Recent progress of XYZ particles

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On behalf of Belle Collaboration

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Outline

1. The 1^{--} Y family produced via ISR.

- Y(4008), Y(4260), Y(4360), Y(4660), ψ(4040), ψ(4160)…

2. New resonances in $\gamma\gamma$ reaction.

- χ_{c2}(2P), $\gamma\gamma \rightarrow \omega\omega$, $\omega\phi$, $\phi\phi$, $\omega J/\psi$

3. Bottomnium.

- Z_b, Z_c, h_b(1P,2P), η_b(1S,2S), h_c(1P)

4. Summary.

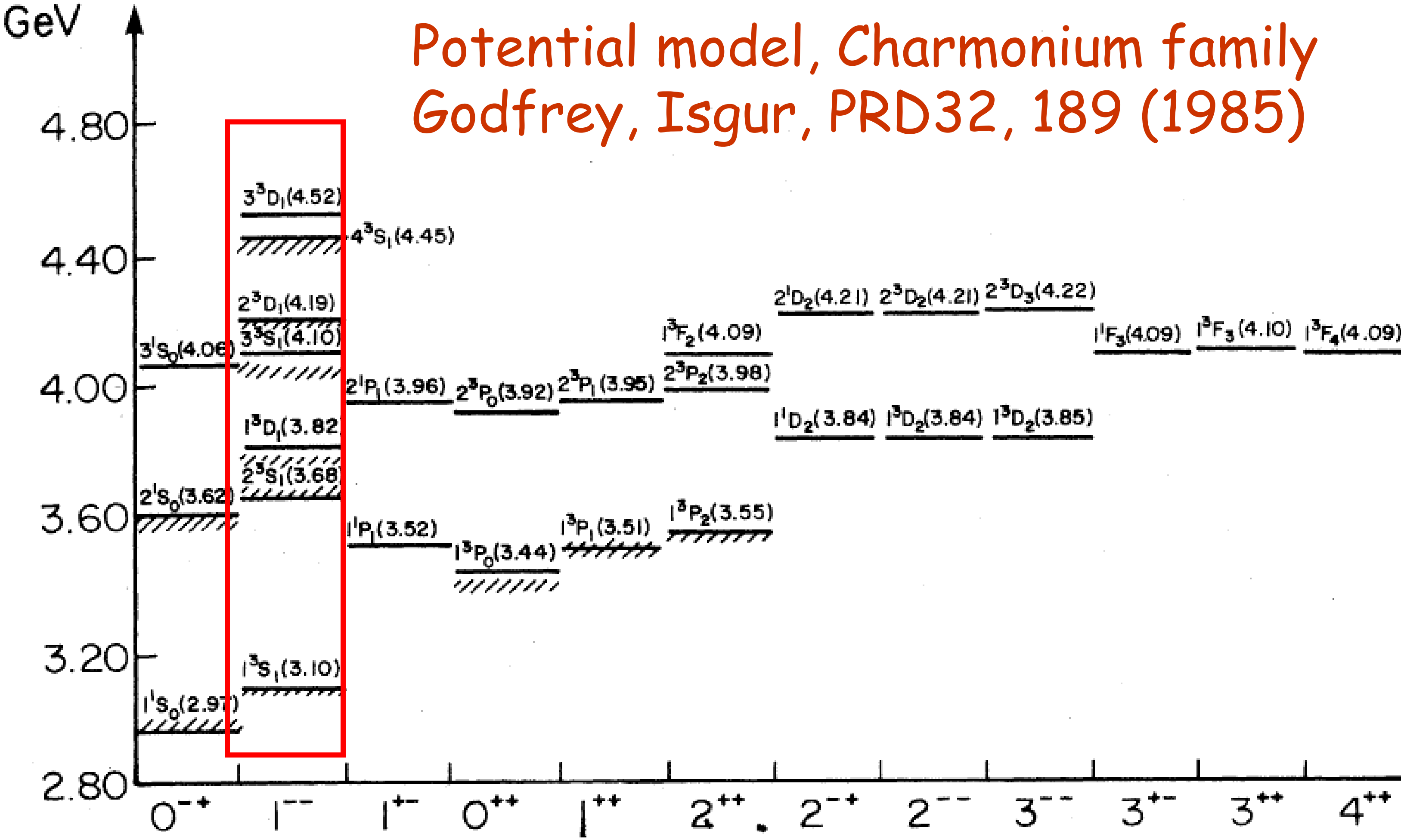
Z(4430)
Z(4250)
Z(4050)

X(3872)

XYZ(3940)

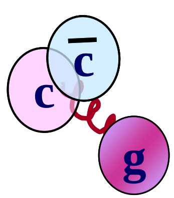
X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)

Potential model, Charmonium family
Godfrey, Isgur, PRD32, 189 (1985)

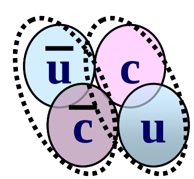


Lots of new particles discovery, which can not be assigned to potential mode naturally. New hadron models:

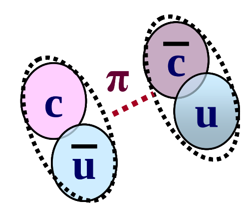
hybrid

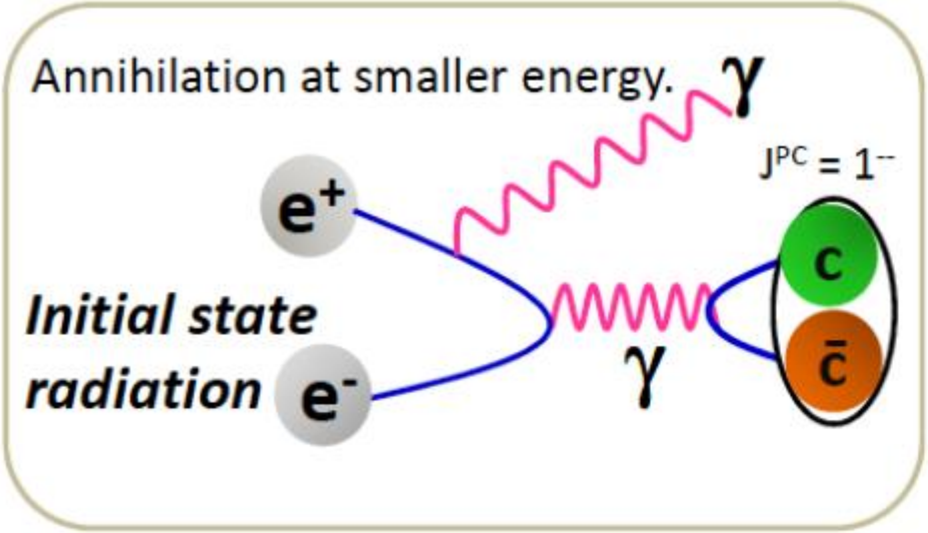


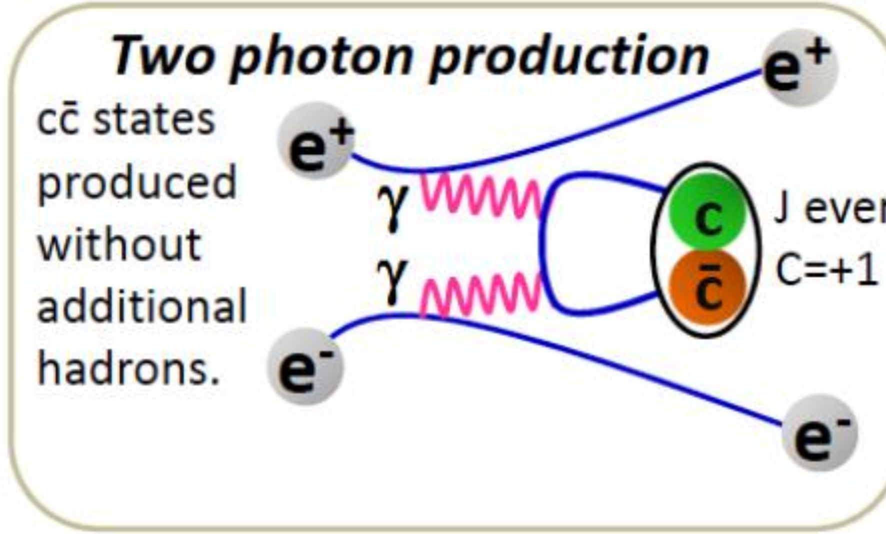
tetraquark

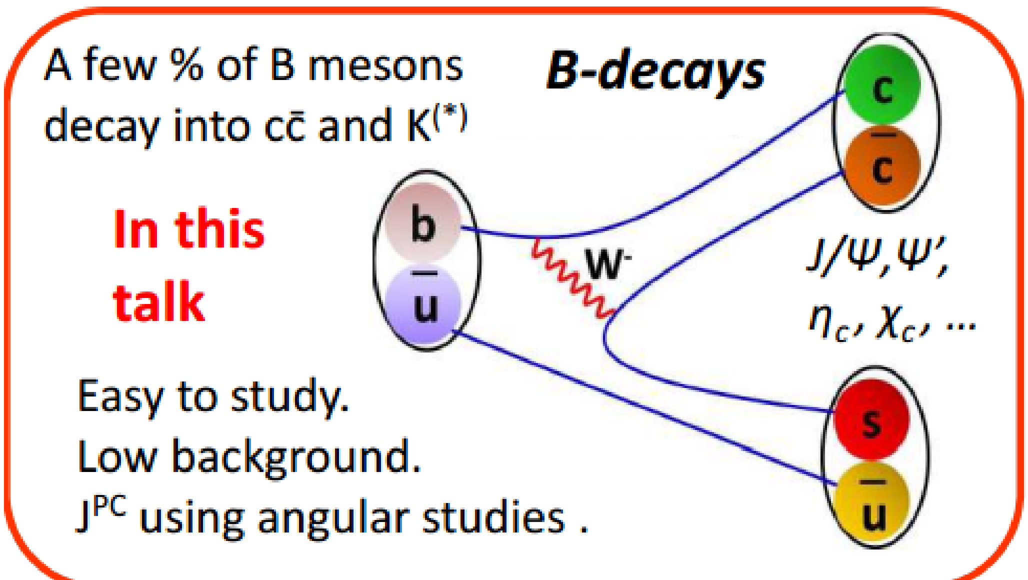


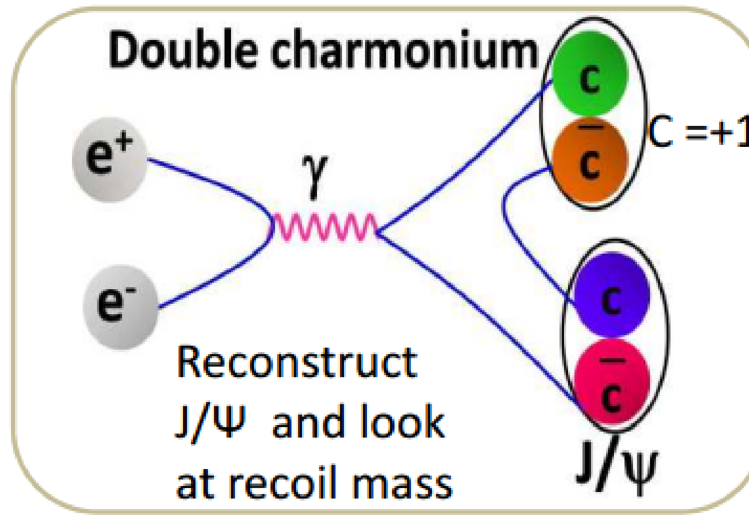
molecule




Annihilation at smaller energy.
γ
$J^{PC} = 1^{--}$
e+
Initial state
radiation
e-
γ
c
c̄


Two photon production
e+
cc̄ states
produced
without
additional
hadrons.
e+
γ
γ
c
c̄
J even
C=+1
e-
e-

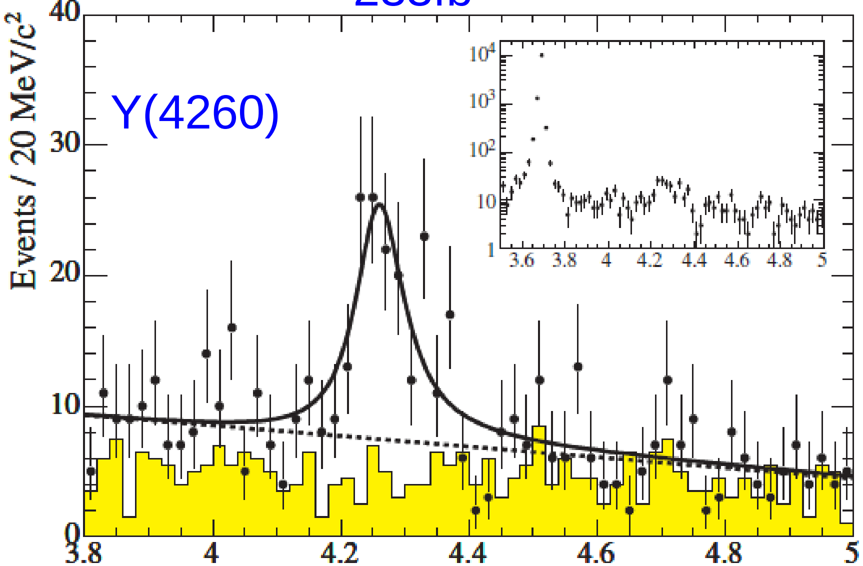

A few % of B mesons
decay into cc̄ and $K^{(*)}$
B-decays
c
c̄
In this
talk
b
ū
W-
J/Ψ,Ψ',
$\eta_c, \chi_c, \ldots$
Easy to study.
Low background.
J^{PC} using angular studies .
s
ū


Double charmonium
c
c̄
C =+1
e+
γ
e-
c
c̄
Reconstruct
J/Ψ and look
at recoil mass
J/ψ

