XYZ at Belle

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(for the Belle collaboration)

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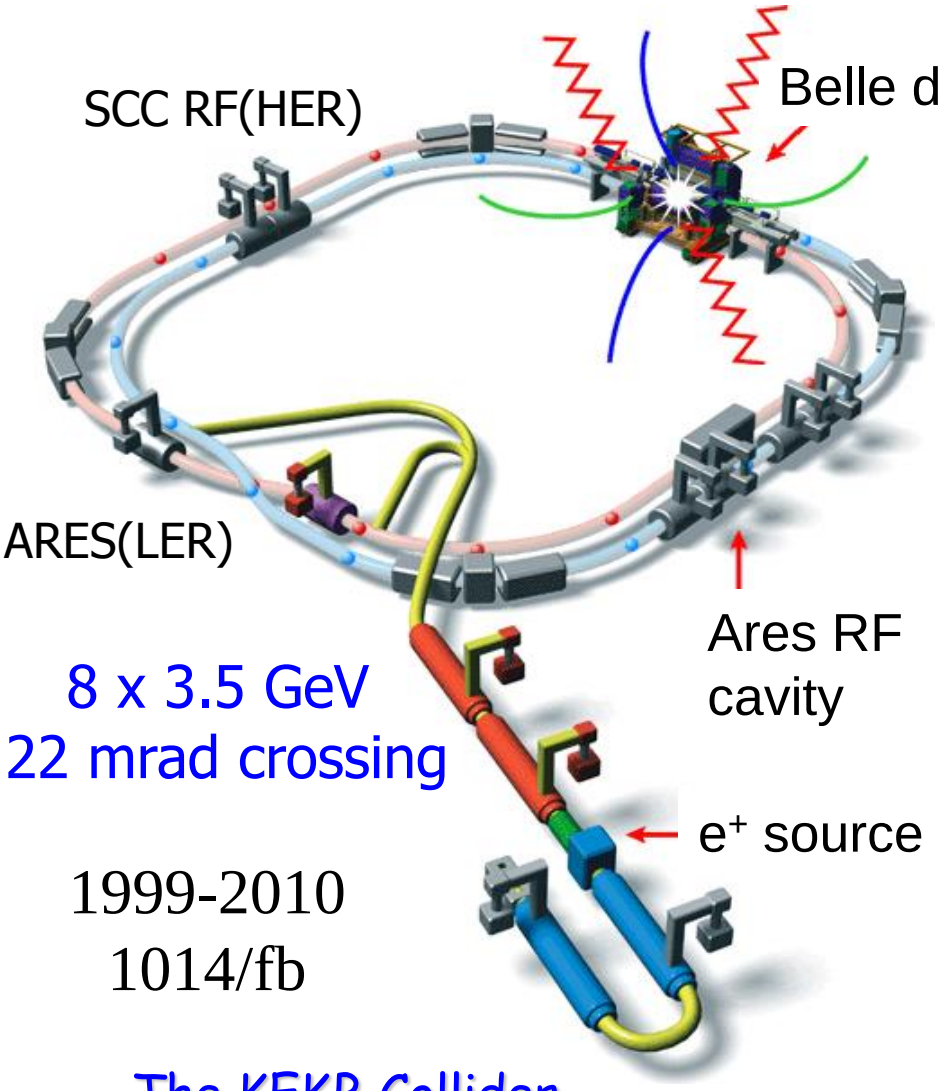
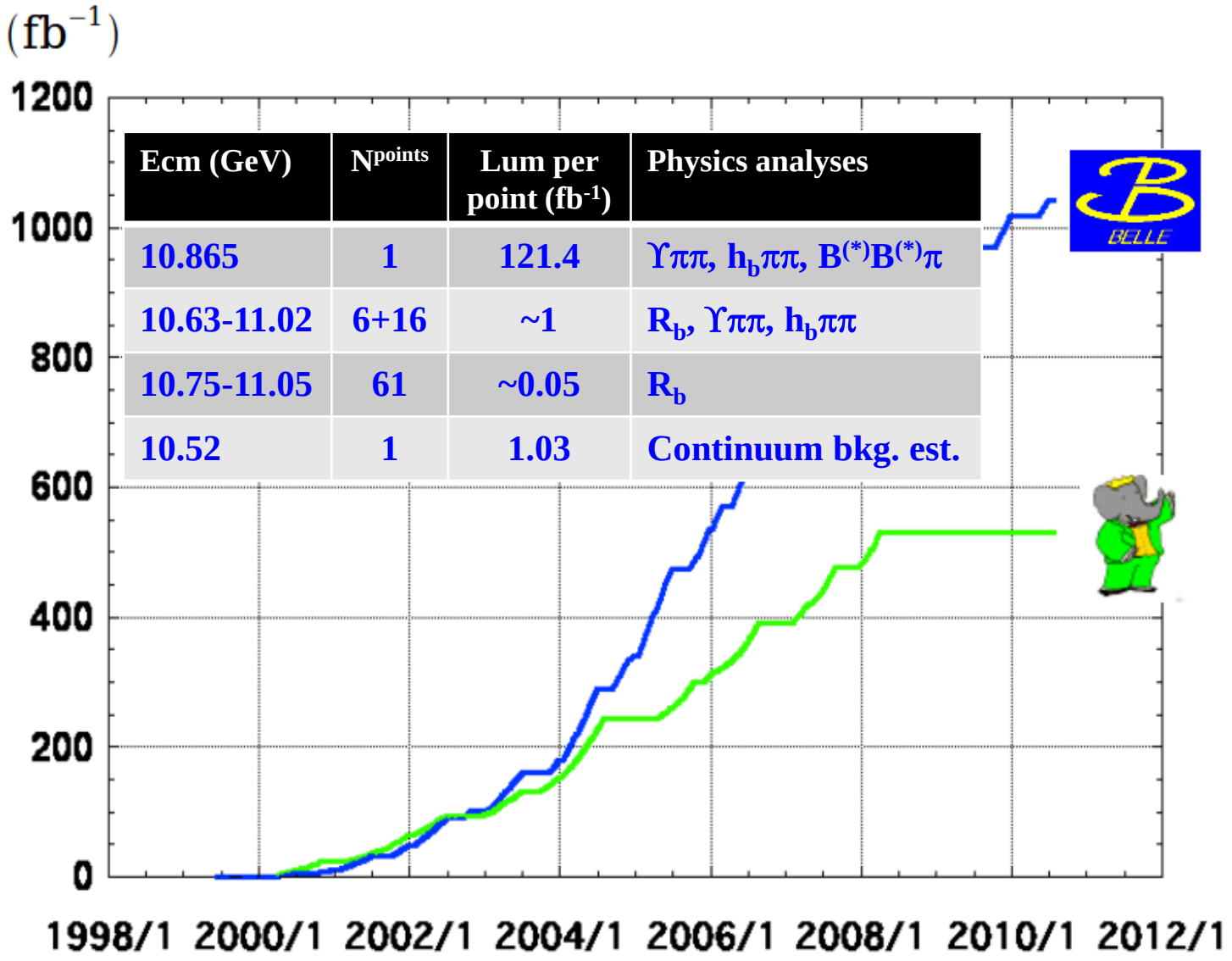
The Belle experiment



