Charged charmonium-like structures and the initial single chiral particle emission mechanism

Takayuki Matsuki

Tokyo Kasei University

matsuki@tokyo-kasei.ac.jp

In collaboration with Dian-Yong Chen (IPM, CAS) and Xiang Liu (LZU)

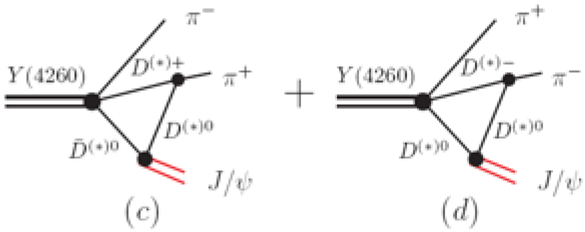
Outline

- Zc(3900) observed by BESIII
- The lessons from studying the hidden-bottom decays of Y(5S)

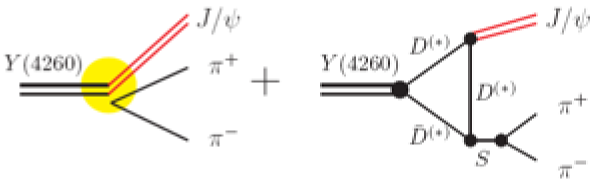
  → ISPE mechanism
- Novel charged structures existing in the hidden-charm dikaon decays of higher charmonia or charmonium-like states
- Summary

Zc(3900) calculated by us

- Describe
  - Not only triangle diagrams



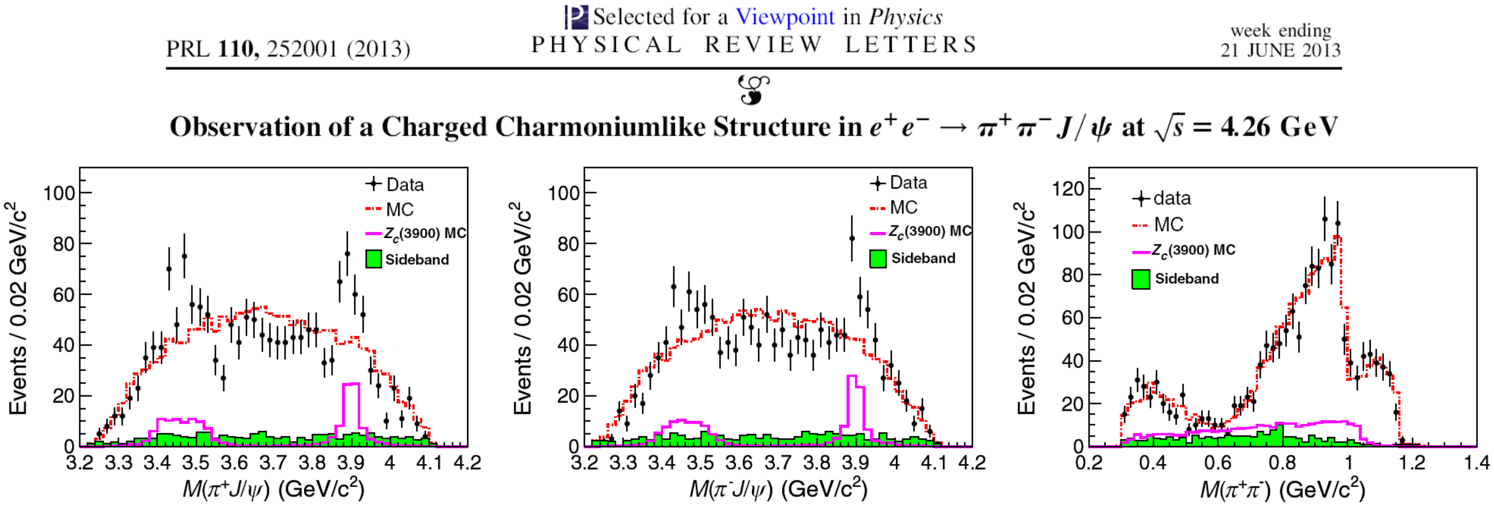
  - Include background, other diagrams, and relative phases

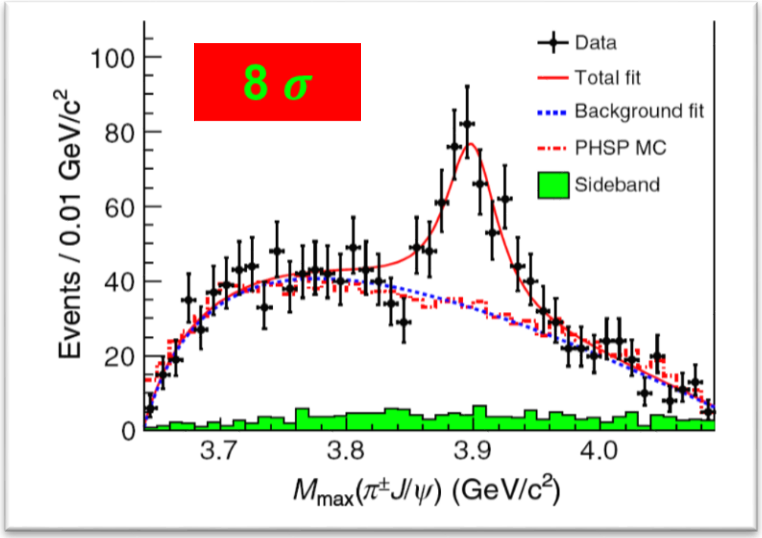


  - Experiment has enough information to include these diagrams

D.Y. Chen, X. Liu, T. Matsuki, Phys.Rev.D88:036008,2013

Zc(3900) observed by BESIII





BESIII, PRL 110, 252001 (2013)

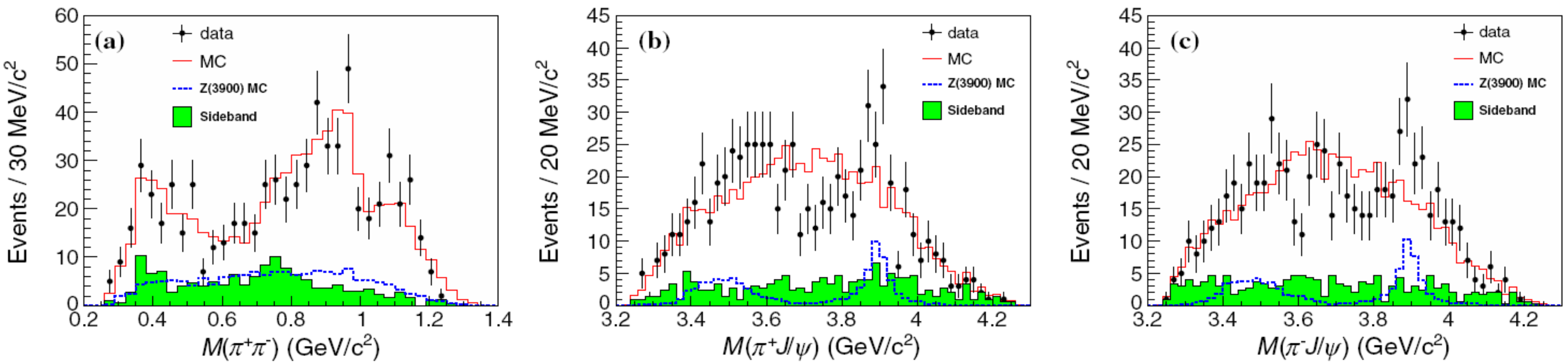
$$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV/c^2}$$
$$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$$

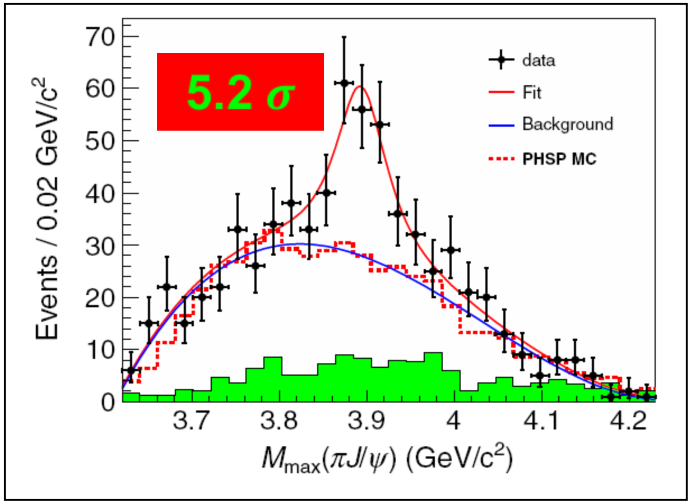
- A **charged** charmonium-like structure
- **Near** the $D\bar{D}^*$ **threshold**

Zc(3900) observed by Belle

Belle, PRL 110, 252002 (2013)

$$e^+e^- \to Y(4260) \to J/\psi\pi^+\pi^-$$



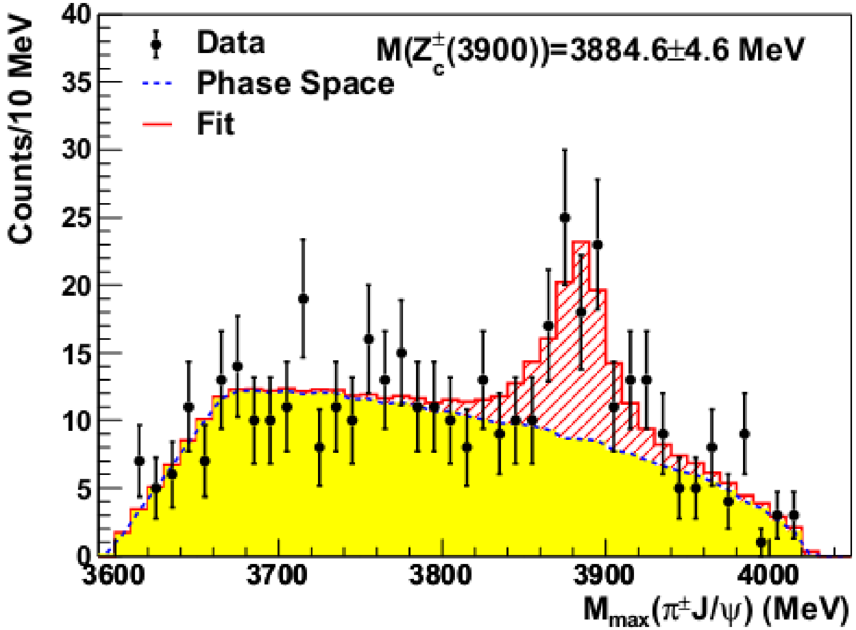


Belle independently observed Zc(3900)

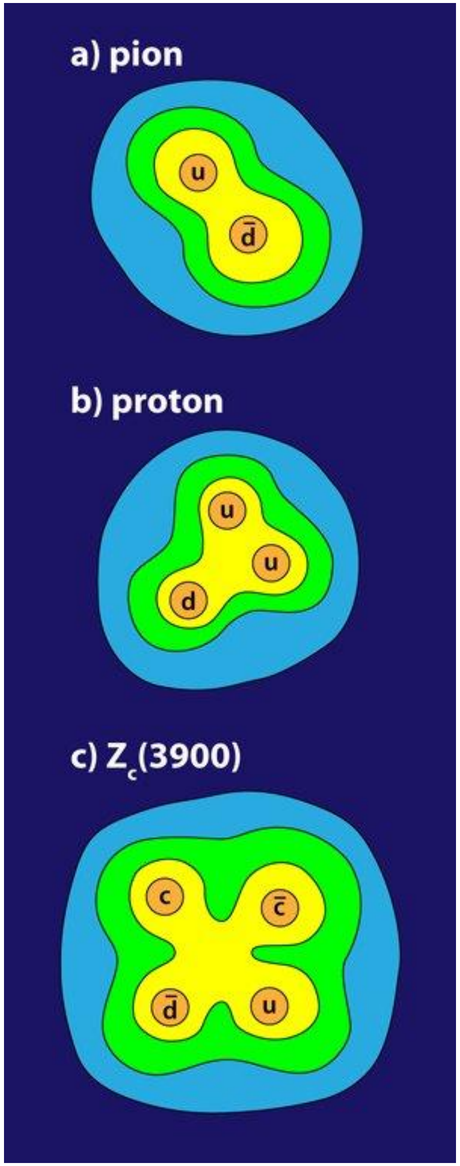
$$m = (3894.5 \pm 6.6 \pm 4.5)\ \mathrm{MeV/c^2}$$
$$\Gamma = (63 \pm 24 \pm 26)\ \mathrm{MeV}$$

Xiao et al., PLB727, 366(2013)

$$e^+e^- \to \psi(4160) \to J/\psi\pi^+\pi^-$$

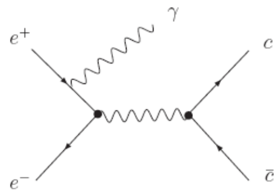
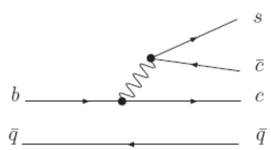
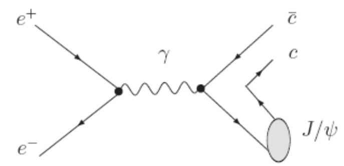
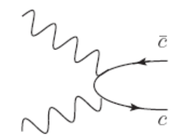


Data of CLEO-c can also reproduce Zc(3900)



Exotic state?