1^{--} Charmonium-like states via ISR

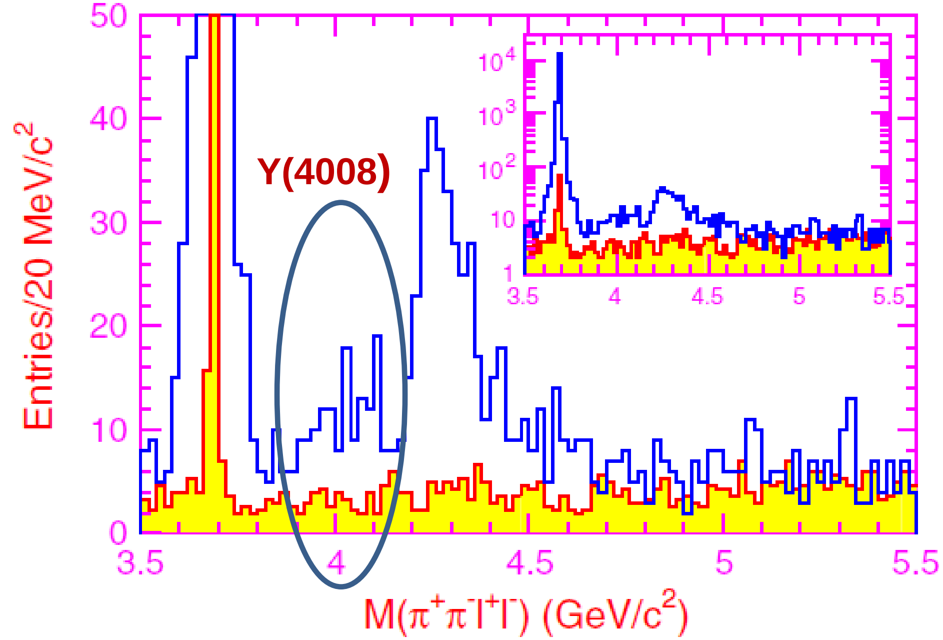
Y(4260)

$233 fb^{-1}$



BaBar, ISR method
PRL**95**,142001(2005)

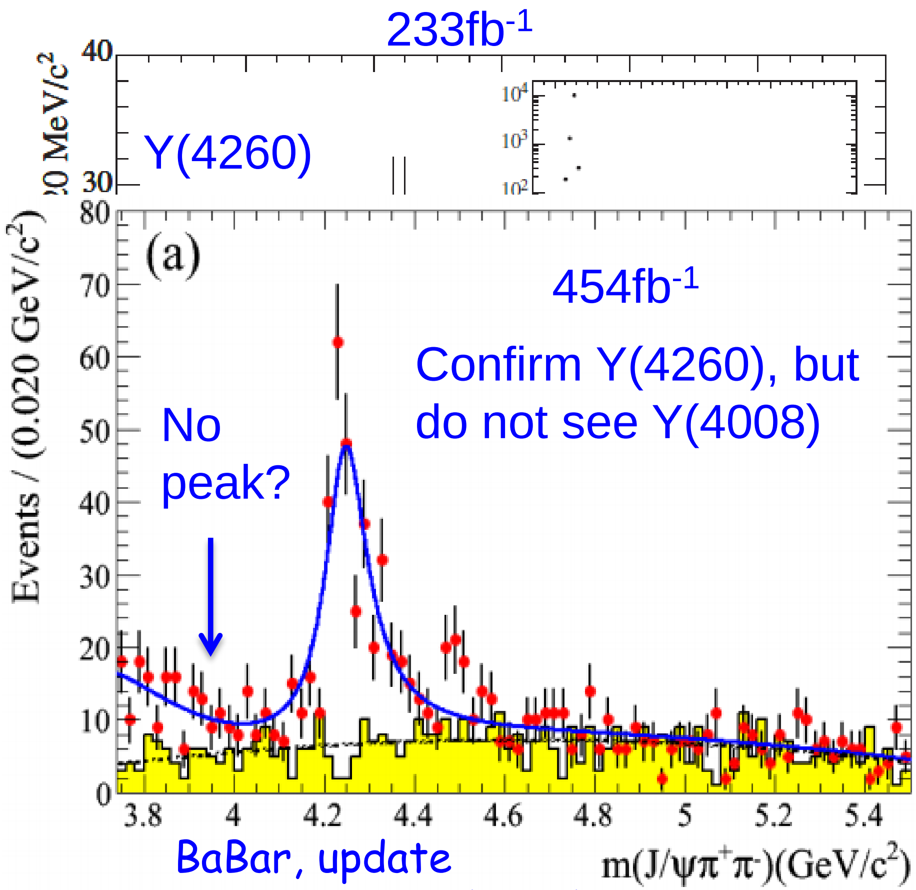
$548 fb^{-1}$



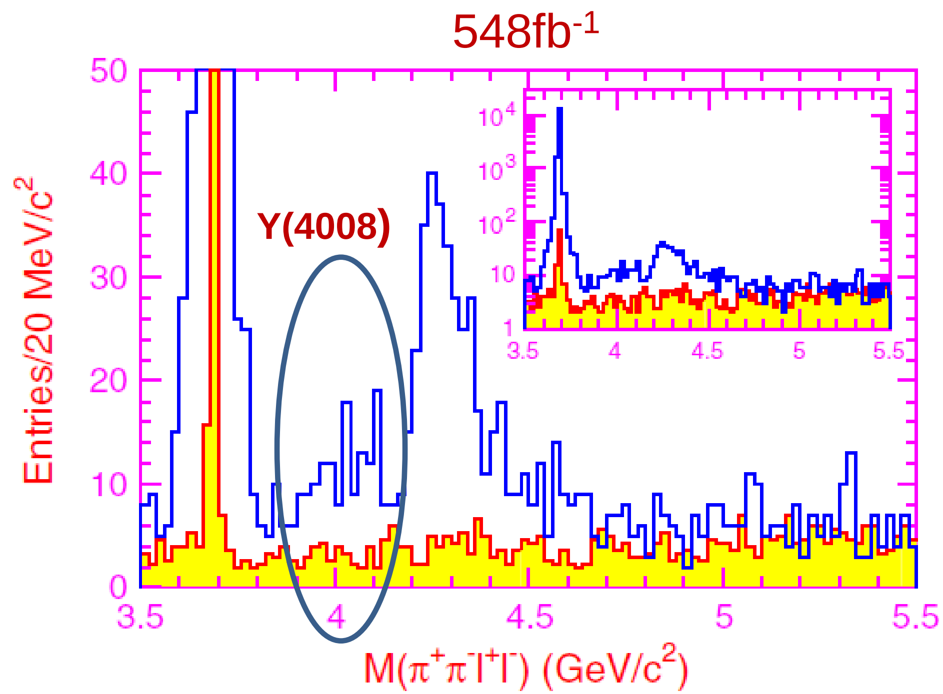
Belle, ISR method
PRL**99**,182004(2007)

Parameters	Solution I	Solution II
$M(R1)$	$4008 \pm 40^{+114}_{-28}$	
$\Gamma_{tot}(R1)$	$226 \pm 44 \pm 87$	
$\mathcal{B}\Gamma_{e^+e^-}(R1)$	$5.0 \pm 1.4^{+6.1}_{-0.9}$	$12.4 \pm 2.4^{+14.8}_{-1.1}$
$M(R2)$	$4247 \pm 12^{+17}_{-32}$	
$\Gamma_{tot}(R2)$	$108 \pm 19 \pm 10$	
$\mathcal{B}\Gamma_{e^+e^-}(R2)$	$6.0 \pm 1.2^{+4.7}_{-0.5}$	$20.6 \pm 2.3^{+9.1}_{-1.7}$
ϕ	$12 \pm 29^{+7}_{-98}$	$-111 \pm 7^{+28}_{-31}$

Y(4260)



BaBar, update
PRD86,051102(2012)



Belle, ISR method
PRL**99**,182004(2007)

$M=(4245 \pm 5 \pm 4)$MeV
$\Gamma=(114^{+16}_{-15} \pm 7)$MeV
$\Gamma_{ee} \times Br=(9.2 \pm 0.8 \pm 0.7)$eV

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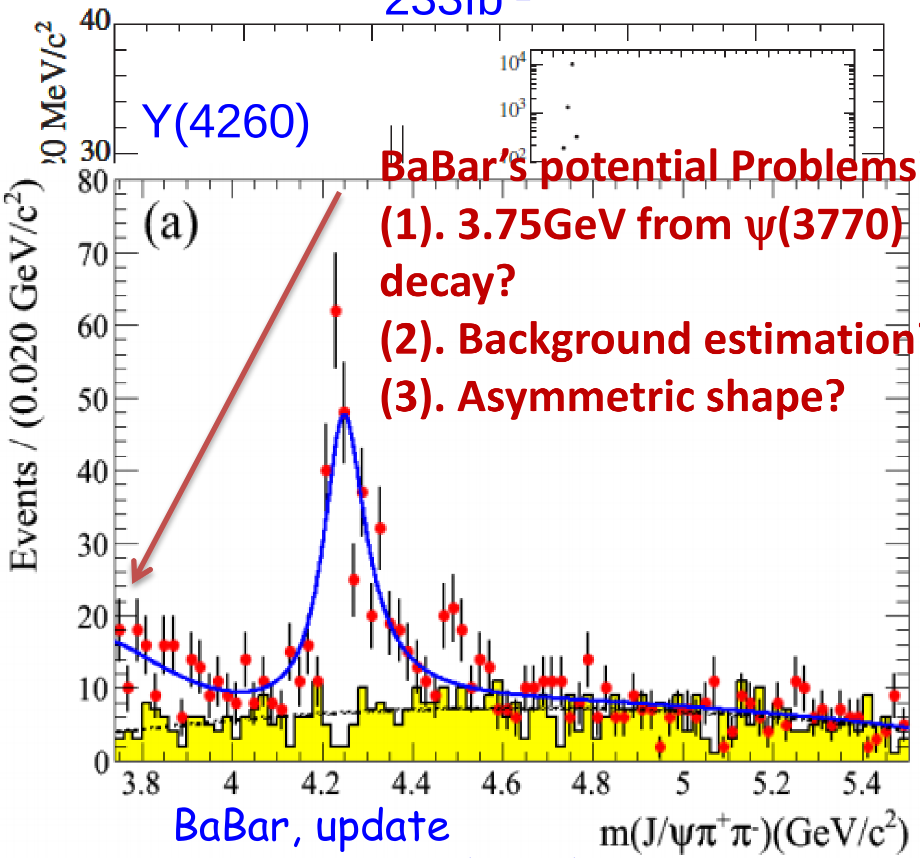
Y(4260)

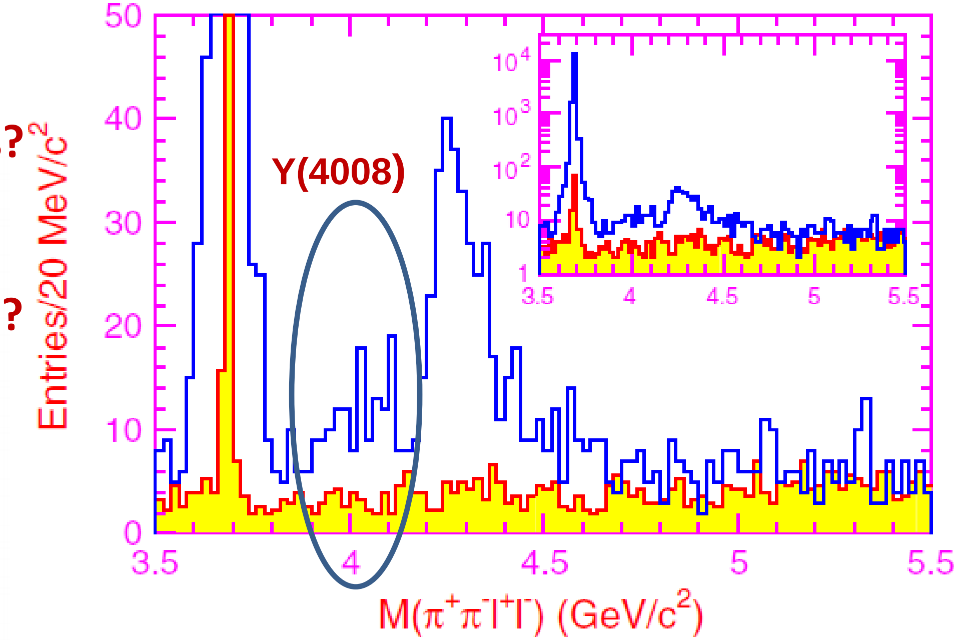
233fb^{-1}



BaBar's potential Problems?
(1). 3.75GeV from ψ(3770) decay?
(2). Background estimation?
(3). Asymmetric shape?

BaBar, update
PRD86,051102(2012)

548fb^{-1}



Belle, ISR method
PRL**99**,182004(2007)

$M=(4245 \pm 5 \pm 4)$MeV
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Belle's new result is coming

Parameters	Solution I	Solution II
$M(R1)$	$4008 \pm 40^{+114}_{-28}$	
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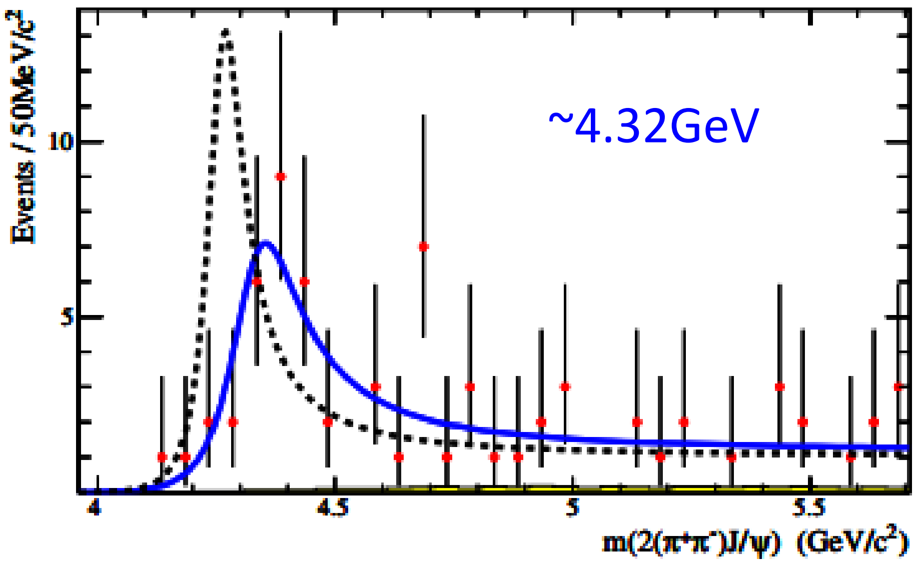
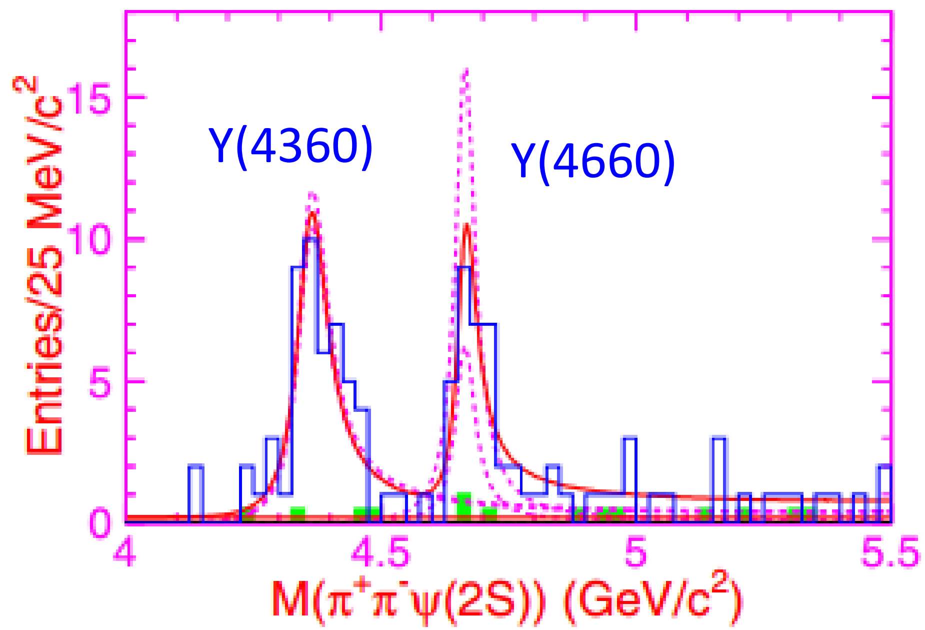
Y(4360) and Y(4660)

298fb^{-1}



BaBar PRL98,212001(2007).