World record:

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

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}

$\Upsilon(3S)$: 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}

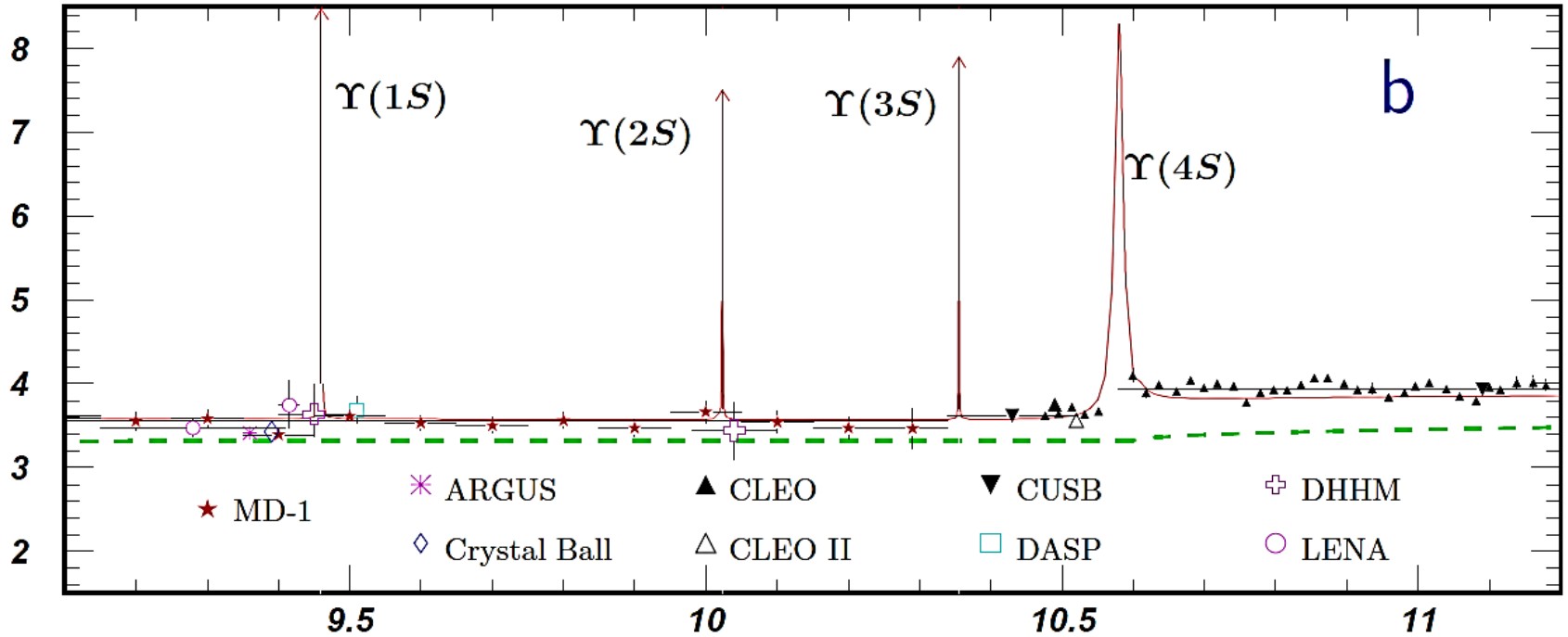
$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

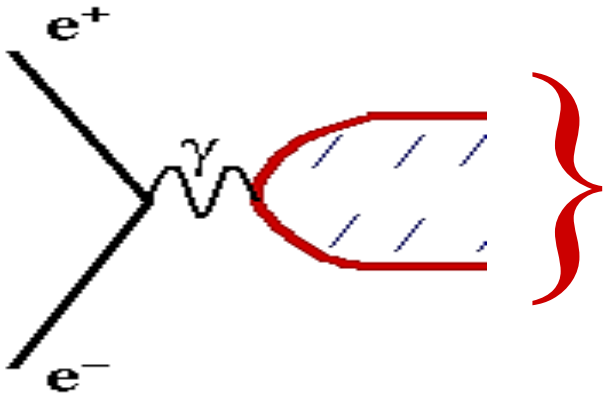
Off resonance:

~ 54 fb^{-1}

e^+e^- annihilation of vector bottomonia

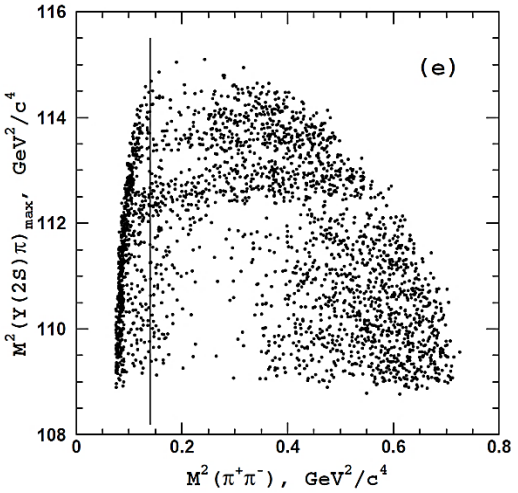


$\sqrt{s}$ [GeV]

