Recent Results on XYZ from Belle

4th workshop on the XYZ particles

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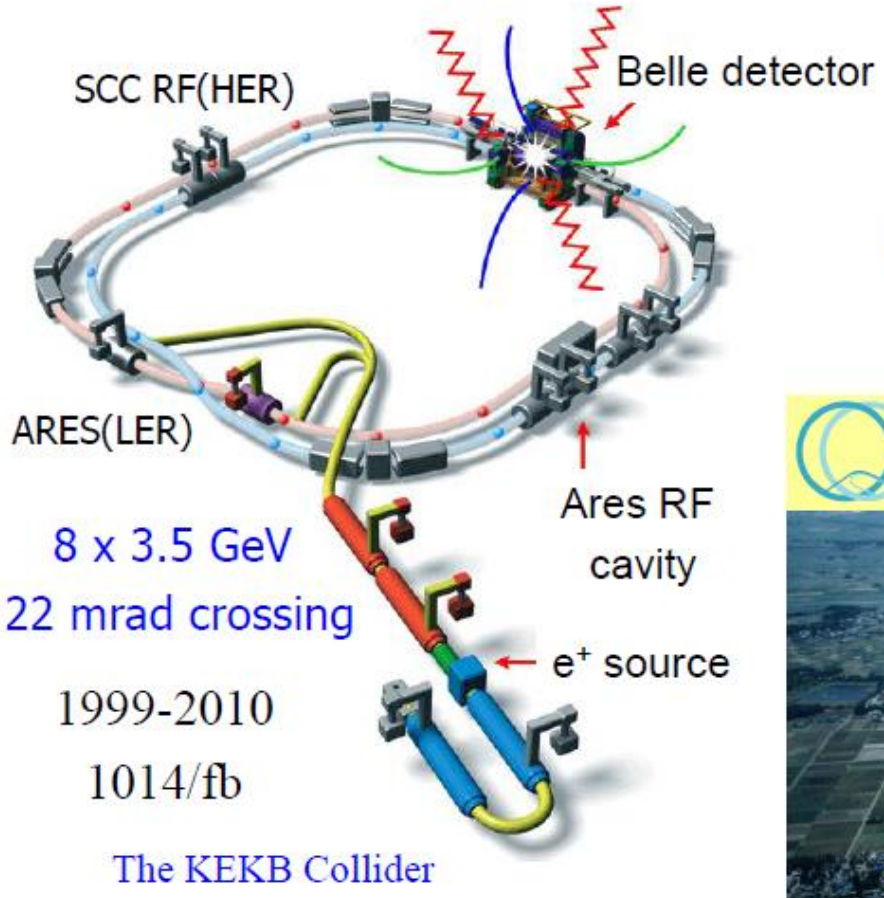
Outline

- KEKB/Belle
- The X states
- The Y states
- The Z states
- Other topics
- Summary

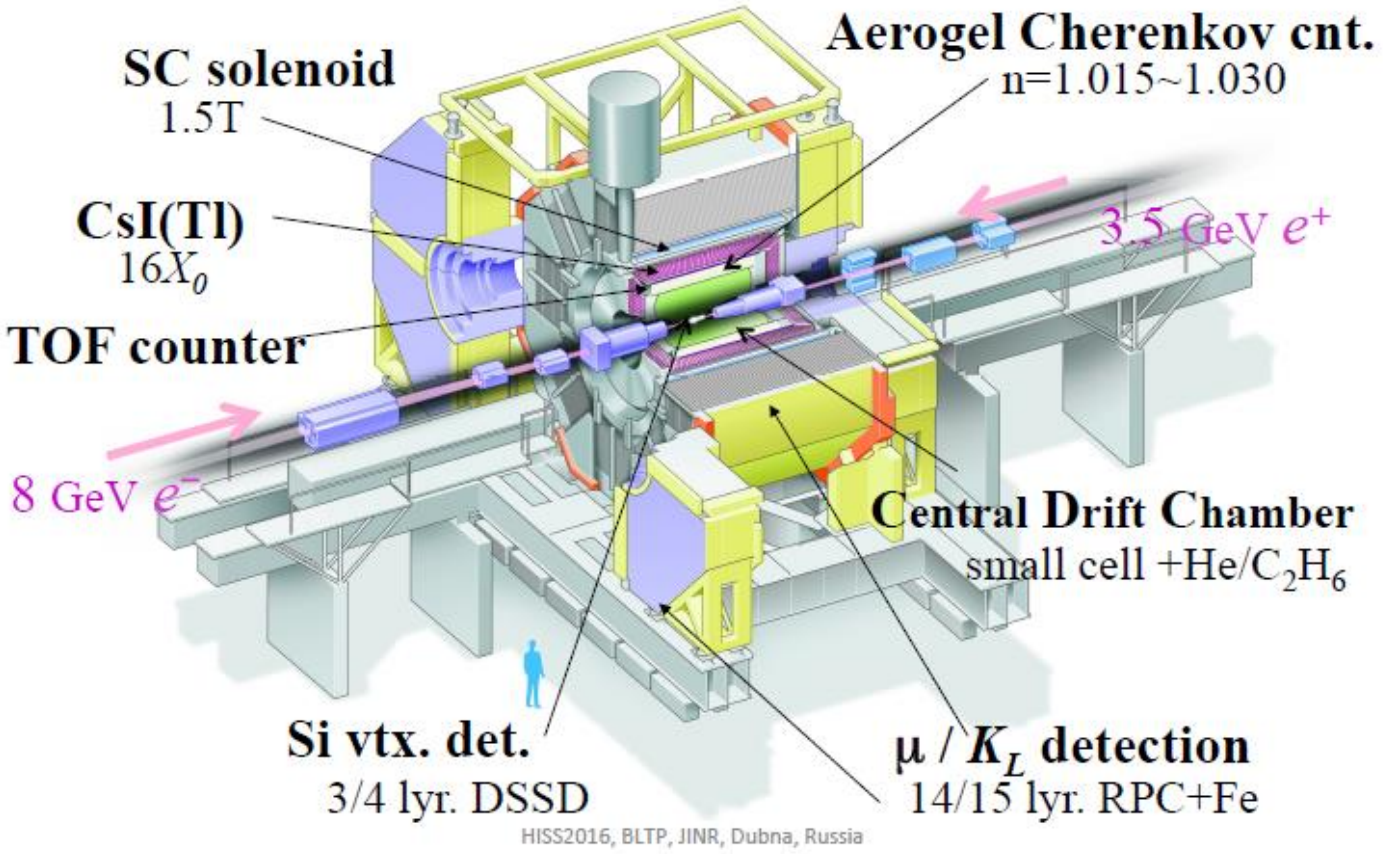
KEKB/Belle : world highest luminosity e^+e^- collider



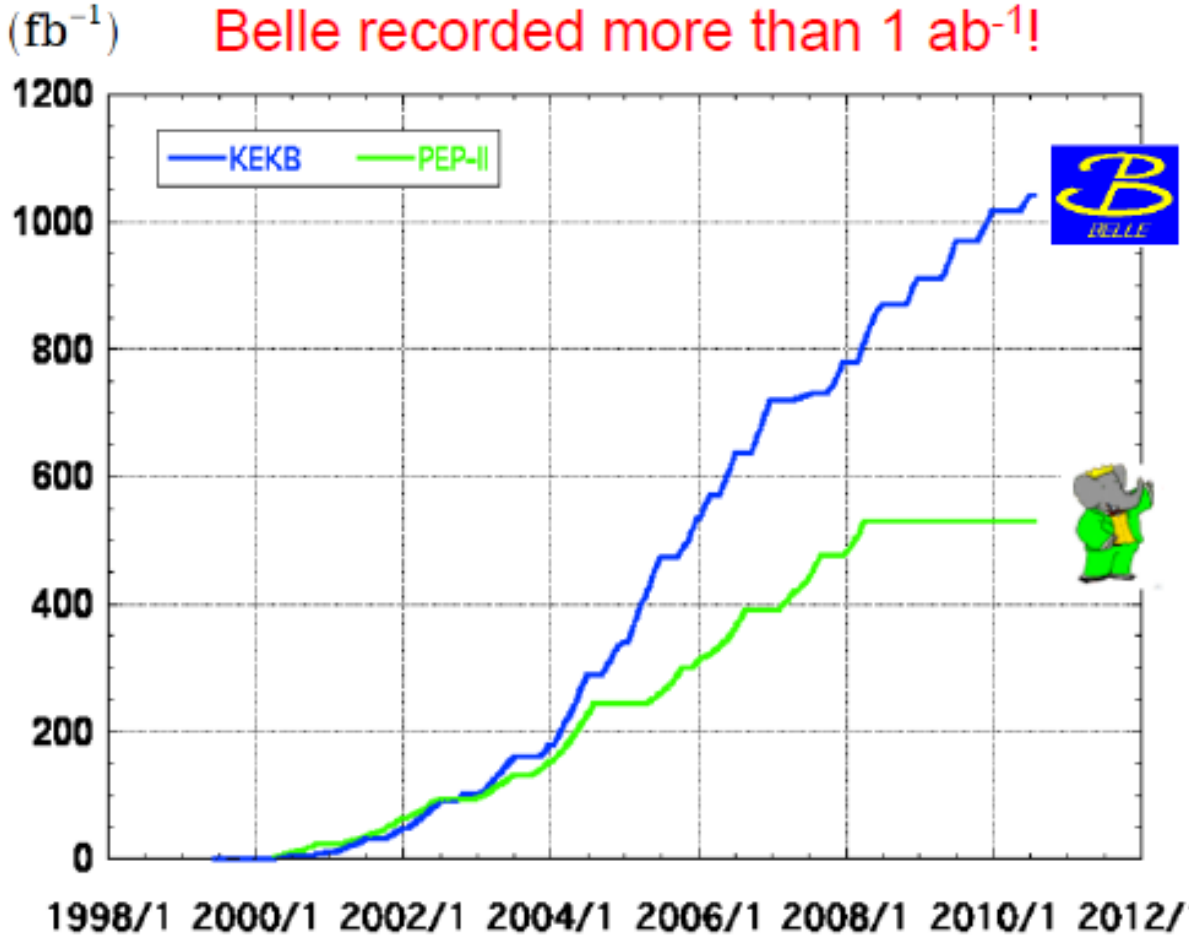
World record:

$L = 2.1 \times 10^{34}/cm^2/sec$

Belle Detector



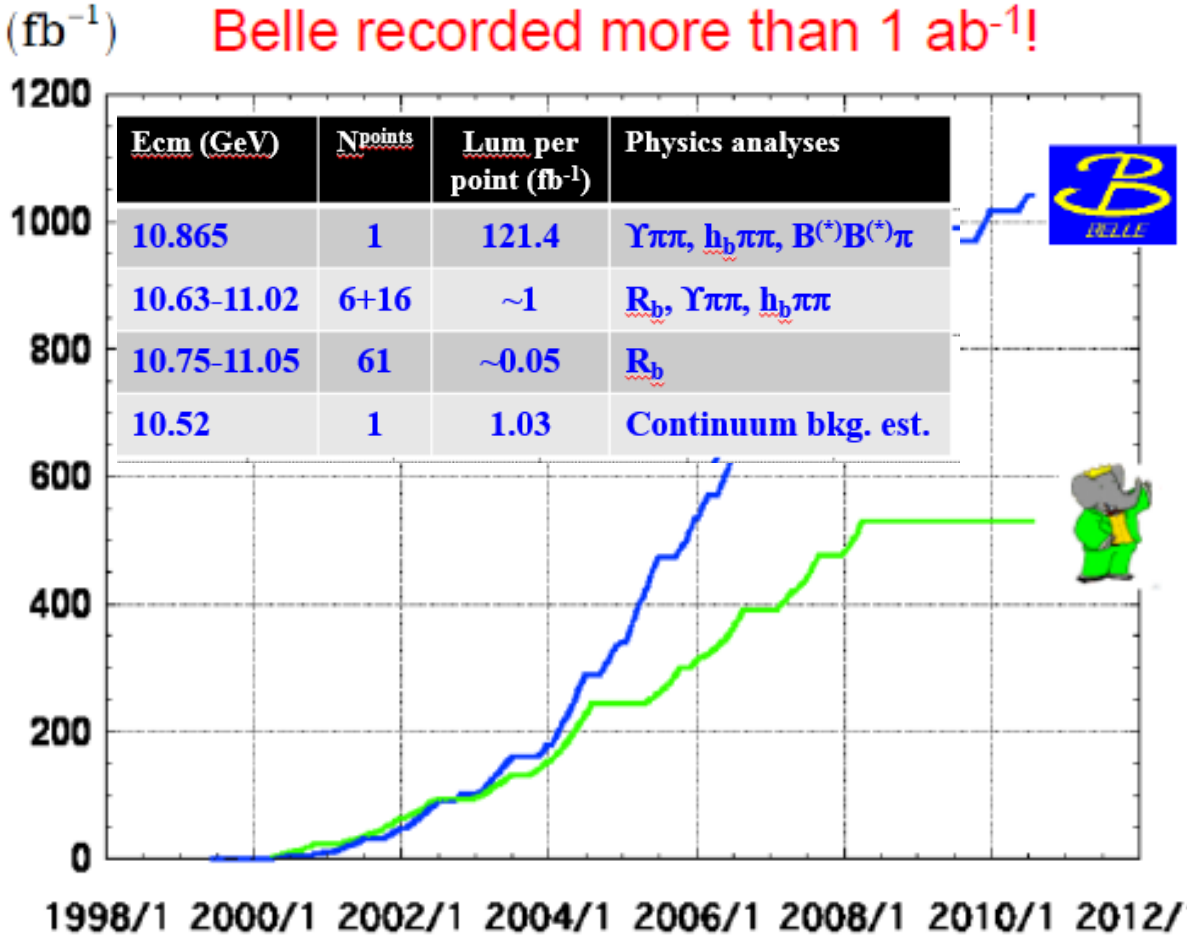
Integrated Luminosity of B factories



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1} 772M $B\bar{B}$
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Integrated Luminosity of B factories



Ecm (GeV)	N^{points}	Lum per point (fb^{-1})	Physics analyses
10.865	1	121.4	$\Upsilon\pi\pi$, $h_b\pi\pi$, $B^{(*)}B^{(*)}\pi$
10.63-11.02	6+16	~1	R_b, $\Upsilon\pi\pi$, $h_b\pi\pi$
10.75-11.05	61	~0.05	R_b
10.52	1	1.03	Continuum bkg. est.

> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1} 772M $B\bar{B}$
$\Upsilon(3S)$: 3 fb^{-1}
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On resonance:
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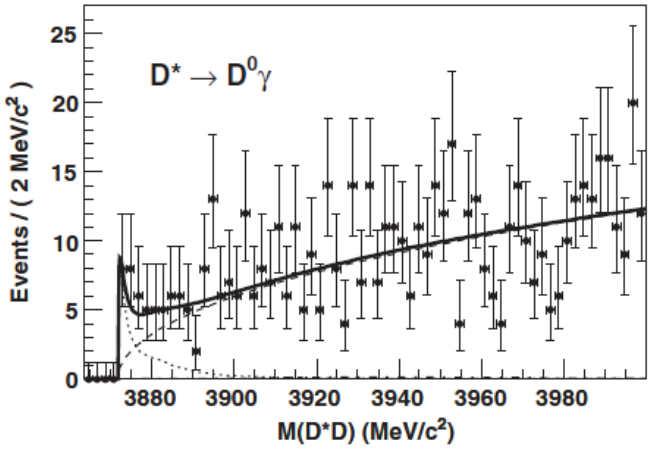
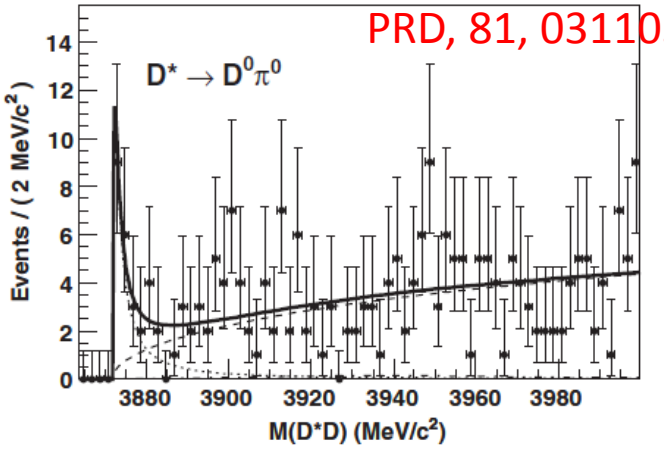
Off resonance:
~ 54 fb^{-1}

The X states

Search for more decay modes of X(3872)

- X(3872) was discovered in 2003 but still unclassified.
- X(3872) is very close to the $\bar{D}^0 D^{*0}$ threshold $(3871.81 \pm 0.36)\ \mathrm{MeV}/c^2$.