673fb^{-1}

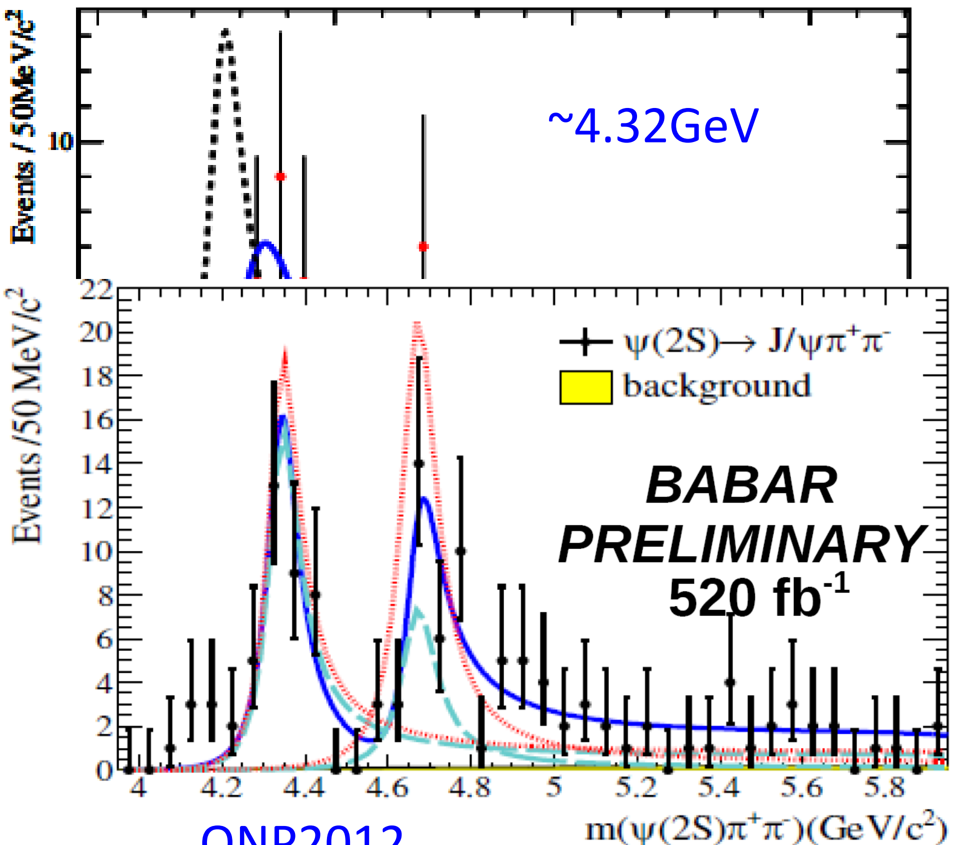


Belle PRL99,142002(2007).

Parameters	Solution I	Solution II
$M(Y(4360))$	$4361 \pm 9 \pm 9$	
$\Gamma_{tot}(Y(4360))$	$74 \pm 15 \pm 10$	
$\mathcal{B}\Gamma_{e^+e^-}(Y(4360))$	$10.4 \pm 1.7 \pm 1.5$	$11.8 \pm 1.8 \pm 1.4$
$M(Y(4660))$	$4664 \pm 11 \pm 5$	
$\Gamma_{tot}(Y(4660))$	$48 \pm 15 \pm 3$	
$\mathcal{B}\Gamma_{e^+e^-}(Y(4660))$	$3.0 \pm 0.9 \pm 0.3$	$7.6 \pm 1.8 \pm 0.8$
ϕ	$39 \pm 30 \pm 22$	$-79 \pm 17 \pm 20$

Y(4360) and Y(4660)

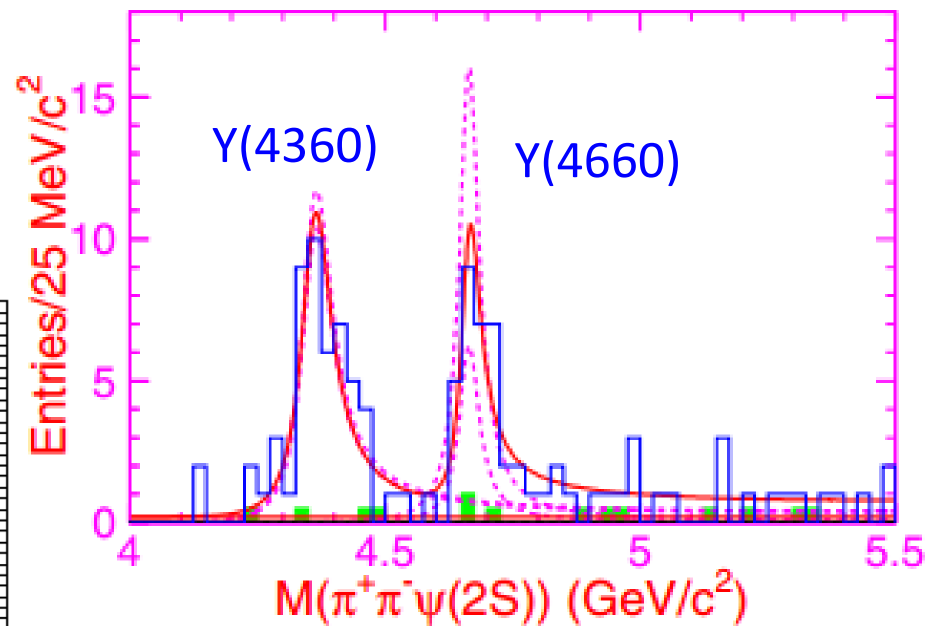
$298 fb^{-1}$



QNP2012

$$m(Y(4360)) = 4340 \pm 16 \pm 9\,\text{MeV}/c^2$$
$$\Gamma = 94 \pm 32 \pm 13\,\text{MeV}$$
$$m(Y(4660)) = 4669 \pm 21 \pm 10\,\text{MeV}/c^2$$
$$\Gamma = 104 \pm 48 \pm 10\,\text{MeV}$$

$673 fb^{-1}$



Belle PRL99,142002(2007).

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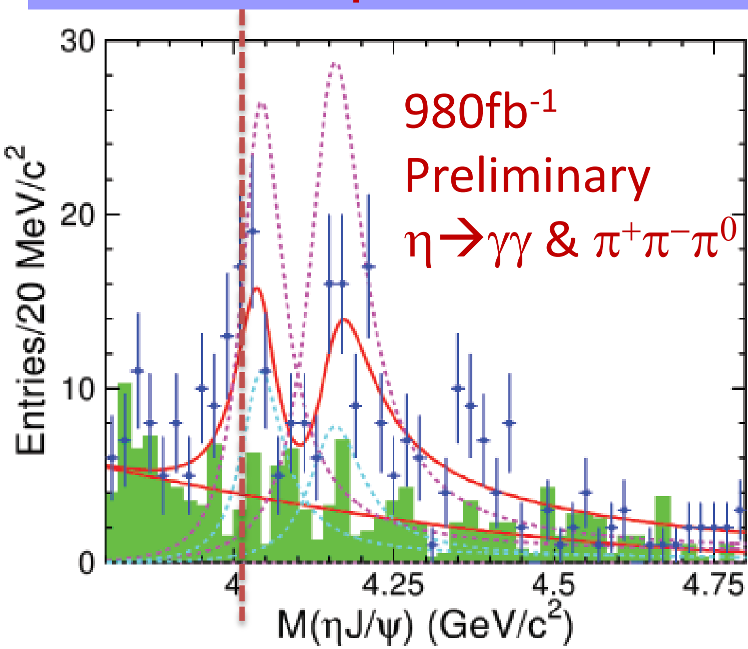
Belle is updating

$\psi(4040)$ & $\psi(4160) \rightarrow \eta J/\psi$



Belle, FPCP2012

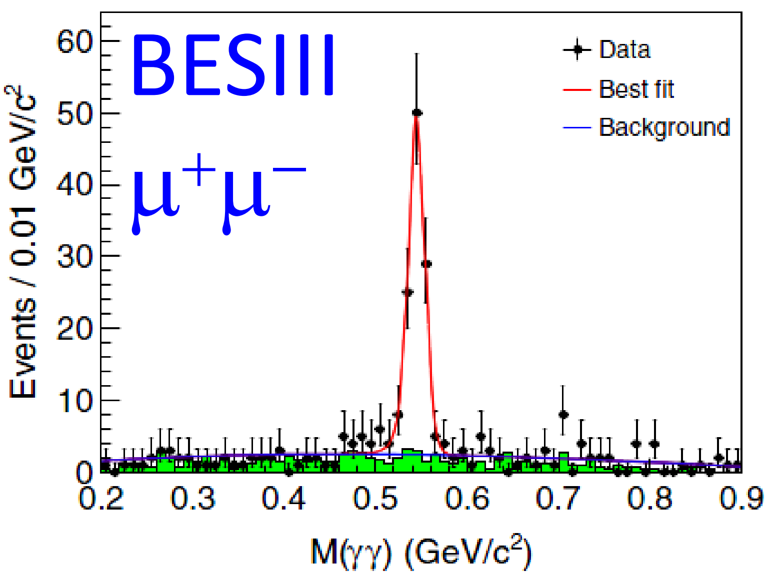
$\psi(4040)$ & $\psi(4160)$ signal

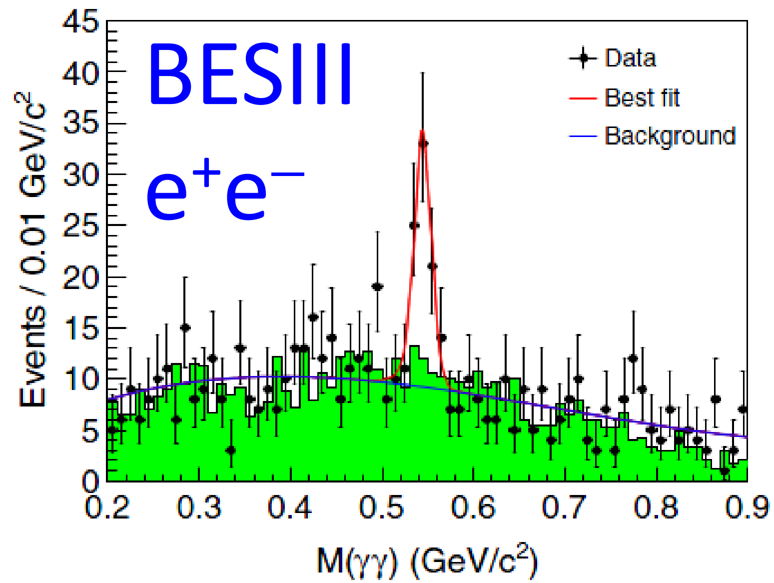
BESIII 478pb^{-1}@ 4.009GeV

$\sigma(\eta J/\psi)=(32.1 \pm 2.8 \pm 1.3)$ pb

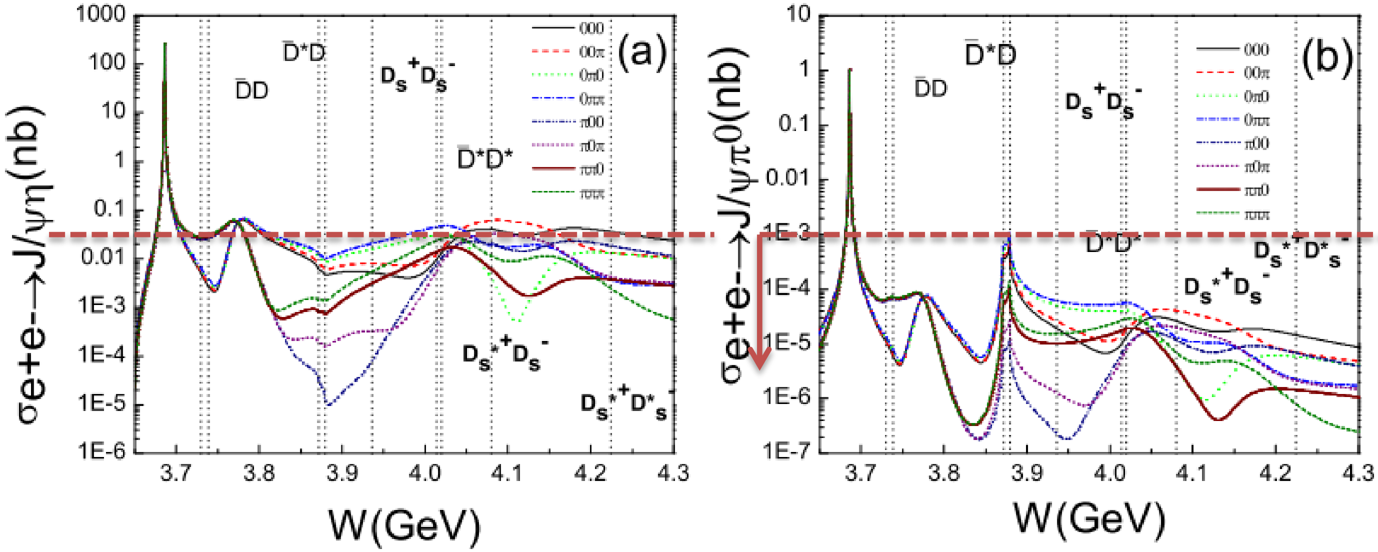
$\sigma(\pi^0 J/\psi)<1.6$ pb

PRD86,071101(R)(2012).

