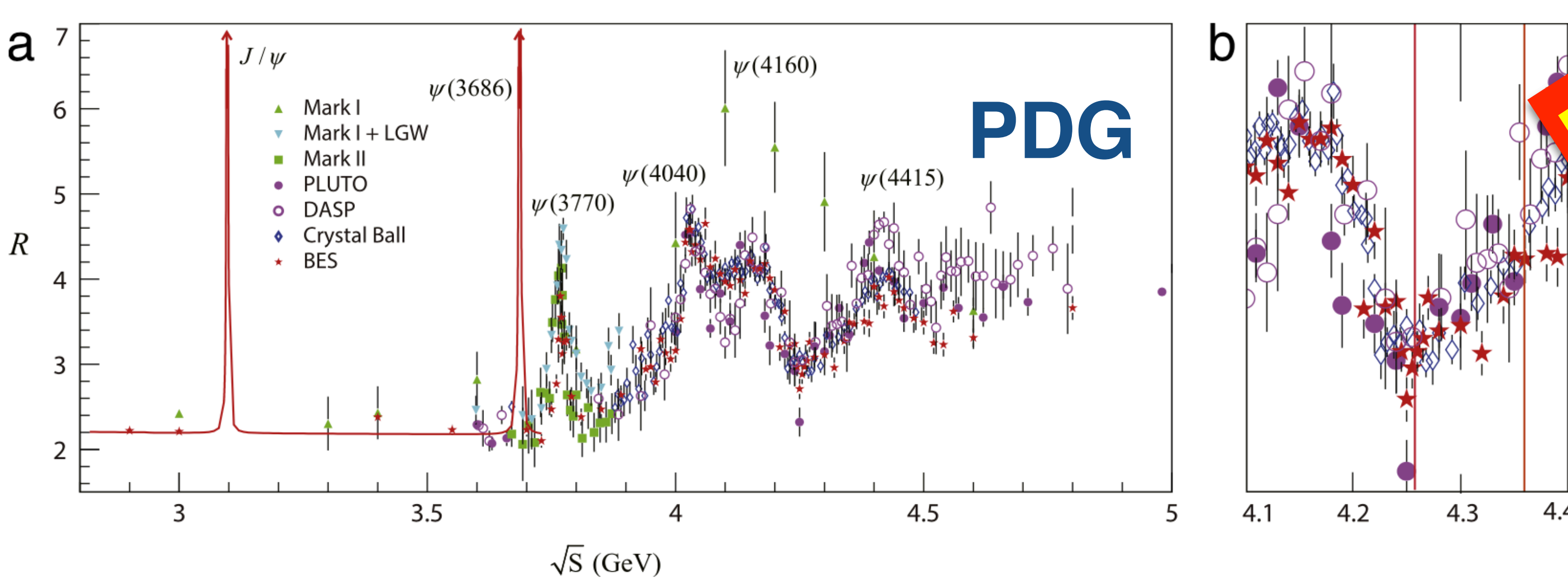


Y(4260)

Phys. Rev. Lett. 95 (2005) 142001







Puzzle!

No evidence of Y(4260) in R scan data and open-charm decay channels

Theoretical explanations

Exotic state

Charmonium hybrid

Zhu, Kou&Pene, Close&Page

Diquark-antidiquark state

Maiani&Riquer&Piccinini&Polosa

Ebert&Faustov&Galkin

Molecular state

Liu&Zeng&Li, Yuan&Wang&Mo, Qiao,Ding,Torres&Khemchandani&Gamermann&Oset, Close&Downum&Thomas

Charmonium hybrid state with strong coupling with DD1 and DD0

Kalashnikova &Nefediev

Conventional charmonium

4S-3D vector charmonium

Lanes-Estrada

2^3D_1 state decay behavior

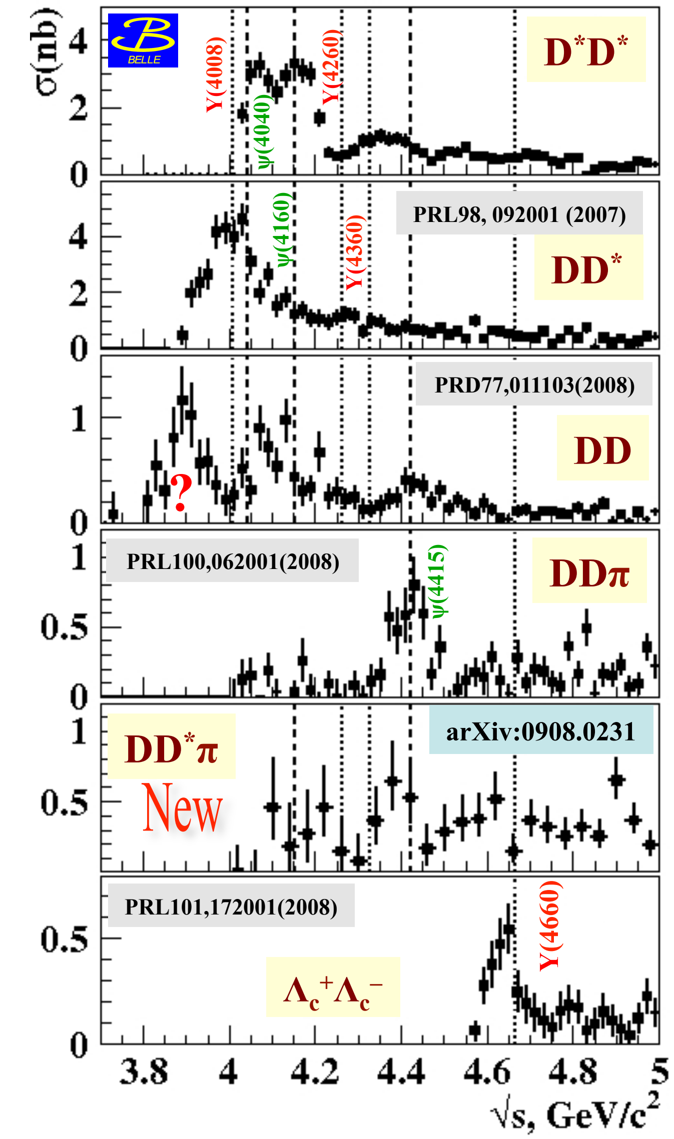
Eichten&Lane&Quigg

Mass spectrum Y(4260) ≠charmonium

Segovia&Yasser&Entem&Fernandez

Screened potential Y(4260) =Ψ(4S)