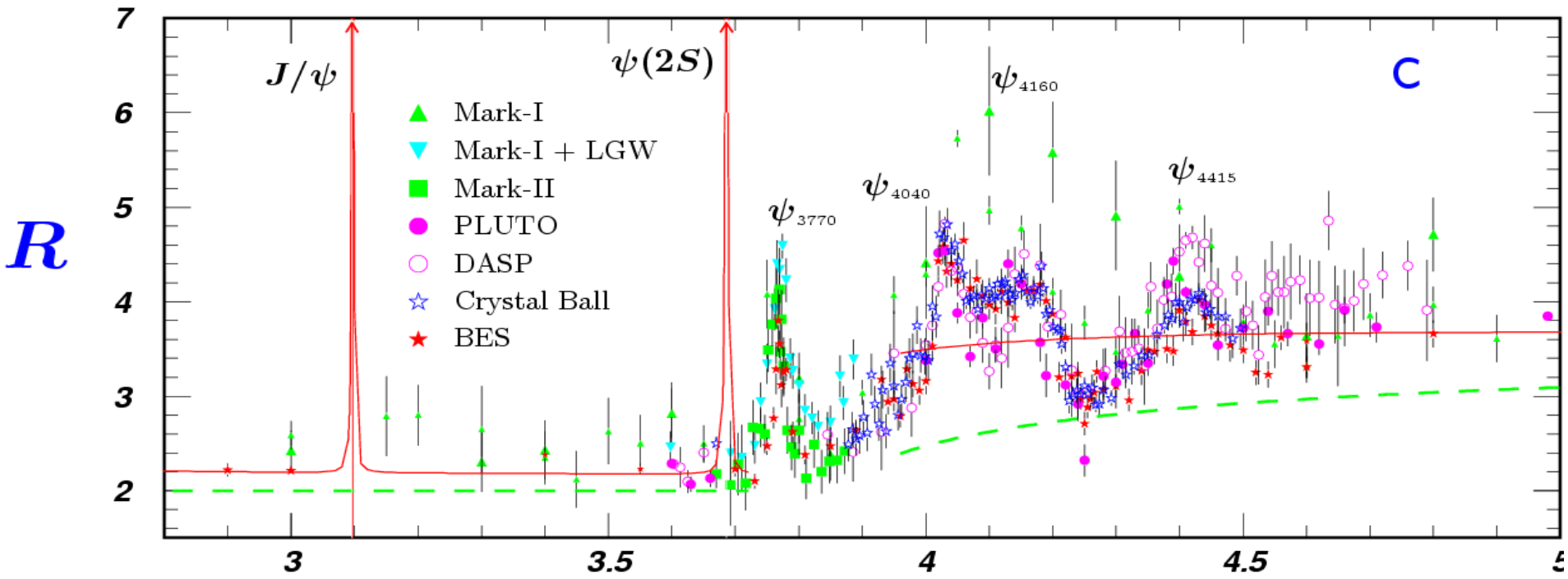


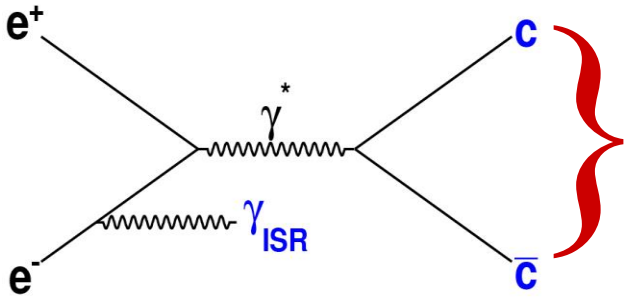
$J^{PC} = 1^{--}$

$\Upsilon(nS)$, Y_b…



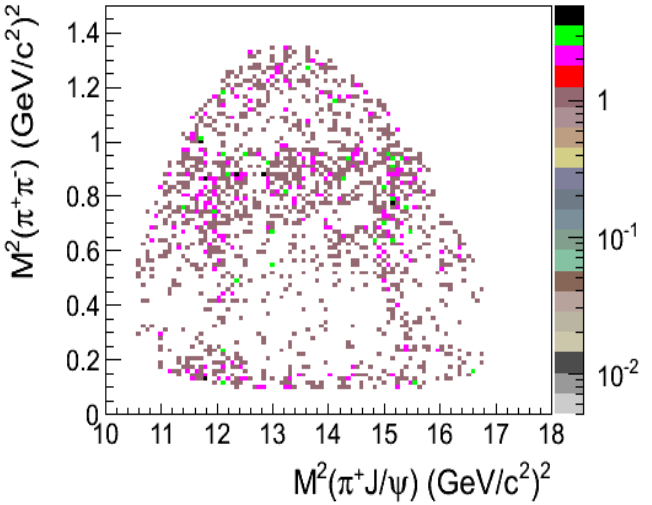
ISR production of vector charmonia





$J^{PC} = 1^{--}$

ψ', ψ'', Υ…

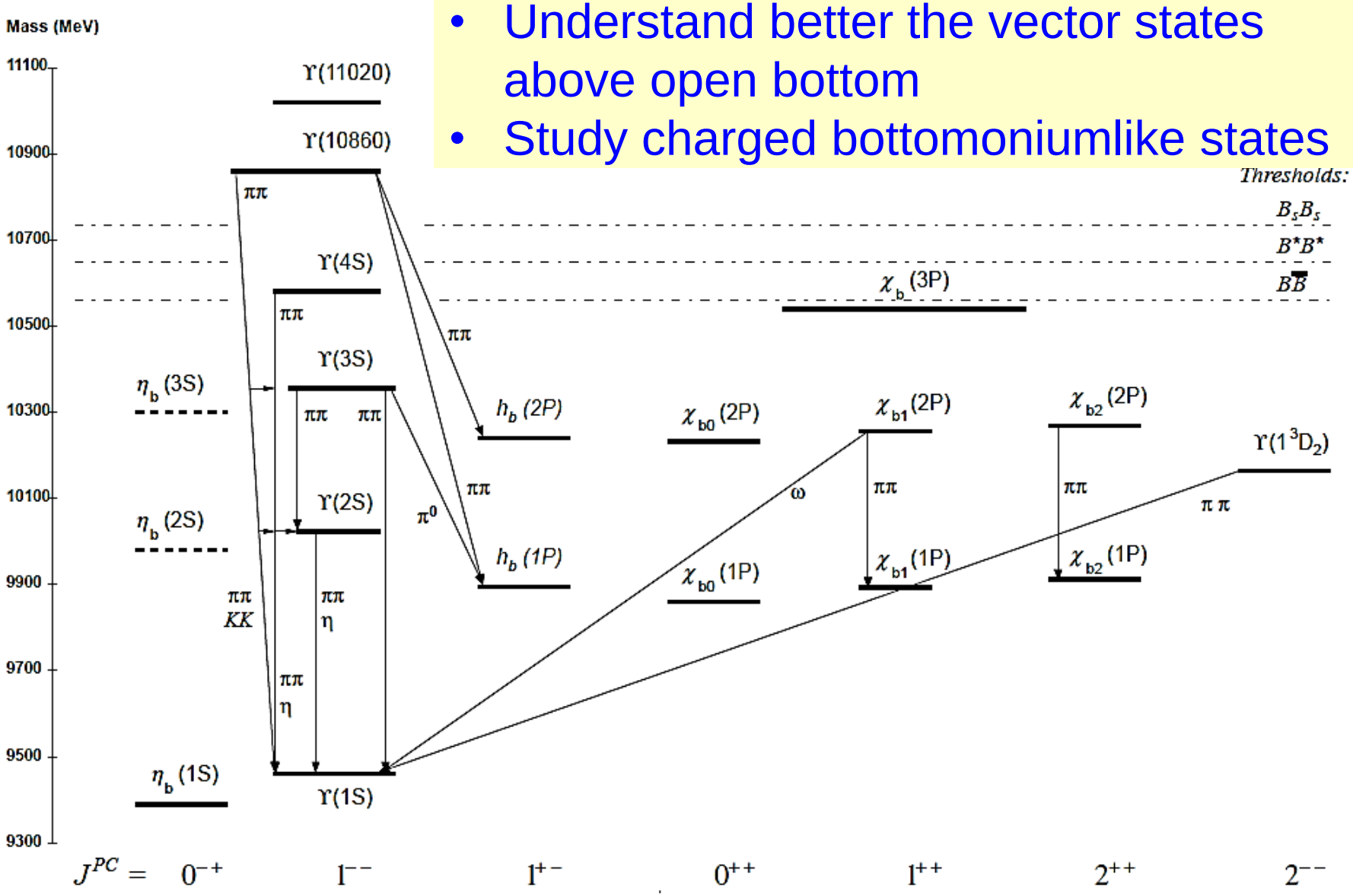


Outline

- R_b measurement $R_b = \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma^0(e^+e^- \to \mu^+\mu^-)}$
- $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$, $\pi^+\pi^- h_b(nP)$, $B^{(*)}B^{(*)}\pi$
  - $\Upsilon(5S)$, $\Upsilon(6S)$, Z_b
- $e^+e^- \to \pi^+\pi^-\psi(nS)$, $K^+K^- J/\psi$
  - Y(4260), Y(4360), Y(4660), Z_c & Z_{cs}
- Summary