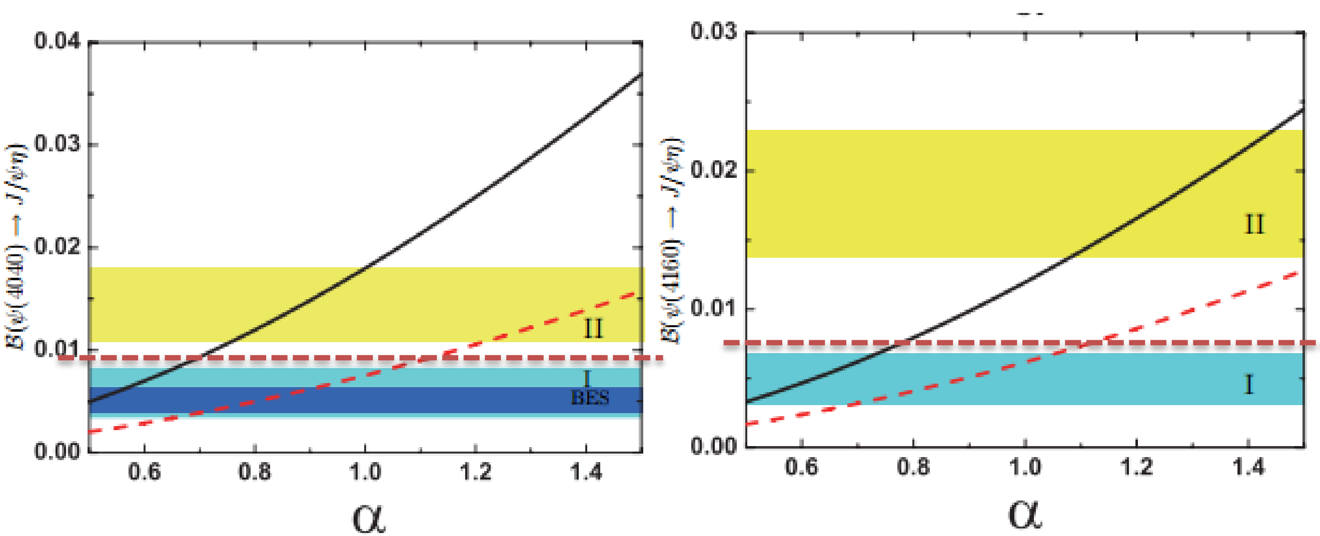




ψ(4040) & ψ(4160)→η J/ψ



Q. Wang, G. Li, X. H. Liu and Q. Zhao arXiv:1206.4511



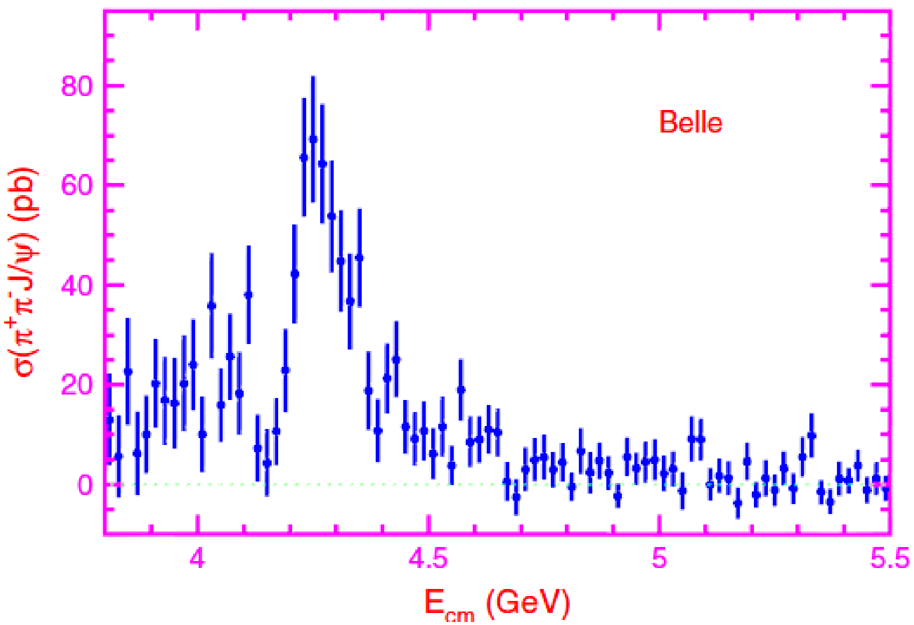
D. Y. Chen, X. Liu and T. Matsuki arXiv:1209.0064

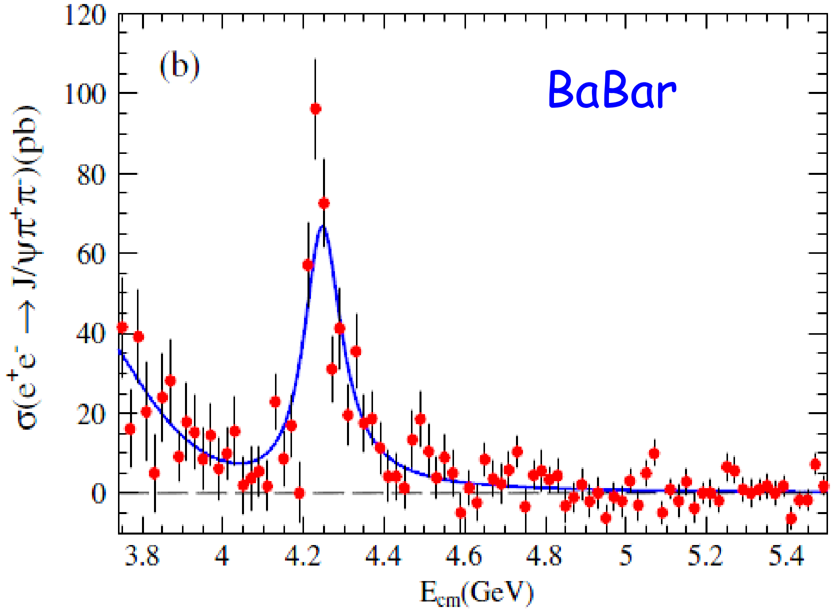
BESIII

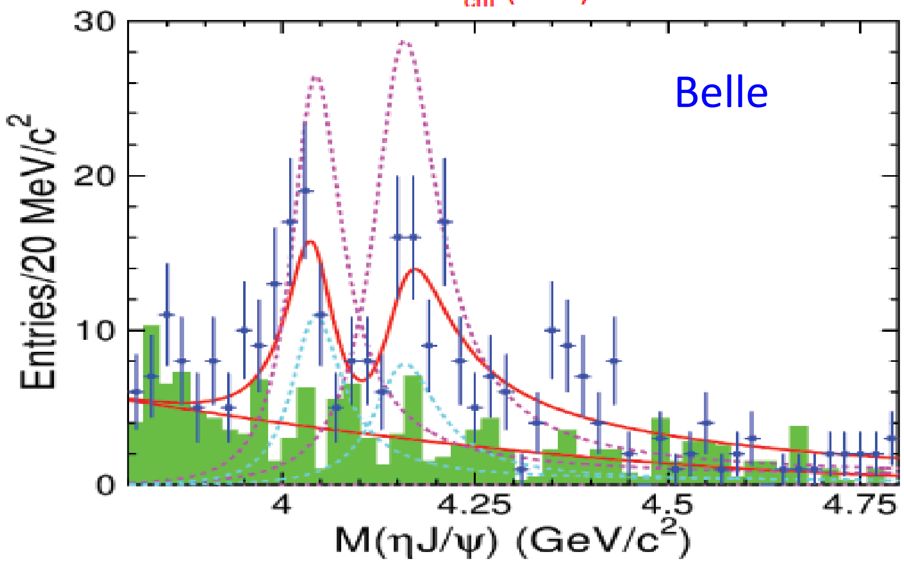
PRD(RC)86,071101(2012).

Br(ψ(4040)→ηJ/ψ) =(5.5±0.5±0.2±0.5) $\times 10^{-3}$

$\pi^+\pi^- J/\psi$ vs. $\eta J/\psi$

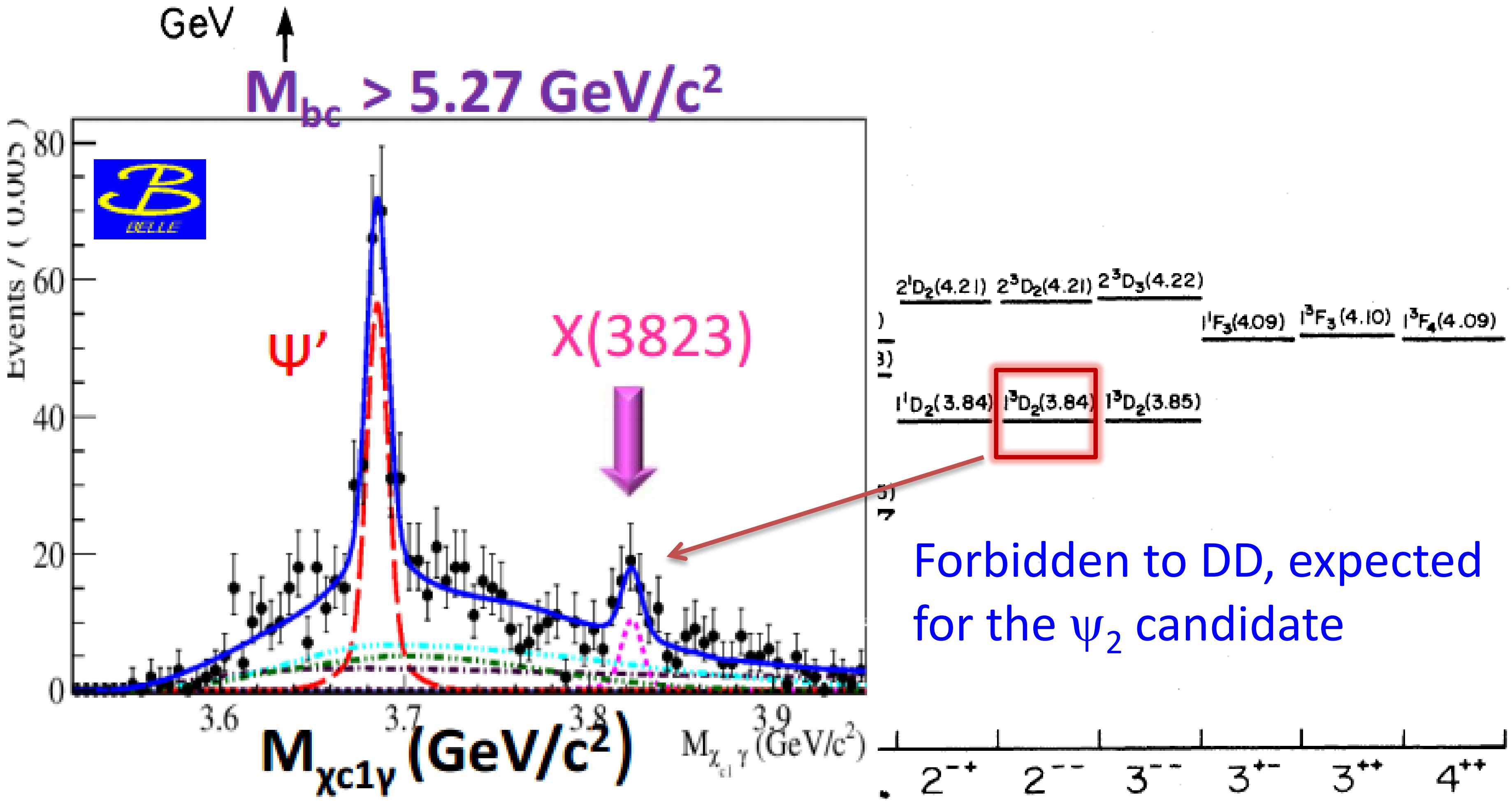






1. Y(4008)? & Y(4260) observed in $\pi^+\pi^- J/\psi$.
2. $\psi(4040)$ & $\psi(4160)$ observed in $\eta J/\psi$.
3. Huge difference in exclusive hadron channels?