Charmonium-like states XYZ

$(e^+ + e^-)_{\rm ISR} \to (c\bar{c})$	$b \to s(c\bar{c})$	$e^+ + e^- \to J/\psi + (c\bar{c})$	$\gamma\gamma$ fusion
			
$Y(4260)$ $Y(4008)$ $Y(4320)$ $Y(4664)$ $X(3773)^{¶}$	$X(3872)$ $Y(3940)$ $Z^+(4430)$ $Z^+(4051)$ $Z^+(4248)$ $Y(4140)$	$X(3940)$ $X(4160)$	$Z(3930)$ $Y(3915)$ $Y(4350)$

- **Abundant observations** of charmonium-like states XYZ in the past decade

  BaBar, Belle, CLEO, CDF, CMS, LHCb
- **Four** different production **mechanisms**
- QCD strong interaction (**nonperturbative QCD effect**)

□ Zc(3900) makes the spectrum of XYZ become more **abundant**
□ **New process** different from former four production mechanisms

The lessons from studying the hidden-bottom decays of Υ(5S)

D.Y. Chen, X. Liu, Phys.Rev.D84:074032,2011

D.Y. Chen, X. Liu, Phys.Rev.D84:094003,2011

D.Y. Chen, X. Liu, T. Matsuki, Chin.Phys.C38:053102,2014

Experiment

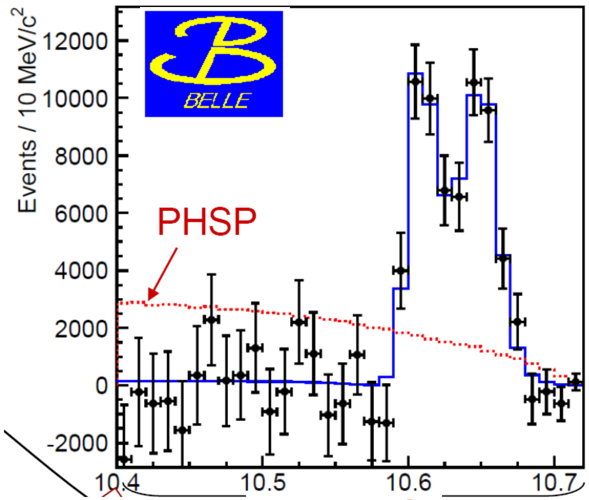
Belle Collaboration

arXiv:1105.4583

$Z_b(10610)$

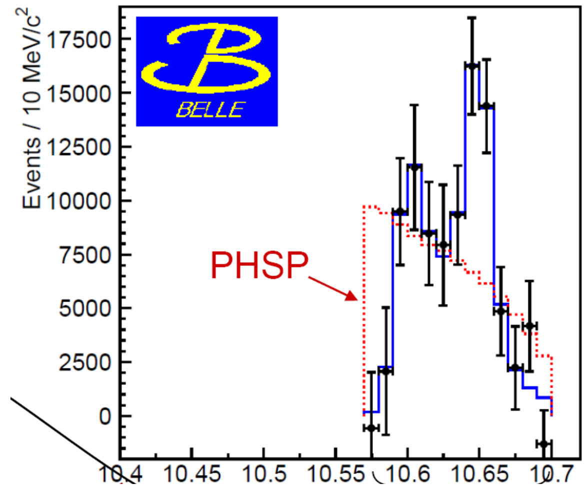
$Z_b(10650)$

$\Upsilon(5S) \to h_b(1P)\,\pi^+\pi^-$



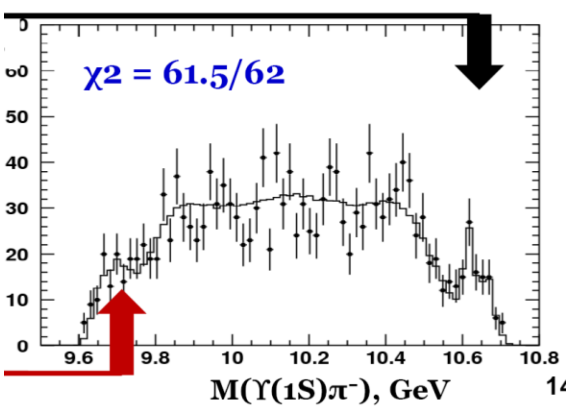
$M(h_b\pi^+)$

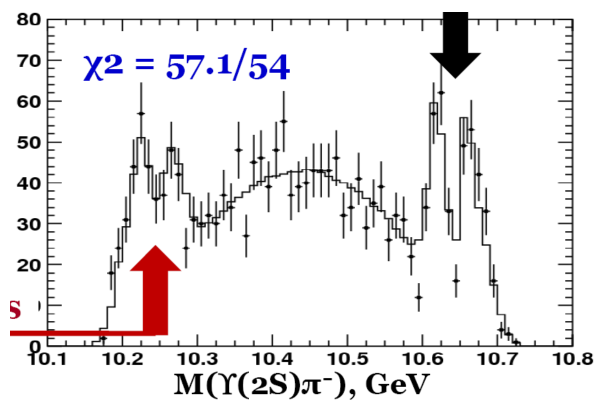
$\Upsilon(5S) \to h_b(2P)\,\pi^+\pi^-$

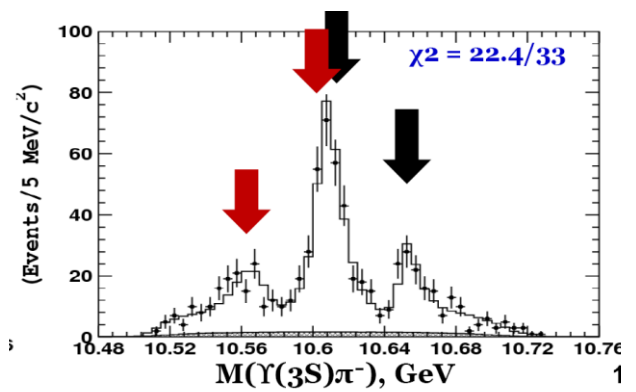


$M(h_b\pi^+)$

$\Upsilon(5S) \to \Upsilon(nS)\,\pi^+\pi^-$







	$Z_b(10610)$		$Z_b(10650)$	
Channels	Mass	Width	Mass	Width
$\Upsilon(1S)\pi^{\pm}$	$10609 \pm 3 \pm 2$	$22.9 \pm 7.3 \pm 2$	$10660 \pm 6 \pm 2$	$12 \pm 10 \pm 3$
$\Upsilon(2S)\pi^{\pm}$	$10616 \pm 2^{+3}_{-4}$	$21.1 \pm 4^{+2}_{-3}$	$10653 \pm 2 \pm 2$	$16.4 \pm 3.6^{+4}_{-6}$
$\Upsilon(3S)\pi^{\pm}$	$10608 \pm 2^{+5}_{-2}$	$12.2 \pm 1.7 \pm 4$	$10652 \pm 2 \pm 2$	$10.9 \pm 2.6^{+4}_{-2}$
$h_b(1P)\pi^{\pm}$	$10605.1 \pm 2.2^{+3.0}_{-1.0}$	$11.4^{+4.5}_{-3.9}{}^{+2.1}_{-1.2}$	$10654.5 \pm 2.5^{+1.0}_{-1.9}$	$20.9^{+5.4}_{-4.7}{}^{+2.1}_{-5.7}$
$h_b(2P)\pi^{\pm}$	$10596 \pm 7^{+5}_{-2}$	$16^{+16}_{-10}{}^{+13}_{-4}$	$10651 \pm 4 \pm 2$	$12^{+11}_{-9}{}^{+8}_{-2}$
Thresholds	$m_{B\bar{B}^*} = 10604.4$		$m_{B^*\bar{B}^*} = 10650.2$	

FIG. 1: (Color online.) The measured parameters of $Z_b(10610)$ and $Z_b(10650)$ by five different decay channels [1], and the comparison of these parameters with the $B\bar{B}^*$ and $B^*\bar{B}^*$ threshold [2]. Here, all values are in units of MeV.

- ✓ **Charged bottomonium-like structures**
- ✓ **Close to the $B\bar{B}^*$ and $B^*\bar{B}^*$ threshold**

Dipion hidden-bottom decays of Y(5S)

Puzzle of Y(5S) decays

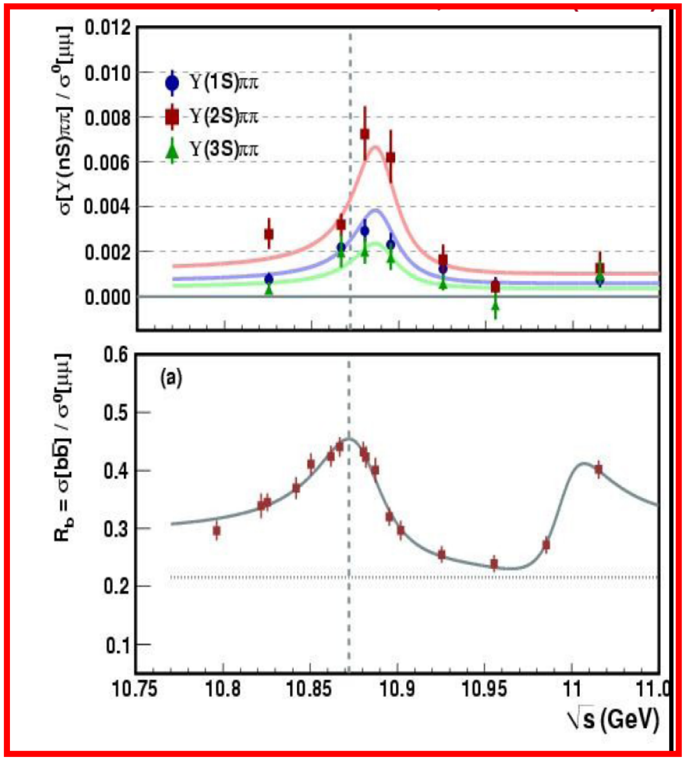
Anomalous production of Y(ns) $\pi^+\pi^-$ with 21.7 fb^{-1}

PRL100, 112001 (2008)

	Γ (MeV)
Y(5S)→Y(1S) $\pi^+\pi^-$	**0.59±0.04±0.09**
Y(5S)→**Y(2S)** $\pi^+\pi^-$	0.85±0.07±0.16
Y(5S)→**Y(3S)** $\pi^+\pi^-$	0.52
Y(2S)→**Y(1S)** $\pi^+\pi^-$	0.0060
Y(3S)→**Y(1S)** $\pi^+\pi^-$	0.0009
Y(4S)→**Y(1S)** $\pi^+\pi^-$	0.0019

10^2

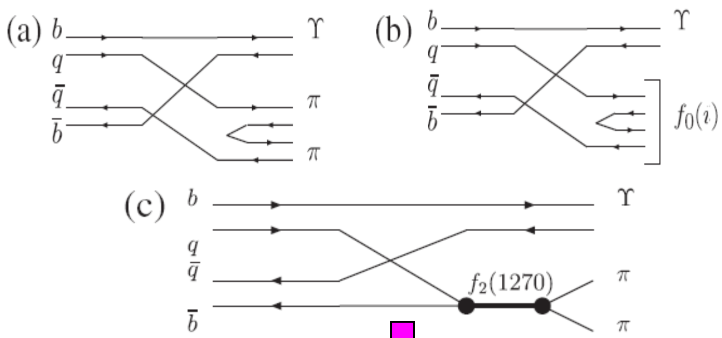
PRD82, 091106R (2011)

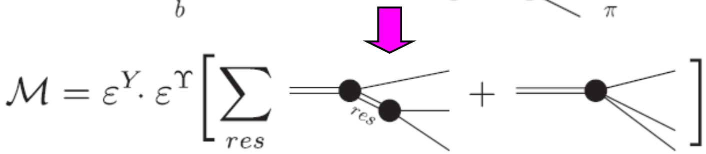


- ✓ Rescattering mechnism
  Meng, Chao, PRD77, 074003 (2008)
- ✓ Tetraquakr state Yb near Y(5S)
  Ali et. al., PLB684, 28-39 (2010)