Li&Chao

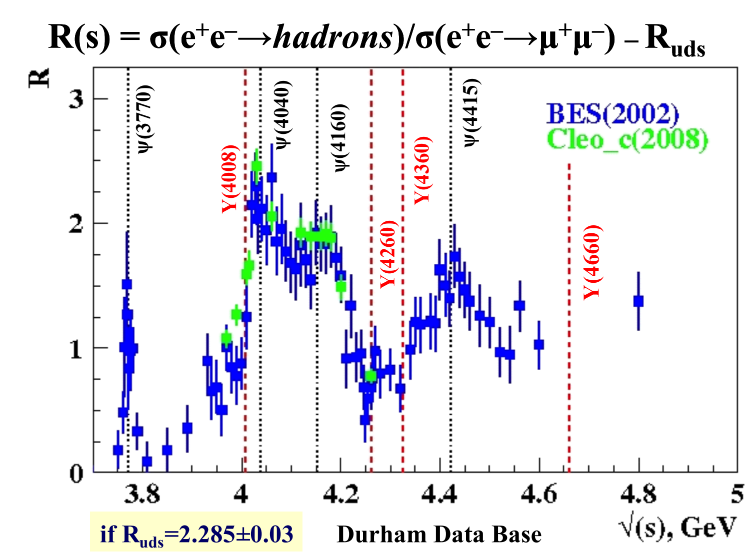


Difficulty

The **lack of signal in certain channels** also poses **a serious challenge** to a number of the explanations proposed in the framework of an exotic state

Difficulty

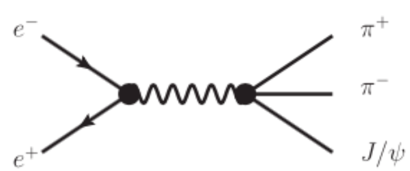
No evidence of Y(4260) in R scan data and open-charm decay channels



Non-resonant picture of Y(4260)

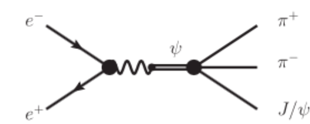
- **Asymmetric Y(4260) structure can be reproduced by Fano-like interference picture**

Continuum



$$\widehat{=} g\, u^2 e^{-au^2}$$

Charmonium

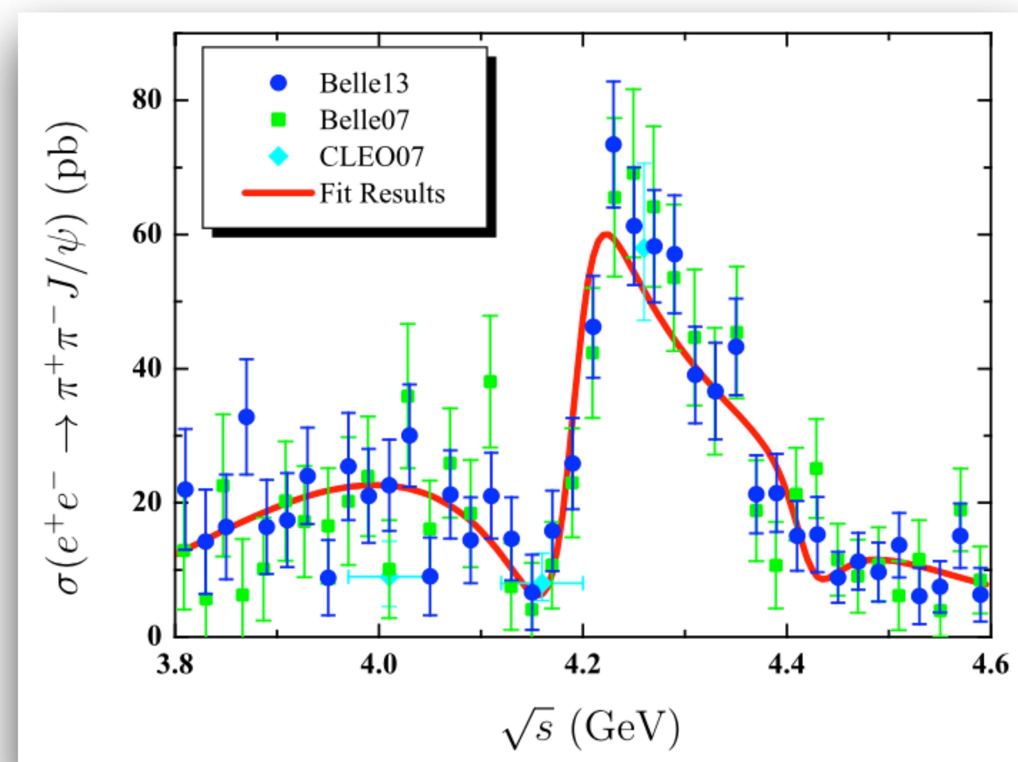


$$\widehat{=} \frac{\sqrt{12\pi\Gamma_\psi^{e^+e^-}\times\mathcal{B}(\psi\to\pi^+\pi^- J/\psi)\Gamma_\psi}}{s-m_\psi^2+im_\psi\Gamma_\psi}\sqrt{\frac{\Phi_{2\to3}(s)}{\Phi_{2\to3}(m_\psi^2)}}$$

Interference

$$\mathcal{A}^{\mathrm{Total}} = \mathcal{A}_{\mathrm{Continuum}} + e^{i\phi_1}\mathcal{A}_{\psi(4160)} + e^{i\phi_2}\mathcal{A}_{\psi(4415)},$$

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



Success:

- **Explain why ψ(4160) and ψ(4415) signals are missing in data**
- **Naturally understand why no evidence of Y(4260) in R scan data and the open-charm decay channels**

Very recently BESIII gave more precise data of $e^+e^- \to J/\psi\pi^+\pi^-$

PRL **118,** 092001 (2017) PHYSICAL REVIEW LETTERS week ending 3 MARCH 2017

Precise Measurement of the $e^+e^- \to \pi^+\pi^- J/\psi$ Cross Section at Center-of-Mass Energies from 3.77 to 4.60 GeV