$B \to K(\gamma\chi_{c1})$



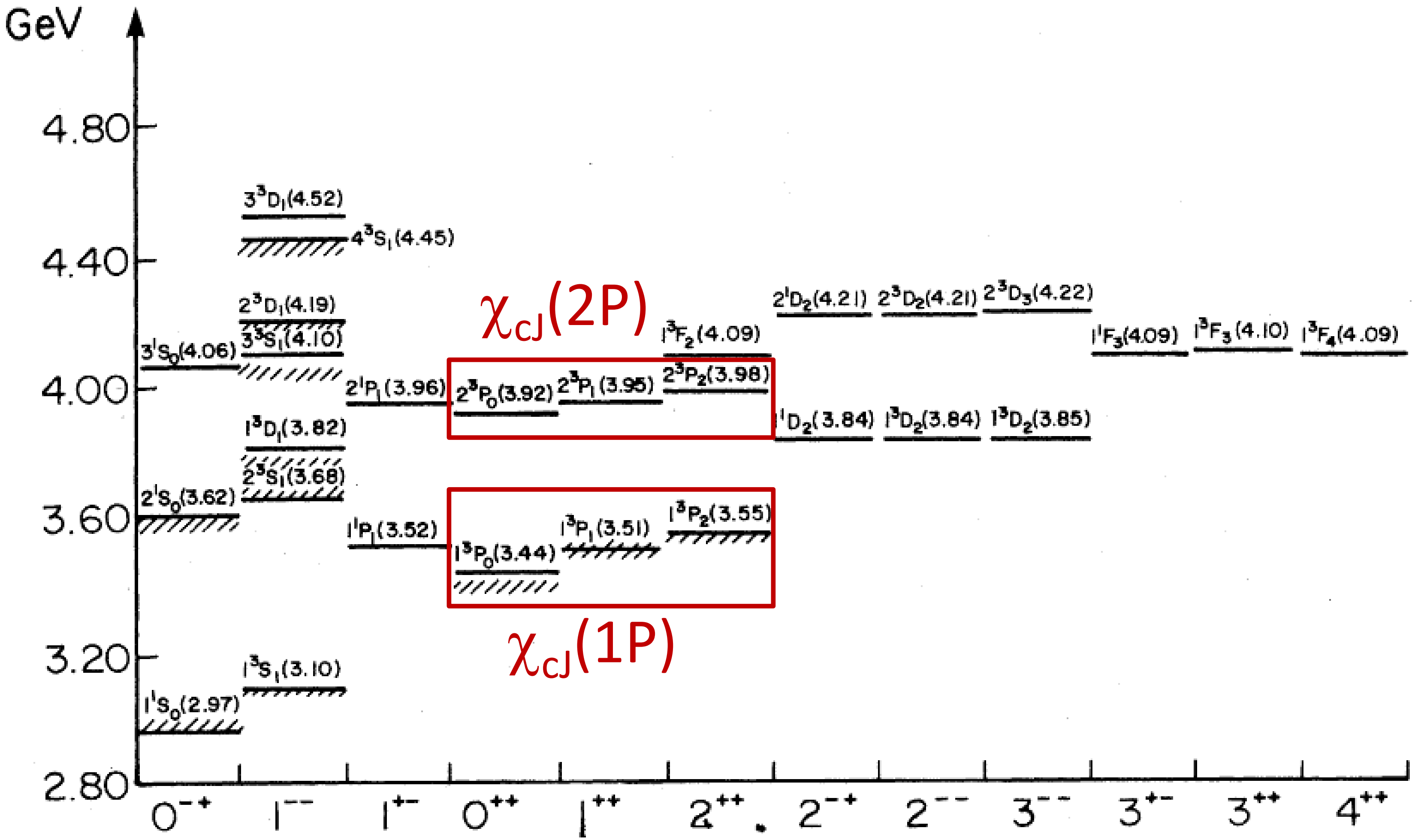
Forbidden to DD, expected for the ψ_2 candidate

M=(3823±2.8) MeV

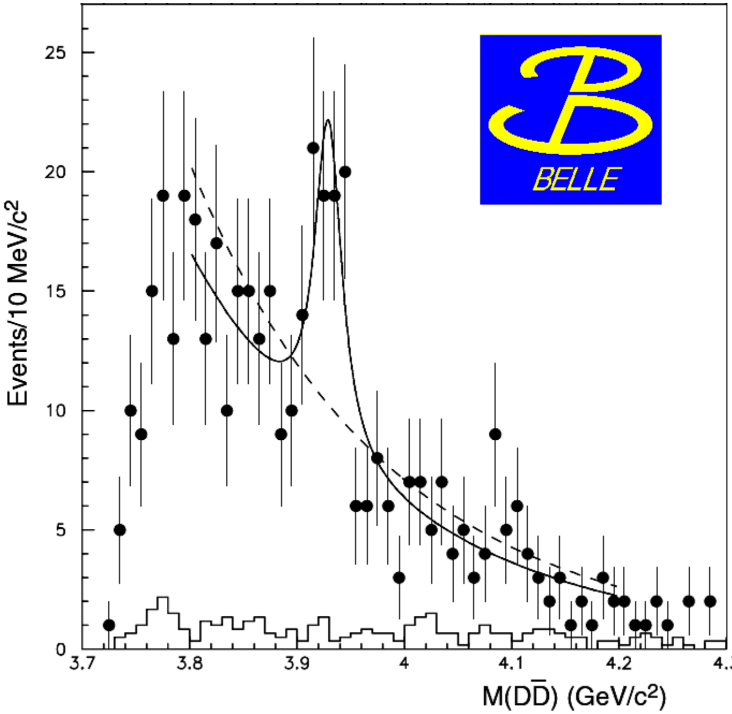
Γ=(4±6) MeV, narrow state

Charmonium-like states in $\gamma\gamma$ production

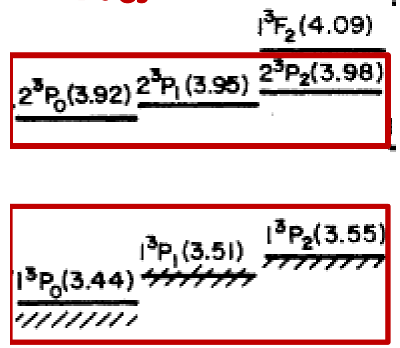
Where is $\chi_{cJ}(2P)$ triplet?



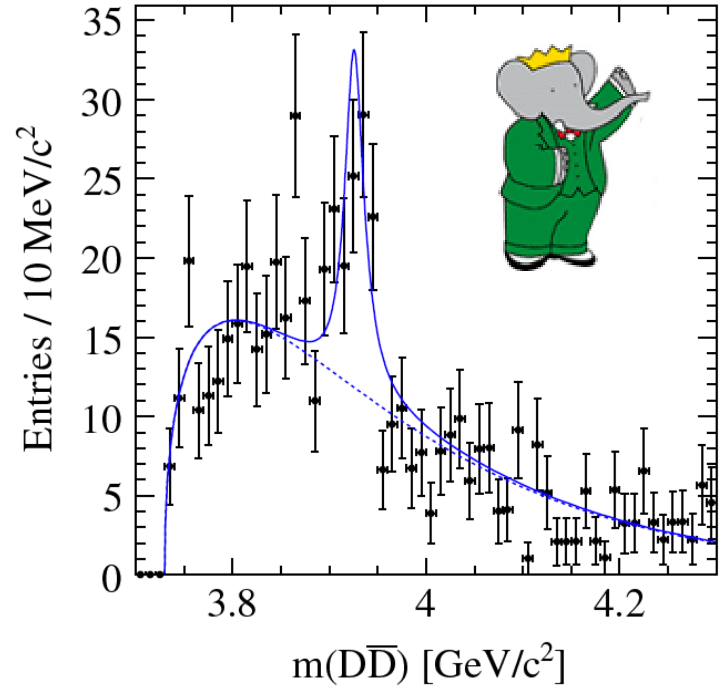
Where is $\chi_{cJ}(2P)$ triplet?



$\chi_{cJ}(2P)$



$\chi_{cJ}(1P)$



M = 3929±5±2 MeV

Γ_{tot} = 29±10±2 MeV

M = 3926.7±2.7±1.1 MeV

Γ_{tot} = 21.3±6.8±3.6 MeV

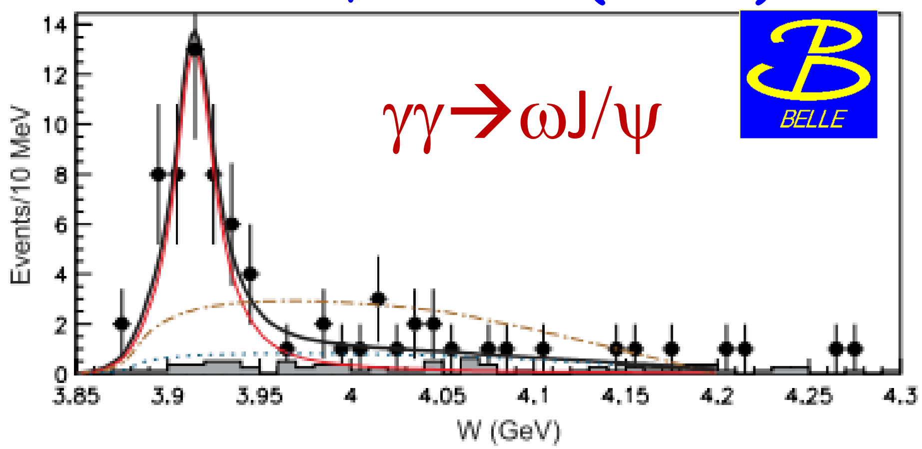
$\chi_{c2}(2P)$	$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3927.2 \pm 2.6$ MeV
Full width $\Gamma = 24 \pm 6$ MeV

$\chi_{c0,c1}(2P)$??

Where is $\chi_{cJ}(2P)$ triplet?

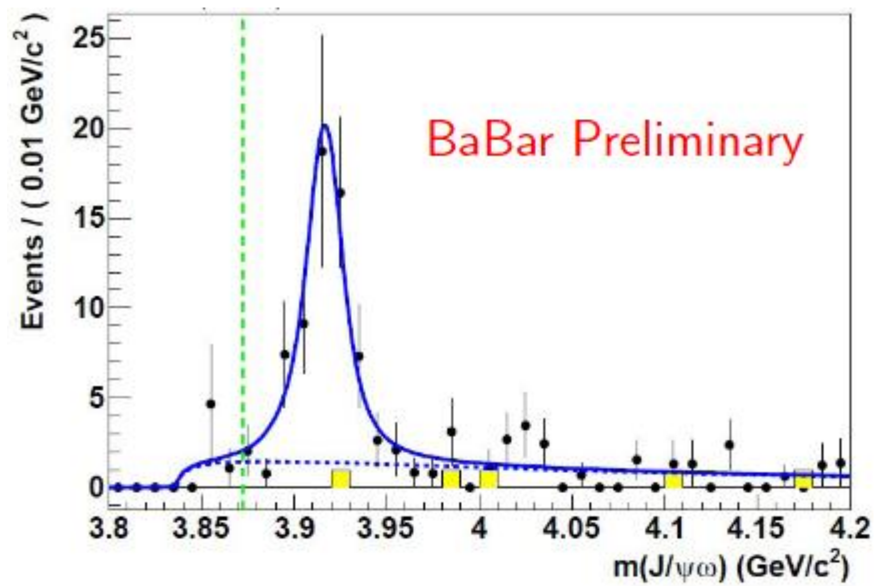
PRL104,092001(2010)



M=(3915±3±2)MeV

Γ=(17±10±3)MeV

Possible $\chi_{c0}(2P)$?

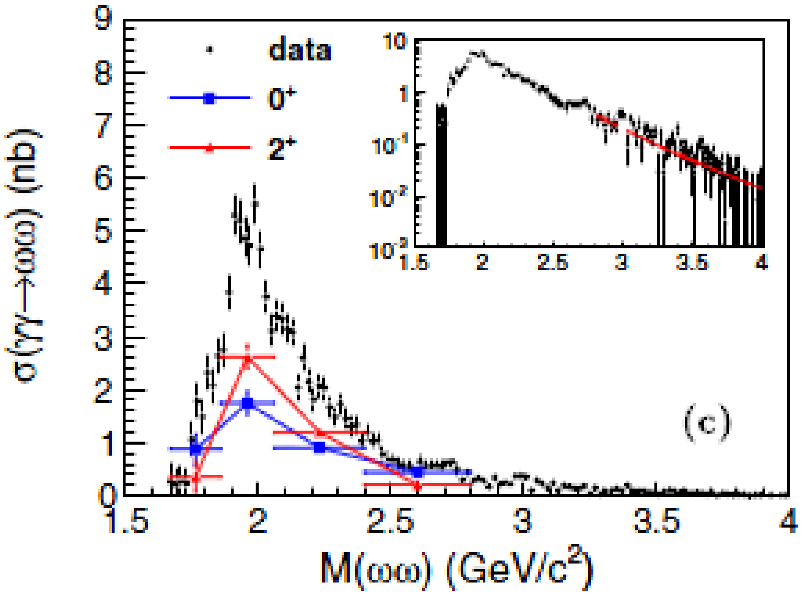


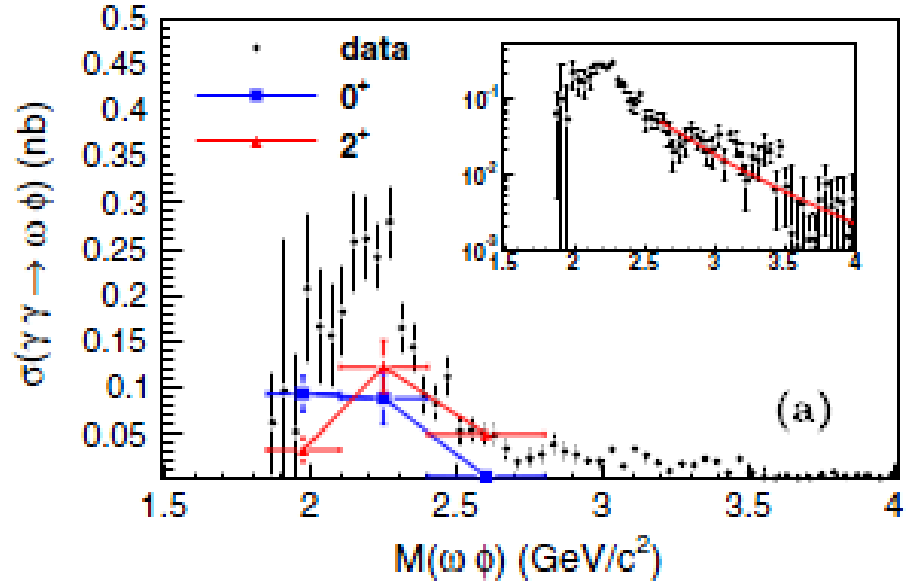
M=(3919.4±2.2±1.6)MeV

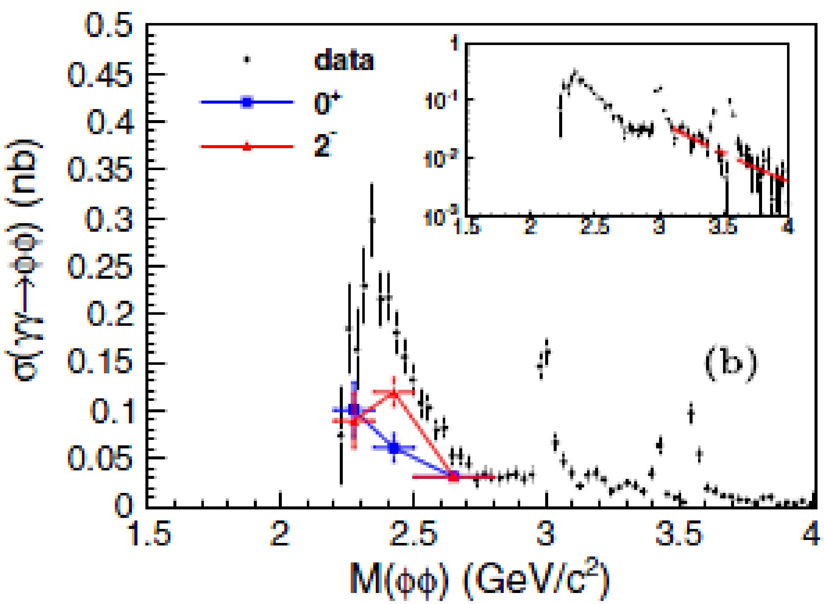
Γ=(13±6±3)MeV

Still need experimental effort to identify the $\chi_{cJ}(2P)$ triplet.
BESIII also provide opportunity in ψ(4040) E1 transition.