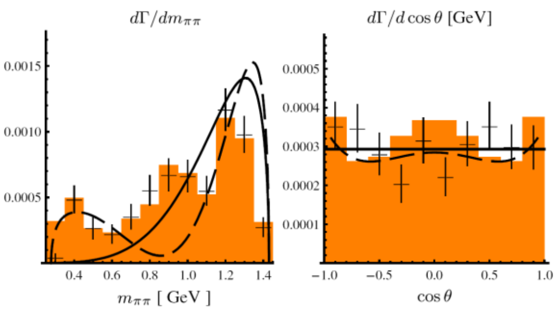
Ali et al., PRL104, 162001

Tetraquark explanation to Y(10870)

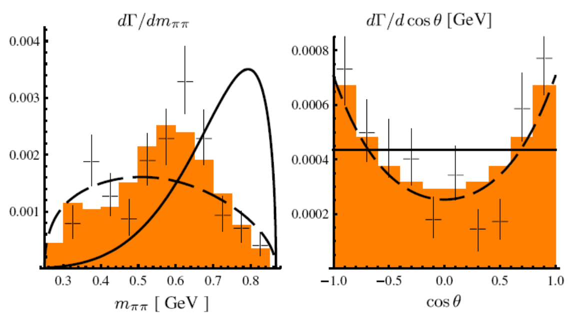




$$Y_b \rightarrow \Upsilon(1S)\pi^+\pi^-$$

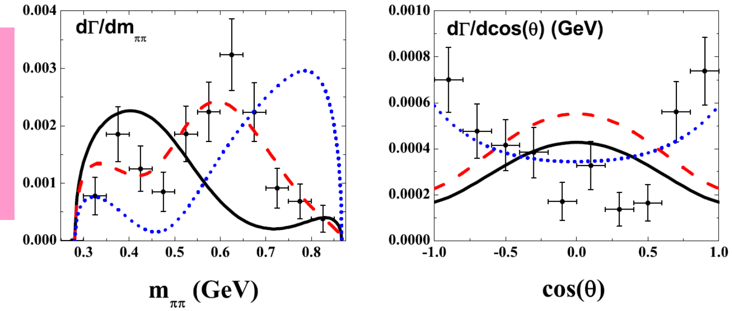


$$Y_b \rightarrow \Upsilon(2S)\pi^+\pi^-$$



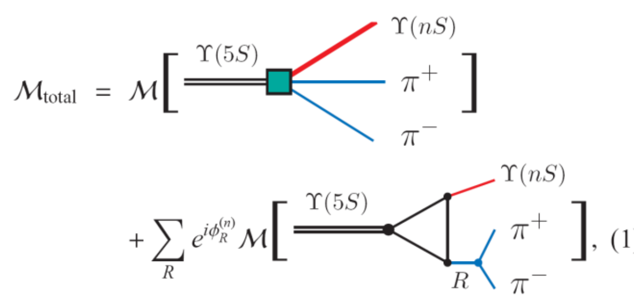
Chen, He, Li, Liu, Phys.Rev.D84:074006,2011

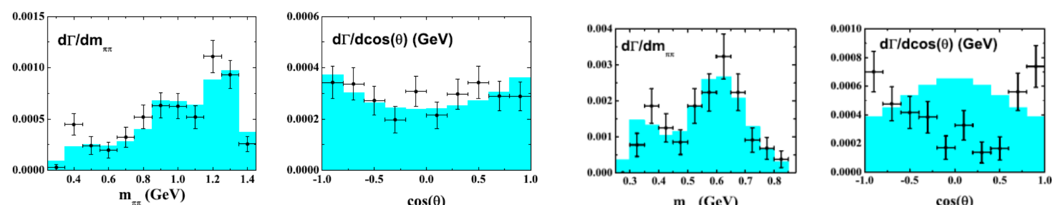
Indicate the mistake in Ali's work



Propose interference effect

In this work, we suggest that the total decay amplitude of $\Upsilon(5S) \to \Upsilon(1S, 2S)\pi^+\pi^-$ should include a few terms as





However, a new and intriguing puzzle is proposed since the predicted $d\Gamma/d\cos\theta$ of $\Upsilon(10860) \to \Upsilon(2S)\pi^+\pi^-$ is inverse to the Belle data just presented in the the right panels of Figs. 1 and 3. Associated with further theoretical exploration, future experimental study from Belle-II and SuperB will be helpful to clarify this new puzzle and give a definite conclusion.

New puzzle!

Zb structues and New Puzzle

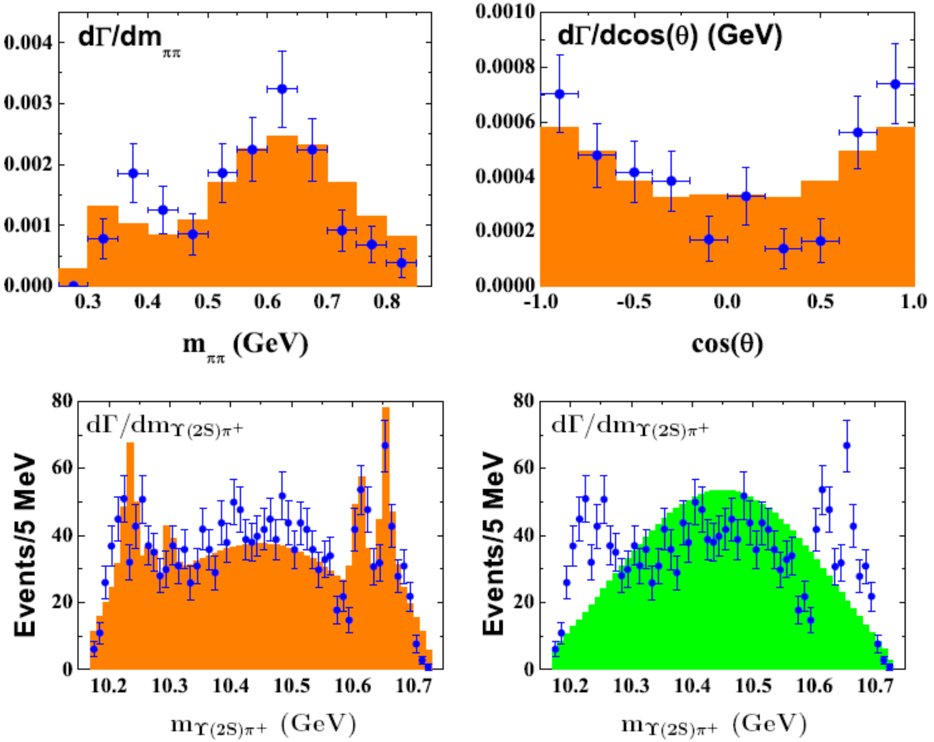
Chen, Liu, Zhu, PRD84, 074016 (2011)

Charged bottomonium-like states $Z_b(10610)$ and $Z_b(10650)$ and the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay

Dian-Yong Chen[1,3,*], Xiang Liu[1,2†,‡] and Shi-Lin Zhu[4§¶]

[1] *Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics of CAS, Lanzhou 730000, China*
[2] *School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China*
[3] *Nuclear Theory Group, Institute of Modern Physics of CAS, Lanzhou 730000, China*
[4] *Department of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China*

(Dated: May 27, 2011)



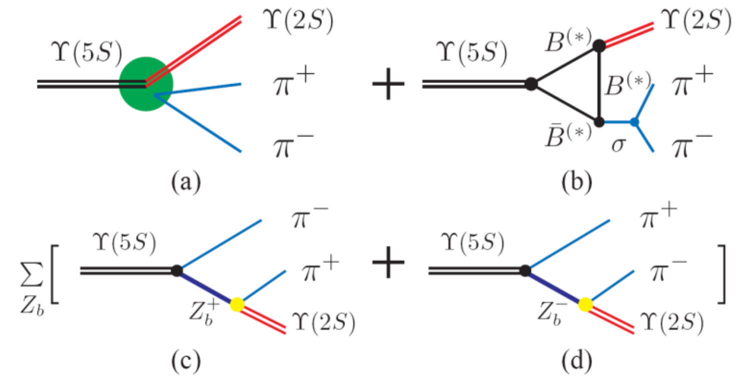
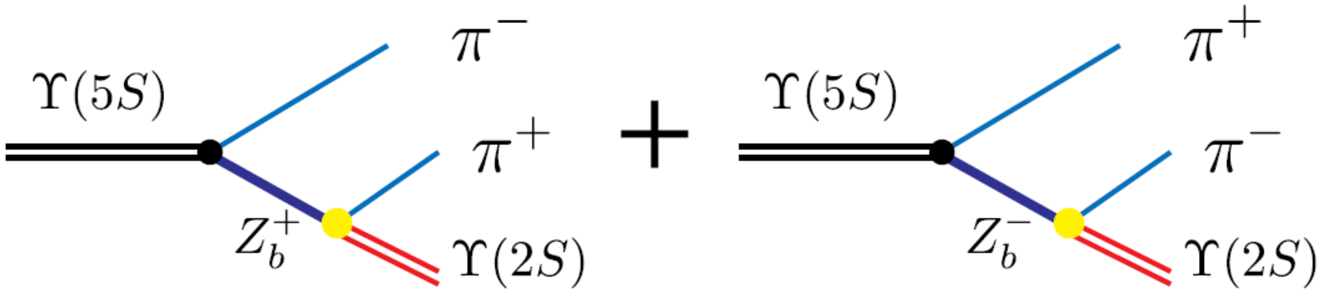


FIG. 1: The diagrams in the $\Upsilon(5S)$ hidden-bottom decay. Here, Fig. 1 (a) represents the $\Upsilon(5S)$ direct decay into $\Upsilon(2S)\pi^+\pi^-$, while Fig. 1 (b) denotes the intermediate hadronic loop contribution to $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$. (c) and (d) describe the intermediate $Z_b^\pm$ contribution to $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$, where $Z_b^\pm = \{Z_b(10610)^\pm, Z_b(10650)^\pm\}$.

Two newly observed Zb structures play an important role to solve "New puzzle" in Υ(5S)→Υ(2S)π+π- decay

Question: what is the source to generate Zb(10610) and Zb(10650)?



- ✓ Charged bottomonium-like structures
- ✓ Close to the $B^*\bar{B}$ and $B^*\bar{B}^*$ threshold

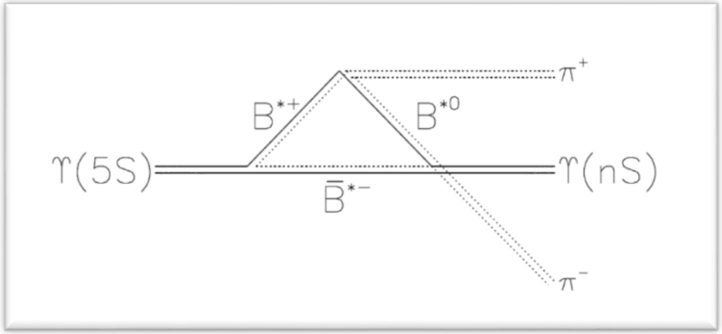
Exotic states?

$B\bar{B}^*$ and $B^*\bar{B}^*$ molecular states

Tetraquark states

Cusp effect from $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds

Bugg, Europhys. Lett.96:11002, 2011



Can we find other mechanisms to explain it?