PRD, 81, 031103.

Mass: $3872.9^{+0.6}_{-0.4}(\mathrm{stat})^{+0.4}_{-0.5}(\mathrm{sysm})\ \mathrm{MeV}/c^2$.

Width: $3.9^{+2.8}_{-1.4}(\mathrm{stat})^{+0.2}_{-1.1}(\mathrm{sysm})\ \mathrm{MeV}$

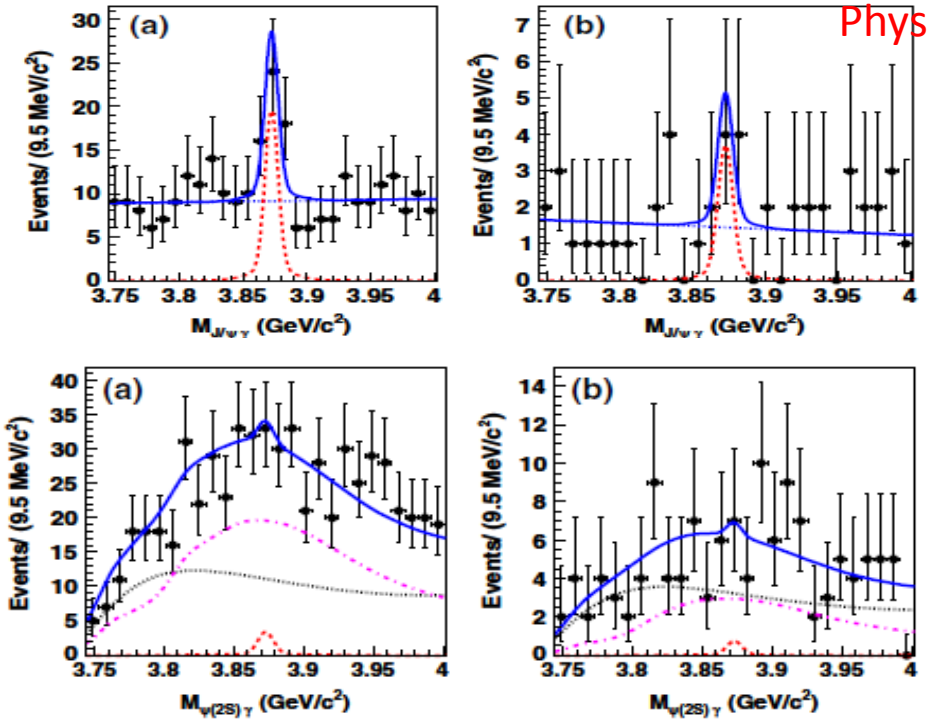
$\mathrm{Br}(X \to D^0 \bar{D}^{*0})/\mathrm{Br}(X \to J/\psi \pi^2)$

= 8.92±2.42, 19.9±8.05 (calc from papers)

Belle BABAR

Search for more decay modes of X(3872)

- In the molecular mode, $X(3872) \to \gamma J/\psi$ is dominated by VMD while $\gamma\psi'$ is mostly by LQA (Phys. Lett. B 598, 197, Phys. Rep. 429, 243).
- But Barbar report $\mathcal{B}(X(3872) \to \gamma\psi')/\mathcal{B}(X(3872) \to \gamma J/\psi)$=3.4 ± 1.4. (Phys. Rev. Lett. 102, 132001)
- Observe $X(3872) \to \gamma J/\psi$ but no significant signal for $\gamma\psi'$.



Phys. Rev. Lett. 107, 091803

$$\frac{\mathcal{B}(X(3872) \to \gamma\psi')}{\mathcal{B}(X(3872) \to \gamma J/\psi)} < 2.1 \text{ (at 90\% C. L.)}$$

Compared with LHCb result:

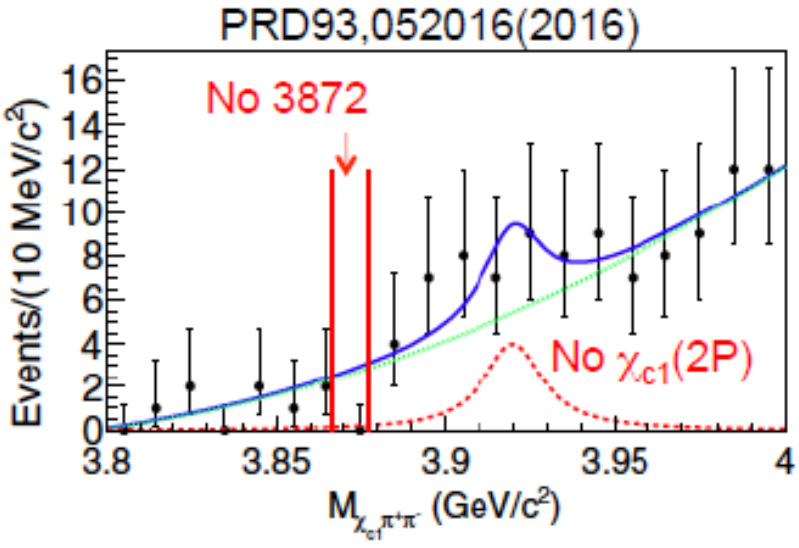
(NPB 886 (2014) 665)

$$\frac{\mathcal{B}(\mathrm{X}(3872) \to \psi(2\mathrm{S})\gamma)}{\mathcal{B}(\mathrm{X}(3872) \to \mathrm{J}/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29,$$

Pure $D\bar{D}^*$ molecule is unlikely…
It agrees with expectation for a pure charmonium interpretation and a molecular-charmonium mixture interpretations.

Search for more decay modes of X(3872)

Using 772×10^6 $\Upsilon(4S)$ $B\bar{B}$ events, $X(3872)$ and $\chi_{c1}(2P)$ is searched in $B^+ \to (\chi_{c1}\pi^+\pi^-)\, K^+$ decay.
No signal of X(3872) or $\chi_{c1}(2P)$.

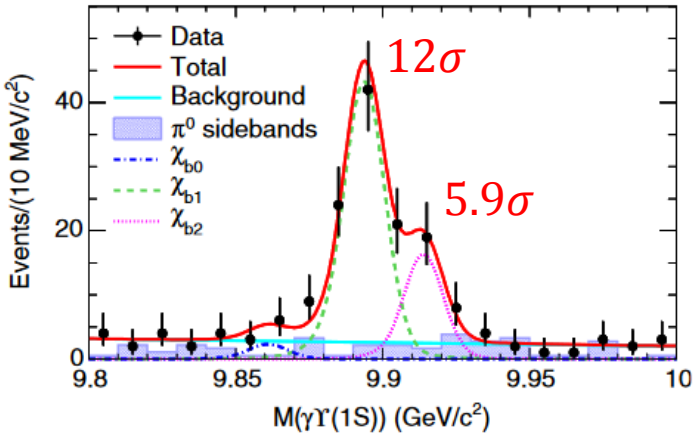


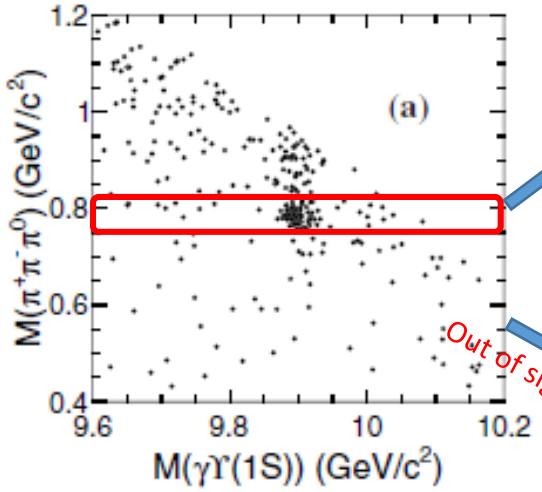
$\mathcal{B}(B^+ \to X(3872)K^+) \times \mathcal{B}(X(3872) \to \chi_{c1}\pi^+\pi^-)$
$< 1.5 \times 10^{-6}\ (at\ 90\%\ C.L)$

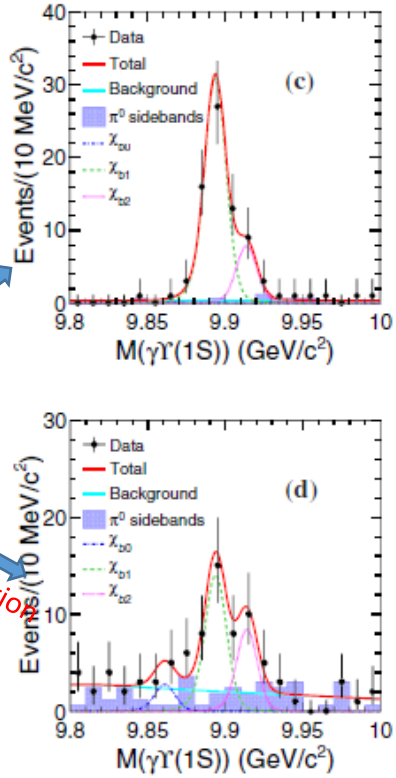
$\mathcal{B}(B^+ \to \chi_{c1}(2P)K^+) \times \mathcal{B}(\chi_{c1}(2P) \to \chi_{c1}\pi^+\pi^-)$
$< 1.1 \times 10^{-5}\ (at\ 90\%\ C.L)$

Search for X_b

- The $\mathrm{X}(3872)$ counterpart in the bottomonium sector X_b.
- As X_b is above $\omega\Upsilon(1S)$ threshold, this isospin conversing process should be a more promising decay mode (PRD, 88, 054007).
- $\omega\chi_{b1/b2}$ are observed for the first time!







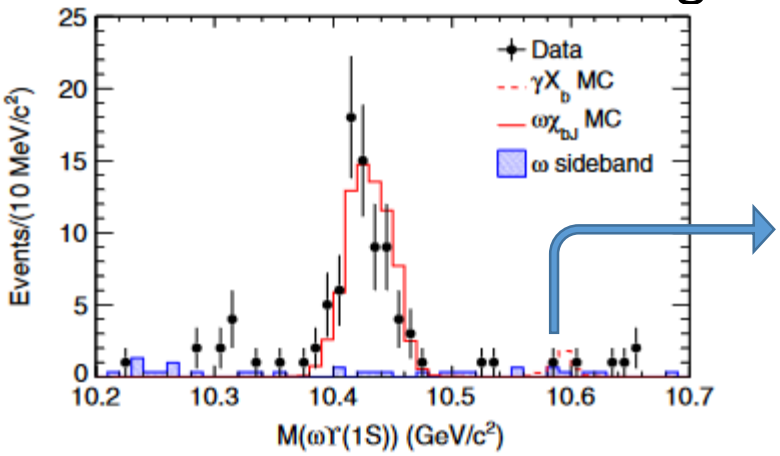
PRL, 113, 142001.

From the 2D fit of the $M(\pi^+\pi^-\pi^0)$ *vs* $M(\gamma\Upsilon(1S))$:

Mode	Yield	Σ (σ)	ε (%)	σ_B (pb)	$\mathcal{B}$ (10^{-3})	$\sigma_{\rm sys}^{(1)}$ (%)	$\sigma_{\rm sys}^{(2)}$ (%)
$\pi^+\pi^-\pi^0\chi_{b0}$	< 13.6	1.0	6.43	< 3.1	< 6.3	25	24
$\pi^+\pi^-\pi^0\chi_{b1}$	80.1 ± 9.9	12	6.61	$0.90 \pm 0.11 \pm 0.13$	$1.85 \pm 0.23 \pm 0.23$	14	12
$\pi^+\pi^-\pi^0\chi_{b2}$	28.6 ± 6.5	5.9	6.65	$0.57 \pm 0.13 \pm 0.08$	$1.17 \pm 0.27 \pm 0.14$	14	12
$\omega\chi_{b0}$	< 7.5	0.5	6.35	< 1.9	< 3.9	29	28
$\omega\chi_{b1}$	59.9 ± 8.3	12	6.53	$0.76 \pm 0.11 \pm 0.11$	$1.57 \pm 0.22 \pm 0.21$	14	13
$\omega\chi_{b2}$	12.9 ± 4.8	3.5	6.56	$0.29 \pm 0.11 \pm 0.08$	$0.60 \pm 0.23 \pm 0.15$	26	25
$(\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b0}$	< 10.7	0.4	6.68	< 2.3	< 4.8	41	41
$(\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b1}$	23.6 ± 6.4	4.9	6.88	$0.25 \pm 0.07 \pm 0.06$	$0.52 \pm 0.15 \pm 0.11$	21	20
$(\pi^+\pi^-\pi^0)_{\text{non-}\omega}\chi_{b2}$	15.6 ± 5.4	3.1	6.91	$0.30 \pm 0.11 \pm 0.14$	$0.61 \pm 0.22 \pm 0.28$	45	45

$\frac{\sigma(e^+e^-\to\omega\chi_{b1})}{\sigma(e^+e^-\to\omega\chi_{b2})} = 0.38 \pm 0.16 \pm 0.09$, where the common systematic uncertainties cancel.

No significant signal of X_b is observed.



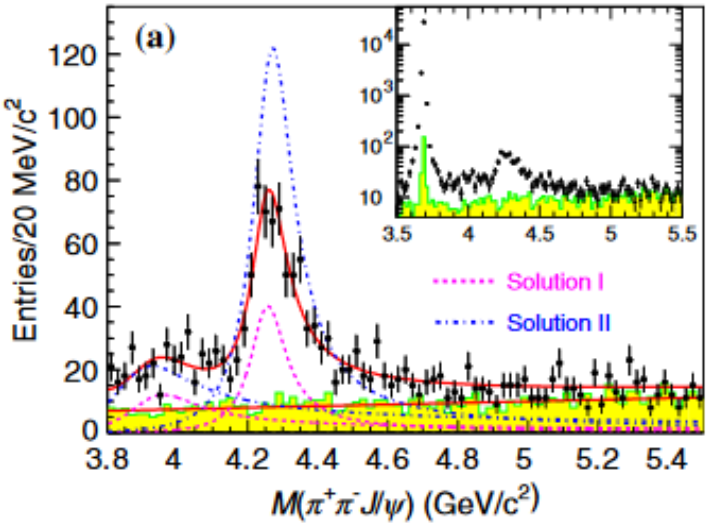
-0.4 ± 2.0 X_b from the fit.

$\mathcal{B}(\Upsilon(10860) \to \gamma X_b)\mathcal{B}\big(X_b \to \omega\Upsilon(1S)\big) < 2.9 \times 10^{-5}$ at 90% C.L.

The Y states

- J^{PC}: 1^{--}
- Production: $e^+e^- \rightarrow (\gamma_{ISR})Y$
- Y has c and $\bar{c}$ quarks.
- But not the simple charmonium.

PRL, 110, 252002.