$e^+e^- \rightarrow \bar{b}b$ inclusive & exclusive

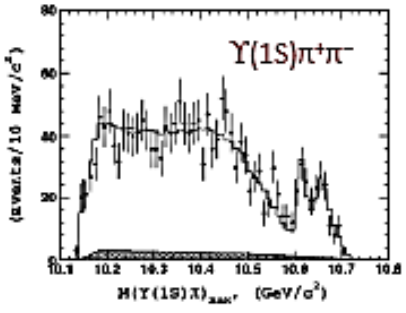
- Understand better the vector states above open bottom
- Study charged bottomoniumlike states

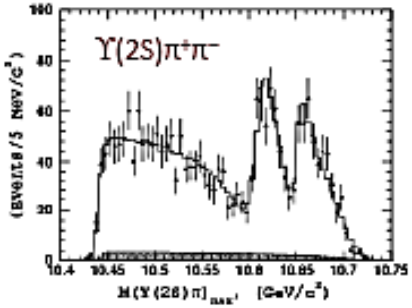


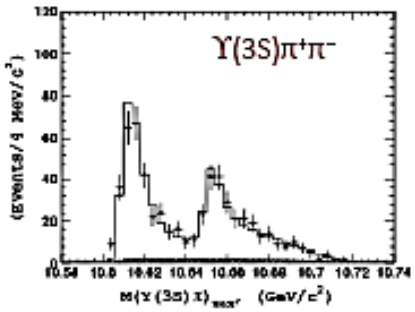
Previous results on Z_b states

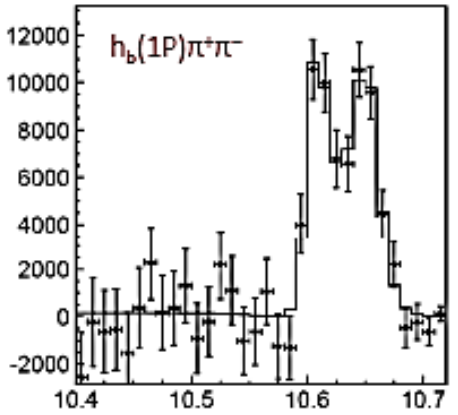
$Z_b^{\pm}$ Observed in five different modes:

PRL 108, 122001(2012)

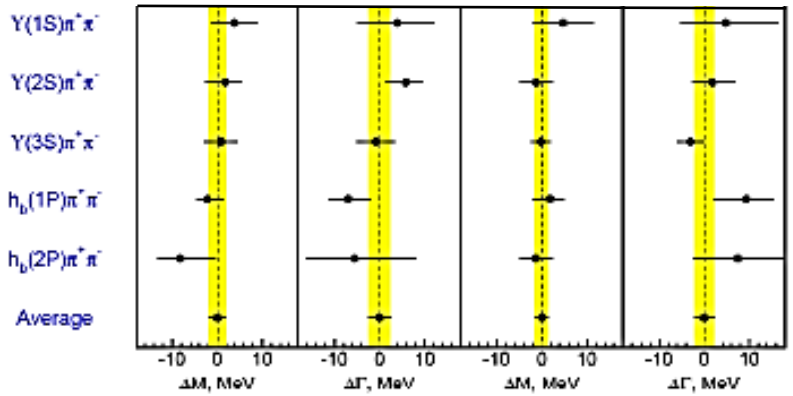








$Z_b(10610)$ $Z_b(10650)$



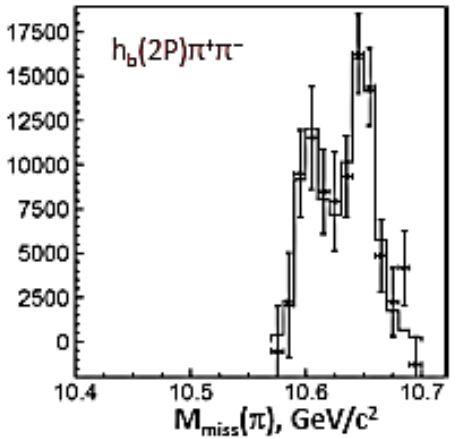
Average for $Z_b^{\pm}$:

$\langle M_1 \rangle = 10607.2 \pm 2.0$ MeV

$\langle \Gamma_1 \rangle = 18.4 \pm 2.4$ MeV

$\langle M_2 \rangle = 10652.2 \pm 1.5$ MeV

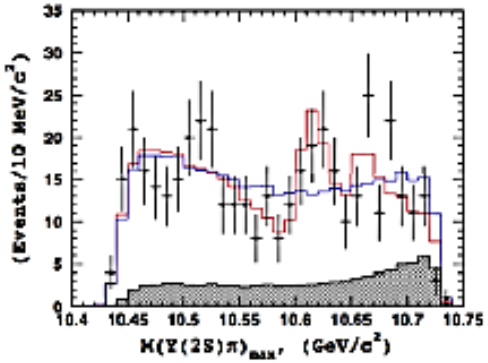
$\langle \Gamma_2 \rangle = 11.5 \pm 2.2$ MeV



Z_b^0 Results:

$\langle M_1 \rangle = 10609 \pm 7 \pm 6$ MeV

Consistent with $Z_b^{\pm}$



M_1-M_B-M_{B^*} = 2.4 ± 2.1 MeV

M_2-M_{B^*}-M_{B^*} = 1.8 ± 1.8 MeV

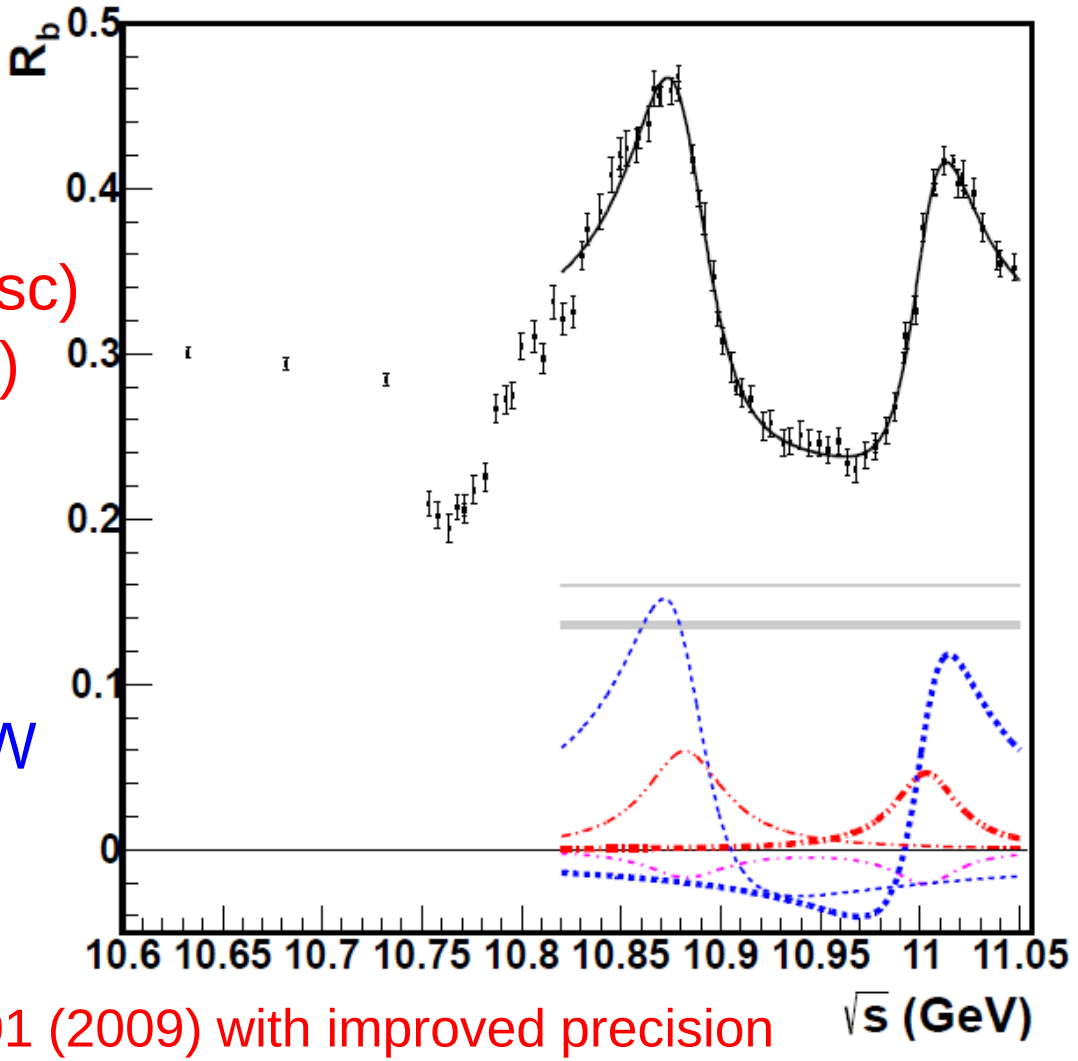
$$R_b = \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma^0(e^+e^- \to \mu^+\mu^-)}$$

$$\mathcal{F} = |A_{\rm nr}|^2 + |A_{\rm r} + A_{5S}e^{i\phi_{5S}}f_{5S} + A_{6S}e^{i\phi_{6S}}f_{6S}|^2$$

Procedure:

1. Count hadronic events
2. Subtract scaled cont. (udsc)
3. Subtract ISR Υ(1S,2S,3S)
4. Do efficiency correction
5. Divided by lum & $\sigma^0(\mu\mu)$

- No ISR corr.; no VP corr.
- Fit with constant width BW in small energy range.
- Need better model to fit



Agree with BaBar:PRL102, 012001 (2009) with improved precision

Ecm=10.54-11.20 GeV, 5 MeV step for >300 points, 3.9 fb^{-1} in total

Belle: arXiv:1501.01137

R_b

$$\mathcal{F} = |A_{\rm nr}|^2 + |A_{\rm r} + A_{5S}e^{i\phi_{5S}} f_{5S} + A_{6S}e^{i\phi_{6S}} f_{6S}|^2$$

Υ(5S):
Mass = (10881.9$\pm$1.0 $\pm$1.2) MeV
Width = (49.8 $\pm$1.9 $\pm^{2.1}_{2.8}$) MeV

Υ(6S):
Mass = (11002.9$\pm$1.1 $\pm^{0.8}_{0.9}$) MeV
Width = (38.5 $\pm^{1.6}_{1.5}$ $\pm^{1.3}_{2.4}$) MeV

$\Delta\phi$=-1.86 $\pm^{0.24}_{0.10}$ $\pm$0.10 rad

- Results agree with previous measurements
- Suffers from model uncertainties (signal, background parametrization, interference, thresholds, coupled channel effect)

Belle: arXiv:1501.01137

$e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)$

- tag $\Upsilon(nS) \rightarrow \mu^+\mu^-$ and select $\pi^+\pi^-$, fit to $|A_{5S}+e^{i\phi}A_{6S}|^2$

$\Upsilon(5S)$:

Mass = $(10891.9 \pm 3.2 \pm^{0.6}_{1.5})$ MeV

Width = $(53.7 \pm^{7.1}_{5.6} \pm^{0.9}_{5.4})$ MeV

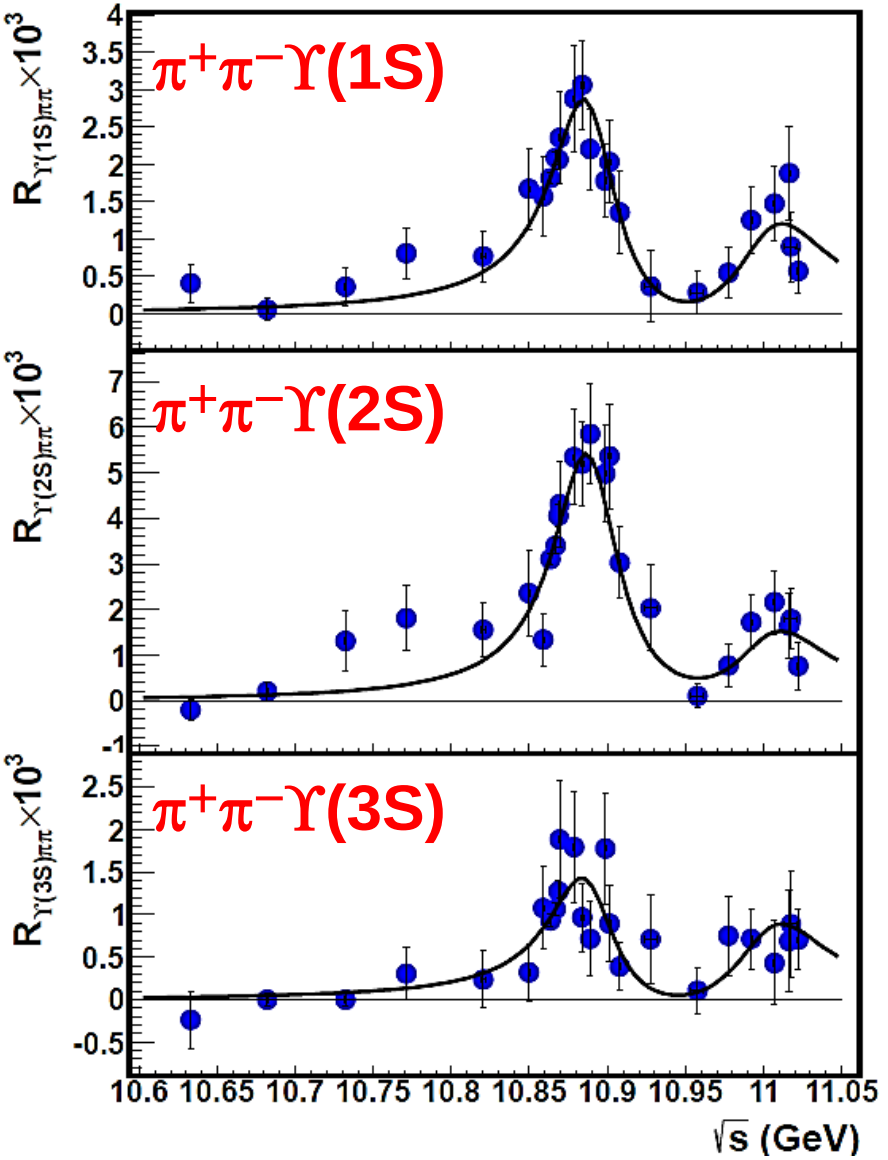
$\Upsilon(6S)$:

Mass = $(10987.5 \pm^{6.4}_{2.5} \pm^{2.2}_{2.1})$ MeV

Width = $(61 \pm^{9}_{19} \pm^{2}_{20})$ MeV

$\Delta\phi = -1.0 \pm 0.4 \pm^{1.0}_{0.1}$ rad

- Results agree with previous measurements
- Also agree with fit with Rb reasonably well
- Still room for improvement

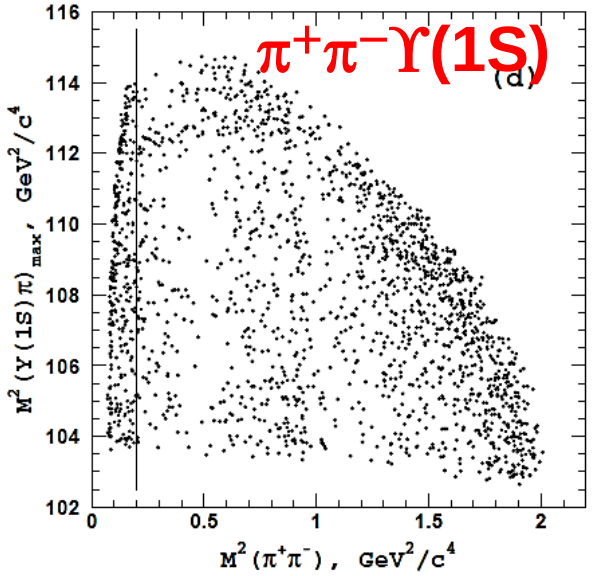


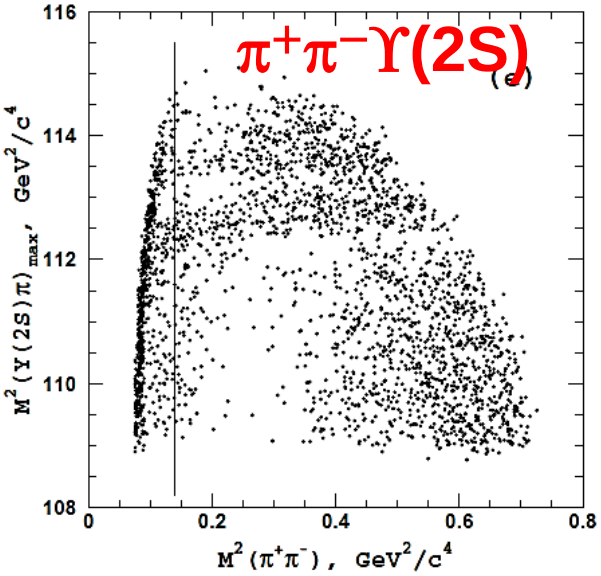
Belle: arXiv:1501.01137

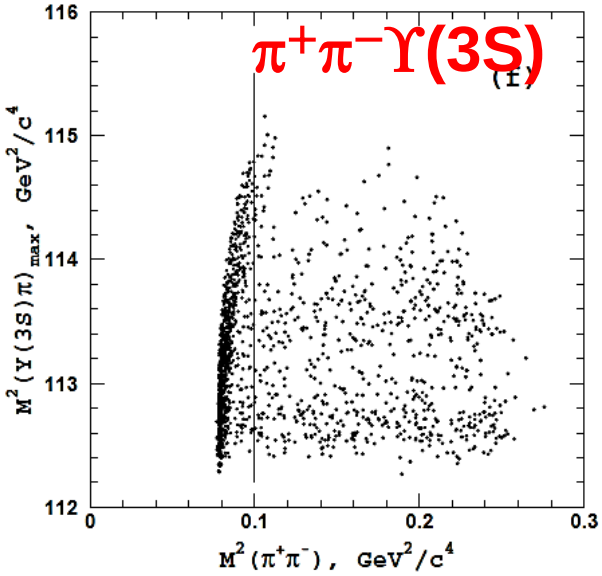
Z_b in $\Upsilon(5S)\to\pi^+\pi^-\Upsilon(nS)$

- 121 fb^{-1} data, tag $\Upsilon(nS)\to\mu^+\mu^-$ and select $\pi^+\pi^-$

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]	$1.61 \pm 0.10 \pm 0.12$	$2.35 \pm 0.19 \pm 0.32$	$1.44^{+0.55}_{-0.45} \pm 0.19$