$\gamma\gamma \rightarrow \omega\omega, \omega\phi, \phi\phi$







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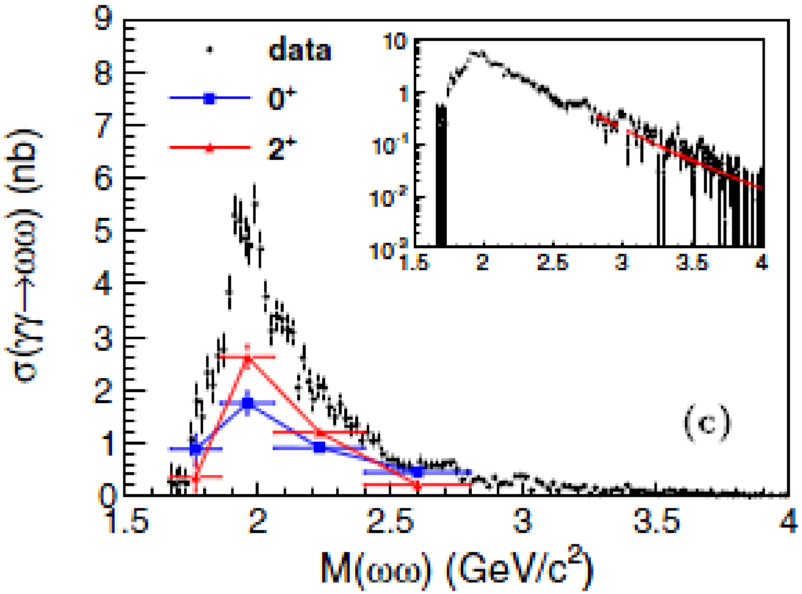
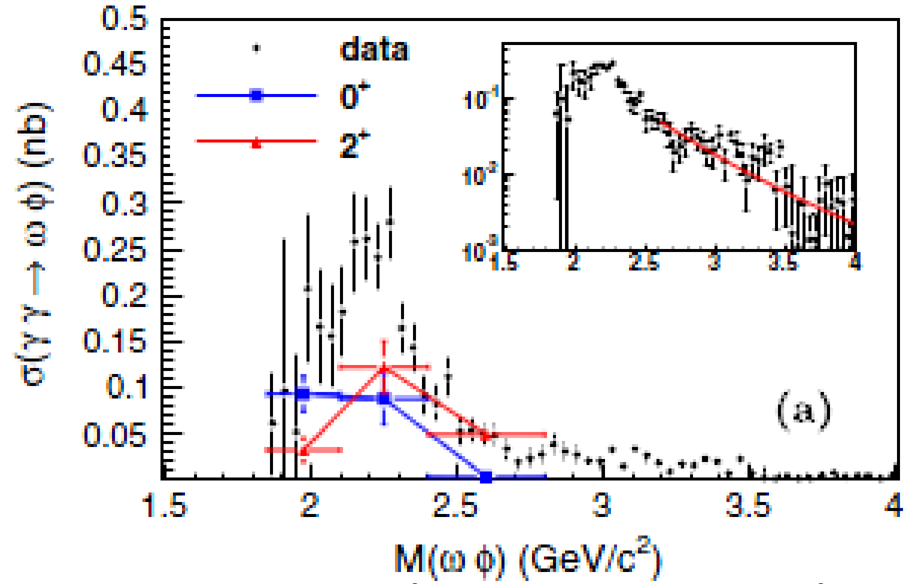
PRL108,232001(2012)

1. $\gamma\gamma \rightarrow VV$ cross section measurement from thershold to 4GeV
2. Resonant structures have been observed. Spin-2 components are significant.
3. W^{-n} power law fit high energy region: n~8, agree with pQCD calculation.
V. L. Chernyak arXiv:0912.0623

$\gamma\gamma \rightarrow \omega\omega, \omega\phi, \phi\phi$





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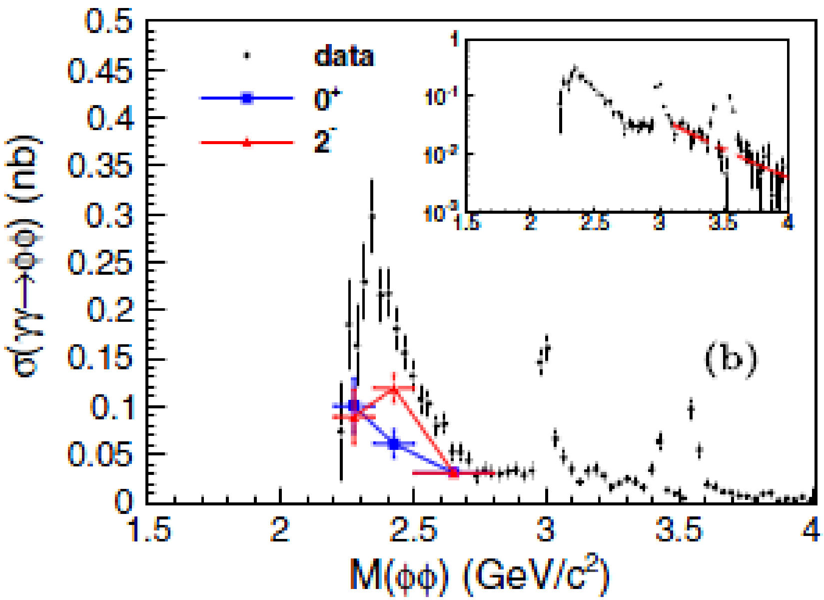
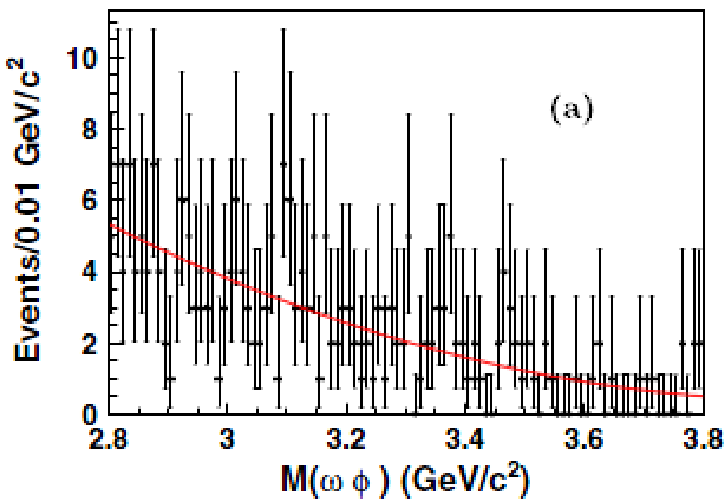
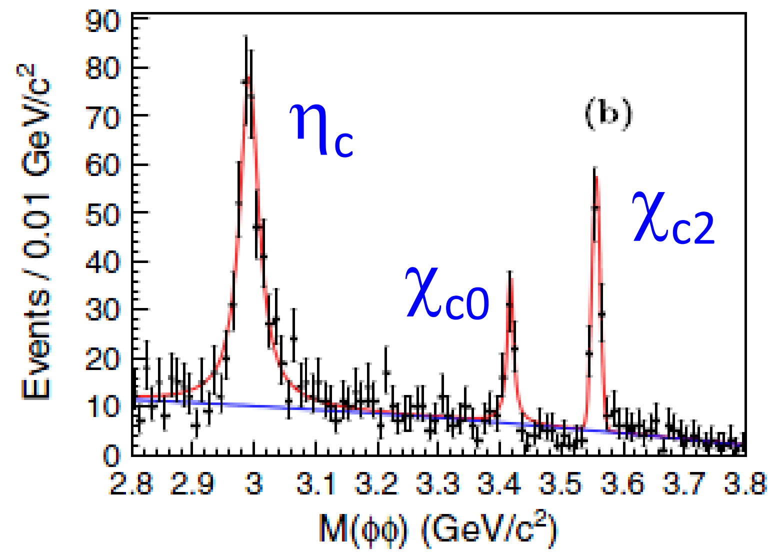
PRL108,232001(2012)

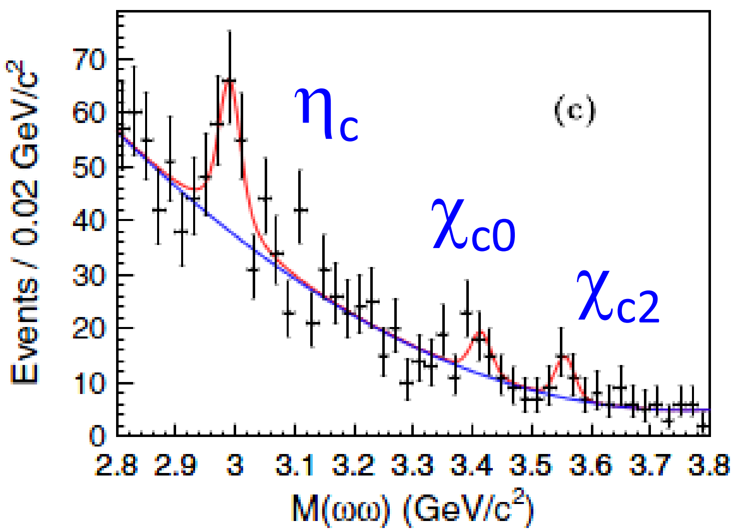


1. What's nature of enhancement?
2. Threshold effect can not explain simply.
3. 4-qurak states? "golden mode", but not compatible with current models (q^2q^2 tetra-quark, t-channel factorization, one-pion exchange).
4. Molecule? "QCD sum-rule" J. R. Zhang et al . arXiv:1203.0700

γγ→ωω, ωϕ, ϕϕ







1. Charmonium results at high energy region.
2. First observation of $\eta_c \to \omega\omega$

Z. Q. Liu, C. P. Shen, C. Z .Yuan et al.

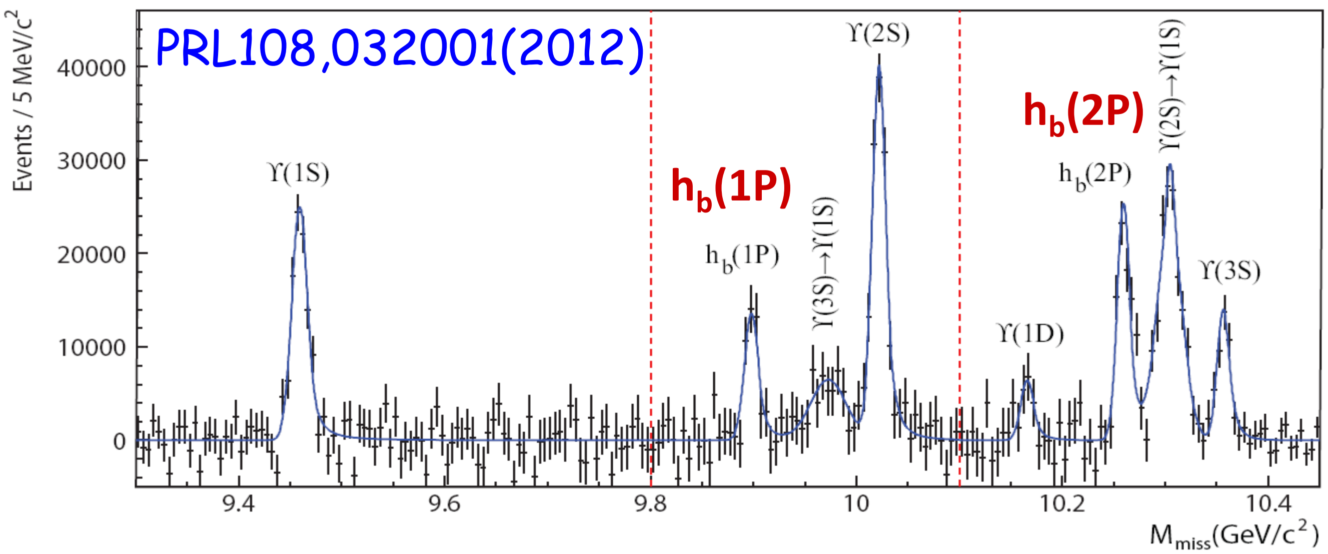
PRL108,232001(2012)

Mode	$\omega\phi$	$\phi\phi$	$\omega\omega$
η_c	<0.49 [< 7.9]	$7.75 \pm 0.66 \pm 0.62$ [386 ± 31]	$8.67 \pm 2.86 \pm 0.96$ [85 ± 29]
χ_{c0}	<0.34 [< 4.3]	$1.72 \pm 0.33 \pm 0.14$ [56 ± 11]	<3.9 [< 35]
χ_{c2}	<0.04 [< 2.4]	$0.62 \pm 0.07 \pm 0.05$ [89 ± 11]	<0.64 [< 28]

Bottomonium-like Spectroscopy

$h_b(1P)$ and $h_b(2P)$

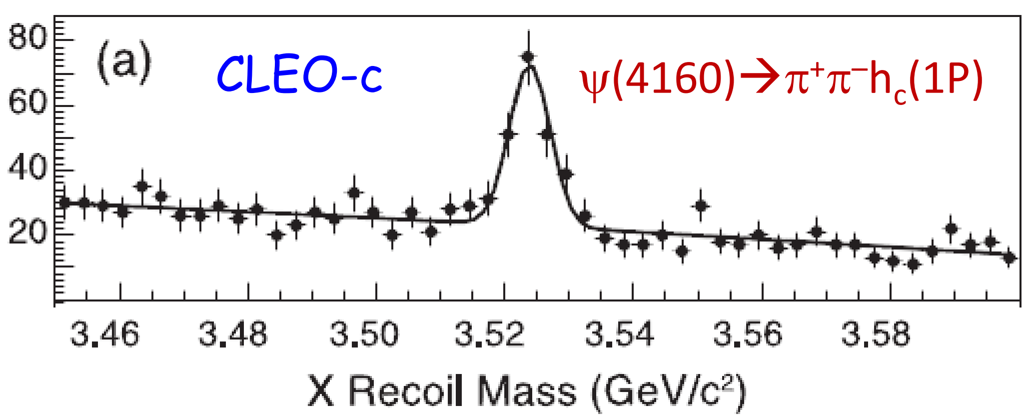
$e^+e^- \to \Upsilon(5S) \to h_b(nP)\pi^+\pi^-$ → reconstructed, use $\mathbf{M_{miss}(\pi^+\pi^-)}$