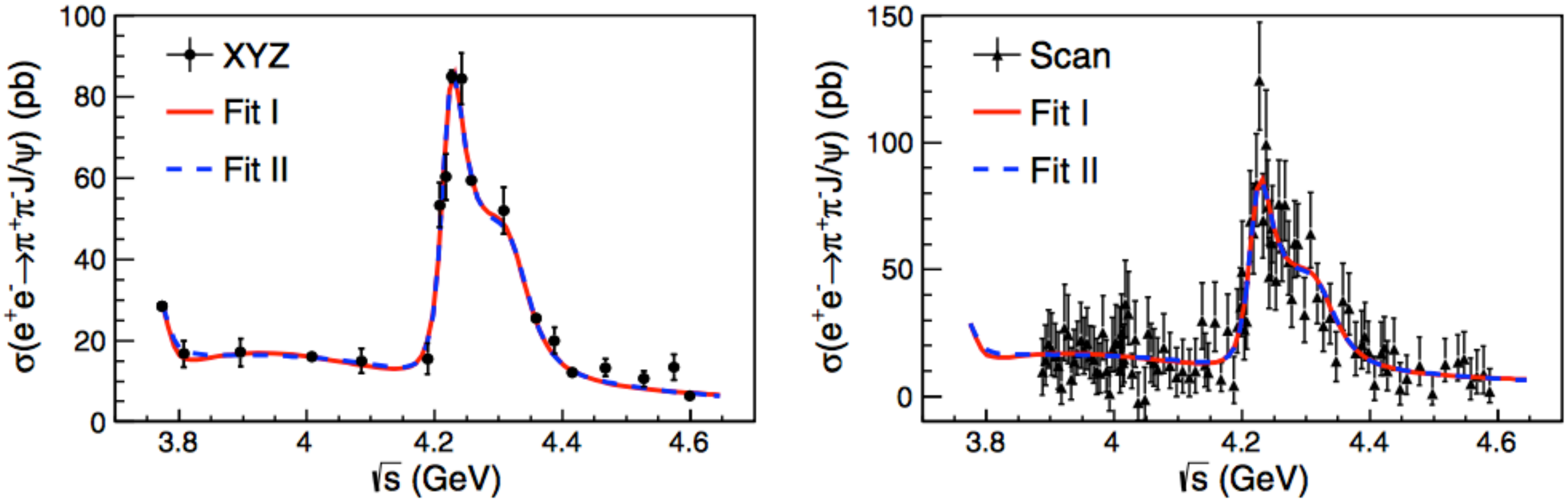


FIG. 1. Measured cross section $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ and simultaneous fit to the *XYZ* data (left) and scan data (right) with the coherent sum of three Breit-Wigner functions (red solid curves) and the coherent sum of an exponential continuum and two Breit-Wigner functions (blue dashed curves). Dots with error bars are data.

Y(4260) ⟶ Y(4220) + Y(4330)

Introducing a narrow structure Y(4220) and considering Fano-like interference picture can reproduce the data well!

Chen, Liu, Matsuki, arXiv:1708.06918

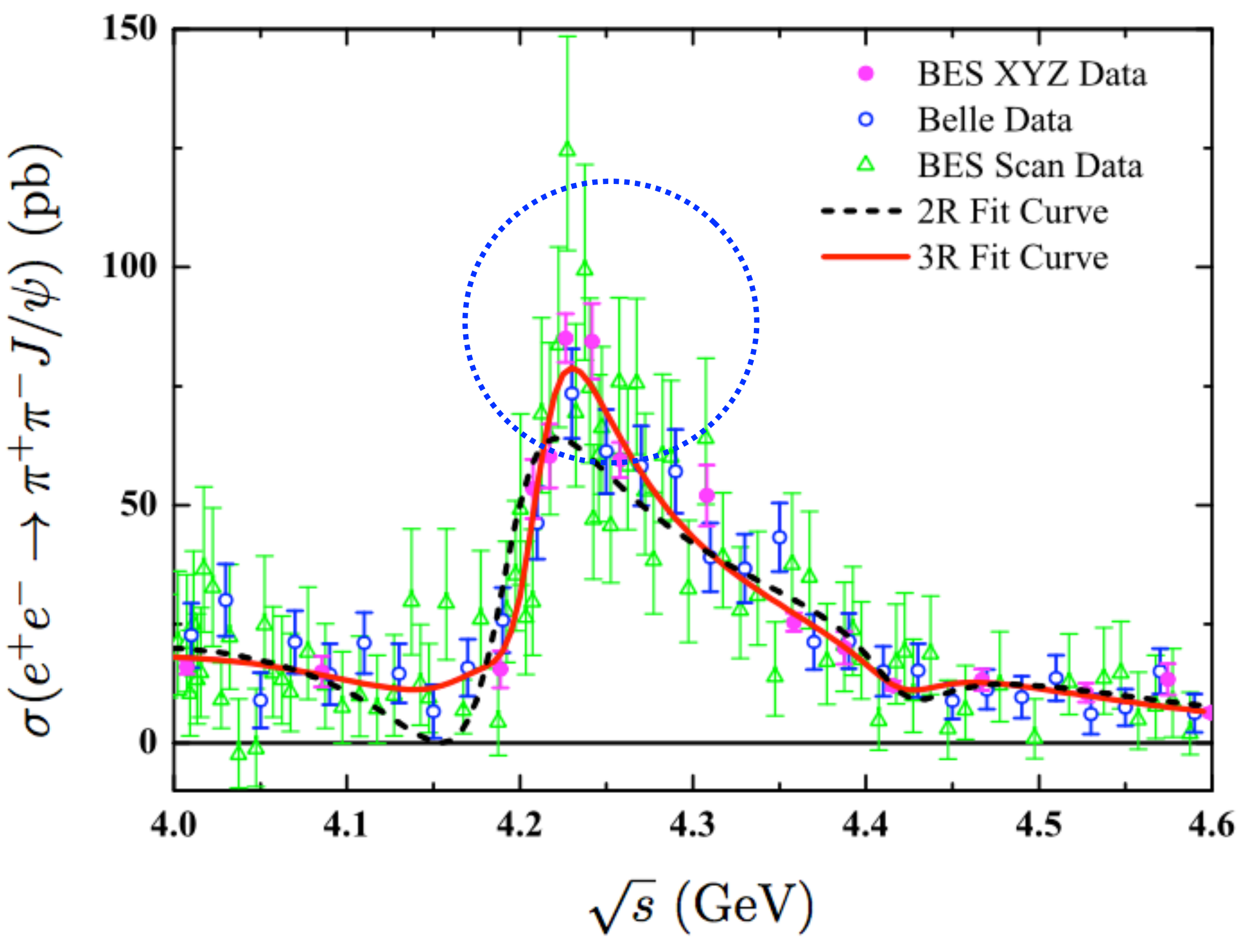


FIG. 2: (color online). Our fit to the cross sections for the $e^+e^- \to \pi^+\pi^- J/\psi$ process measured by the Belle [8] and BESIII collaborations [11] under the 2R and 3R fit schemes. Here, the BES scan data [11] are also listed for comparison.

Parameters	$e^+e^- \to \pi^+\pi^- J/\psi$ 2R Fit	3R Fit
g (GeV^{-1})	49.93 ± 6.51	49.86 ± 5.89
a (GeV^{-2})	2.00 ± 0.17	2.11 ± 0.16
$\mathcal{R}_{\psi(4160)}$ (eV)	5.59 ± 0.25	2.38 ± 1.37
ϕ_1 (rad)	5.70 ± 0.23	1.59 ± 0.76
$\mathcal{R}_{\psi(4415)}$ (eV)	5.14 ± 1.82	5.05 ± 2.54
ϕ_2 (rad)	4.41 ± 0.21	4.62 ± 0.46
$m_{Y(4220)}$	–	4207 ± 12
$\Gamma_{Y(4220)}$	–	58 ± 38
$R_{Y(4220)}$	–	6.59 ± 4.88
ϕ_3	–	5.75 ± 0.93
χ^2/n.d.f	205/157	118/153

Fano-like interference picture plays resonance killer to Y(4330)