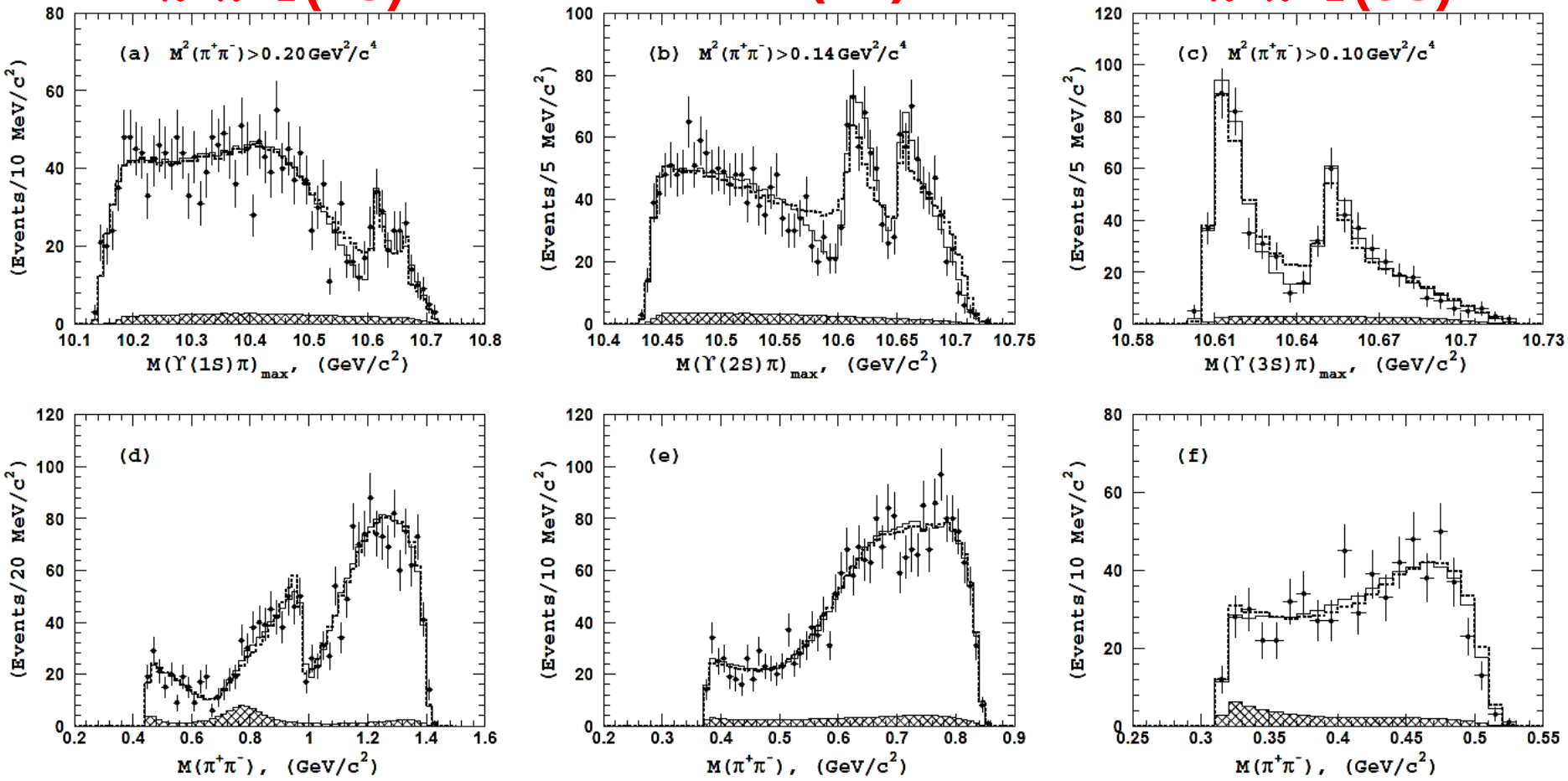


Belle: PRD91, 072003 (2015)

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

- Full partial wave analysis of $\Upsilon(5S)\to\pi^+\pi^-\mu^+\mu^-$
- Mass, width, fraction, and JP=1+ of Z_b states determined

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



Belle: PRD91, 072003 (2015)

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

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

$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(1S)\pi^\mp} = 109 \pm 27^{+35}_{-10}$ fb

$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(2S)\pi^\mp} = 737 \pm 126^{+188}_{-85}$ fb

$\sigma_{Z_b^\pm(10610)\pi^\mp} \times \mathcal{B}_{\Upsilon(3S)\pi^\mp} = 438 \pm 92^{+92}_{-114}$ fb

$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(1S)\pi^\mp} = 20 \pm 7^{+4}_{-3}$ fb

$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(2S)\pi^\mp} = 165 \pm 49^{+43}_{-20}$ fb

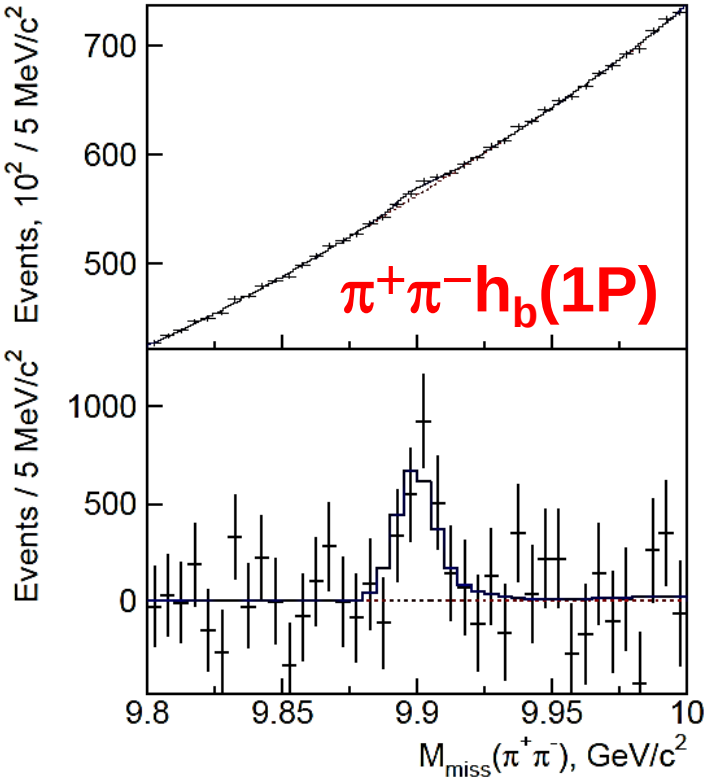
$\sigma_{Z_b^\pm(10650)\pi^\mp} \times \mathcal{B}_{\Upsilon(3S)\pi^\mp} = 194 \pm 53^{+43}_{-25}$ fb

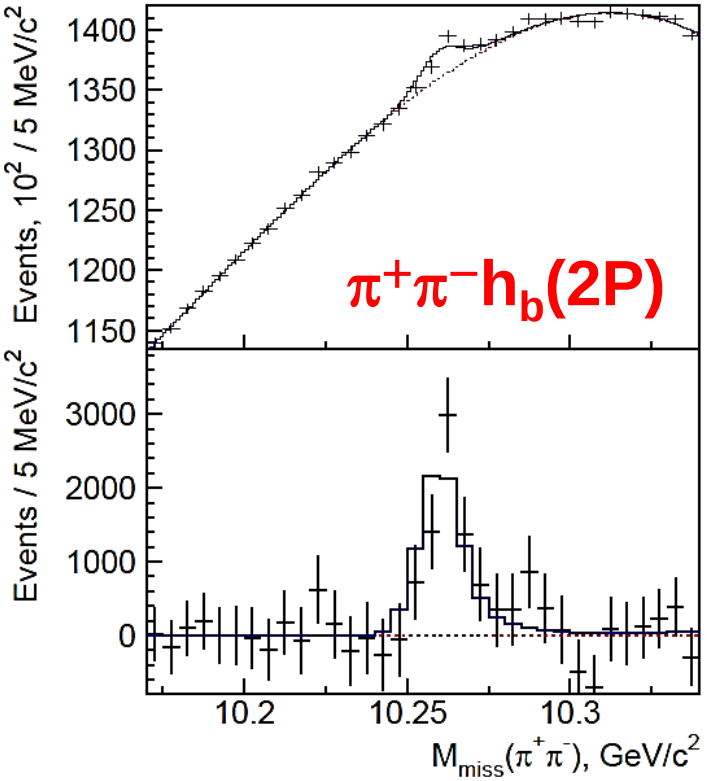
- Relative BR of Z_b decays

Belle: PRD91, 072003 (2015)