$M(h_b(1P))=(9898.2 \pm 1.1 \pm 1.1)$MeV

$M(hb(2P))=(10259.8 \pm 0.6^{+1.4}_{-1.0})$MeV

PRL107,041803(2011)



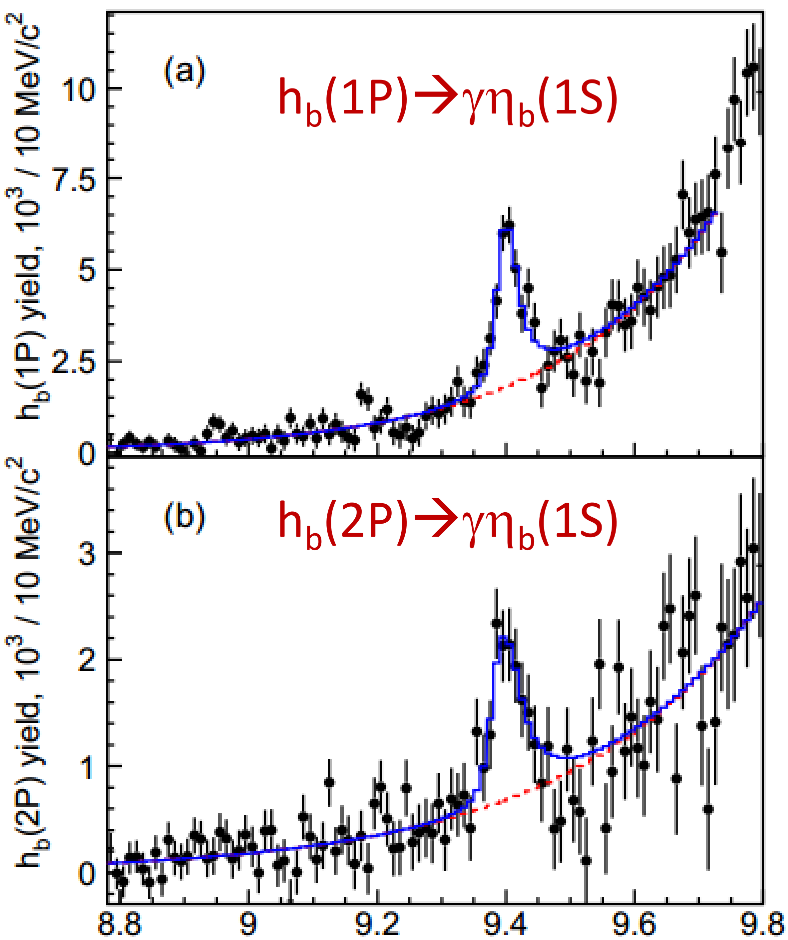
$h_c(2P)$?

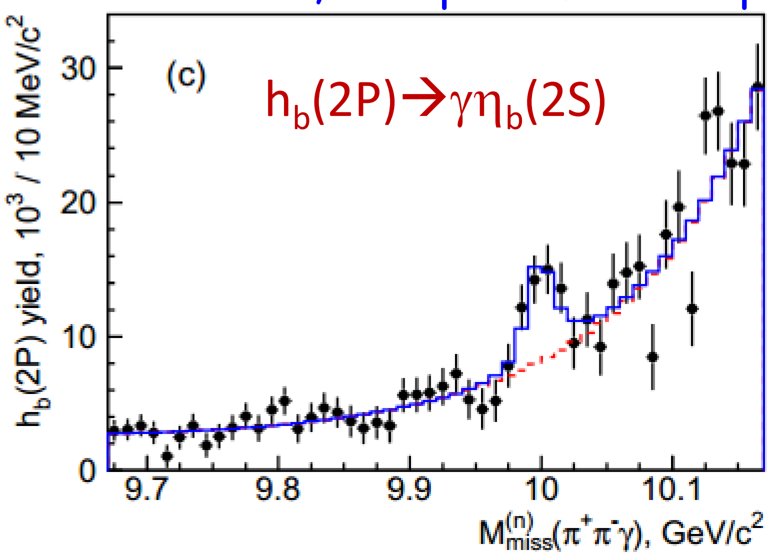
Y(4260), Y(4360)→ $\pi^+\pi^-h_c(2P)$

$\eta_b(1S)$ and $\eta_b(2S)$

$e^+e^- \rightarrow \Upsilon(5S) \rightarrow h_b(nP)\,\pi^+\pi^-$
$\quad\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \gamma\eta_b(1S,2S)$

arXiv:1205.6351, accepted for PRL publication





$M(\eta_b(1S))=(9402.4\pm1.5\pm1.8)$MeV
$\Gamma(\eta_b(1S))=(10.8^{+4.0}_{-3.7}\,{}^{+4.5}_{-2.0})$MeV
$M(\eta_b(2S))=(9999.0\pm3.5^{+2.8}_{-1.9})$MeV
$\Delta M_{hf}(\eta_b(1S))=(48.7\pm2.3\pm2.1)$MeV

$h_b(1P)\rightarrow\gamma\eta_b(1S) = (49.8\pm5.7\,{}^{+5.6}_{-3.3})\%$

$h_b(2P)\rightarrow\gamma\eta_b(1S) = (22.3\pm3.8\,{}^{+3.1}_{-3.3})\%$

$h_b(2P)\rightarrow\gamma\eta_b(2S) = (47.5\pm10.5^{+6.9}_{-7.7})\%$

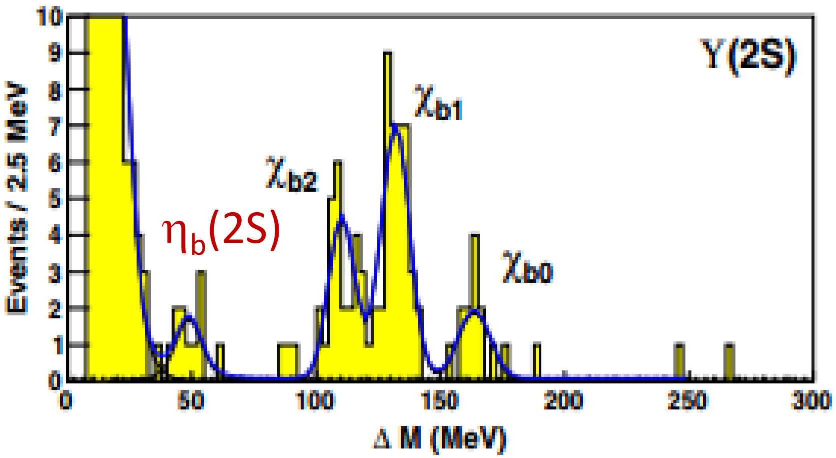
BESIII $h_c(1P)\rightarrow\gamma\eta_c(1S) = (54.3\pm8.5)$ %

$\eta_b(1S)$ and $\eta_b(2S)$

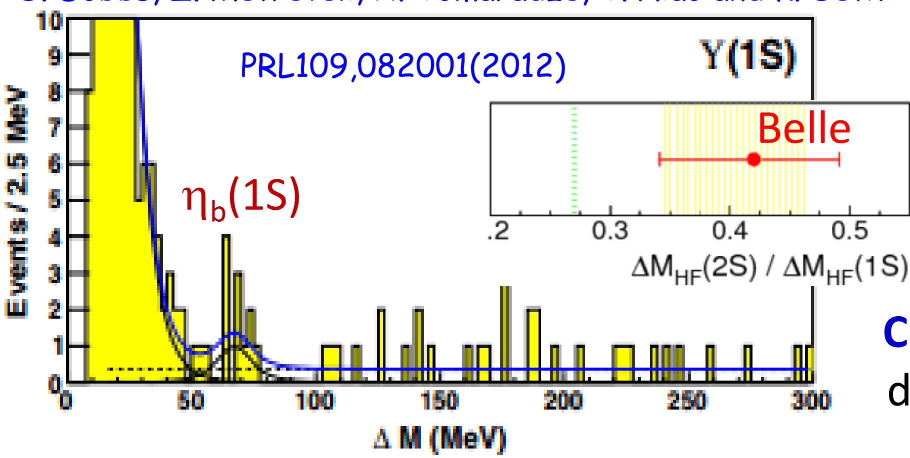
$\Upsilon(1S,2S) \rightarrow n(p, \pi, K\ldots)$

26 light hadron modes in total

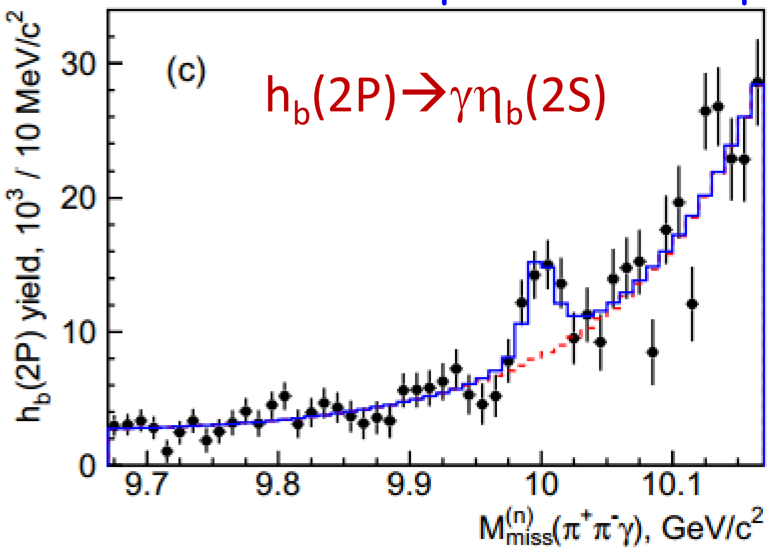
CLEO data, but not from CLEO collaboration



S. Dobbs, Z. Metreveli, A. Tomaradze, T. Xiao and K. Seth



arXiv:1205.6351, accepted for PRL publication



Belle agree

$M(\eta_b(1S))=(9402.4 \pm 1.5 \pm 1.8)$MeV

$\Gamma(\eta_b(1S))=(10.8^{+4.0}_{-3.7}{}^{+4.5}_{-2.0})$MeV

$M(\eta_b(2S))=(9999.0 \pm 3.5^{+2.8}_{-1.9})$MeV

$\Delta M_{hf}(\eta_b(2S))=(24.3^{+4.0}_{-4.5})$MeV

CLEO disagree

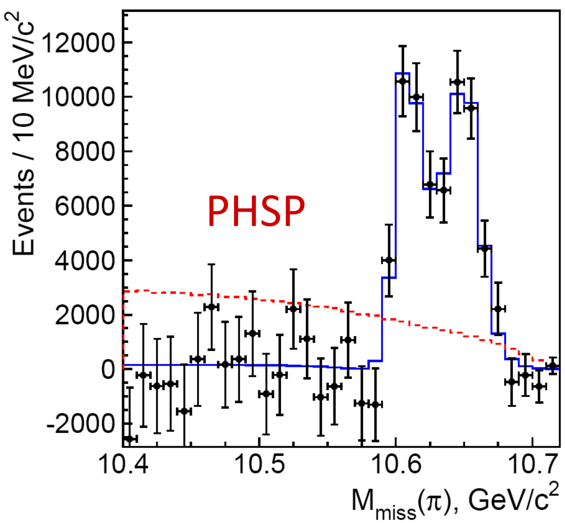
$M(\eta_b(1S))=(9393.2 \pm 3.4 \pm 2.3)$MeV

$M(\eta_b(2S))=(9974.6 \pm 2.3 \pm 2.1)$MeV

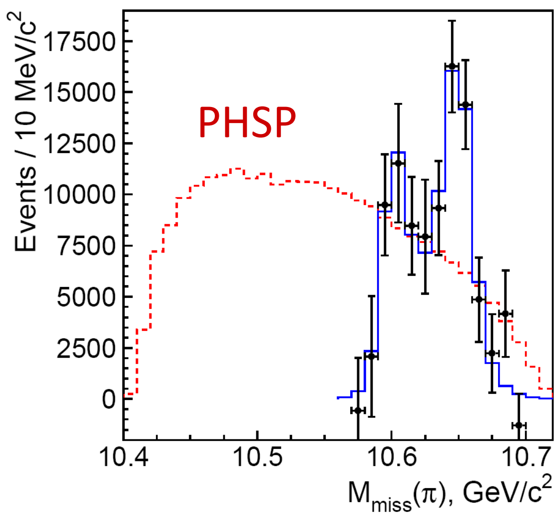
$\Delta M_{hf}(\eta_b(2S))=(48.7 \pm 2.3 \pm 2.1)$MeV

$Z_b(10610)$ & $Z_b(10650) \rightarrow \pi^{+/-}\Upsilon(1S,2S)$

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



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

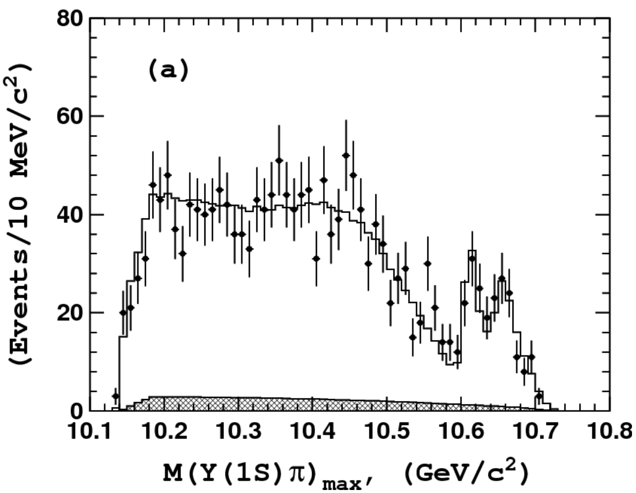


Belle PRL108,122001(2012)