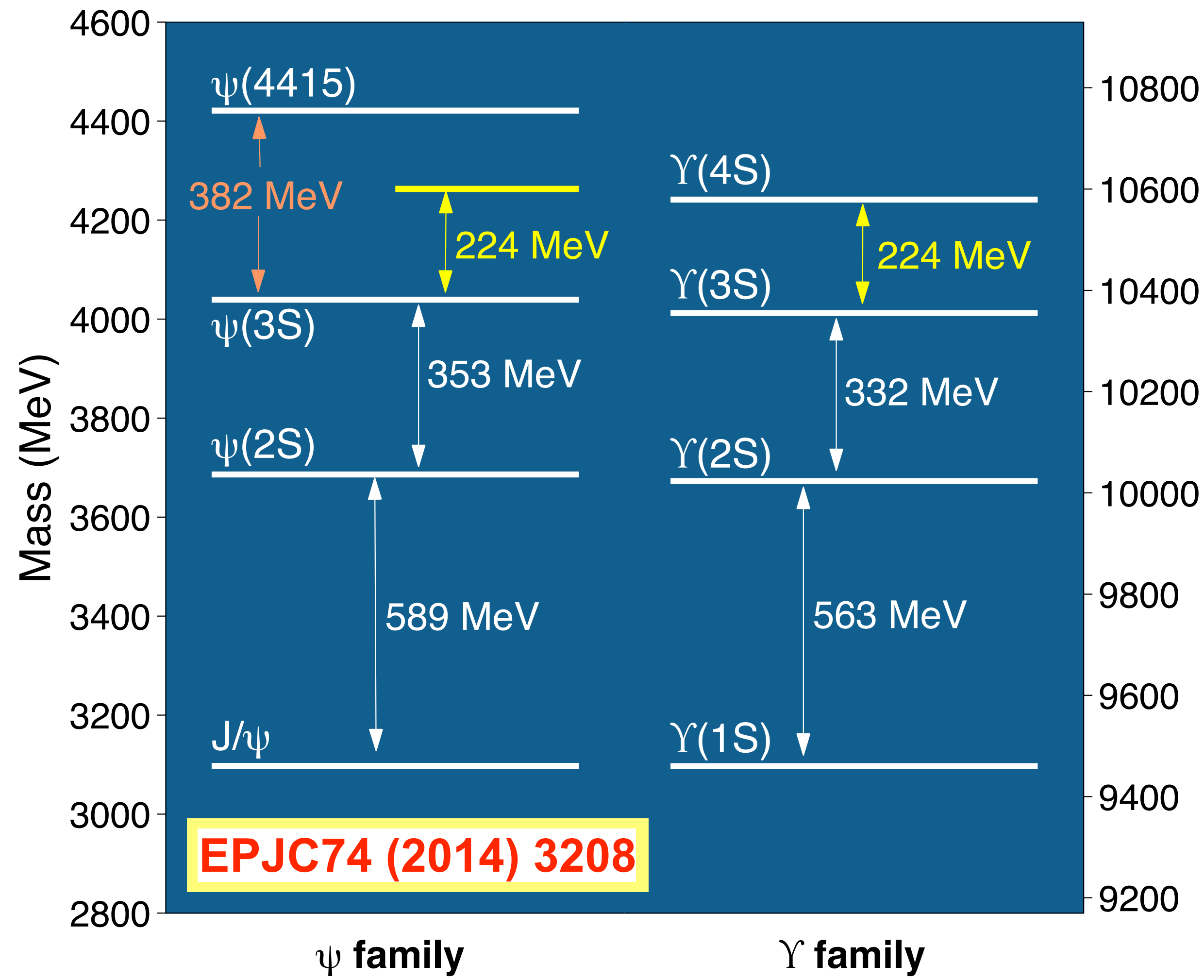
Resonance parameter

$$M = (4207 \pm 12) \quad \text{MeV}$$
$$\Gamma = (58 \pm 38) \quad \text{MeV}$$

What is Y(4220)?

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

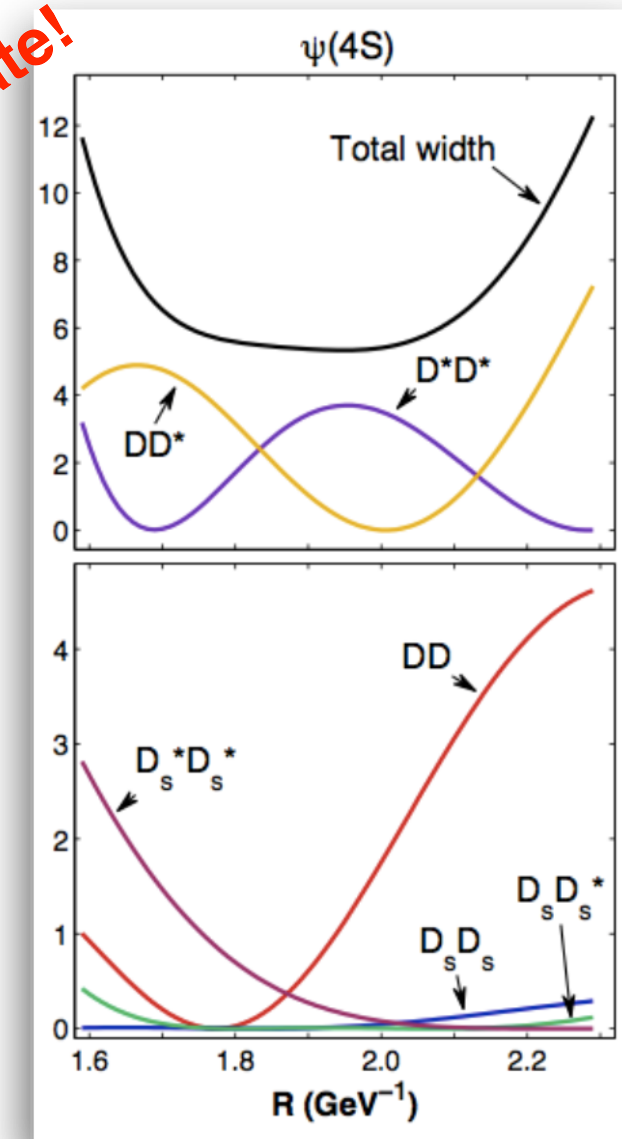
Consistent

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)?