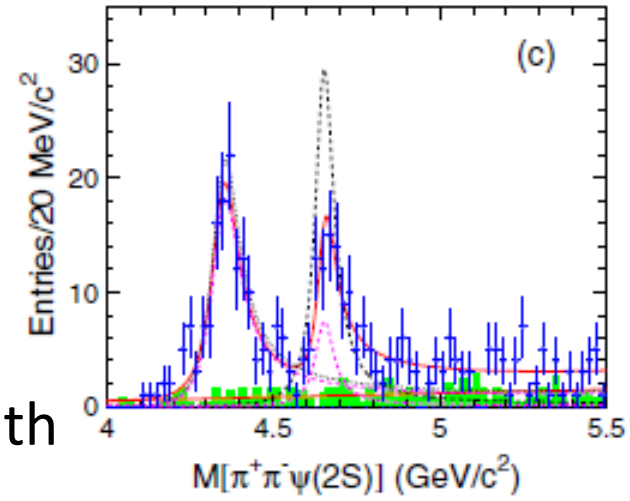


- Two enhancement, $Y(4008)$ and $Y(4260)$ are observed.
- Two solutions for the unbinned maximum likelihood fit.

Parameters	Solution I	Solution II
$M(R_1)$	$3890.8 \pm 40.5 \pm 11.5$	
$\Gamma_{tot}(R_1)$	$254.5 \pm 39.5 \pm 13.6$	
$\Gamma_{ee}\mathcal{B}(R_1 \rightarrow \pi^+\pi^- J/\psi)$	$(3.8 \pm 0.6 \pm 0.4)$	$(8.4 \pm 1.2 \pm 1.1)$
$M(R_2)$	$4258.6 \pm 8.3 \pm 12.1$	
$\Gamma_{tot}(R_2)$	$134.1 \pm 16.4 \pm 5.5$	
$\Gamma_{ee}\mathcal{B}(R_2 \rightarrow \pi^+\pi^- J/\psi)$	$(6.4 \pm 0.8 \pm 0.6)$	$(20.5 \pm 1.4 \pm 2.0)$
ϕ	$59 \pm 17 \pm 11$	$-116 \pm 6 \pm 11$

Y(4360) and Y(4660)

PRL,91, 112007.

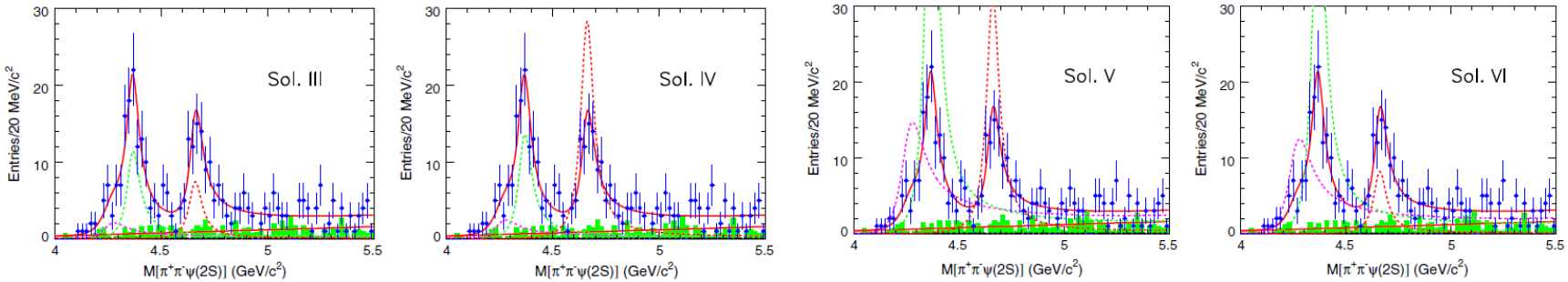


- Based on 980 pb^{-1} data.
- Reconstructed with $\pi^+\pi^-\psi'$.
- Clear $Y(4360)$ and $Y(4660)$.
- Unbinned maximum likelihood fit without $Y(4260)$, get two solutions with same mass and width:

Parameters	Solution I		Solution II
$M_{Y(4360)}$		$4347 \pm 6 \pm 3$	
$\Gamma_{Y(4360)}$		$103 \pm 9 \pm 5$	
$\mathcal{B}[Y(4360) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4360)}$	$9.2 \pm 0.6 \pm 0.6$		$10.9 \pm 0.6 \pm 0.7$
$M_{Y(4660)}$		$4652 \pm 10 \pm 11$	
$\Gamma_{Y(4660)}$		$68 \pm 11 \pm 5$	
$\mathcal{B}[Y(4660) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4660)}$	$2.0 \pm 0.3 \pm 0.2$		$8.1 \pm 1.1 \pm 1.0$
ϕ	$32 \pm 18 \pm 20$		$272 \pm 8 \pm 7$

Add $Y(4260)$ in the fit with constrained mass and width.

$Amp = BW_1 + e^{i\phi} \cdot BW_2 + e^{i\phi} \cdot BW_3$



Parameters	Solution III	Solution IV	Solution V	Solution VI
$M_{Y(4260)}$		4259 (fixed)		
$\Gamma_{Y(4260)}$		134 (fixed)		
$\mathcal{B}[Y(4260) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4260)}$	$1.5 \pm 0.6 \pm 0.4$	$1.7 \pm 0.7 \pm 0.5$	$10.4 \pm 1.3 \pm 0.8$	$8.9 \pm 1.2 \pm 0.8$
$M_{Y(4360)}$		$4365 \pm 7 \pm 4$		
$\Gamma_{Y(4360)}$		$74 \pm 14 \pm 4$		
$\mathcal{B}[Y(4360) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4360)}$	$4.1 \pm 1.0 \pm 0.6$	$4.9 \pm 1.3 \pm 0.6$	$21.1 \pm 3.5 \pm 1.4$	$17.7 \pm 2.6 \pm 1.5$
$M_{Y(4660)}$		$4660 \pm 9 \pm 12$		
$\Gamma_{Y(4660)}$		$74 \pm 12 \pm 4$		
$\mathcal{B}[Y(4660) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4660)}$	$2.2 \pm 0.4 \pm 0.2$	$8.4 \pm 0.9 \pm 0.9$	$9.3 \pm 1.2 \pm 1.0$	$2.4 \pm 0.5 \pm 0.3$
ϕ_1	$304 \pm 24 \pm 21$	$294 \pm 25 \pm 23$	$130 \pm 4 \pm 2$	$141 \pm 5 \pm 4$
ϕ_2	$26 \pm 19 \pm 10$	$238 \pm 14 \pm 21$	$329 \pm 8 \pm 5$	$117 \pm 23 \pm 25$

The significance of Y(4260) is only 2.8σ, but it affects Y(4360) and Y(4660) masses and widths.

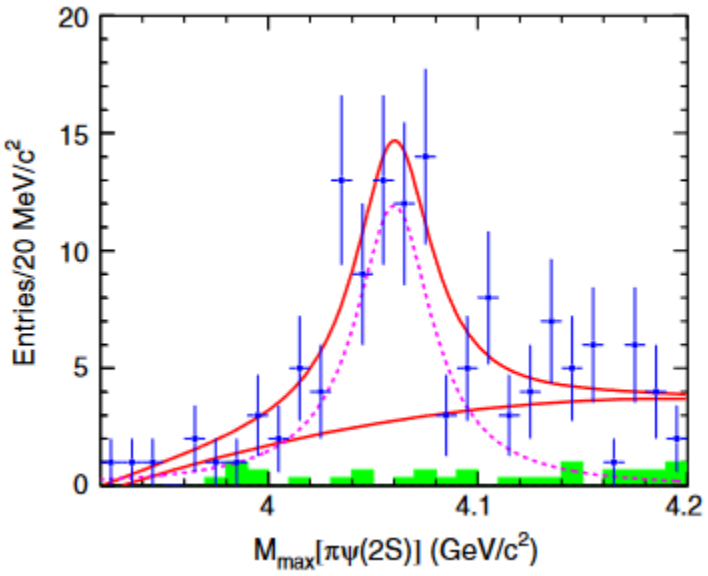
The Z states

- Many Z states have been observed now.

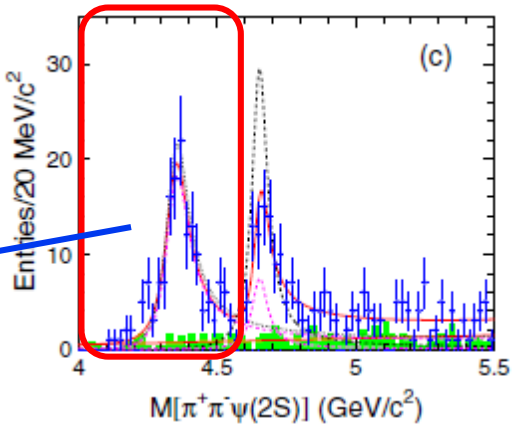
Particle	C	J^C	Decay	Year	Collaboration
$Z_C(3900)^+$	-	?	$\pi^+ J/\psi$	2013	BESIII, Belle, CLEOc
$Z_C(3885)^+$	-	$\mathbf{1}^+$	$(DD^*)^+$	2013	BESIII
$Z_C(4020)^+$	-	?	$\pi^+ h_c(1P)$	2013	BESIII
$Z_C(4025)^+$	-	?	$(D^*D^*)^+$	2013	BESIII
$Z_C(4200)^+$	-	$\mathbf{1}^+$	$\pi^+ J/\psi$	2014	Belle
$Z_C(4200)^0$	-	$\mathbf{1}^+$	$\pi^0 J/\psi$	2014	BESIII
$Z_C(4050)^+$	+	?	$\pi^+ \chi_{c1}$	2008	Belle
$Z_C(4250)^+$	+	?	$\pi^+ \chi_{c1}$	2008	Belle
$Z_C(4430)^+$	-	$\mathbf{1}^+$	$\pi^+ \psi(2S)$	2008	Belle, LHCb
$Z_b(10610)^\pm$		$\mathbf{1}^+$	$\pi^+ \Upsilon(nS)$	2012	Belle
$Z_b(10650)^\pm$		$\mathbf{1}^+$	$\pi^+ \Upsilon(nS)$	2012	Belle
$Z_b(10610)^0$		$\mathbf{1}^+$	$\pi^0 \Upsilon(nS)$	2013	Belle

$Z_C(4050)^{\pm} \rightarrow \pi^{\pm}\psi(2S)$.

PRD, 91, 112007.



The $M(\pi^{\pm}\psi(2S))$ in $Y(4360)$ singal region.



Unbinned maximum likelihood fit is performed to the maximum of $M(\pi^{+}\psi(2S))$ and $M(\pi^{-}\psi(2S))$.

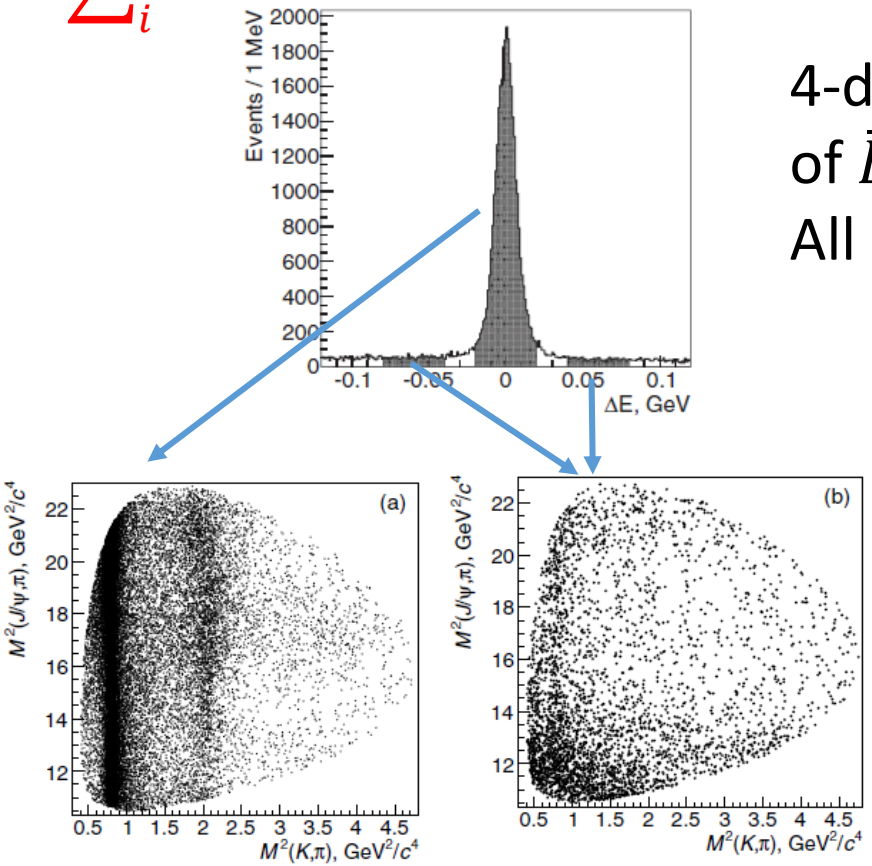
- $M(Z_c) = 4054 \pm 3 \pm 1$ MeV/c²
  - $\Gamma = 45 \pm 11 \pm 6$ MeV
  - Significance: >3.5σ

No significant structure in the $\pi^{\pm}\psi(2S)$ system in $Y(4660)$ singal region.

$Z_C(4200)^+ \to \pi^+ J/\psi$

PRD, 90, 112009.

$$\Delta E = \sum_i E_i - E_{beam}$$



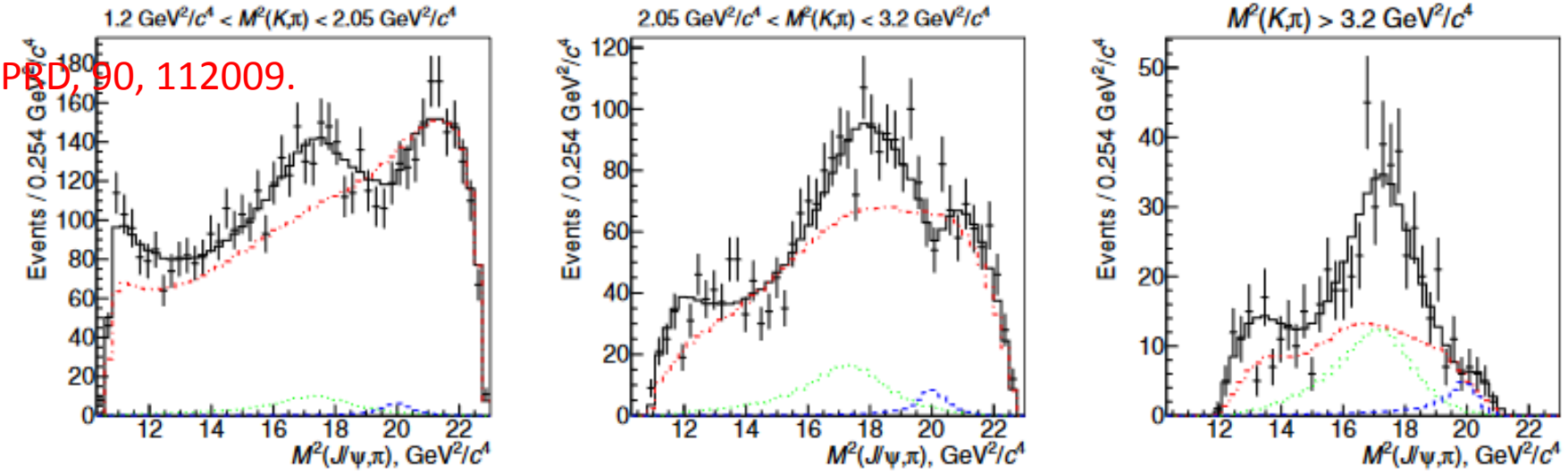
4-dimensional Amplitude analysis of $\bar{B}^0 \to J/\psi K^- \pi^+$:
All K^* and $Z_C(4430)^+$ resonances.