Initial Single Pion Emission (ISPE) mechanism

D.Y. Chen, X. Liu, Phys.Rev.D84:094003,2011

First proposal for a new decay mechanism existing in Y(5S) decay

ISPE mechanism

The emitted pion with continuous energy distribution

→B* and $\bar{B}$* with low momentum

→Easily interact with each other

→B*$\bar{B}$*→Y(nS)π

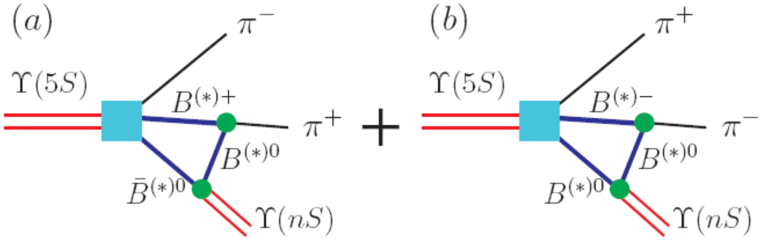
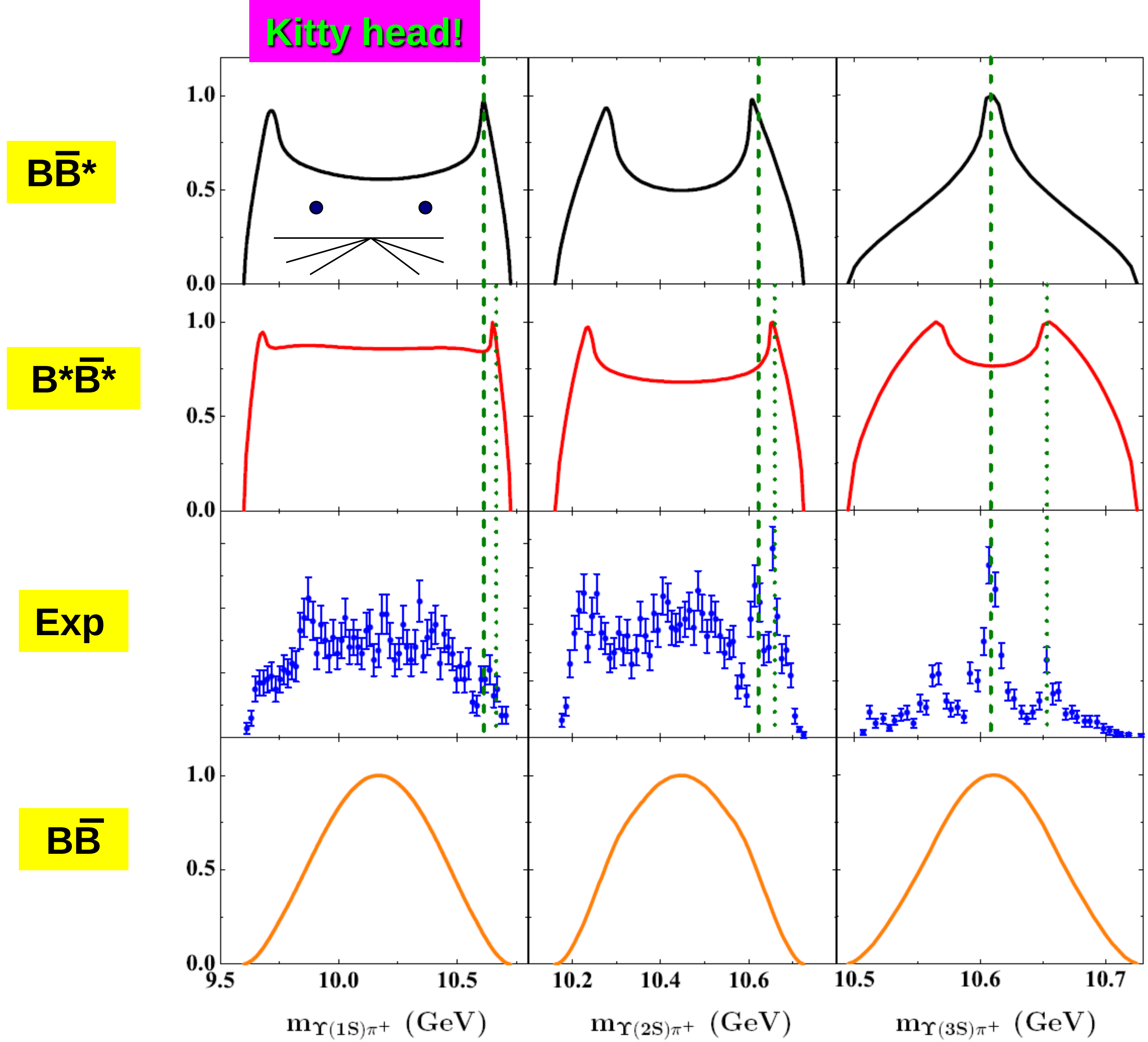
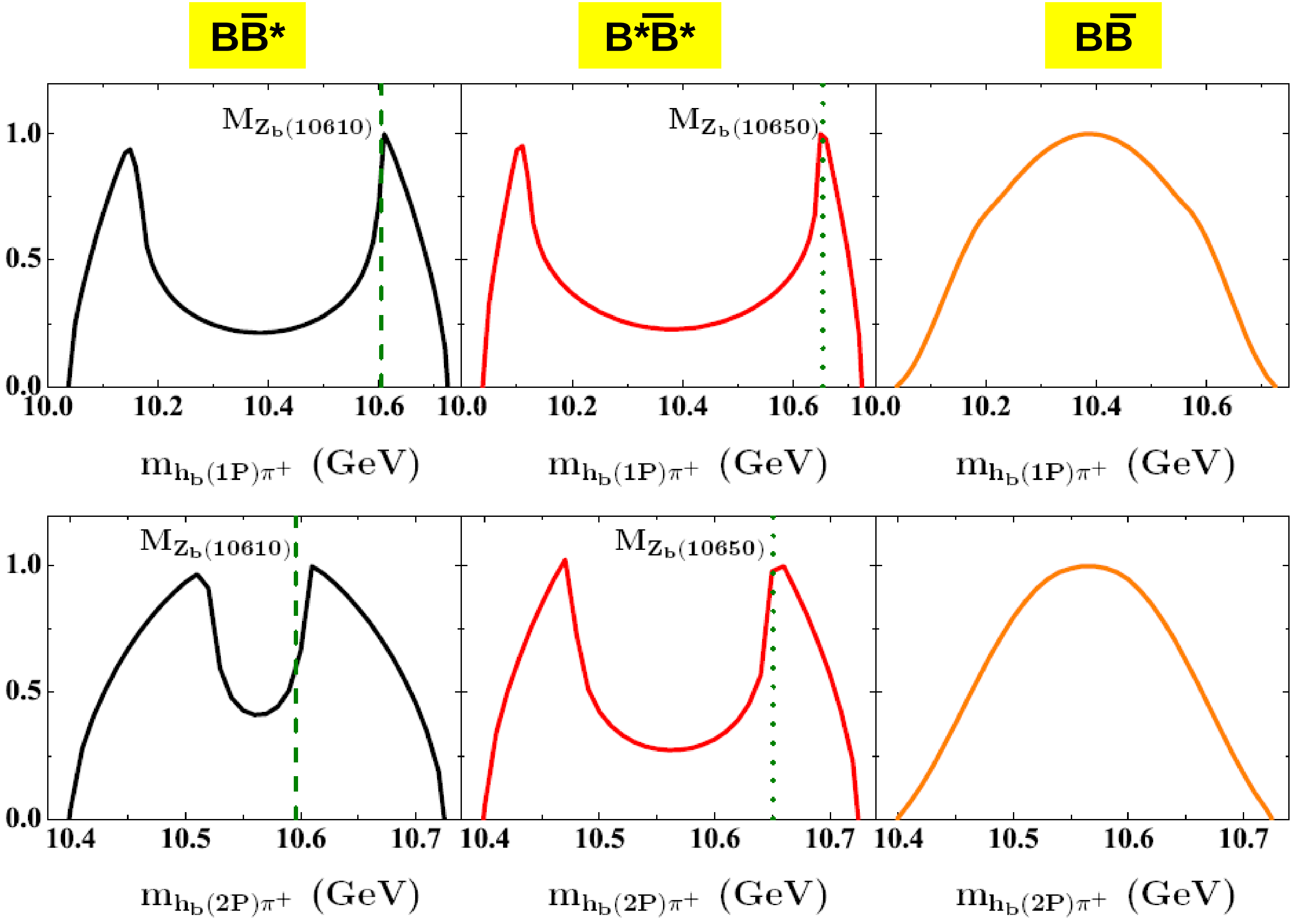


FIG. 2: (Color online.) The schematic diagrams for $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$ by the ISPE mechanism. Here, diagrams (a) and (b) are related to each other by particle antiparticle conjugation, i.e., $B^{(*)} \rightleftharpoons \bar{B}^{(*)}$ and $\pi^+ \rightleftharpoons \pi^-$. After performing the transformations $B^{(*)+} \rightleftharpoons B^{(*)0}$, $B^{(*)-} \rightleftharpoons \bar{B}^{(*)0}$ and $\pi^+ \rightleftharpoons \pi^-$, we obtain the remaining diagrams. By replacing $\Upsilon(nS)$ with $h_b(mP)$, one obtains the diagrams for $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$.


Kitty head!
$B\bar{B}^*$
$B^*\bar{B}^*$
Exp
$B\bar{B}$
1.0
0.5
0.0
9.5
10.0
10.5
10.2
10.4
10.6
10.5
10.6
10.7
$m_{\Upsilon(1S)\pi^+}$ (GeV)
$m_{\Upsilon(2S)\pi^+}$ (GeV)
$m_{\Upsilon(3S)\pi^+}$ (GeV)



D.Y. Chen, X. Liu, Phys.Rev.D84:094003,2011

Chen, Liu, Zhu, PRD84, 074016 (2011)

Charged bottomonium-like states $Z_b(10610)$ and $Z_b(10650)$ and the $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$ decay

Dian-Yong Chen[1,3,*] Xiang Liu[1,2†,‡] and Shi-Lin Zhu[4§¶]
[1]Research Center for Hadron and CSR Physics, Lanzhou University and Institute of Modern Physics of CAS, Lanzhou 730000, China
[2]School of Physical Science and Technology, Lanzhou University, Lanzhou 730000, China
[3]Nuclear Theory Group, Institute of Modern Physics of CAS, Lanzhou 730000, China
[4]Department of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
(Dated: May 27, 2011)

A underlying mechanism without introducing exotic explanation!

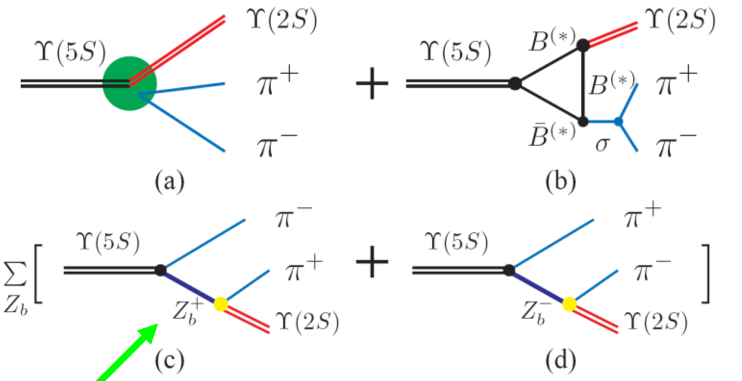
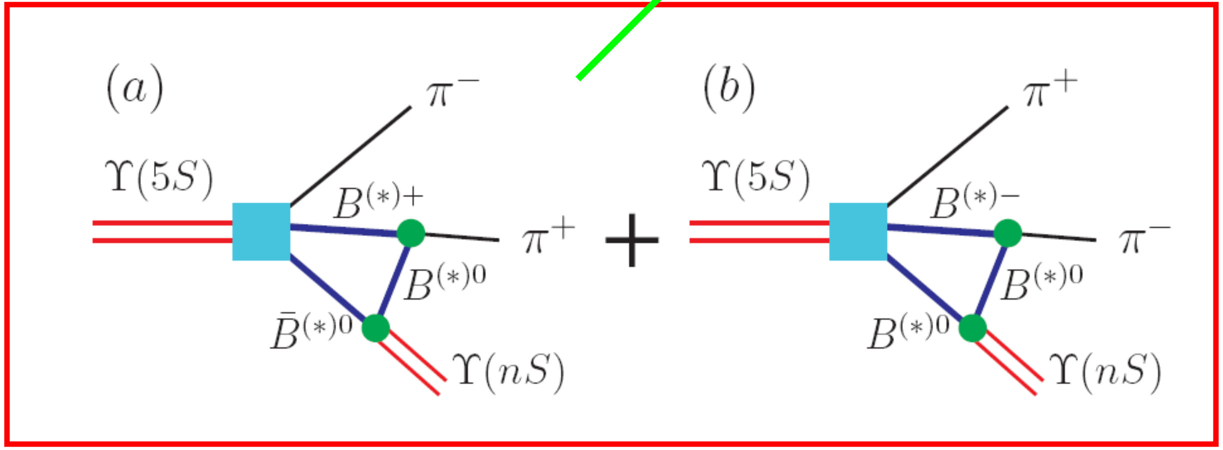


FIG. 1: The diagrams in the $\Upsilon(5S)$ hidden-bottom decay. Here, Fig. 1 (a) represents the $\Upsilon(5S)$ direct decay into $\Upsilon(2S)\pi^+\pi^-$, while Fig. 1 (b) denotes the intermediate hadronic loop contribution to $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$. (c) and (d) describe the intermediate $Z_b^\pm$ contribution to $\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$, where $Z_b^\pm = \{Z_b(10610)^\pm, Z_b(10650)^\pm\}$.