Selected topic III

Charged Zc states

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

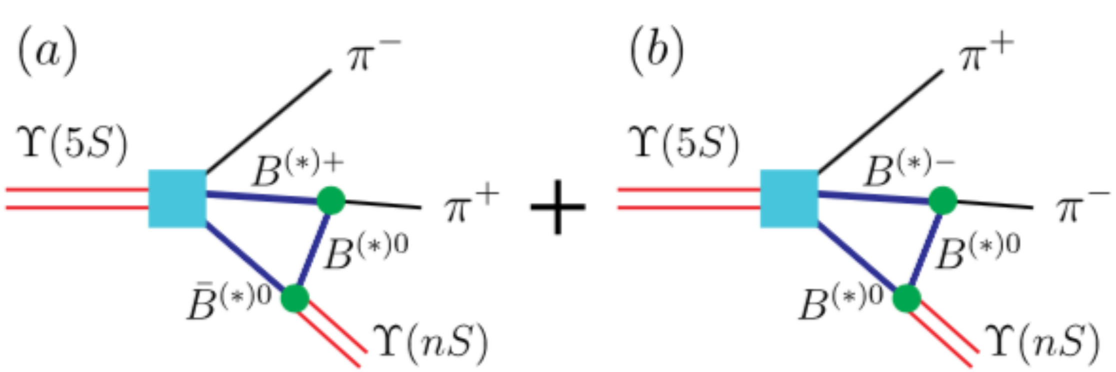
Predicted charged charmoniumlike structures in the hidden-charm dipion decay of higher charmonia

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

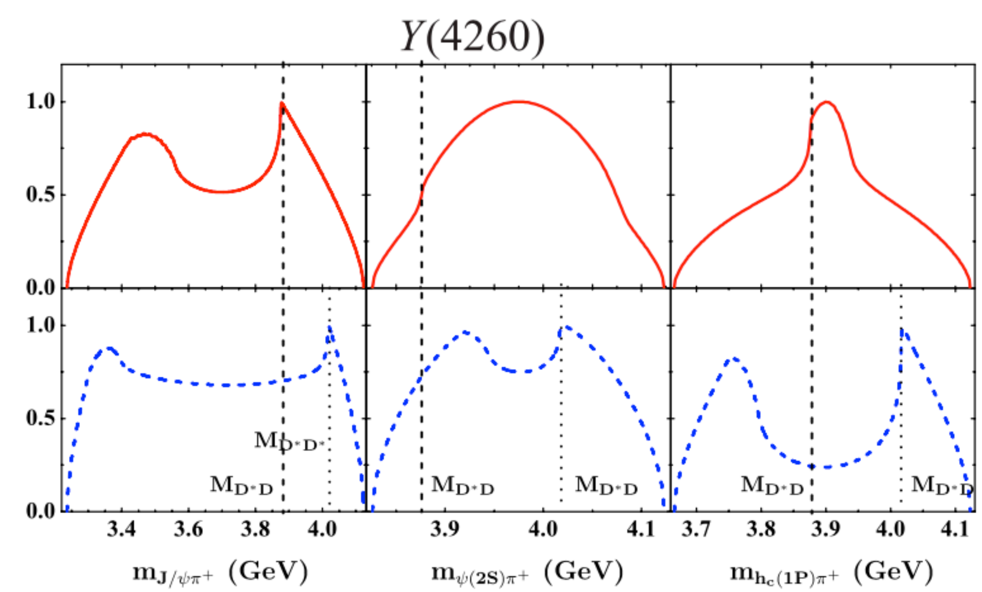
In this work, we predict two charged charmoniumlike enhancement structures close to the $D^*\bar{D}$ and $D^*\bar{D}^*$ thresholds, where the Initial Single Pion Emission mechanism is introduced in the hidden-charm dipion decays of higher charmonia $\psi(4040)$, $\psi(4160)$, $\psi(4415)$ and charmoniumlike 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 $h_c(1P)\pi^+\pi^-$. 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

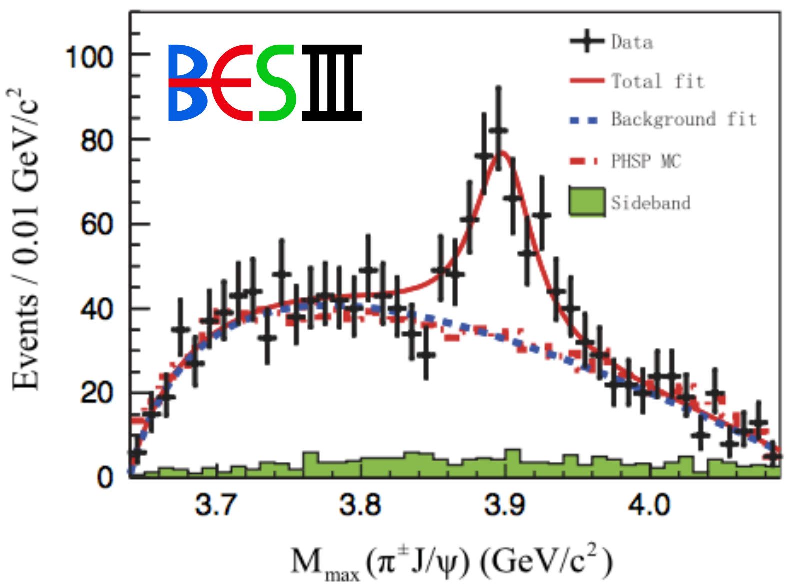


Chen, Liu, PRD84 (2011) 094003

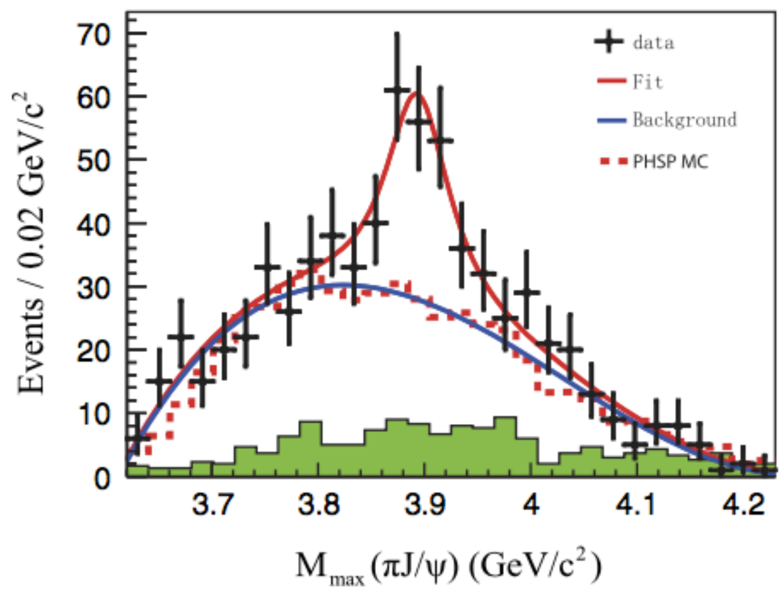


Discovery of Zc(3900)