The known mass and width of the $Z_C(4430)^+$ (PRD, 88, 074026) are used to limit the floating mass and width:

$$-2\ln L \to -2\ln L + \frac{(M - M_0)^2}{\sigma_{M_0}^2} + \frac{(\Gamma - \Gamma_0)^2}{\sigma_{\Gamma_0}^2},$$

- $Z_C(4200)^+$ is observed with a significance of 6.2σ.
- The preferred assignment of the quantum number J^P: 1^+ with global significance of 7.9σ.
- Find evidence for $Z_C(4430)^+ \to \pi^+ J/\psi$, 4.0σ.

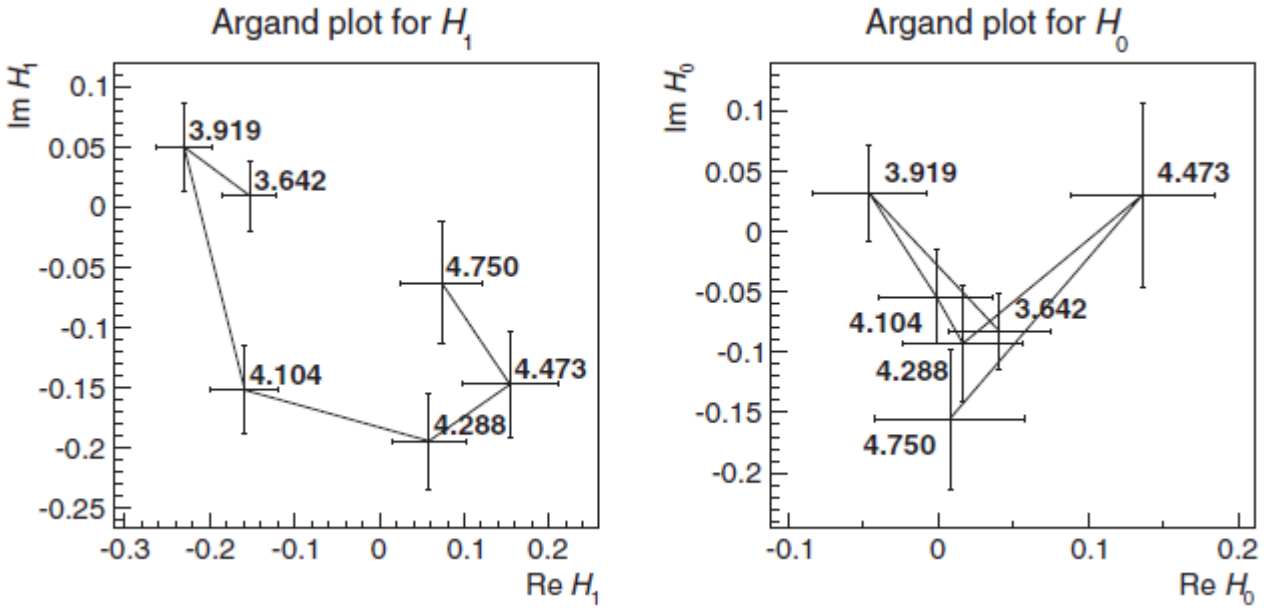
PRD, 90, 112009.



Mass: $4190^{+31}_{-29}(\text{stat})^{+17}_{-13}(\text{sysm})$ MeV/c^2.

Width:$370^{+70}_{-70}(\text{stat})^{+70}_{-132}(\text{sysm})$ MeV

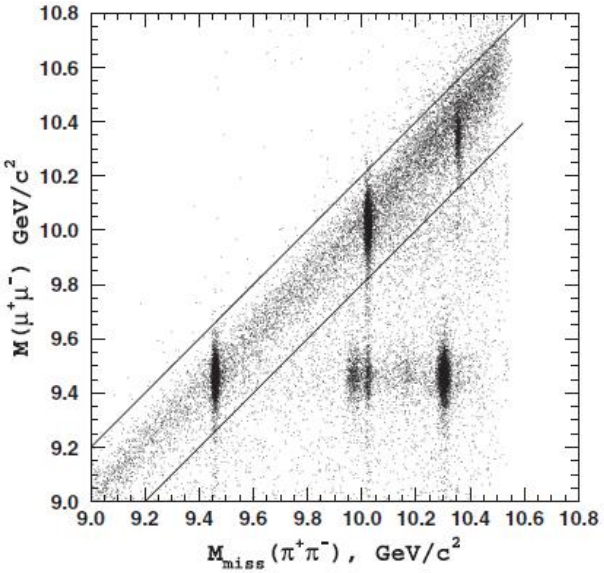
A fit with the $Z_C(4200)^+$ Breit-Wigner amplitude changed to a combination of constant amplitudes is performed.



The plot for H_1 shows a resonancelike change of the amplitude absolute value and phase.

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

Study on 121.4 fb^{-1} $\Upsilon(5S)$ data, select $\pi^+\pi^-$ by requiring $M(\pi^+\pi^-)$ with tagged $\mu^+\mu^-$. Clear signal of $\pi^+\pi^-\Upsilon(nS)$.



PRD, 91, 072003.

- Amplitude analysis on $\pi^+\pi^-\Upsilon(nS)$:

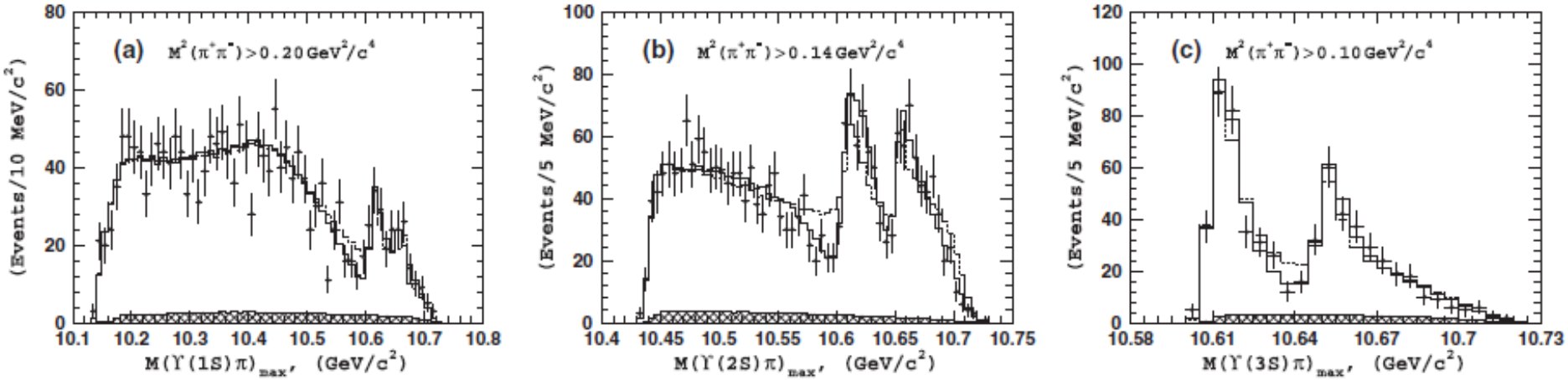
$A_{\pi\pi\Upsilon} = A_{\pi Z_1} + A_{\pi Z_2} + A_{\sigma\Upsilon} + A_{f_0\Upsilon} + A_{f_2\Upsilon} + A_{NR}$,

where A_{NR} is the non-resonance components.

- Remove the background contribution:

$$\mathcal{L} = -2 \sum_{events} \ln(f_{sig}S + (1 - f_{sig})B)$$

$\pi^+\pi^-\Upsilon(1S)$ $\pi^+\pi^-\Upsilon(2S)$ $\pi^+\pi^-\Upsilon(3S)$



PRD, 91, 072003.

- By comparing the fitted maximum likelihood, the favored quantum number J^P=$1^+$for both Z_b.
- J^P=1^-, $2^\pm$ are rejected at confidence levels exceeding 6σ.

	$Z_b(10650)$			
$Z_b(10610)$	1^+	1^-	2^+	2^-
1^+	0(0)	60(33)	42(33)	77(63)
1^-	226(47)	264(73)	224(68)	277(106)
2^+	205(33)	235(104)	207(87)	223(128)
2^-	289(99)	319(111)	321(110)	304(125)

Masses, widths and branching fractions are also determined.

Born cross section

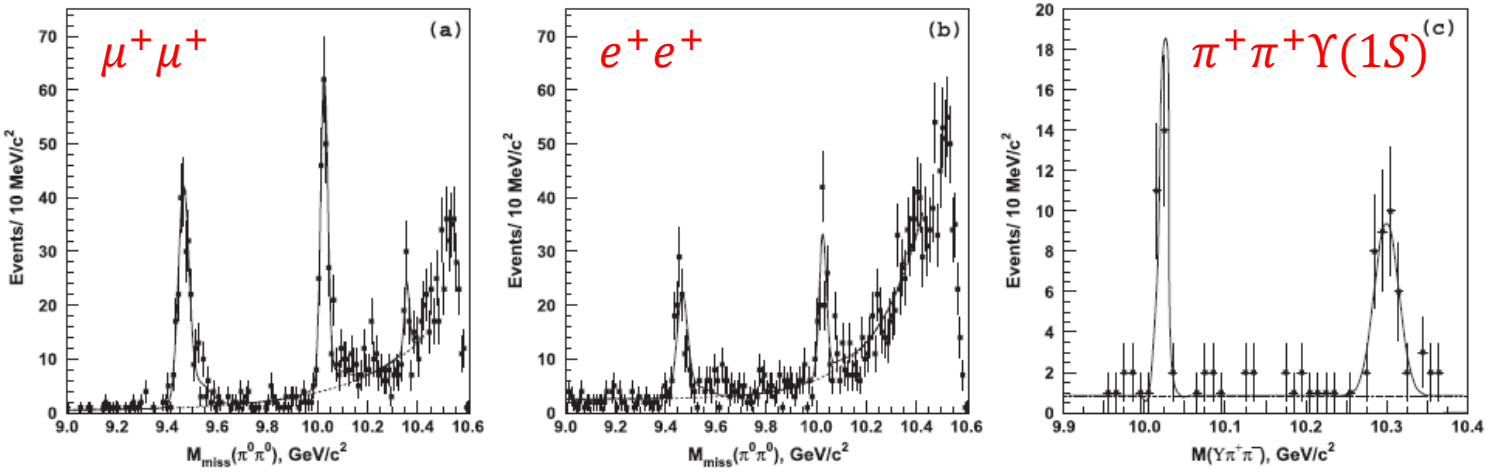
Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
Signal yield	2090 ± 115	2476 ± 97	628 ± 41
Efficiency, %	45.9	39.0	24.4
$\mathcal{B}_{\Upsilon(nS)\to\mu^+\mu^-}$, % [14]	2.48 ± 0.05	1.93 ± 0.17	2.18 ± 0.21
$\sigma^{\rm vis}_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb	$1.51 \pm 0.08 \pm 0.09$	$2.71 \pm 0.11 \pm 0.30$	$0.97 \pm 0.06 \pm 0.11$
$\sigma_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb	$2.27 \pm 0.12 \pm 0.14$	$4.07 \pm 0.16 \pm 0.45$	$1.46 \pm 0.09 \pm 0.16$
$\sigma^{\rm vis}_{e^+e^-\to\Upsilon(nS)\pi^+\pi^-}$, pb [1]	$1.61 \pm 0.10 \pm 0.12$	$2.35 \pm 0.19 \pm 0.32$	$1.44^{+0.55}_{-0.45} \pm 0.19$

Parameter	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
$f_{Z_b^\mp(10610)\pi^\pm}$, %	$4.8 \pm 1.2^{+1.5}_{-0.3}$	$18.1 \pm 3.1^{+4.2}_{-0.3}$	$30.0 \pm 6.3^{+5.4}_{-7.1}$
$Z_b(10610)$ mass, MeV/c^2	$10608.5 \pm 3.4^{+3.7}_{-1.4}$	$10608.1 \pm 1.2^{+1.5}_{-0.2}$	$10607.4 \pm 1.5^{+0.8}_{-0.2}$
$Z_b(10610)$ width, MeV	$18.5 \pm 5.3^{+6.1}_{-2.3}$	$20.8 \pm 2.5^{+0.3}_{-2.1}$	$18.7 \pm 3.4^{+2.5}_{-1.3}$
$f_{Z_b^\mp(10650)\pi^\pm}$, %	$0.87 \pm 0.32^{+0.16}_{-0.12}$	$4.05 \pm 1.2^{+0.95}_{-0.15}$	$13.3 \pm 3.6^{+2.6}_{-1.4}$
$Z_b(10650)$ mass, MeV/c^2	$10656.7 \pm 5.0^{+1.1}_{-3.1}$	$10650.7 \pm 1.5^{+0.5}_{-0.2}$	$10651.2 \pm 1.0^{+0.4}_{-0.3}$
$Z_b(10650)$ width, MeV	$12.1^{+11.3+2.7}_{-4.8-0.6}$	$14.2 \pm 3.7^{+0.9}_{-0.4}$	$9.3 \pm 2.2^{+0.3}_{-0.5}$
ϕ_Z, degrees	$67 \pm 36^{+24}_{-52}$	$-10 \pm 13^{+34}_{-12}$	$-5 \pm 22^{+15}_{-33}$
$c_{Z_b(10650)}/c_{Z_b(10610)}$	$0.40 \pm 0.12^{+0.05}_{-0.11}$	$0.53 \pm 0.07^{+0.32}_{-0.11}$	$0.69 \pm 0.09^{+0.18}_{-0.07}$
$f_{\Upsilon(nS)f_2(1270)}$, %	$14.6 \pm 1.5^{+6.3}_{-0.7}$	$4.09 \pm 1.0^{+0.33}_{-1.0}$	–
$f_{\Upsilon(nS)(\pi^+\pi^-)_S}$, %	$86.5 \pm 3.2^{+3.3}_{-4.9}$	$101.0 \pm 4.2^{+6.5}_{-3.5}$	$44.0 \pm 6.2^{+1.8}_{-4.3}$
$f_{\Upsilon(nS)f_0(980)}$, %	$6.9 \pm 1.6^{+0.8}_{-2.8}$	–	–

PRD, 91, 072003.

Z_b^0 in $\pi^0\pi^0\Upsilon(nS)$

- It's natural to expect the existence of neutral partners of the $Z_b^{\pm}(10610)$, $Z_b^{\pm}(10650)$ States.
- $\pi^0\pi^0\Upsilon(nS)$ are observed in $\Upsilon(10860)$ decays for the first time.