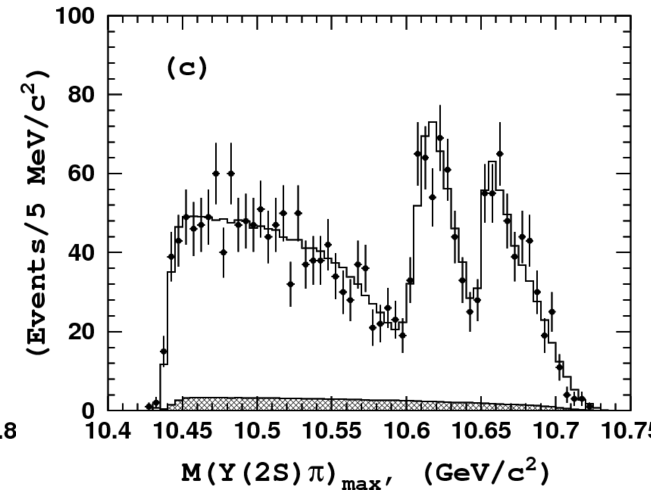
$M_1 = 10607.2 \pm 2.0$ MeV
$\Gamma_1 = 18.4 \pm 2.4$ MeV

$M_2 = 10652.2 \pm 1.5$ MeV
$\Gamma_2 = 11.5 \pm 2.2$ MeV

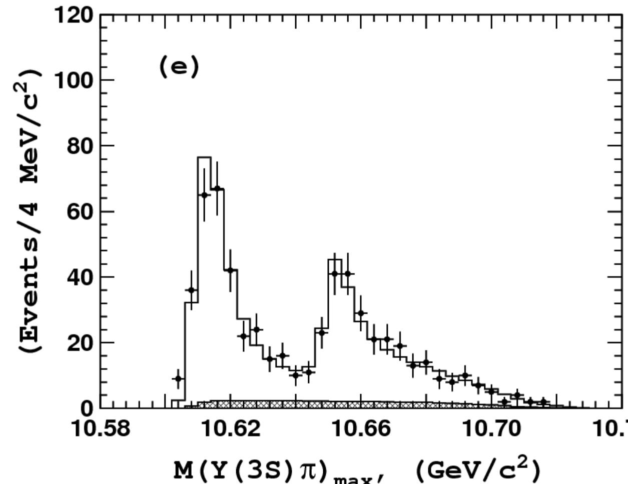
$\Upsilon(5S) \rightarrow \Upsilon(1S)\pi^+\pi^-$



$\Upsilon(5S) \rightarrow \Upsilon(2S)\pi^+\pi^-$

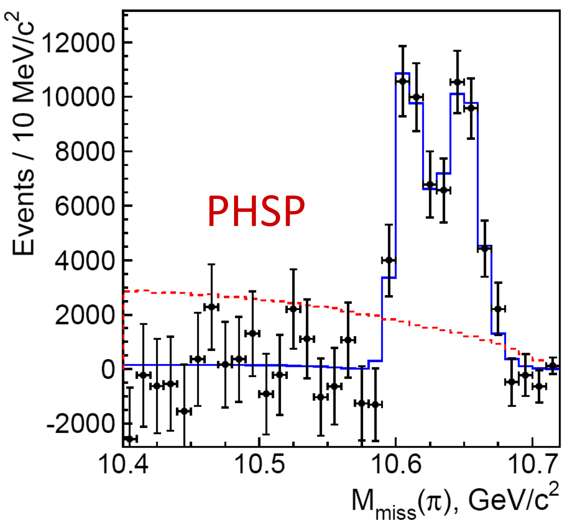


$\Upsilon(5S) \rightarrow \Upsilon(3S)\pi^+\pi^-$

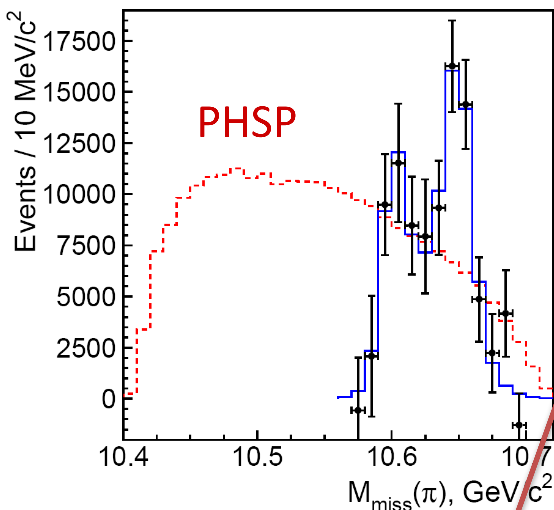


$Z_b(10610)$ & $Z_b(10650) \to \pi^0 \Upsilon(1S,2S)$

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



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



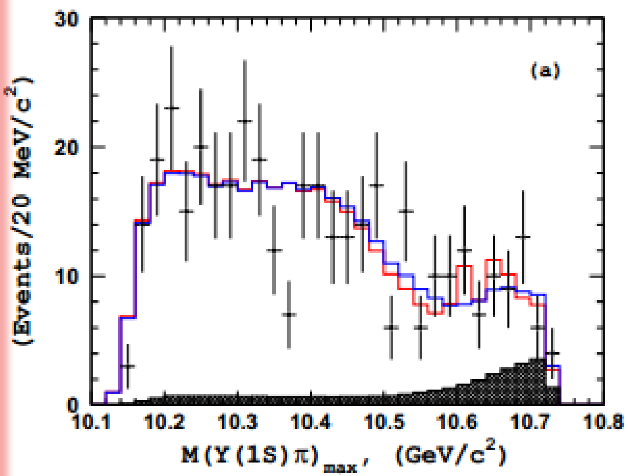
Belle PRL108,122001(2012)

$M_1 = 10607.2 \pm 2.0$ MeV
$\Gamma_1 = 18.4 \pm 2.4$ MeV

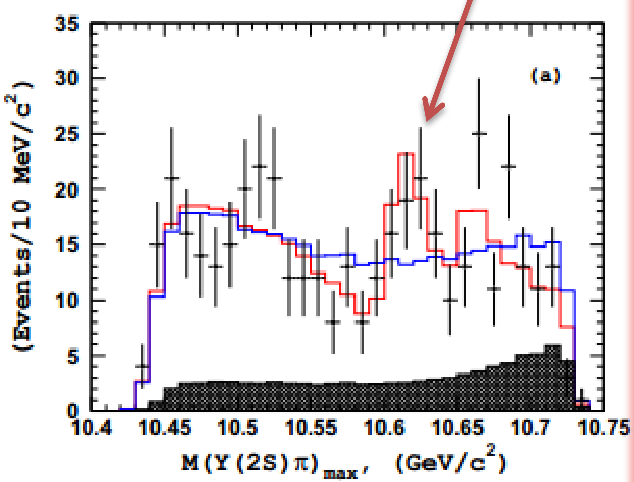
$M_2 = 10652.2 \pm 1.5$ MeV
$\Gamma_2 = 11.5 \pm 2.2$ MeV

arXiv:1207.4345

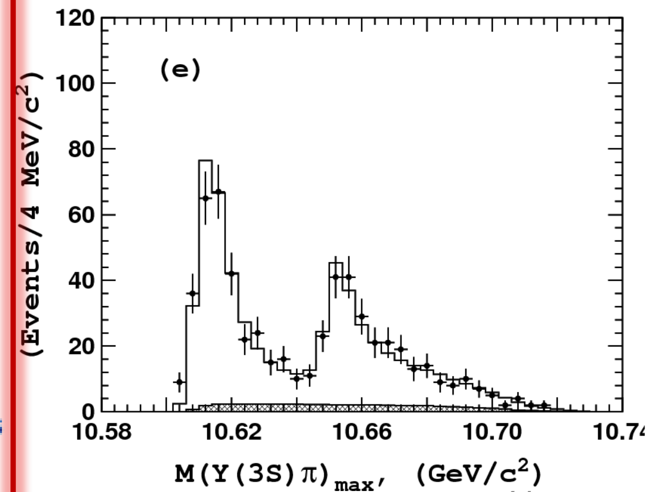
$\Upsilon(5S) \to \Upsilon(1S)\pi^0\pi^0$



$\Upsilon(5S) \to \Upsilon(2S)\pi^0\pi^0$

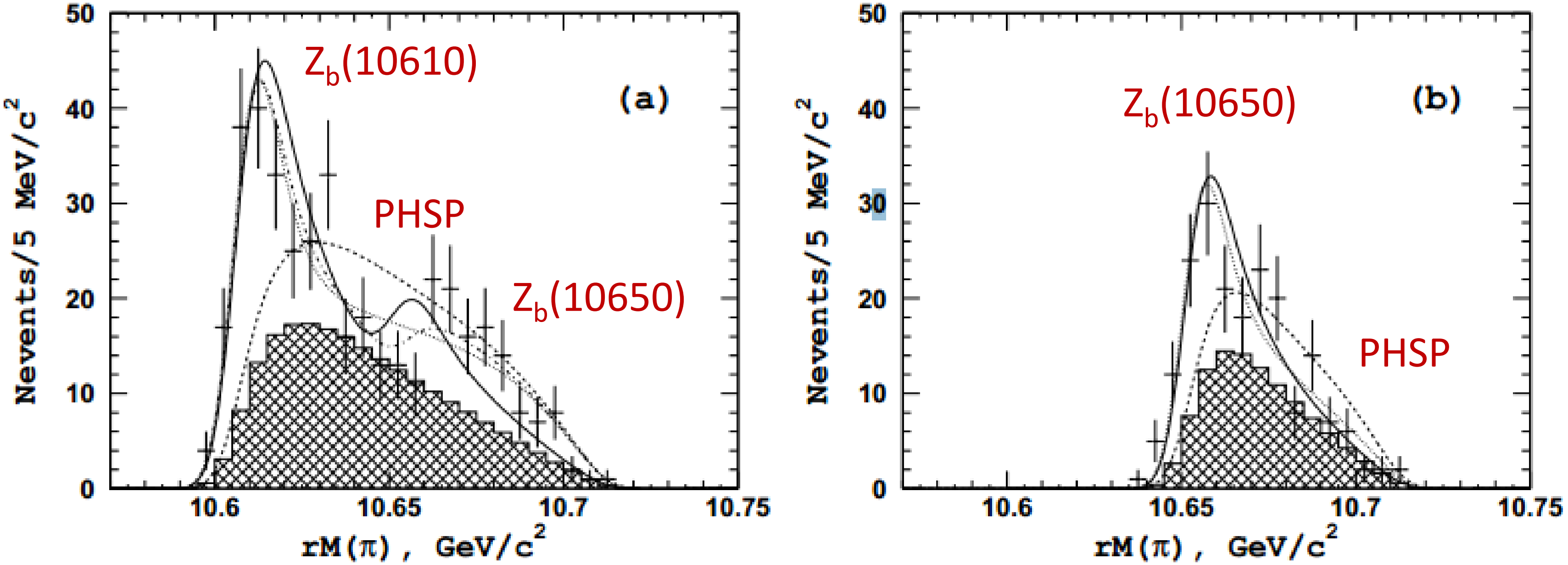


$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$



$Z_b(10610)$ & $Z_b(10650) \rightarrow B^{(*)}B^{*}\pi^{+/-}$

arXiv:1209.6450

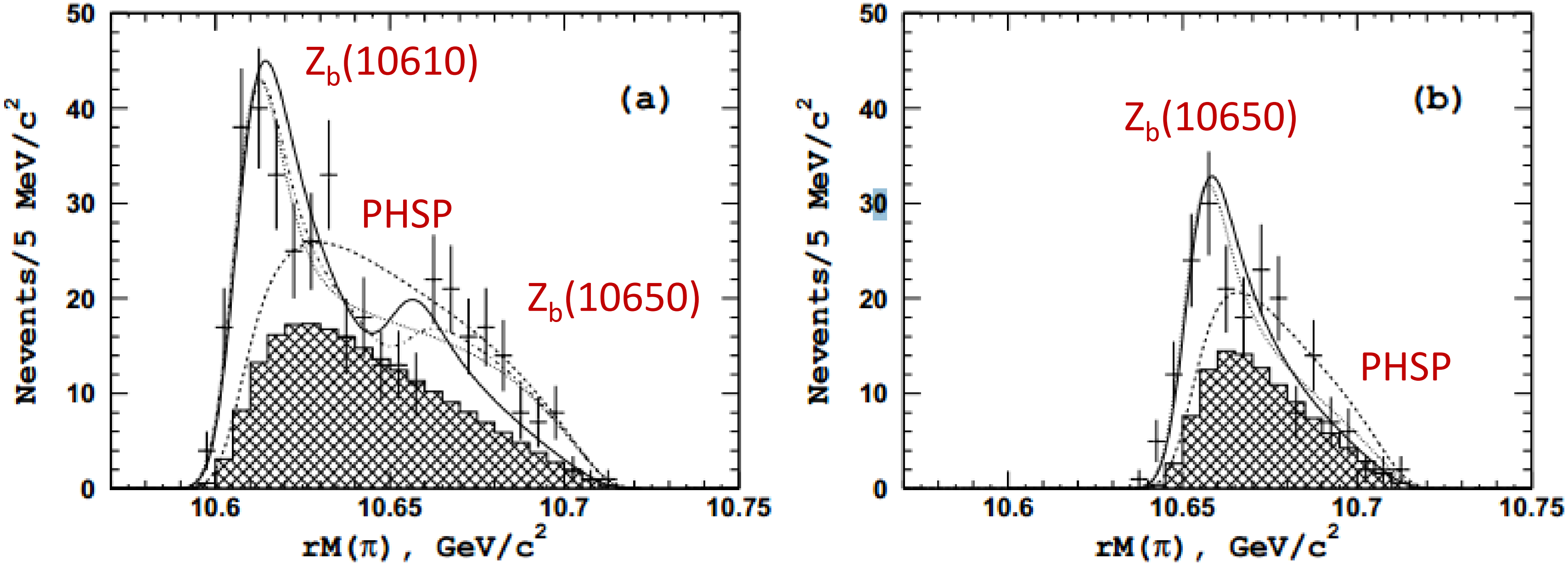


Near BB* and B*B* threshold

1. BB* & B*B* bound states? $Z_b \sim M(B^{(*)})+M(B^*)$
2. Unbound threshold resonance? $Z_b(10610)-[M(B)+M(B^*)] \sim (3.6 \pm 1.8)$ MeV / Zb(10650)-[M(B*)+M(B*)] ~(3.1 ± 1.8) MeV
3. Multi-quark states?

$Z_b(10610)$ & $Z_b(10650) \rightarrow B^{(*)}B^{*}\pi^{+/-}$

arXiv:1209.6450



Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ± 3.6	–
$B^{*+}\bar{B}^{*0}$	–	73.4 ± 7.0

$B^{(*)}B^{*}$ channel dominate!

Summary

- 1. Conventional charmonium & bottomonium is more and more mature.
- 2. More and more new states have been discovered.
- 3. Hadron spectroscopy still need more effort both in experiment and theory.

Thanks!