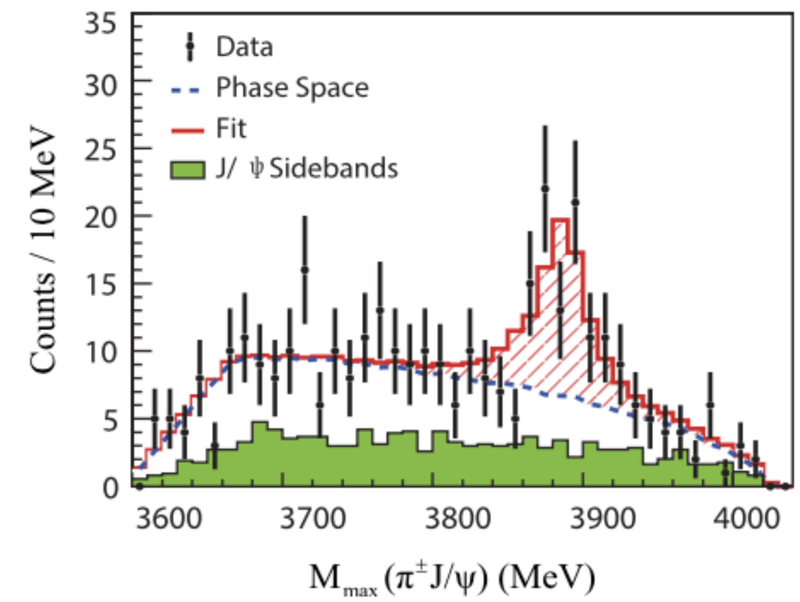
PRL110 (2013) 252001



PRL110 (2013) 252002

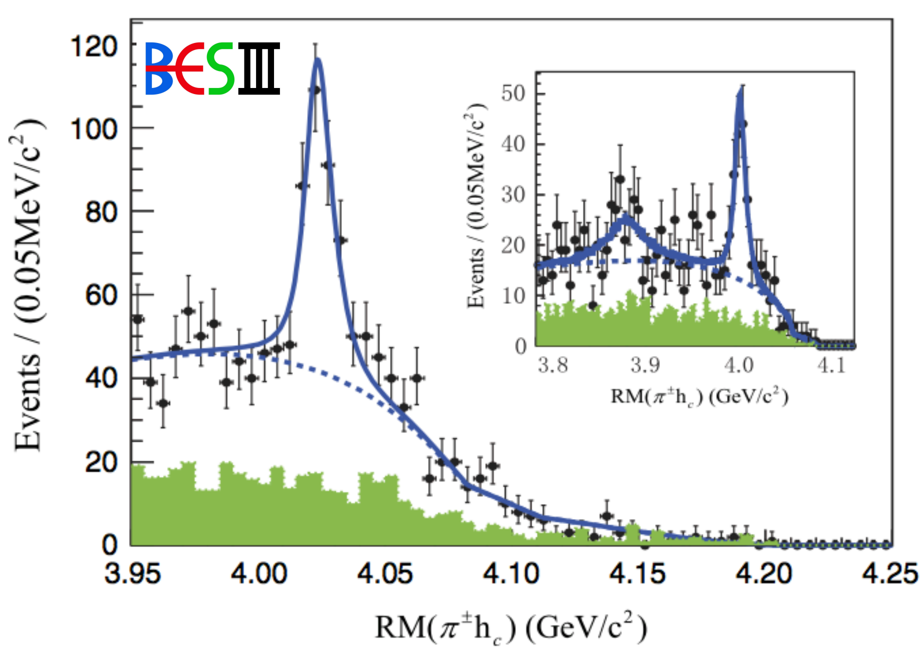


PLB773 (2013) 366



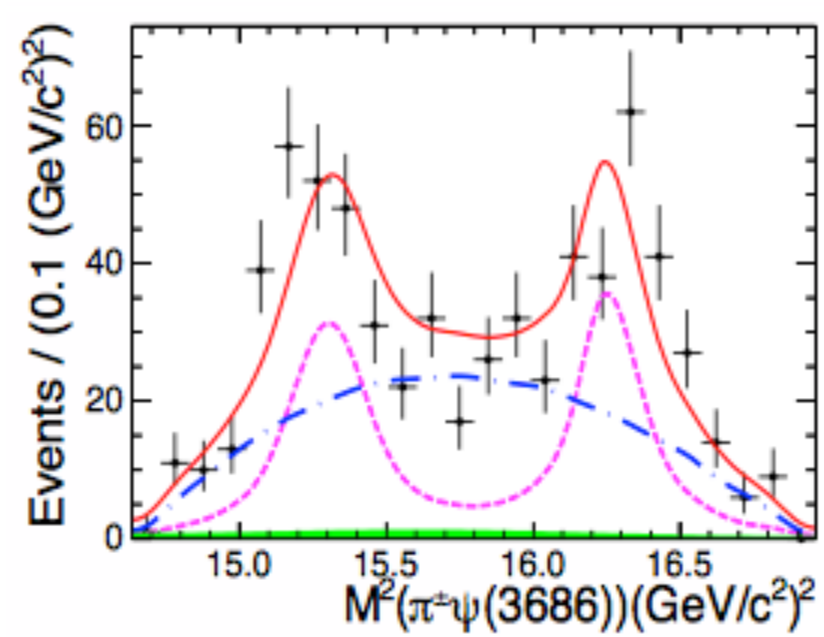
Discovery of Zc(4020)

PRL111 (2013) 242001



Discovery of Zc(4032)