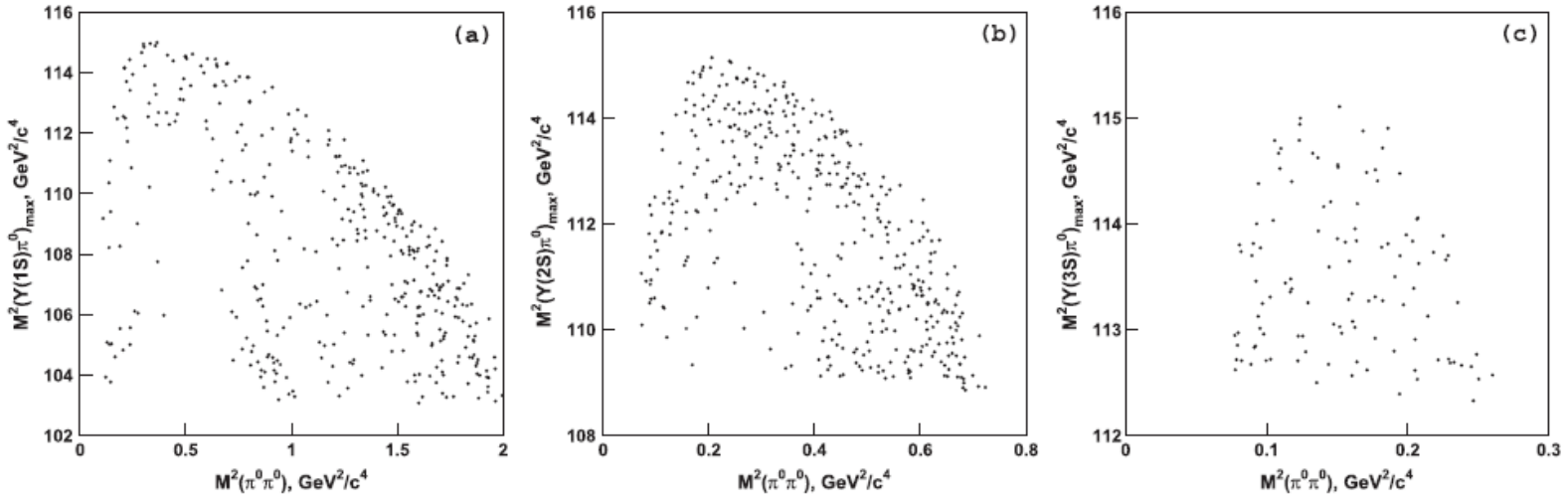
PRD88, 052016 (2013)

Born cross section:

$$\sigma(e^+e^- \to \Upsilon(1S)\pi^0\pi^0) = (1.16 \pm 0.06 \pm 0.10)\ \text{pb},$$
$$\sigma(e^+e^- \to \Upsilon(2S)\pi^0\pi^0) = (1.87 \pm 0.11 \pm 0.23)\ \text{pb},$$
$$\sigma(e^+e^- \to \Upsilon(3S)\pi^0\pi^0) = (0.98 \pm 0.24 \pm 0.19)\ \text{pb}.$$

Approximately ½ of the corresponding values of $e^+e^+ \to \pi^+\pi^-\Upsilon(nS)$.

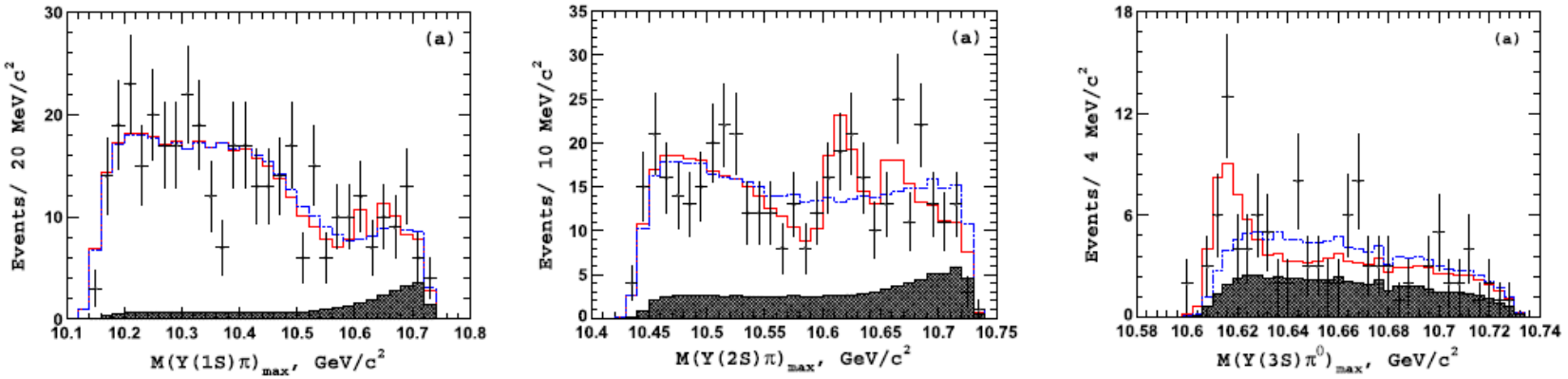
A mass constrained Dalitz Analysis is performed:



Two solutions are found for $\pi^0\pi^0\Upsilon(2S)$ sample while single solutions for $\pi^0\pi^0\Upsilon(1,3S)$.

PRD88, 052016 (2013)

- 5.3σ for the $Z_b^0(10610)$ in both solutions for $\pi^0\pi^0\Upsilon(2S)$ while 4.7σ for $\pi^0\pi^0\Upsilon(3S)$.
- Simultaneous fit of $\pi^0\pi^0\Upsilon(2,3S)$, 6.8σ of statistical significance for $Z_b^0(10610)$.
- $Z_b^0(10650)$ is not significant although the data are consistent with the existence of $Z_b^0(10650)$.



Free the $Z_b^0(10610)$ parameters:

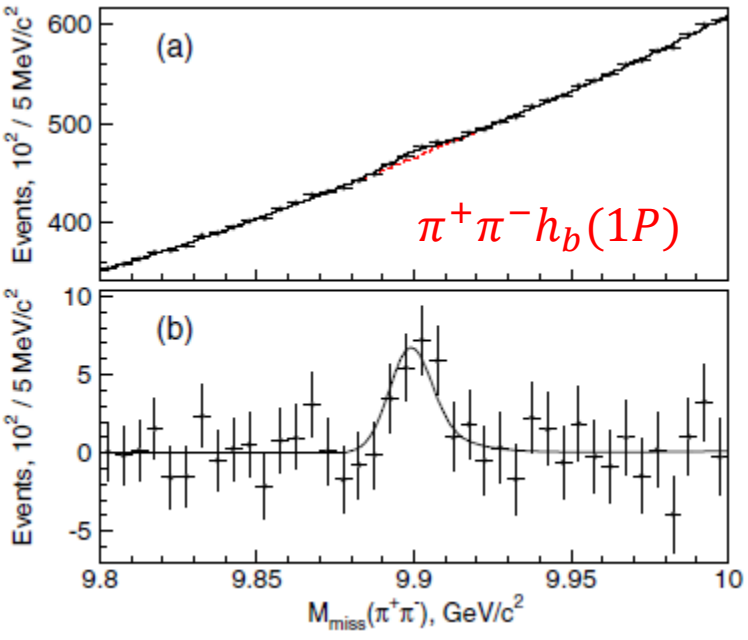
PRD88, 052016 (2013)

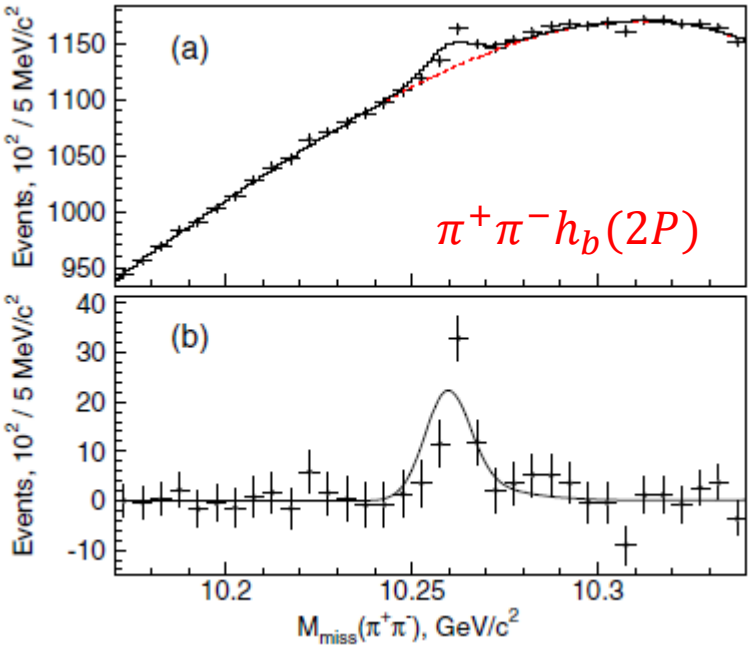
Mass: $10609 \pm 4 \pm 4\ \mathrm{MeV}/c^2$.

First isospin partner among "XYZ".

$e^+e^- \to \pi^+\pi^- h_b(nP)$

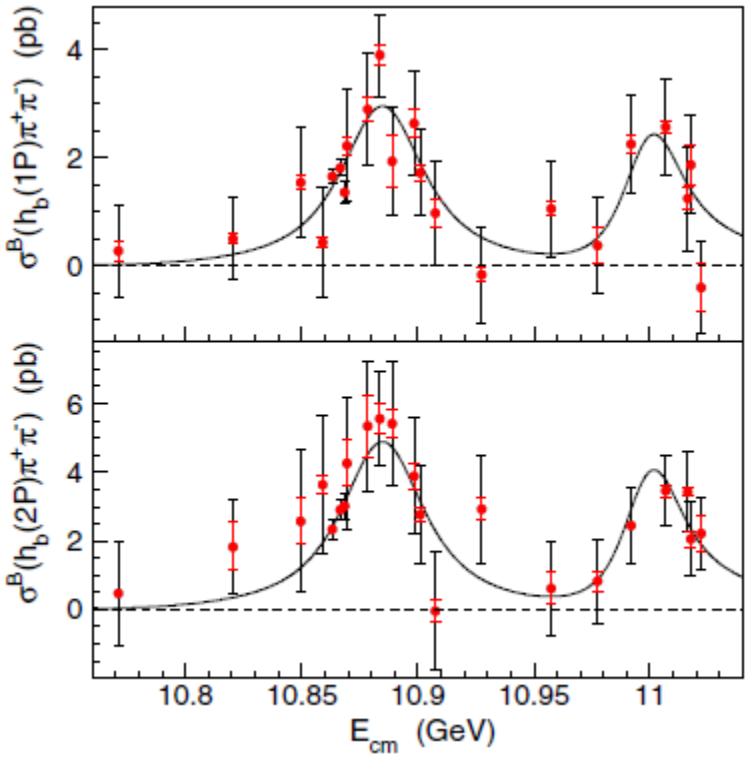
- Using the scan data collected between $\Upsilon(5S)$ to $\Upsilon(6S)$.
- Reconstructed $\pi^+\pi^-$ and require $M_{miss}(\pi^{\pm})$ in mass region: [10.59, 10.67] GeV/c^2, which is Z_b signal region.





PRL, 117, 142001.

With tagged $\pi^+\pi^- h_b(nP)$ signal, find evidence of $\Upsilon(5S)$ and observe $\Upsilon(6S)$ with significance of 3.5σ and 5.3σ, repectively.



$\Upsilon(5S)$

Mass: $10884.7^{+3.6}_{-3.4}(\text{stat})^{+8.9}_{-1.0}(\text{sysm})$ MeV/c^2

Width: $40.6^{+12.7}_{-8.0}(\text{stat})^{+1.1}_{-19.1}(\text{sysm})$ MeV

$\Upsilon(6S)$

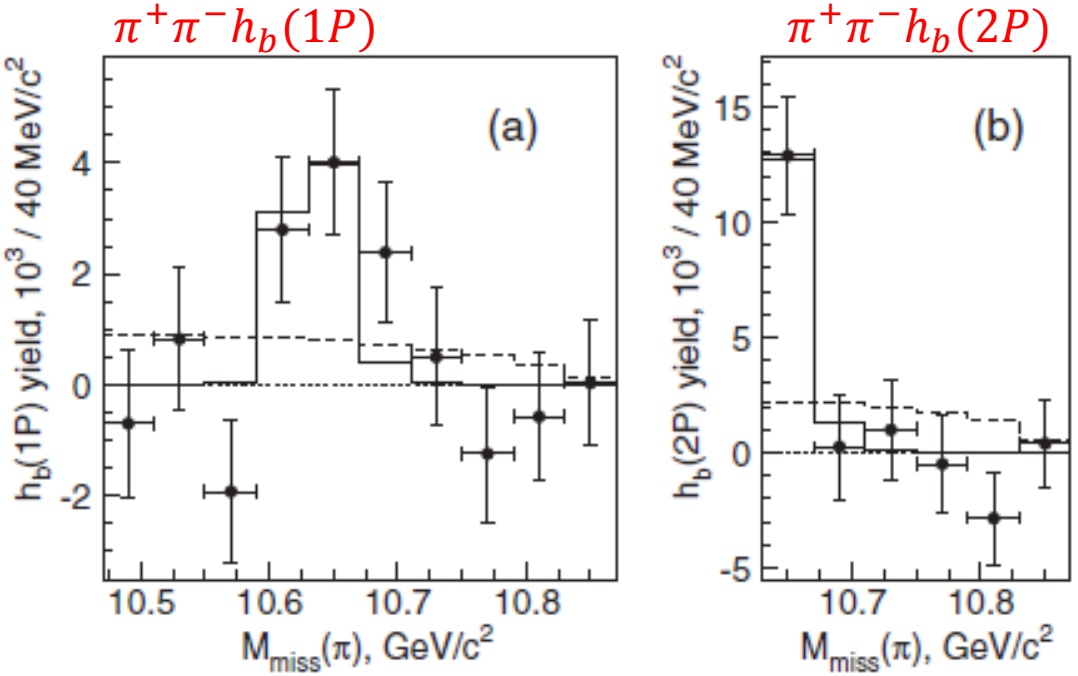
Mass: $10999.0^{+7.3}_{-7.8}(\text{stat})^{+16.9}_{-1.0}(\text{sysm})$ MeV/c^2

Width: $27^{+27}_{-11}(\text{stat})^{+5}_{-12}(\text{sysm})$ MeV

$$\sigma^B(e^+e^- \to h_b(1P)\pi^+\pi^-) = 1.66 \pm 0.09 \pm 0.10\,\text{pb},$$
$$\sigma^B(e^+e^- \to h_b(2P)\pi^+\pi^-) = 2.70 \pm 0.17 \pm 0.19\,\text{pb}.$$

PRL, 117, 142001.

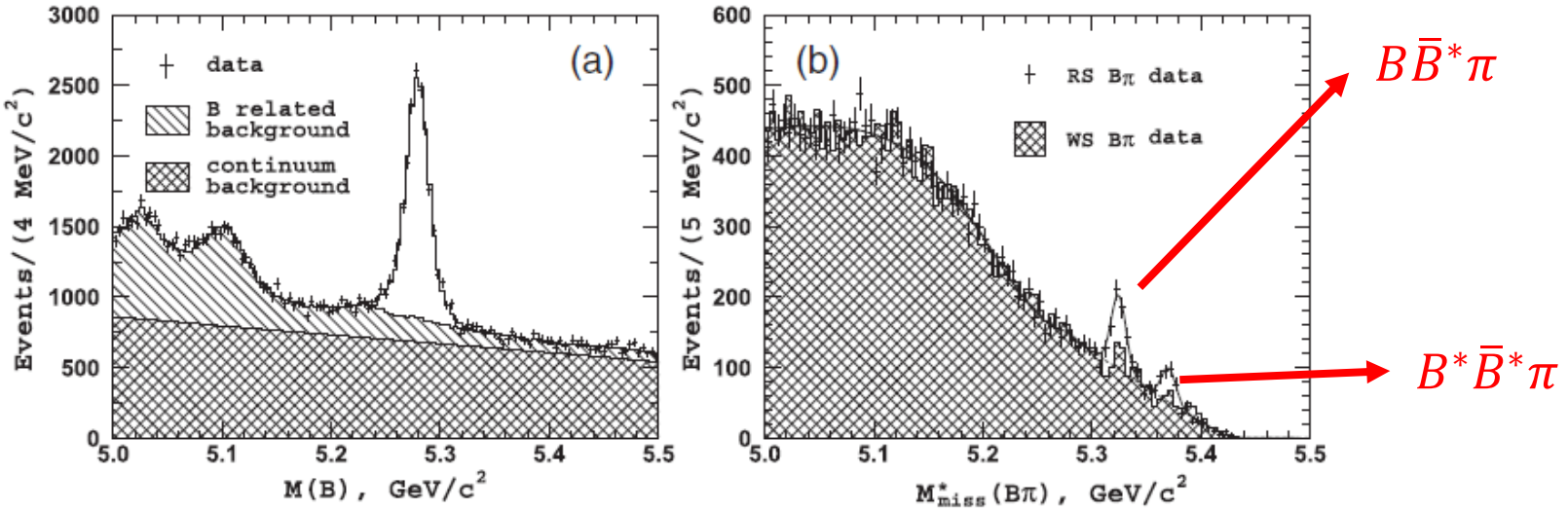
- Release the requirement of an intermediate Z_b and yield the h_b.
- Fit the data where Z_b parameters are fixed and non-resonance background is set to zero.
- The hypothesis that only $Z_b(10610)$ if produced in $\pi^+\pi^- h_b(1P)$ channel is excluded at the 3.3σ level.