- ➢ Explain why the charged structures near $B\bar{B}^*$ and $B^*\bar{B}^*$ thresholds can be found in the hidden-charm dipion decays of Y(5S)
- ➢ We cannot find the sharp peak close to the $B\bar{B}$ threshold

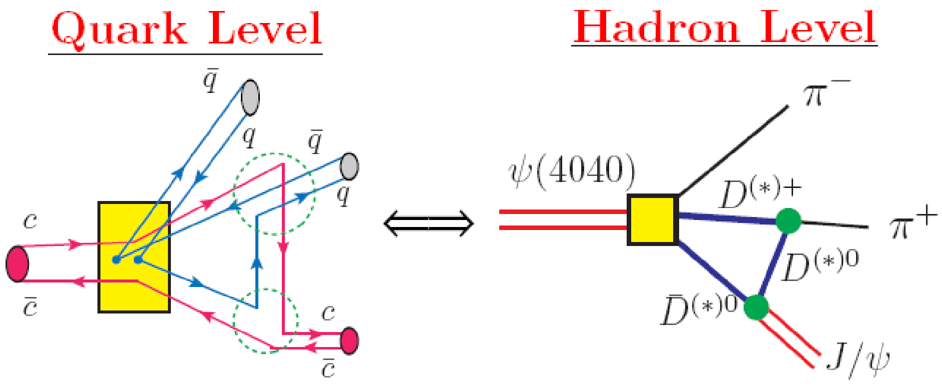
Novel charged structures
existing in the hidden-charm dipion decays of
higher charmonia or charmonium-like states

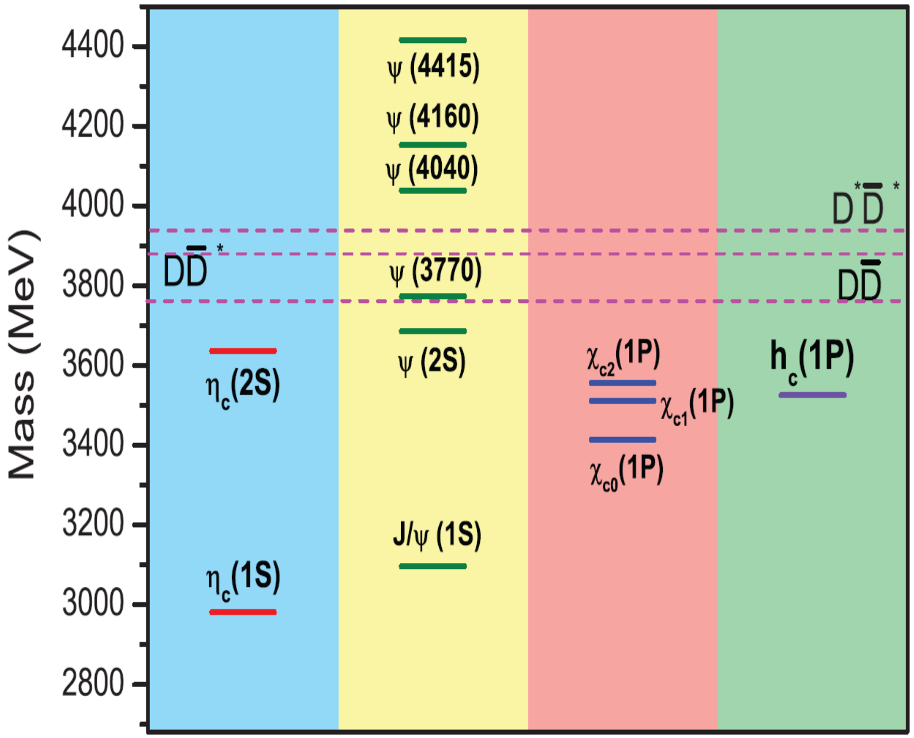
Motivation:

If the ISPE mechanism is a universal mechanism in heavy quarkonium dipion decays, Chen and Liu naturally extend the ISPE mechanism to study the hidden-charm dipion decays of higher charmonia

- The **similarity** between **charmonium and bottomonium**
- Give **predictions** for future experiments
- **An important test to the ISPE mechanism**

D.Y. Chen, X. Liu, Phys.Rev.D84:094003,2011





ISPE mechanism

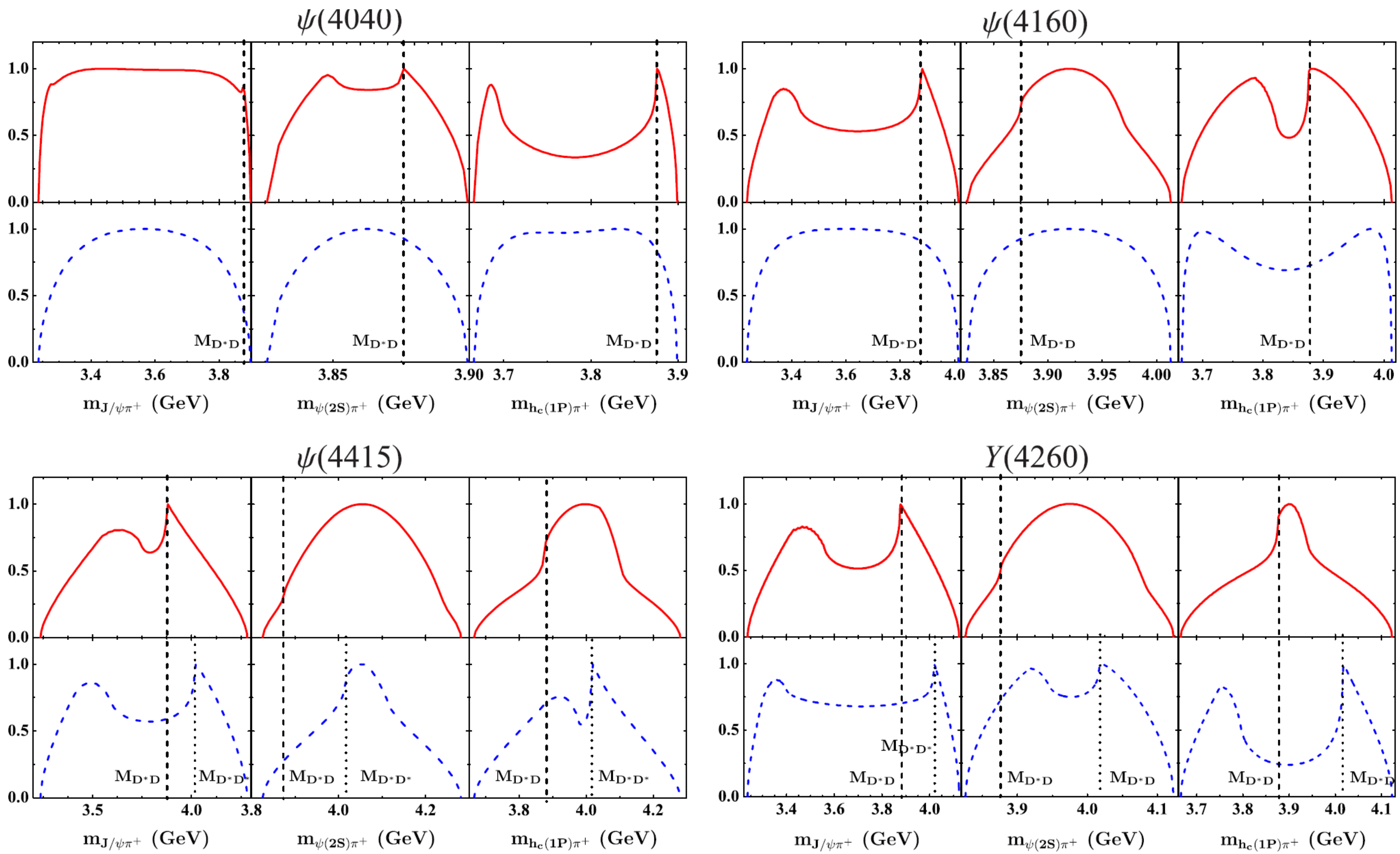
- ✓ **Higher charmonia**

  Ψ(4040),Ψ(4160),Ψ(4415)

- ✓ **Charmonium-like state**

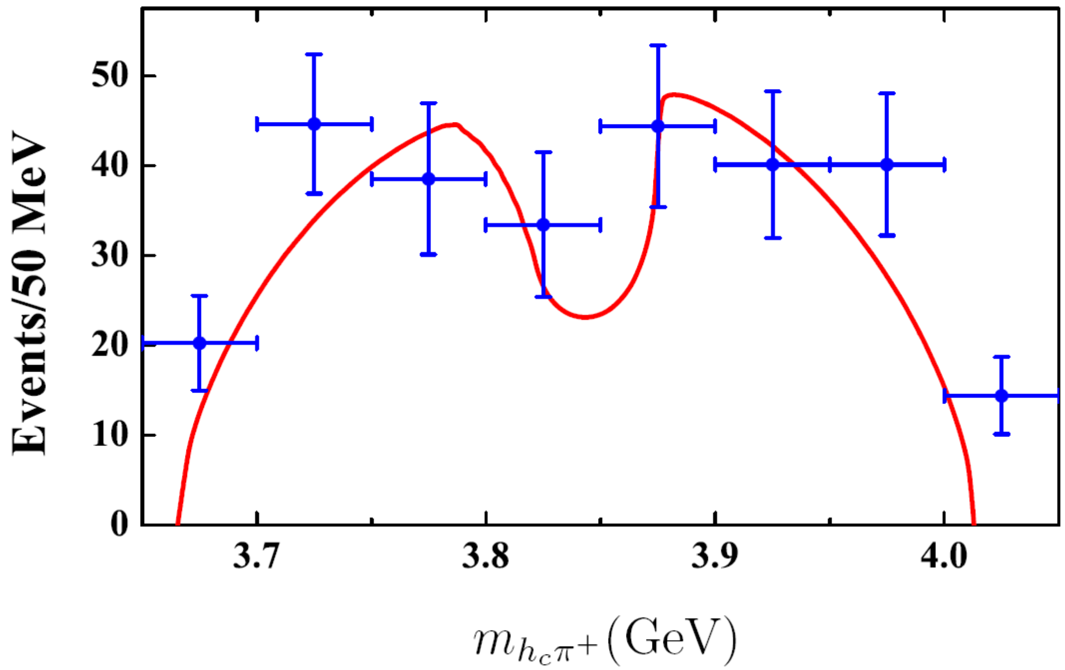
  Y(4260), Y(4360)

Predict the charged charmonium-like structures near the $D\bar{D}^*$ and $D^*\bar{D}^*$ thresholds.



D.Y. Chen, X. Liu, Phys.Rev.D84:094003,2011

D.Y. Chen, X. Liu, Phys. Rev. D84, 034032 (2011)



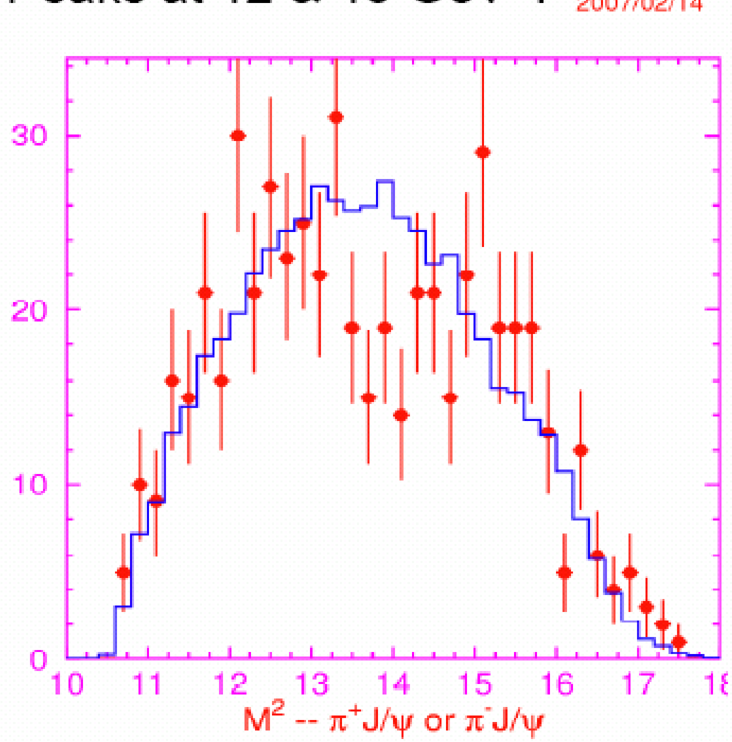
CLEO-c, PRL107, 041803 (2011)

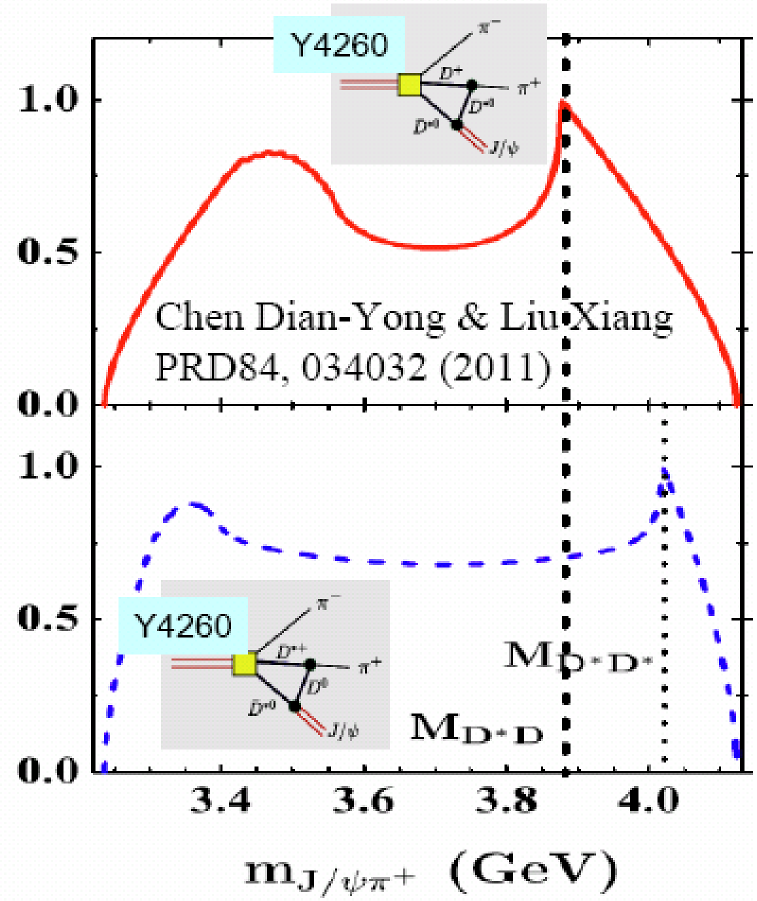
FIG. 6: (Color online.) A comparison of the $h_c\pi^\pm$ mass distribution of $\psi(4160) \to h_c(1P)\pi^+\pi^-$ (red solid line) predicted in this work and measurement by CLEO-c (blue points with errors) [31]. Here, CLEO-c measured the $h_c(1P)\pi^\pm$ mass distribution from $e^+e^- \to h_c(1P)\pi^+\pi^-$ at $E_{CM} = 4170$ MeV [31]. We normalize our numbers for a real comparison with the available CLEO-c data.