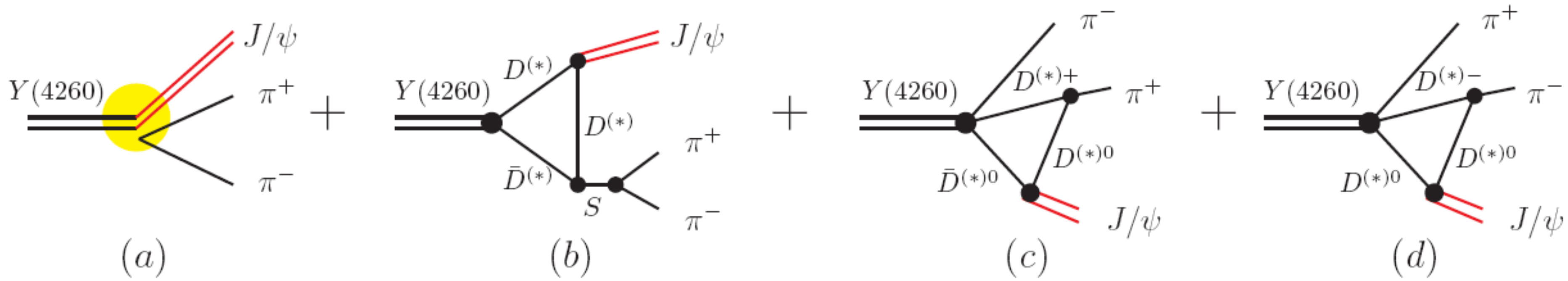
arXiv: 1703.08787



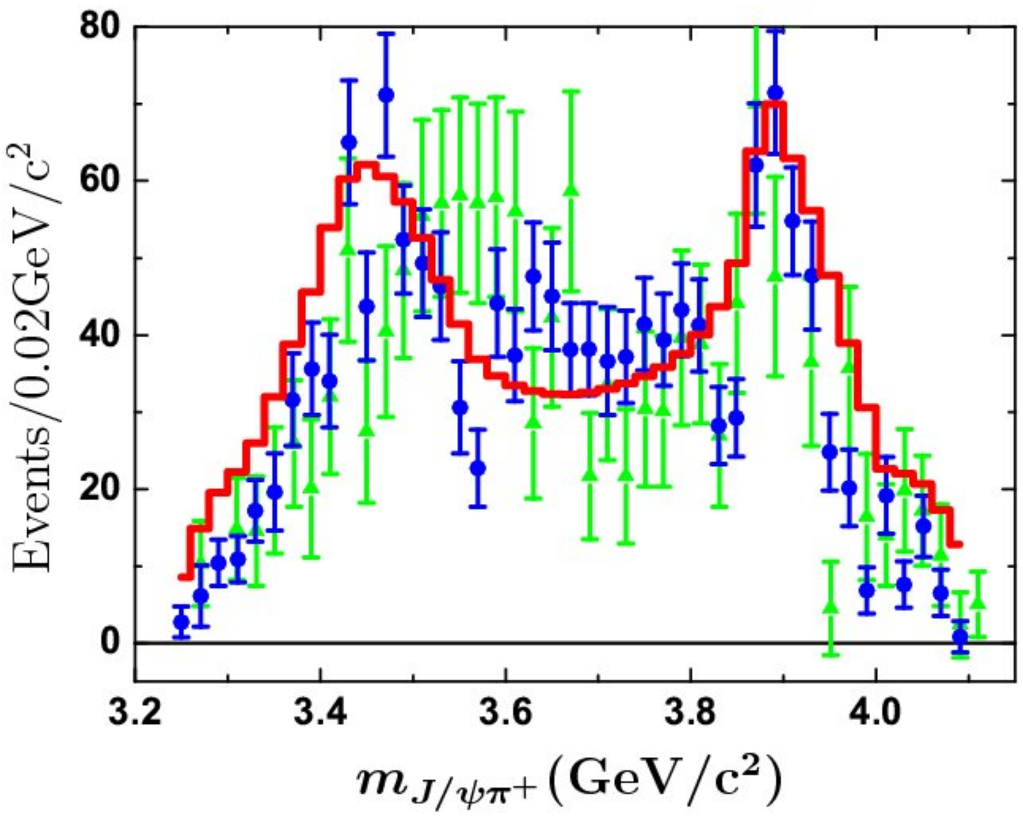
PHYSICAL REVIEW D **88,** 036008 (2013)

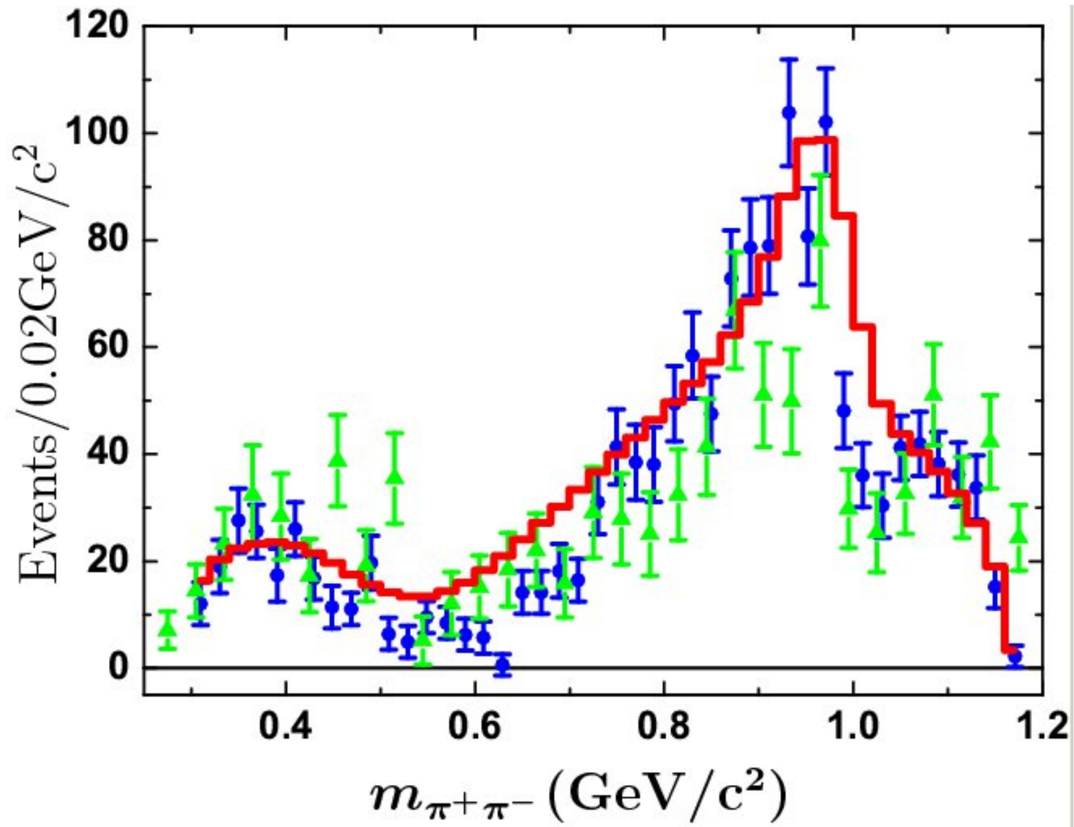
Reproducing the $Z_c(3900)$ structure through the initial-single-pion-emission mechanism

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



Reproduce Zc(3900) via the ISPE mechanism





Lattice QCD simulation

PRL **117**, 242001 (2016) PHYSICAL REVIEW LETTERS week ending 9 DECEMBER 2016

Fate of the Tetraquark Candidate $Z_c(3900)$ from Lattice QCD

Yoichi Ikeda,[1,2] Sinya Aoki,[3,4] Takumi Doi,[2] Shinya Gongyo,[3] Tetsuo Hatsuda,[2,5] Takashi Inoue,[6]
Takumi Iritani,[7] Noriyoshi Ishii,[1] Keiko Murano,[1] and Kenji Sasaki[3,4]