PRL, 117, 142001.

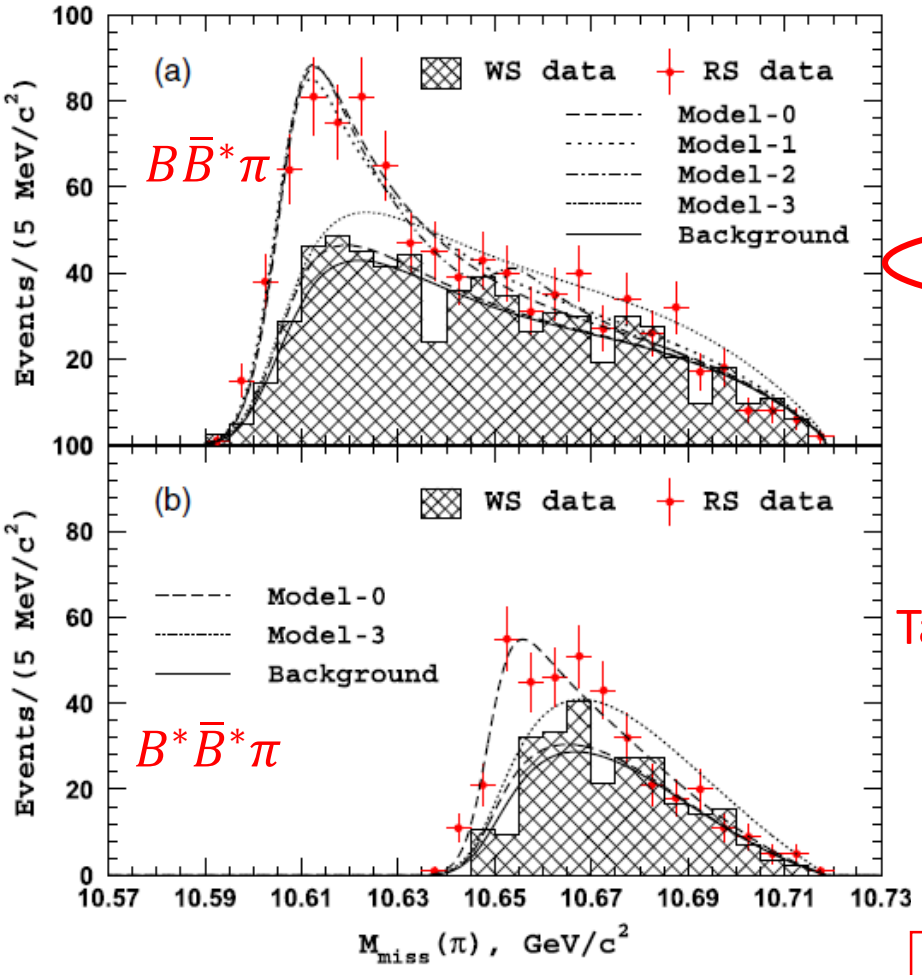
Z_b in $\Upsilon(5S) \to [B^{(*)}B^{(*)}]^{+}\pi^{-} + c.c$

- $Z_b(10610)$ and $Z_b(10650)$ might be loosely bound $B\bar{B}^*$ and $B^*\bar{B}^*$ system, respectively.
- Reconstruct three body $[B^{(*)}B^{(*)}]\pi$. Identify B meson by mass and momentum in c.m.s.



PRL, 116, 212001.

Combined with right π: the right sign combination(RS).
wrong π-wrong sign (WS), studied from MC, normalized in data.



A simultaneous binned maximum likelihood fit to WS and RS data.

Model-0: $Z_b(10610)$ [$Z_b(10650)$] only.
Model-1: Z_b+Non-resonance.
Model-2: $Z_b(10610)$ +$Z_b(10650)$ with interference
Model-3: Non-resonance

Take model 0 as the nominal hypothesis.

Parameter	$BB\pi$	$BB^*\pi$	$B^*B^*\pi$
N_f, events	13 ± 25	357 ± 30	161 ± 21
$\mathcal{B}_f$, 10^{-6}	293 ± 22	276 ± 21	223 ± 17
η	1.0	1.066	1.182
$1+\delta_{ISR}$	0.720 ± 0.017	0.598 ± 0.016	0.594 ± 0.016
σ, pb	< 2.9	$17.4 \pm 1.6 \pm 1.9$	$8.75 \pm 1.15 \pm 1.04$

PRL, 116, 212001.

Assuming that the known Z_b decay table is saturated.
Give the relative branching fraction for Z_b decays.

PRL, 116, 212001.

Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.54^{+0.16+0.11}_{-0.13-0.08}$	$0.17^{+0.07+0.03}_{-0.06-0.02}$
$\Upsilon(2S)\pi^+$	$3.62^{+0.76+0.79}_{-0.59-0.53}$	$1.39^{+0.48+0.34}_{-0.38-0.23}$
$\Upsilon(3S)\pi^+$	$2.15^{+0.55+0.60}_{-0.42-0.43}$	$1.63^{+0.53+0.39}_{-0.42-0.28}$
$h_b(1P)\pi^+$	$3.45^{+0.87+0.86}_{-0.71-0.63}$	$8.41^{+2.43+1.49}_{-2.12-1.06}$
$h_b(2P)\pi^+$	$4.67^{+1.24+1.18}_{-1.00-0.89}$	$14.7^{+3.2+2.8}_{-2.8-2.3}$
$B^+\bar{B}^{*0}+\bar{B}^0B^{*+}$	$85.6^{+1.5+1.5}_{-2.0-2.1}$	...
$B^{*+}\bar{B}^{*0}$	...	$73.7^{+3.4+2.7}_{-4.4-3.5}$

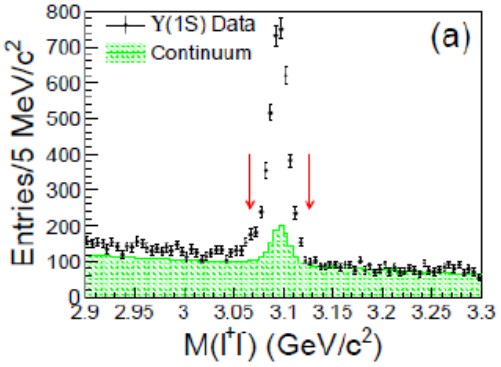
Dominated

Proof of the molecular.

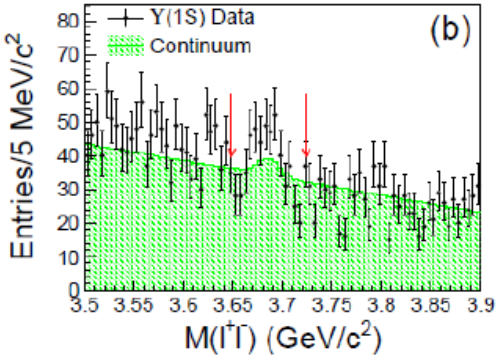
Other topic

Search for XYZ in $\Upsilon(1S)$ inclusive decay

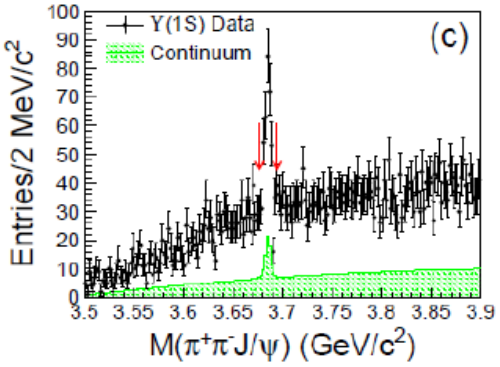
- A common feature of these XYZ states is that they decay into a charmonium state such as J/ψ or ψ'.
- $\Upsilon(1S)$ inclusive to J/ψ or ψ' with large branching ratios $[(6.5 \pm 0.7) \times 10^{-4}$ and $(2.7 \pm 0.9) \times 10^{-4}]$.
- Tag $\Upsilon(1S) \to J/\psi$ or $\psi' +$ anything : PRD, 93, 112032.



$J/\Psi \to l^+l^-$

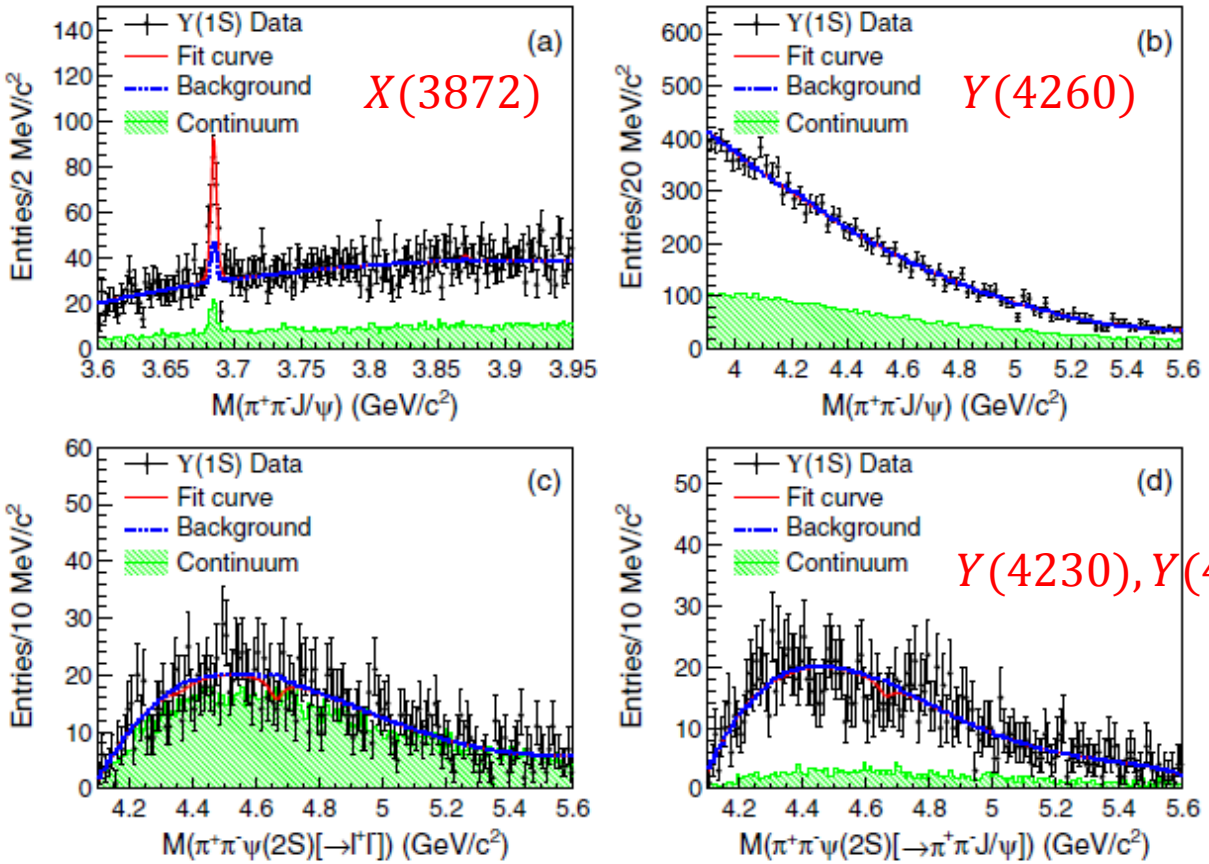


$\Psi(2S) \to l^+l^-$



$\Psi(2S) \to \pi^+\pi^- J/\Psi$

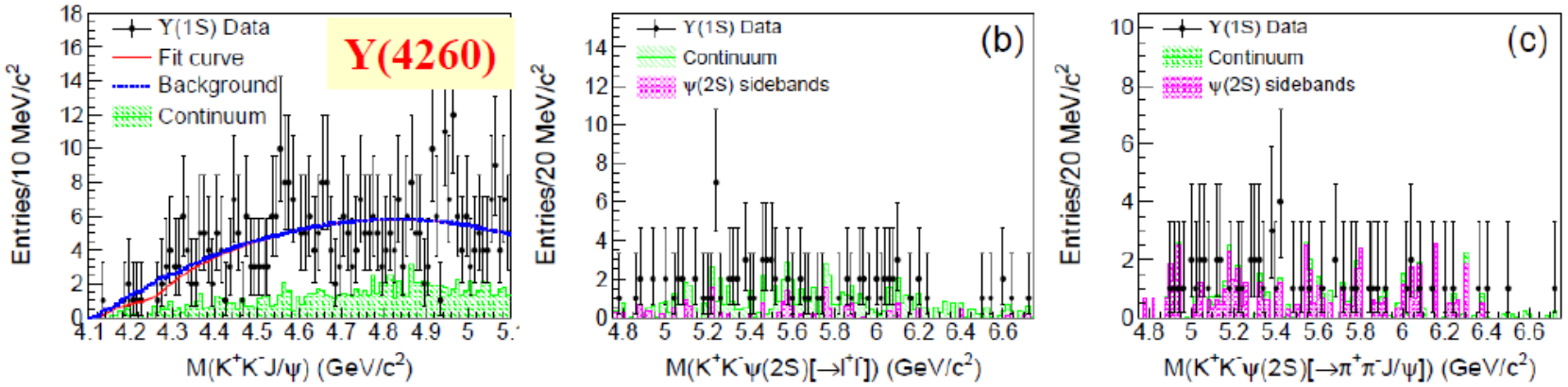
Search for $X(3872), Y(4230), Y(4260), Y(4360)$ by combining J/ψ or ψ' with $\pi^+\pi^-$.



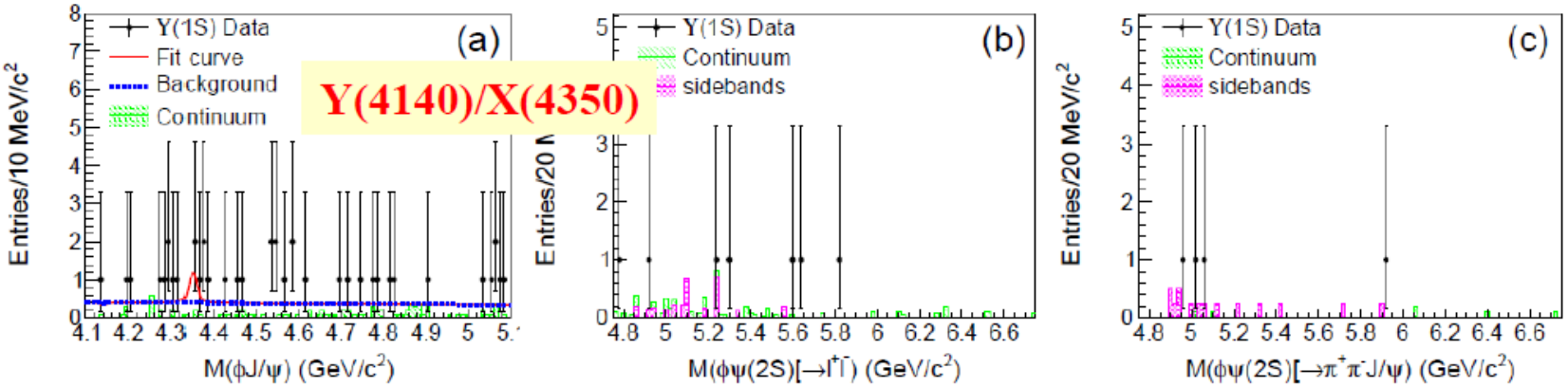
PRD, 93, 112032.