The Belle Collaboration, **Chang-Zheng Yuan's talk** given in "Hadron Structure and interactionin 2011"

Check Dalitz Plots & mass projections $(M(\pi\pi J/\psi)\in[4.2, 4.4]$ GeV)

Peaks at 12 & 15 GeV^2?

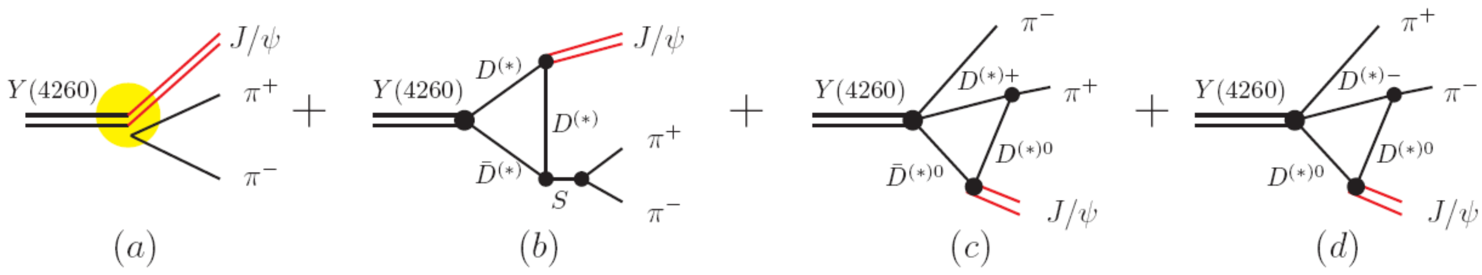




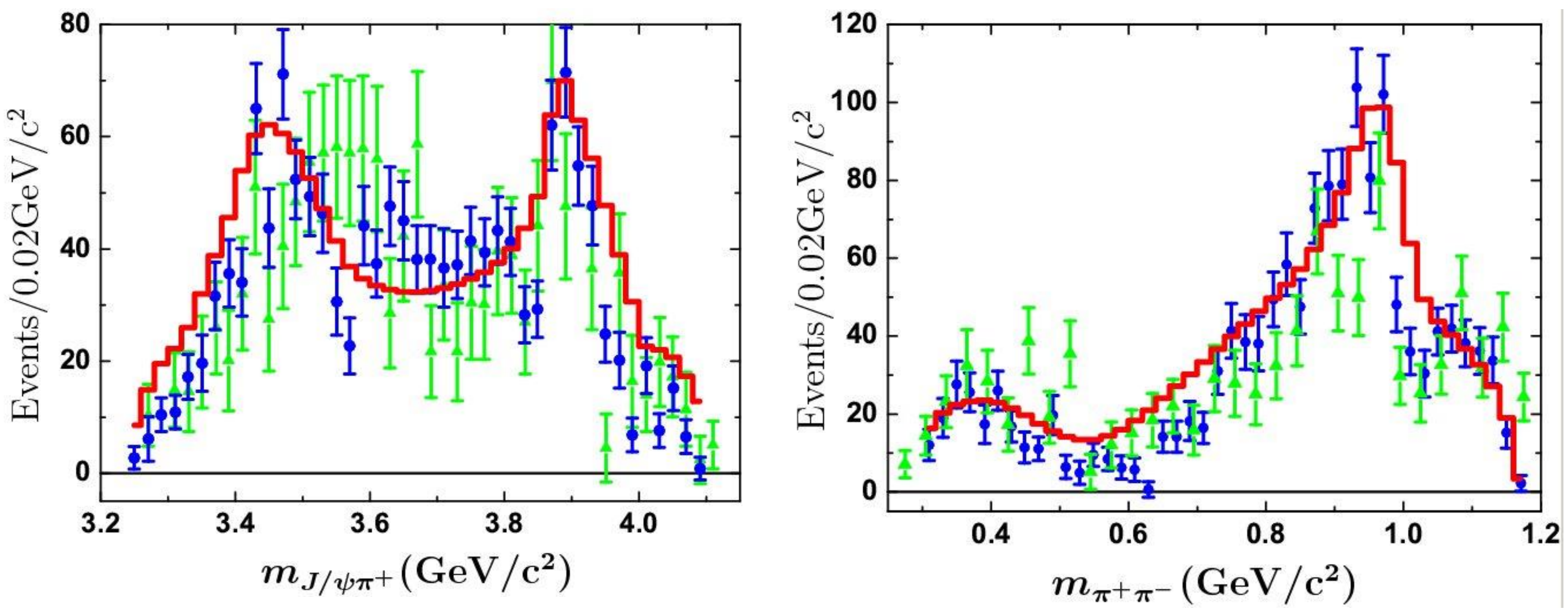
Reproduction of Zc(3900) via ISPE mechanism

D.Y. Chen, X. Liu, T. Matsuki, Phys.Rev.D88:036008,2013

D.Y. Chen, X. Liu, T. Matsuki, Phys.Rev.D88:036008,2013



Reproduce Zc(3900) via the ISPE mechanism

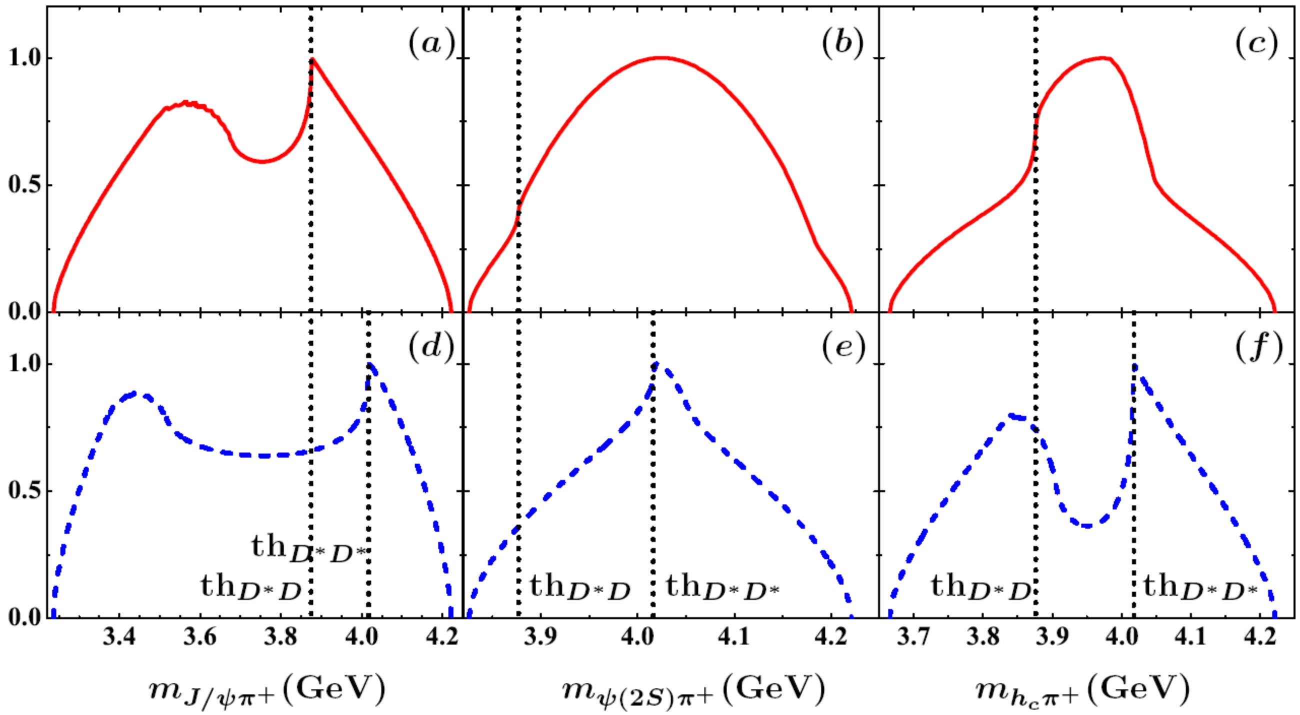


D.Y. Chen, X. Liu, T. Matsuki, Phys.Rev.D88:014034,2013

The similarity between Y(4360) and Y(4260)

Novel charged charmoniumlike structures in the hidden-charm dipion decays of Y(4360)

$$Y(4360) \to \pi^{\pm}[D^{(*)}\bar{D}^{(*)}]^{\mp}_{D^{(*)}} \to \begin{cases} J/\psi\pi^+\pi^- \\ \psi(2S)\pi^+\pi^- \\ h_c(1P)\pi^+\pi^- \end{cases},$$