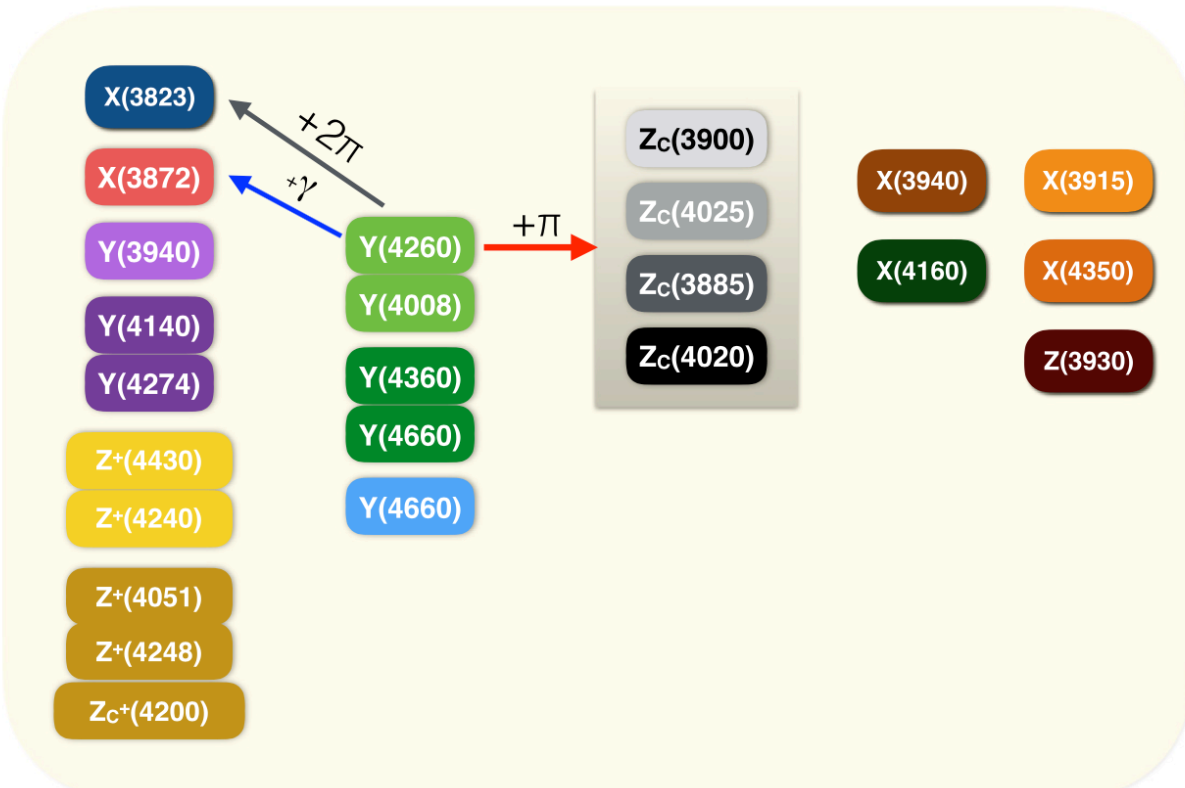
(HAL QCD Collaboration)

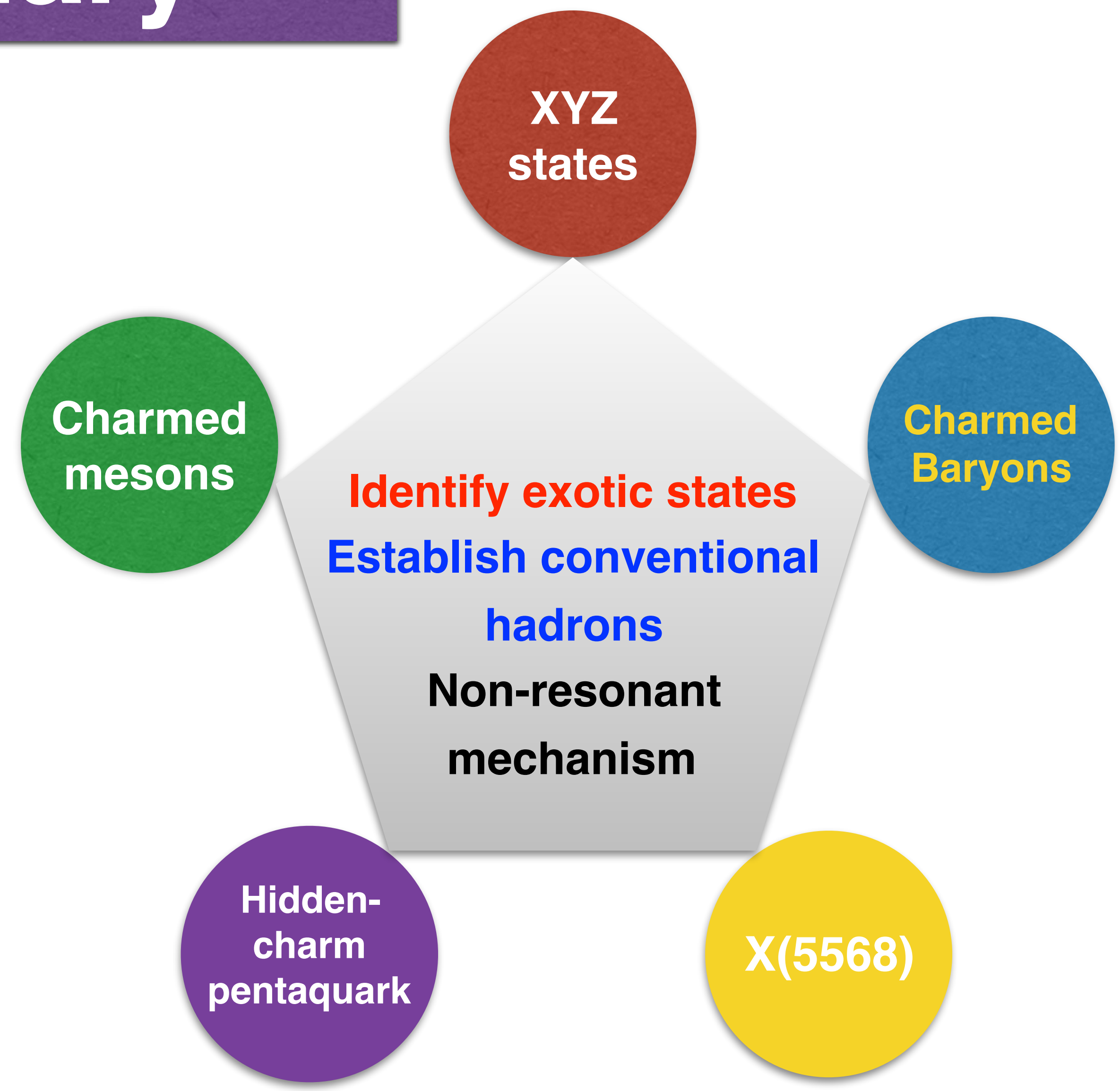
The possible exotic meson $Z_c(3900)$, found in e^+e^- reactions, is studied by the method of coupled-channel scattering in lattice QCD. The interactions among $\pi J/\psi$, $\rho\eta_c$, and $\bar{D}D^*$ channels are derived from $(2+1)$-flavor QCD simulations at $m_\pi = 410$–700 MeV. The interactions are dominated by the off-diagonal $\pi J/\psi$-$\bar{D}D^*$ and $\rho\eta_c$-$\bar{D}D^*$ couplings, which indicates that the $Z_c(3900)$ is not a usual resonance but a threshold cusp. Semiphenomenological analyses with the coupled-channel interaction are also presented to confirm this conclusion.

Lattice QCD simulation does not support exotic resonance explanation to Zc(3900)

Summary

XYZ states are correlated!





Heavy Flavour Spectroscopy

A research field full of challenges and opportunities

Theory ⟷ Experiment

LHCb CMS
BESIII BelleII

Thank you for your attention!