No evidence for any of these states.

Search for $X(4140)$, $X(4350)$, $Y(4260)$ by combining J/ψ or ψ' with $K^+K^-(\phi)$.



- No evidence is found for new structures or any of the known XYZ states.

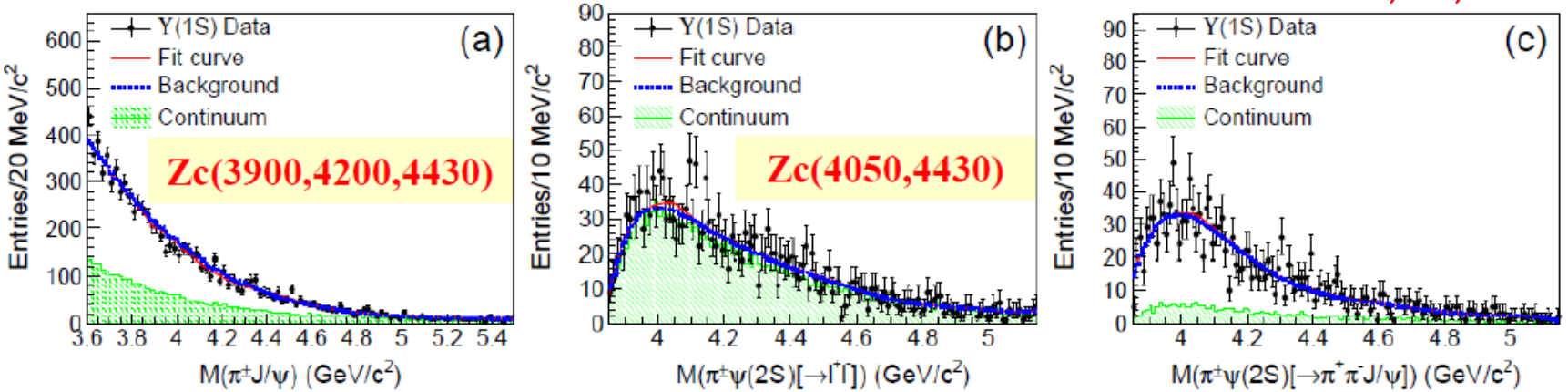


- No structures can be identified.

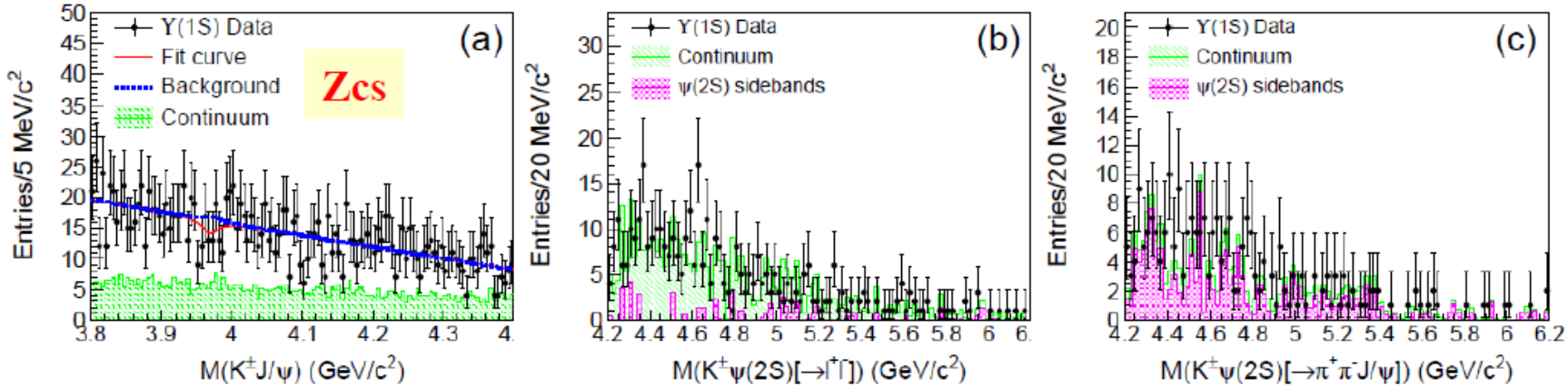
PRD, 93, 112032.

Search for Z states by combining J/ψ or ψ' with an extra π or K.

PRD, 93, 112032.



Zcs: M=(3.97±0.08) GeV/c2, Γ=(24.9±12.6) MeV [J Korean Phys. Soc. 55, 424(2009); PRD88,096014(2013)]



- No structures can be identified.

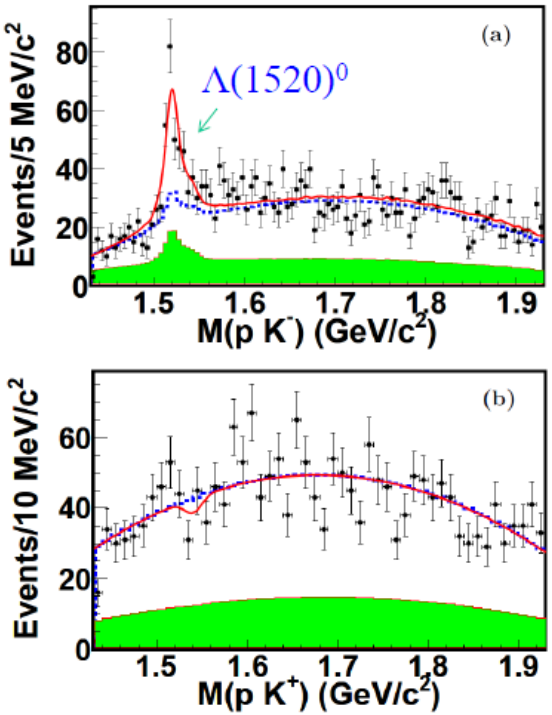
PRD, 93, 112032.

State	$N_{\rm fit}$	$N_{\rm up}$	$\varepsilon(\%)$	$\sigma_{\rm syst}(\%)$	$\Sigma(\sigma)$	$\mathcal{B}_R$
$X(3872) \to \pi^+\pi^- J/\psi$	4.8 ± 15.4	31.4	3.26	18.7	0.3	$< 9.5 \times 10^{-6}$
$Y(4260) \to \pi^+\pi^- J/\psi$	-31.1 ± 88.9	134.6	3.50	35.6	–	$< 3.8 \times 10^{-5}$
$Y(4260) \to \pi^+\pi^- \psi(2S)$	6.7 ± 29.4	56.9	0.71	35.0	0.2	$< 7.9 \times 10^{-5}$
$Y(4360) \to \pi^+\pi^- \psi(2S)$	-25.4 ± 30.1	45.6	0.86	50.0	–	$< 5.2 \times 10^{-5}$
$Y(4660) \to \pi^+\pi^- \psi(2S)$	-55.0 ± 26.2	23.1	1.06	40.7	–	$< 2.2 \times 10^{-5}$
$Y(4260) \to K^+K^- J/\psi$	-13.7 ± 10.9	14.5	1.91	45.8	–	$< 7.5 \times 10^{-6}$
$Y(4140) \to \phi J/\psi$	-0.1 ± 1.2	3.6	0.69	11.0	–	$< 5.2 \times 10^{-6}$
$X(4350) \to \phi J/\psi$	2.3 ± 2.5	7.6	0.92	10.4	1.2	$< 8.1 \times 10^{-6}$
$Z_c(3900)^\pm \to \pi^\pm J/\psi$	-26.5 ± 39.1	57.5	4.39	47.3	–	$< 1.3 \times 10^{-5}$
$Z_c(4200)^\pm \to \pi^\pm J/\psi$	-238.6 ± 154.2	235.1	3.87	48.4	–	$< 6.0 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm J/\psi$	94.2 ± 71.4	195.8	3.97	34.4	1.2	$< 4.9 \times 10^{-5}$
$Z_c(4050)^\pm \to \pi^\pm \psi(2S)$	37.0 ± 47.7	112.7	1.27	46.2	0.4	$< 8.8 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm \psi(2S)$	23.2 ± 42.4	92.0	1.35	47.1	0.1	$< 6.7 \times 10^{-5}$
$Z_{cs}^\pm \to K^\pm J/\psi$	-22.2 ± 17.4	22.4	3.88	48.7	–	$< 5.7 \times 10^{-6}$

We searched for a variety of XYZ states in Υ(1S) inclusive decays for the first Time. No evident signal is found for any of them and 90% C.L. upper limits are set on the product branching fractions .

Search for exotic baryons in *pK* systems

- LHCb report the observation of $P_C(4380)$ and $P_C(4450)$ in $J/\psi p$ system.
- The possibility of exotic baryons is discussed in [J. Phys. G30,1801 (2004)].
- Search for exotic baryons, denoted as $\Theta(1540)^0 \to pK^-$ and $\Theta(1540)^{++} \to pK^+$ in $\gamma\gamma \to p\bar{p}K^+K^-$.



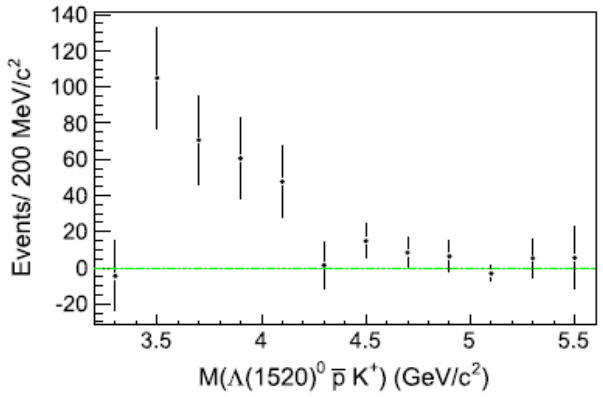
A simultaneous fit to $M(pK^-)$ with $\Lambda(1520)^0$ and $\Theta(1540)^0$ shape:
$\Lambda(1520)^0$ with 8.6σ.
$\Theta(1540)^0$ with 1.4σ.

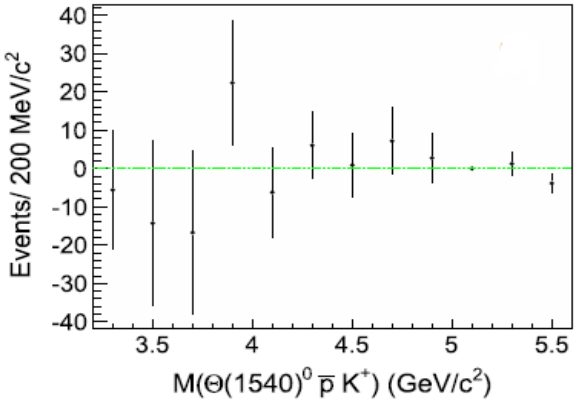
Fit to $M(pK^+)$, with $\Theta(1540)^{++}$shape only.
No $\Theta(1540)^{++}$ singal.

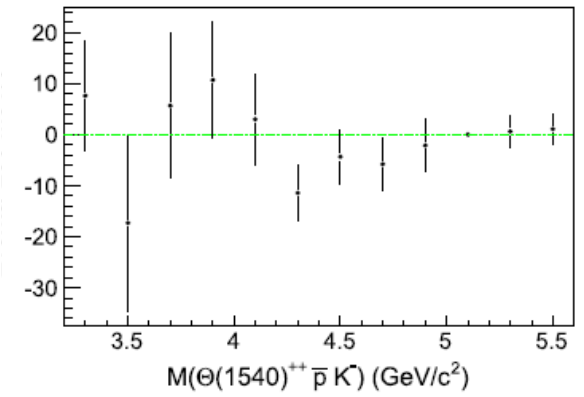
PRD, 93, 112017.

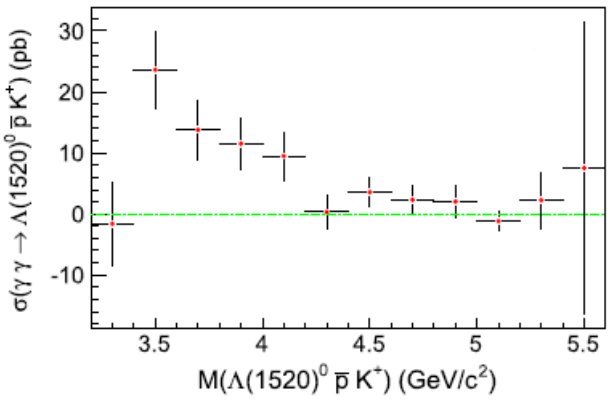
Simultaneous fit to the pK invariant mass distribution in each $p\bar{p}K^+K^-$ mass bin.

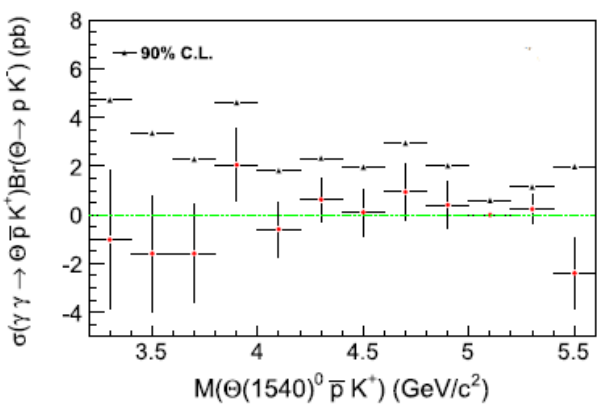
PRD, 93, 112017.