$D\bar{D}^* + H.c.$

$D^*\bar{D}^*$

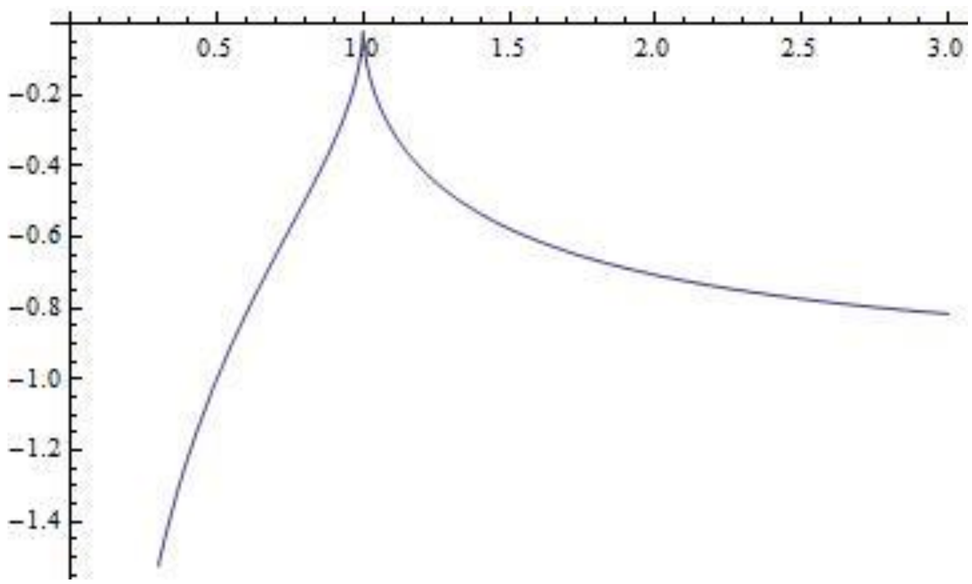
No.	Initial State	Intermediates	Peak	Final State
1)	$\psi(4040)$ [1]	$D^*\bar{D} + H.c.$	?(3860)	$\psi(2S)\pi^+\pi^- / h_c(1P)\pi^+\pi^-$
2)	$\psi(4160)$ [1]	$D^*\bar{D} + H.c.$	?(3860)	$J/\psi\pi^+\pi^- / h_c(1P)\pi^+\pi^-$
3)	$\psi(4415)$ [1]	$D^*\bar{D} + H.c.$ $D^*\bar{D}^*$ $D^*\bar{D}^*$	?(3860) ?(4016) ?(4016)	$\psi/J\pi^+\pi^-$ $\psi(2S)\pi^+\pi^-$ $h_c(1P)\pi^+\pi^-$
4)	$Y(4260)$ [1]	$D^*\bar{D} + H.c.$	?(3860)	$J/\psi\pi^+\pi^- / h_c(1P)\pi^+\pi^-$
5)	$\Upsilon(5S)$ [2]	$B^*\bar{B} + H.c.$ $B^*\bar{B}^*$ $B^*\bar{B} + H.c.$ $B^*\bar{B}^*$	$\Upsilon(10610)$ $\Upsilon(10650)$ $\Upsilon(10610)$ $\Upsilon(10650)$	$\Upsilon(1,2,3S)\pi^+\pi^-$ $\Upsilon(1,2,3S)\pi^+\pi^-$ $h_b(1,2P)\pi^+\pi^-$ $h_b(1,2P)\pi^+\pi^-$
6)	$\Upsilon(11020)$ [3]	$B^*\bar{B} + H.c.$ $B^*\bar{B}^*$	?(10605) ?(10650)	$\Upsilon(1,2S)\pi^+\pi^- / h_b(1,2P)\pi^+\pi^-$ $\Upsilon(1,2S)\pi^+\pi^- / h_b(1,2P)\pi^+\pi^-$
7)	$\Upsilon(10860)$ [3]	$B^*\bar{B} + H.c.$	?(10605)	$\Upsilon(1,2S)\pi^+\pi^-$ (implicit?)
8)	$Y(2175)/\phi(1680)$ [4]	$K^*(892)\bar{K} + H.c.$	?(1386)	$\phi(1020)\pi^+\pi^-$
9)	$\Upsilon(5S)$ [5]	$B\bar{B}^*$ $B^*\bar{B}^*$	$Z_b(10610)$ $Z_b(10650)$	$B\bar{B}^*\pi$ $B^*\bar{B}^*\pi$
10)	$\psi(4415)$ [5]	$D^{*0}D^-$ $D^{*0}D^{*-}$	?(3877) ?(4017)	$D^{*0}D^-\pi^+$ $D^{*0}D^{*-}\pi^+$
11)	$\psi(4160)$ [5]	$D^{*0}D^-$	?(3877)	$D^{*0}D^-\pi^+$
12)	$Y(4260)$ [6]	$D^{*0}D^- / D^{*0}D^{*-}$	$Z_c(3900)$	$J/\psi\pi^+\pi^-$
13)	$\psi(4360)$ [7]	$D^*\bar{D} + H.c.$	?(3860)	$J/\psi\pi^+\pi^- / h_c(1P)\pi^+\pi^-$
14)	$Y(4660)/\psi(4790)$ [8]	$D^*\bar{D}_s + D\bar{D}_s^* + H.c.$ $D^*\bar{D}_s^* + H.c.$	?(3976/3977)	$J/\psi K^+K^-$
15)	$Y(4660)/\psi(4790)$ [9]	$D^{(*)}\bar{D}^{(*)} / D_s^{(*)}\bar{D}_s^{(*)}$	?(4018/4081/4225)	$J/\psi\eta\eta$
16)	$Y(4260)$ [10], [11]	$D^{*0}D^{*-}$	$Z_c(4025)$	$D^{*0}D^{*-}\pi^+$
17)	$Y(4260)$ [12]	$D^*\bar{D}^*, D^*\bar{D}, D\bar{D}$	$Z_c(4025) + \cdots$	$D^*\bar{D}^{(*)}\pi$ (coupled channel)

[1] D. -Y. Chen and X. Liu, Phys. Rev. D **84**, 034032 (2011) [arXiv:1106.5290 [hep-ph]].
[2] D. -Y. Chen and X. Liu, Phys. Rev. D **84**, 094003 (2011) [arXiv:1106.3798 [hep-ph]].
[3] D. -Y. Chen, X. Liu and T. Matsuki, Phys. Rev. D **84**, 074032 (2011) [arXiv:1108.4458 [hep-ph]].
[4] D. -Y. Chen, X. Liu and T. Matsuki, Eur. Phys. J. C **72**, 2008 (2012) [arXiv:1112.3773 [hep-ph]].
[5] D. -Y. Chen, X. Liu and T. Matsuki, Chinese Phys. C **38**, 053102 (2014) [arXiv:1208.2411 [hep-ph]].
[6] D. -Y. Chen, X. Liu and T. Matsuki, Phys. Rev. D **88**, 036008 (2013) [arXiv:1304.5845 [hep-ph]].
[7] D. -Y. Chen, X. Liu and T. Matsuki, Phys. Rev. D **88**, 014034 (2013) [arXiv:1306.2080 [hep-ph]].
[8] D. -Y. Chen, X. Liu and T. Matsuki, Phys. Rev. Lett. **110**, 232001 (2013) [arXiv:1303.6842 [hep-ph]].
[9] D. Y. Chen, X. Liu and T. Matsuki, arXiv:1309.4528 [hep-ph].
[10] X. Wang, Y. Sun, D. -Y. Chen, X. Liu and T. Matsuki, Eur. Phys. J. C **74**, 2761 (2014) [arXiv:1308.3158 [hep-ph]].
[11] J. He, X. Liu, Z. -F. Sun and S. -L. Zhu, Eur. Phys. J. C **73**, 2635 (2013) [arXiv:1308.2999 [hep-ph]].

Cusp effect / Threshold effect
can be described as (S wave)

$$f(s)=\begin{cases}\sqrt{\frac{1}{s}-1} & 0<s<1\\ \sqrt{1-\frac{1}{s}} & 1<s\end{cases}$$

$$\frac{1}{s}\rightarrow\frac{(m_1+m_2)^2}{s}$$



Peak structure very much looks like **ISChE**

ISChE mechanism and the predicted charged charmoniumlike structures with the hidden-charm and open-strange

D.Y. Chen, X. Liu and T. Matsuki
Phys.Rev.Lett. 110 (2013) 232001

The initial single chiral particle emission (ISChE) mechanism

D.Y. Chen, X. Liu and T. Matsuki, Phys.Rev.Lett. 110 (2013) 232001

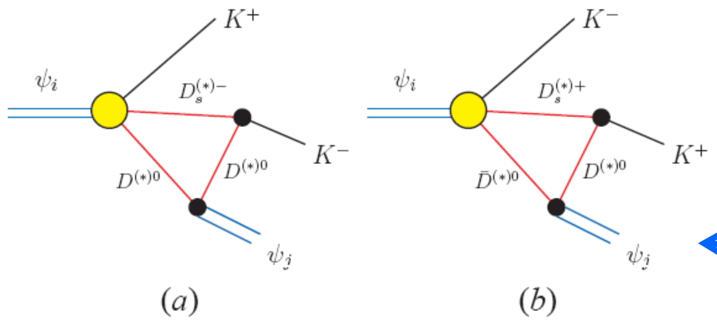


FIG. 1: (color online). Typical hadron-level diagrams of hidden-charm di-kaon decay of higher charmonium by the ISChE mechanism. Here, ψ_i denotes the initial higher charmonium and ψ_j is a charmonium in the final state.

ISChE mechanism is an important extension of ISPE mechnism proposed by us

Both the pion and kaon can be categorized as **chiral particles**.

$$\pi^{\pm} \to K^{\pm}$$

- The **hidden-charm dikaon decays** of a higher charmonium are **intriguing processes**
- The initial single chiral particle emission (**ISChE**) **mechanism** can play an **important role in these decays**

Via ISChE mechanism, we study these processes:

$$\psi(4415) \to \bar{K}[D_s\bar{D}]/K[\bar{D}_sD] \to J/\psi K^+K^-,$$
$$Y(4660) \to \bar{K}[D_s^{(*)}\bar{D}^{(*)}]/K[\bar{D}_s^{(*)}D^{(*)}] \to J/\psi K^+K^-,$$
$$\psi(4790) \to \bar{K}[D_s^{(*)}\bar{D}^{(*)}]/K[\bar{D}_s^{(*)}D^{(*)}] \to J/\psi K^+K^-,$$

Y(4660): a charmonium-like state observed in $e^+e^-\to\psi(2S)\pi^+\pi^-$ Belle, PRL99, 142002 (2007)

$\psi(4790)$: a predicted charmonium with quantum number 5S EPL85, 61002 (2009)

These processes satisfy

$$\begin{cases} m_{\psi_i} > m_K + m_{D^{(*)}} + m_{D_s^{(*)}} \\ m_{\psi_i} > m_{\psi_j} + m_{K^+} + m_{K^-} \end{cases}$$

We will answer the question of whether there exist **charged charmoniumlike structures** with both of **hidden-charm** and **open-strange** channels.

Effective Lagrangian approach is adopted to write out the decay amplitude

Effective Lagrangians

the heavy quark limit + chiral symmetry

$$\mathcal{L}_{\psi' \mathcal{D}^{(*)}\mathcal{D}^{(*)}\mathcal{P}} = -ig_{\psi'\mathcal{DDP}}\varepsilon_{\mu\nu\alpha\beta}\psi'^{\mu}\partial^{\nu}\mathcal{D}\partial^{\alpha}\mathcal{P}\partial^{\beta}\mathcal{D}^{\dagger} + g_{\psi'\mathcal{D}\mathcal{D}^*\mathcal{P}}\psi'^{\mu}(\mathcal{D}\mathcal{P}\mathcal{D}_{\mu}^{*\dagger} + \mathcal{D}_{\mu}^{*}\mathcal{P}\mathcal{D}^{\dagger})$$
$$-ig_{\psi'\mathcal{D}^*\mathcal{D}^*\mathcal{P}}\varepsilon_{\mu\nu\alpha\beta}\psi'^{\mu}\mathcal{D}^{*\nu}\partial^{\alpha}\mathcal{P}\mathcal{D}^{*\beta\dagger} - ih_{\psi'\mathcal{D}^*\mathcal{D}^*\mathcal{P}}\varepsilon_{\mu\nu\alpha\beta}\partial^{\mu}\psi'^{\nu}\mathcal{D}^{*\alpha}\mathcal{P}\mathcal{D}^{*\beta\dagger},$$

$$\mathcal{L}_{\psi\mathcal{D}^{(*)}\mathcal{D}^{(*)}} = ig_{\psi\mathcal{DD}}\psi^{\mu}(\partial_{\mu}\mathcal{D}\mathcal{D}^{\dagger} - \mathcal{D}\partial_{\mu}\mathcal{D}^{\dagger}) - g_{\psi\mathcal{D}^*\mathcal{D}}\varepsilon^{\mu\nu\alpha\beta}\partial_{\mu}\psi_{\nu}(\partial_{\alpha}\mathcal{D}_{\beta}^{*}\mathcal{D}^{\dagger} + \mathcal{D}\partial_{\alpha}\mathcal{D}_{\beta}^{*\dagger})$$
$$- ig_{\psi\mathcal{D}^*\mathcal{D}^*}\{\psi^{\mu}(\partial_{\mu}\mathcal{D}^{*\nu}\mathcal{D}_{\nu}^{*\dagger} - \mathcal{D}^{*\nu}\partial_{\mu}\mathcal{D}_{\nu}^{*\dagger}) + (\partial_{\mu}\psi_{\nu}\mathcal{D}^{*\nu} - \psi_{\nu}\partial_{\mu}\mathcal{D}^{*\nu})\mathcal{D}^{*\mu\dagger}$$
$$+ \mathcal{D}^{*\mu}(\psi^{\nu}\partial_{\mu}\mathcal{D}_{\nu}^{*\dagger} - \partial_{\mu}\psi_{\nu}\mathcal{D}^{*\nu\dagger})\},$$

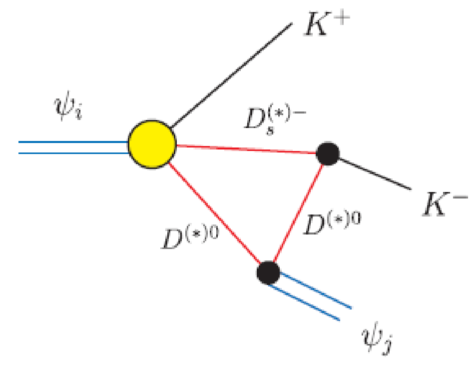
$$\mathcal{L}_{\mathcal{D}^{(*)}\mathcal{D}^{(*)}\mathcal{P}} = -ig_{\mathcal{D}^*\mathcal{DP}}(\mathcal{D}\partial_{\mu}\mathcal{P}\mathcal{D}^{*\mu\dagger} - \mathcal{D}^{*\mu}\partial_{\mu}\mathcal{P}\mathcal{D}^{\dagger}) - g_{\mathcal{D}^*\mathcal{D}^*\mathcal{P}}\varepsilon^{\mu\nu\alpha\beta}\partial_{\mu}\mathcal{D}_{\nu}^{*}\mathcal{P}\partial_{\alpha}\mathcal{D}_{\beta}^{*\dagger},$$

TABLE I. Optimal values of the coupling constants involved in the present work. These coupling constants can be related to the gauge coupling g by $g_{\psi DD} = g_{\psi D^*D^*}m_{D^*}/m_D = g_{\psi D^*D}m_{\psi}\sqrt{m_D/m_D^*} = m_{\psi}/f_{\psi}$, $g_{\psi D_s^{(*)}D_s^{(*)}} = \sqrt{(m_{D_s}^{(*)}m_{D_s}^{(*)})/(m_D^{(*)}m_D^{(*)})}g_{\psi DD}$, $g_{D_s^*D^*K} = \sqrt{m_{D_s}^*/m_{D^*}}2g/f_{\pi}$, and $g_{D_s^*DK}/\sqrt{m_{D_s^*}m_D} = g_{D^*D_sK}/\sqrt{m_{D^*}m_{D_s}} = 2g/f_{\pi}$ [15], where f_{ψ} is the decay constants of J/ψ, which is evaluated from the leptonic decay width of J/ψ. With $\Gamma_{J/\psi\to e^+e^-} = 5.55$ keV [8], we have $f_{\psi} = 416$ MeV. $f_{\pi} = 132$ MeV is the pion decay constant and $g = 0.59$ is estimated from the partial decay width of $D^* \to D\pi$ [8].

Coupling	Value	Coupling	Value	Coupling	Value
$g_{\psi DD}$	7.44	$g_{\psi D^*D}$	2.49 GeV^{-1}	$g_{\psi D^*D^*}$	8.01
$g_{\psi D_sD_s}$	7.84	$g_{\psi D_s^*D_s}$	2.62 GeV^{-1}	$g_{\psi D_s^*D_s^*}$	8.42
$g_{D_s^*DK}$	17.76	$g_{D^*D_sK}$	17.78	$g_{D_s^*D^*K}$	9.16 GeV^{-1}

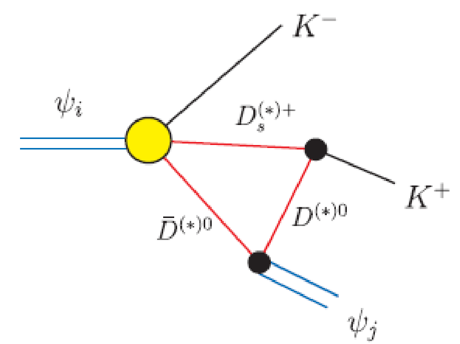
Decay amplitude:

$$\mathcal{M}\{\psi_i \to K^+[\bar{D}_s^{(*)} D^{(*)}] \to K^+ K^- \psi_j\} = \prod_i g_i \int \frac{d^4q}{(2\pi)^4} \frac{[p_3, p_4, p_5, q]_{\mu\nu}\epsilon^{\mu}_{\psi_i}\epsilon^{\nu}_{\psi_j}}{[(p_4+q)^2 - m^2_{D_s^{(*)}}][(p_5-q)^2 - m^2_{D^{(*)}}]} \times \frac{1}{q^2 - m^2_{D^{(*)}}} \mathcal{F}(q^2, m^2_{D^{(*)}}), \quad (7)$$



(a)

$$\mathcal{M}\{\psi_i \to K^-[D_s^{(*)} \bar{D}^{(*)}] \to K^+ K^- \psi_j\} = \prod_i g_i \int \frac{d^4q}{(2\pi)^4} \frac{[p_3, p_4, p_5, q]_{\mu\nu}\epsilon^{\mu}_{\psi_i}\epsilon^{\nu}_{\psi_j}}{[(p_3+q)^2 - m^2_{D_s^{(*)}}][(p_5-q)^2 - m^2_{D^{(*)}}]} \times \frac{1}{q^2 - m^2_{D^{(*)}}} \mathcal{F}(q^2, m^2_{D^{(*)}}), \quad (8)$$



(b)

$$\mathcal{F}(q^2, m_E^2) = (m_E^2 - \Lambda^2)/(q^2 - \Lambda^2)$$

$$\Lambda = \alpha\Lambda_{\rm QCD} + m_E$$

Monoploe form factor

$$
\begin{aligned}
\mathcal{A}^{\rm tot}_{DD_s} &= \mathcal{M}^{D_s^*}_{D\bar{D}_s} + \mathcal{M}^{\bar{D}^*}_{\bar{D}_s D} + \ldots, \\
\mathcal{A}^{\rm tot}_{D^* D_s + D D_s^*} &= \mathcal{M}^{D_s^*}_{D\bar{D}_s^*} + \mathcal{M}^{D_s}_{D^*\bar{D}_s} + \mathcal{M}^{D_s^*}_{D^*\bar{D}_s} + \mathcal{M}^{\bar{D}^*}_{\bar{D}_s D^*} \\
&\quad + \mathcal{M}^{\bar{D}}_{\bar{D}_s^* D} + \mathcal{M}^{\bar{D}^*}_{\bar{D}_s^* D} + \ldots, \\
\mathcal{A}^{\rm tot}_{D_s^* D^*} &= M^{D_s^*}_{D^*\bar{D}_s^*} + M^{D_s^*}_{D^*\bar{D}_s^*} + \mathcal{M}^{\bar{D}}_{\bar{D}_s^* D^*} + \mathcal{M}^{\bar{D}^*}_{\bar{D}_s^* D^*} + \ldots, \quad (14)
\end{aligned}
$$

where '...' denotes the contributions from the ISChE mechanism with K^- emitted from initial charmonia.

$$
\psi_i(p_0) \to K^+(p_3)[D^{(*)}(p_1)\bar{D}_s^{(*)}(p_2)] \to K^+(p_3)K^-(p_4)\psi_j(p_5)
$$

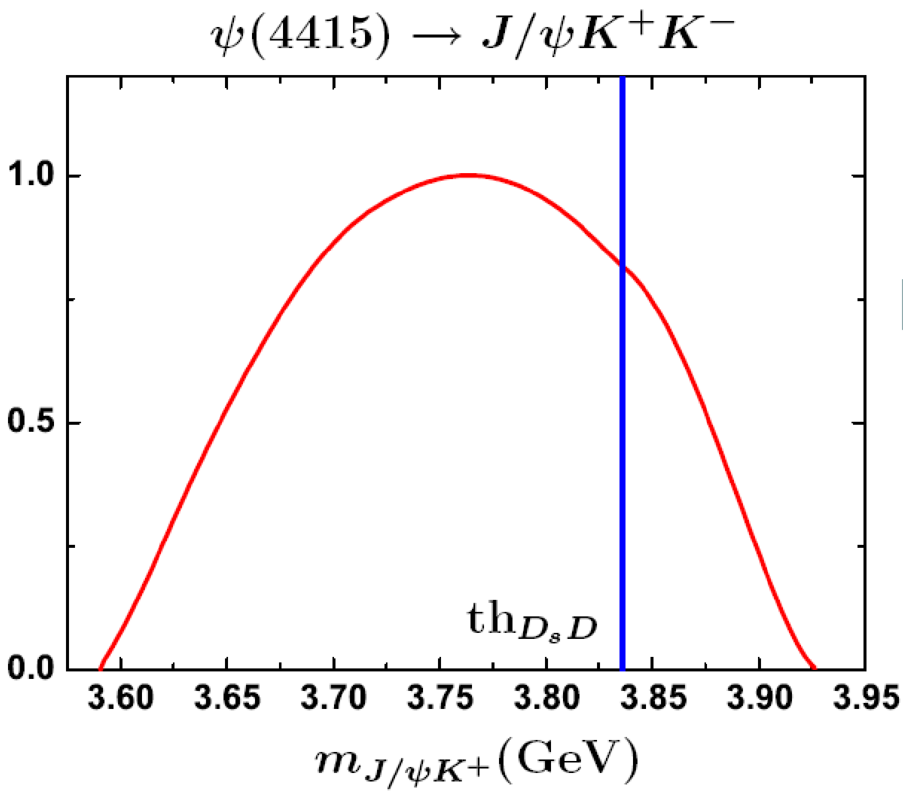
A general expression of the **differential decay width**

$$
d\Gamma = \frac{1}{3}\frac{1}{(2\pi)^3}\frac{1}{32M^3_{\psi_i}}\overline{|\mathcal{M}|^2}dm^2_{\psi_j K^+}dm^2_{K^+K^-}
$$

$$
m^2_{\psi_j K^+} = (p_3 + p_5)^2 \text{ and } m^2_{K^+K^-} = (p_3 + p_4)^2
$$

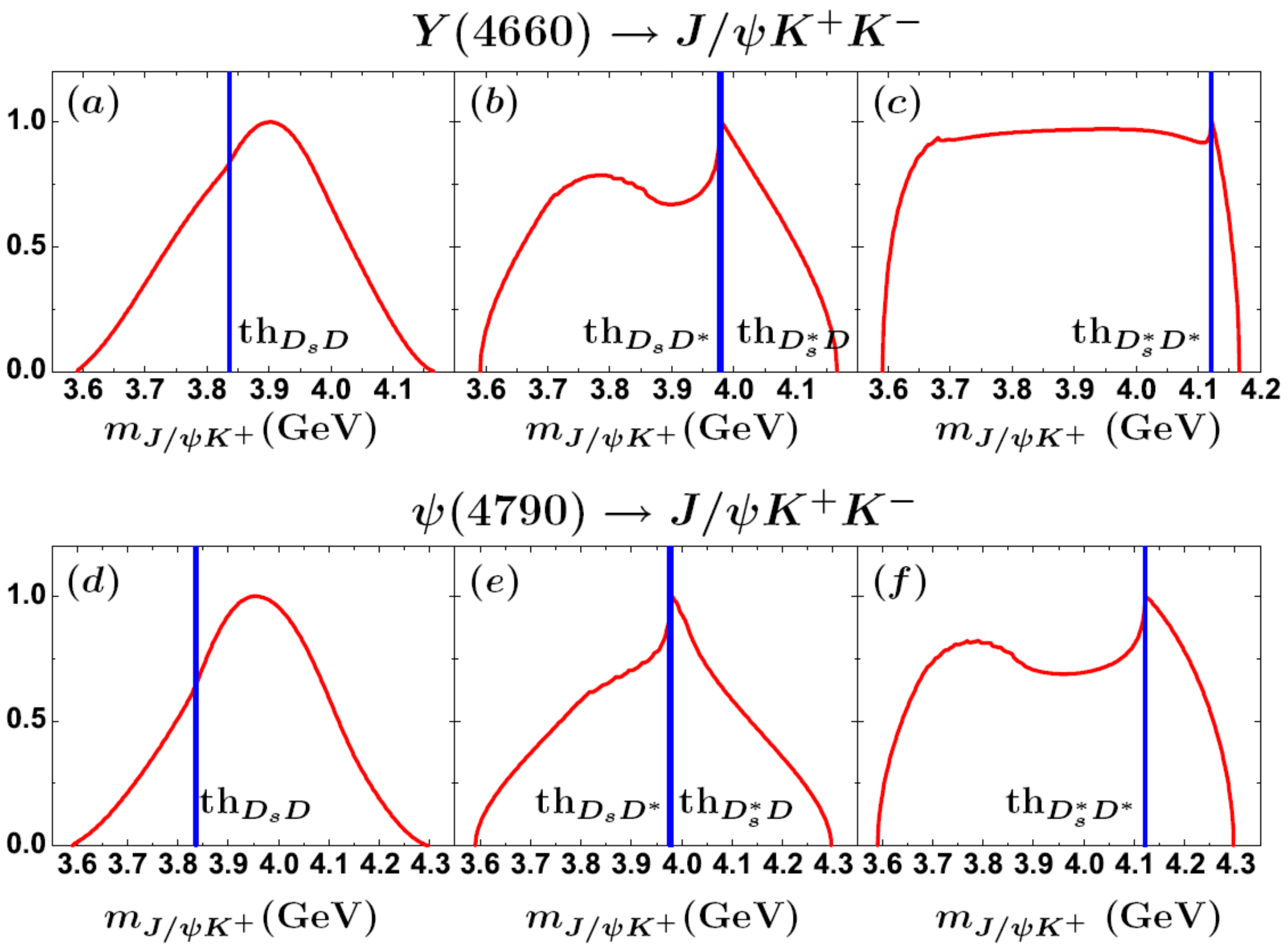
The predicted charged charmoniumlike structures with the hidden-charm and open-strange

D.Y. Chen, X. Liu and T. Matsuki, Phys.Rev.Lett. 110 (2013) 232001



Our result indicates:

No charged charmonium-like structure with hidden-charm and hidden-strange, which is near the DsD threshold can be found.



D.Y. Chen, X. Liu and T. Matsuki, Phys.Rev.Lett. 110 (2013) 232001

- There exist **enhancement structures** with both hidden-charm and open-strange.
- These predicted charged charmonium-like structures can be accessible at future experiment, especially **BESIII, BelleII** and **LHCb**.

Summary

- Charmonium-like states XYZ→ Hot research topic
- ISPE/ISChE mechanism

Predict **abundant phenomena** of charged charmonium-like structures

Recent EX: BESIII's observation Zc(3900)

- **Accessible at Belle, BESIII, BelleII, LHCb**

Good opportunity!

Thank you for your attention!