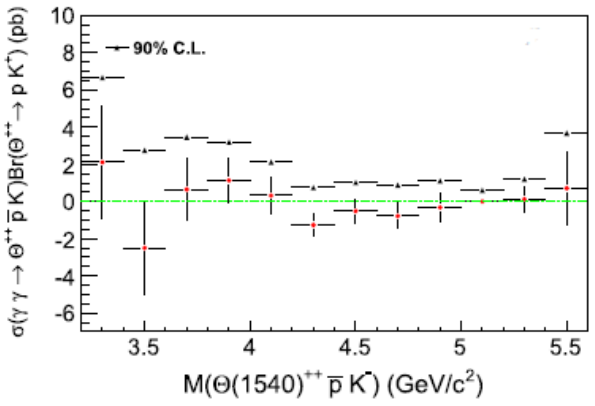






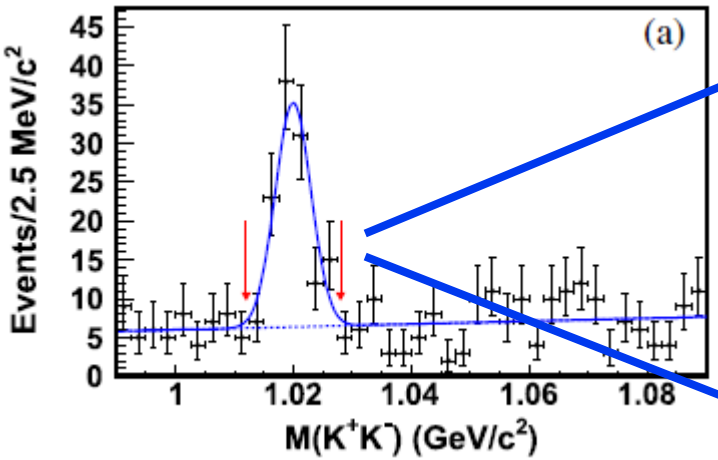


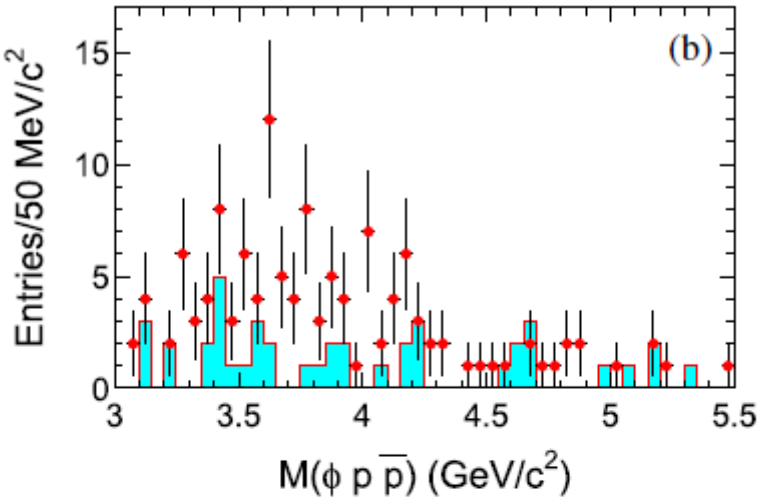


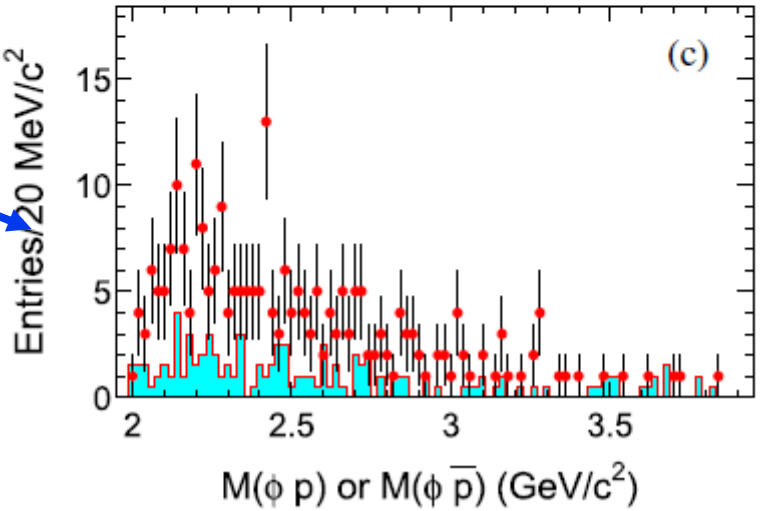


No evidence of $\Theta(1540)^0 \to pK^-$ and $\Theta(1540)^{++}$ is seen in $\mathrm{M}(pK^-)$ or $\mathrm{M}(pK^+)$.

PRD, 93, 112017.







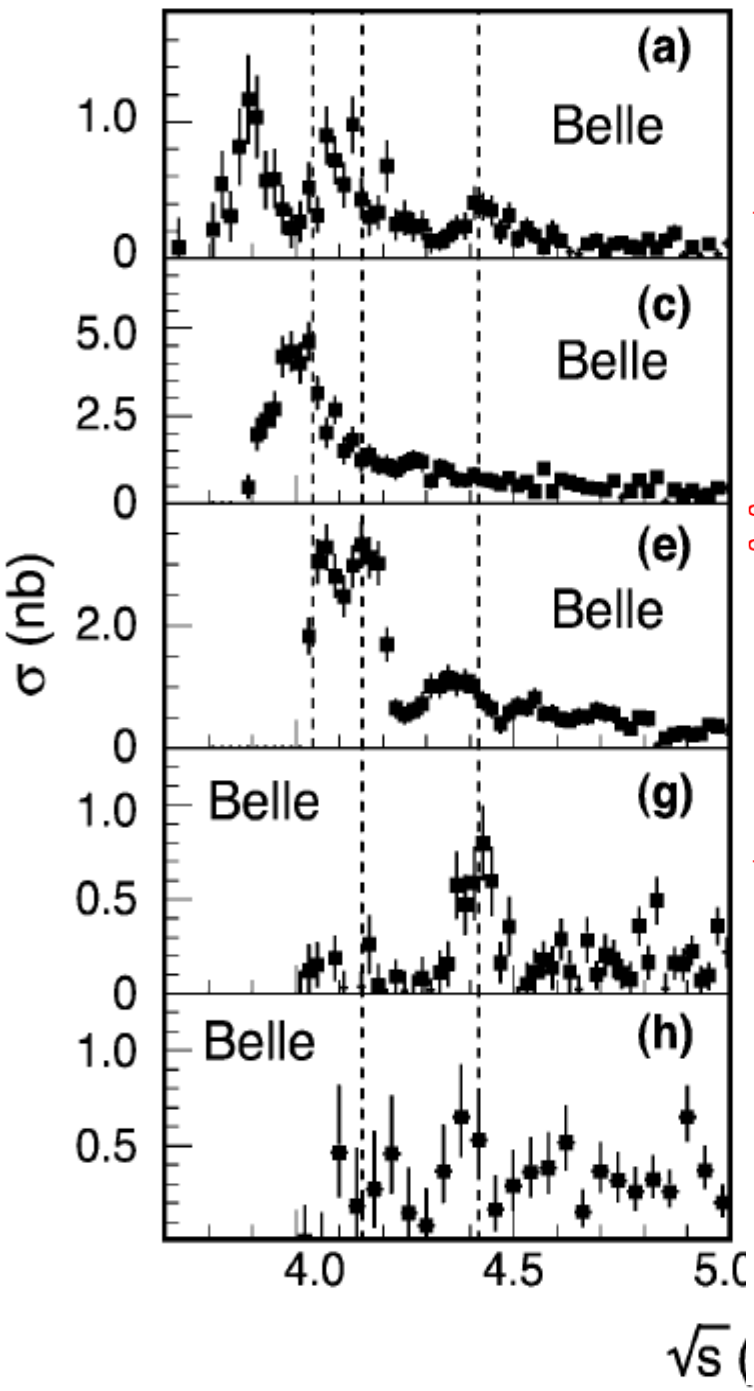
No evidence of an $s\bar{s}$ partner of the $P_C(4380, 4450)$ is observed.

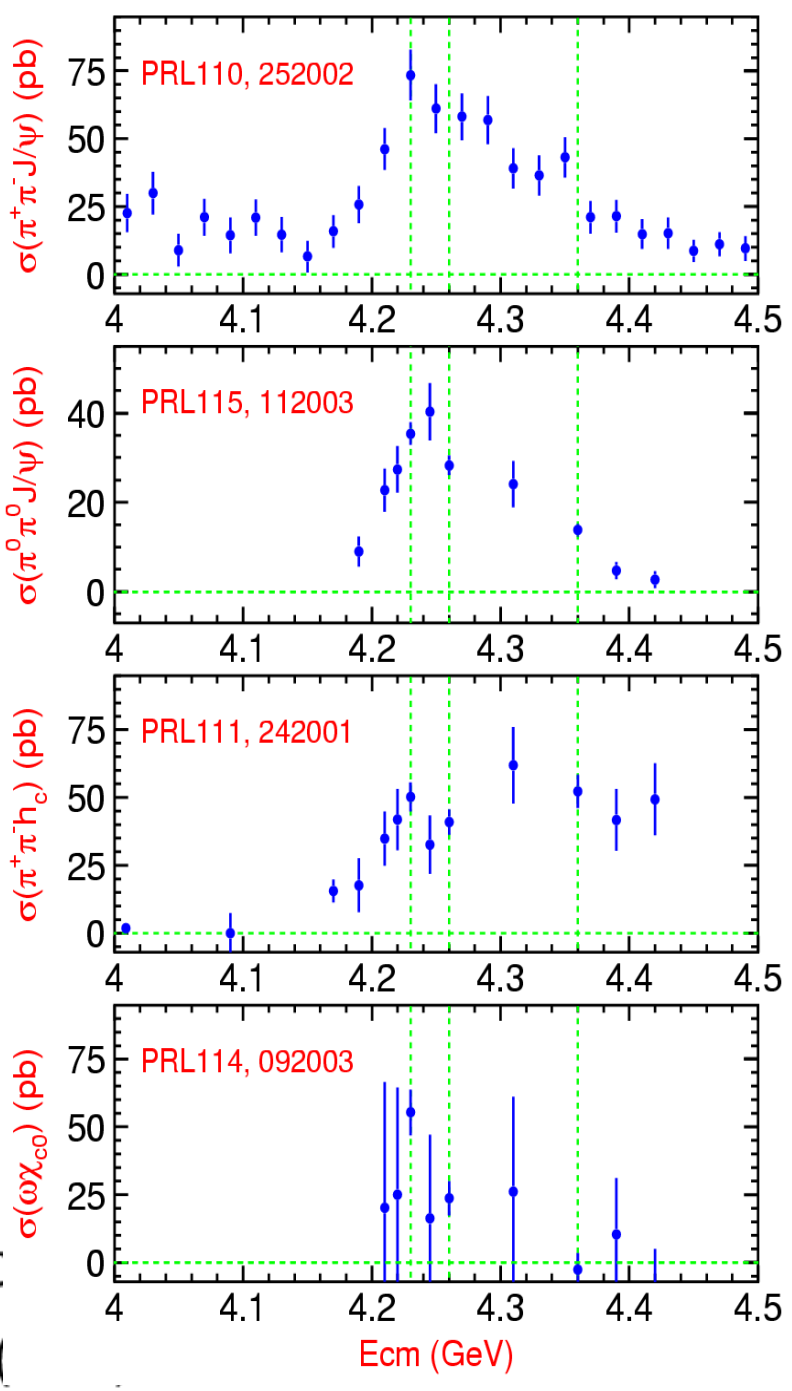
Summary

- Although the data taking was finished on June 30, 2010, there may be rich physics to be analyzed in Belle data, both for charmonium (-like) and bottomonium (-like) states.
- Partner state is a a key to go further, which also needs more data.
- Belle II will start data taking soon, about 50 times larger integrated luminosity!!

Thank you!

Back up





Left:

a: $\bar{D}D$

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

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

g: $\bar{D}D\pi$

h: $\bar{D}D^*\pi$

Right:

$\pi^+\pi^- J/\psi$

$\pi^0\pi^0 J/\psi$

$\pi^+\pi^- h_c$

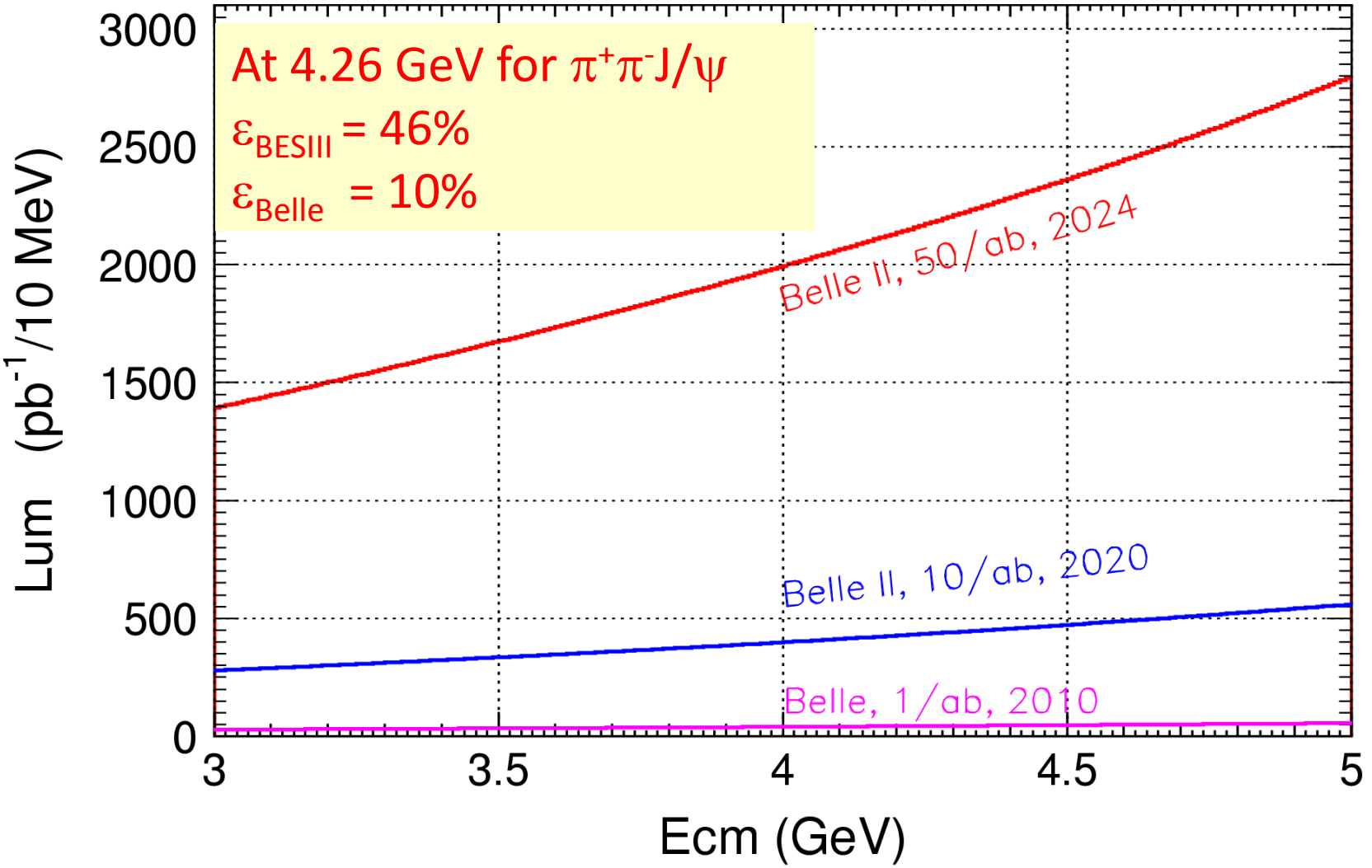
$\omega\chi_{c0}$

Very rich structure!

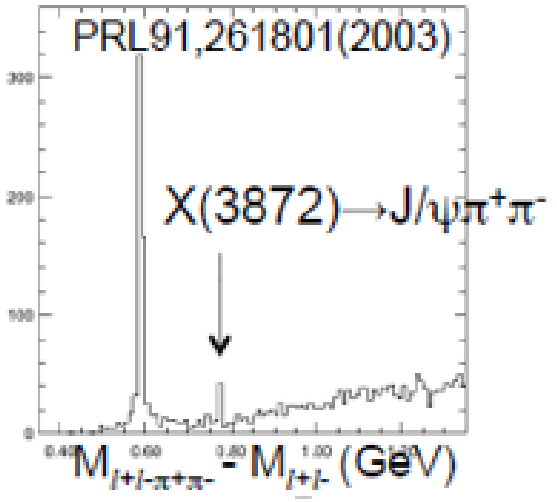
Is $\bar{c}cg$ already there?

Charmonium region at Belle II

ISR produces events at all CM energies BESIII can reach



X(3872)



In $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decay mode

Mass: Very close to $\bar{D}^0 D^{*0}$ threshold.

Width: Very narrow, < 1.2 MeV.

J^{PC}: 1^{++}.

Observed with significance of 10.3σ.

$$M_X = M_X^{meas} - M_\psi^{meas} + M_\psi^{PDG} = 3872.0 \pm 0.6 \pm 0.5 \text{ MeV}$$

$$\Gamma < 2.3 \text{ MeV}$$

Nature (very likely exotic)

Loosely $\bar{D}^0 D^{*0}$ bound state (like deuteron?)?

Mixture of excited χ'_{c1} and $\bar{D}^0 D^{*0}$ bound state?

Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)