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

- Reconstruct $\pi^+\pi^-$, require π^+/π^- recoil mass in Z_b region: $10.59 < M_{miss}(\pi) < 10.67$ GeV/c^2
- check the $\pi^+\pi^-$ recoil mass for $h_b(nP)$





Belle: arXiv:1508.06562

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

$\Upsilon(5S)$:

Mass = $(10884.7 \pm^{3.2}_{2.9} \pm^{8.6}_{0.6})$ MeV

Width = $(44.2 \pm^{11.9}_{7.8} \pm^{2.2}_{15.8})$ MeV

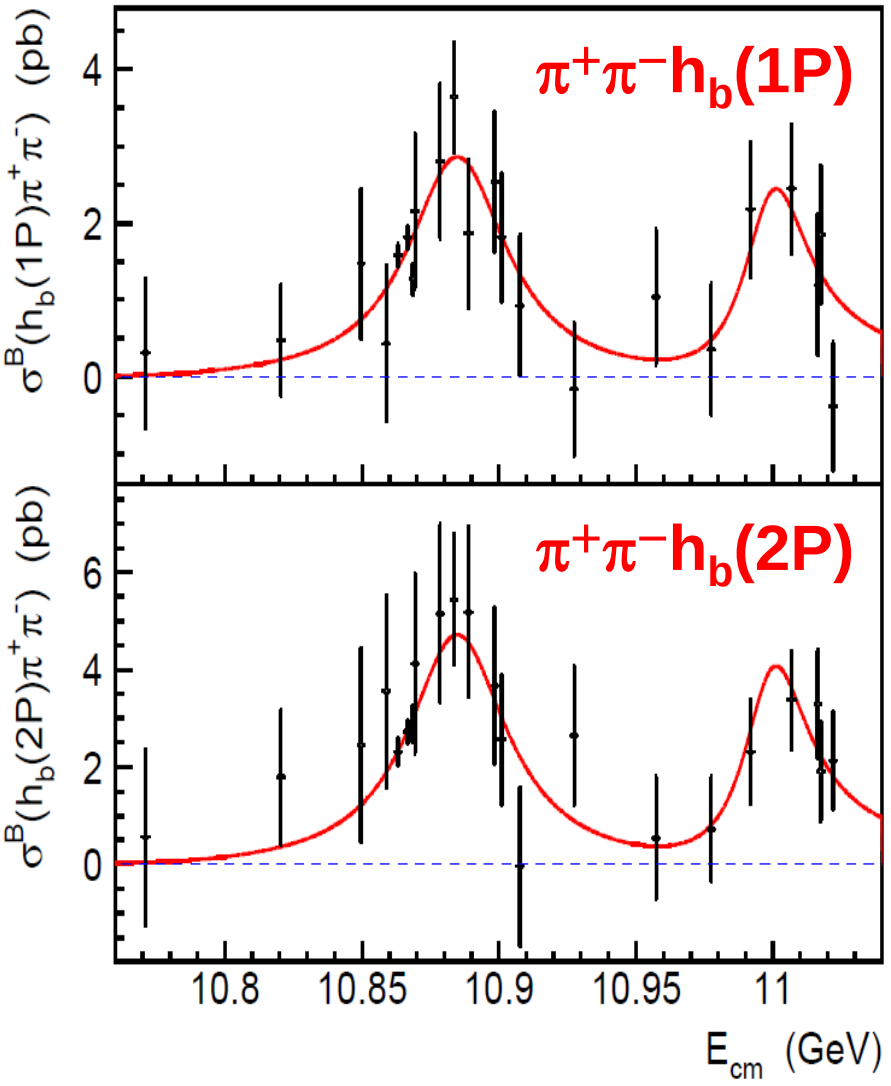
$\Upsilon(6S)$:

Mass = $(10998.6 \pm 6.1 \pm^{16.1}_{1.1})$ MeV

Width = $(29 \pm^{20}_{12} \pm^{2}_{7})$ MeV

$\Delta\phi = 0.64 \pm^{0.37}_{0.11} \pm^{0.13}_{0.0}$ rad

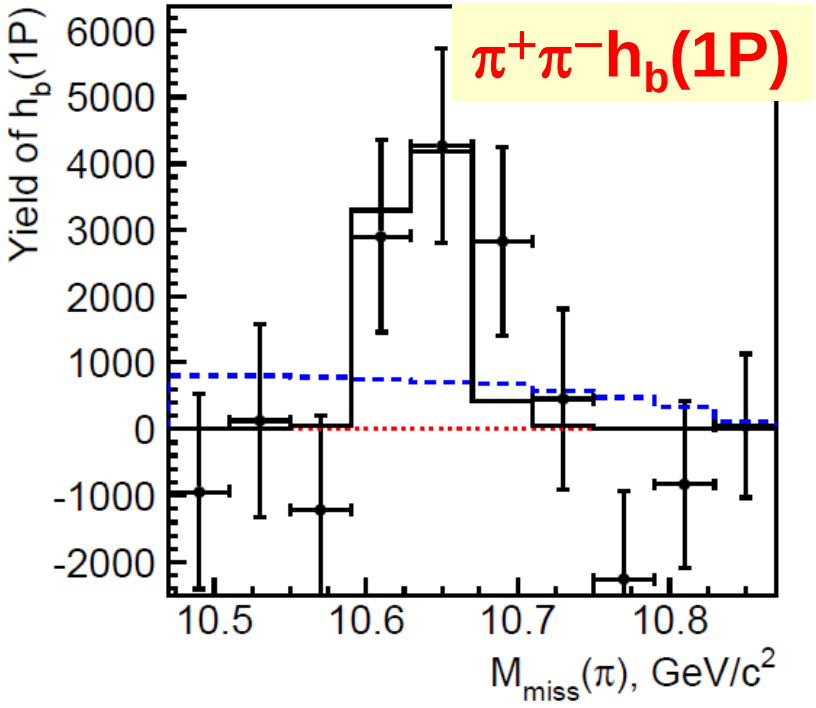
- Resonant parameters agree with from $e^+e^- \to \pi^+\pi^- \Upsilon(nS)$
- $e^+e^- \to \pi^+\pi^- h_b(nP)$ at the same level as $e^+e^- \to \pi^+\pi^- \Upsilon(nS)$
- 1st obs. of $\Upsilon(6S) \to \pi^+\pi^- h_b(nP)$

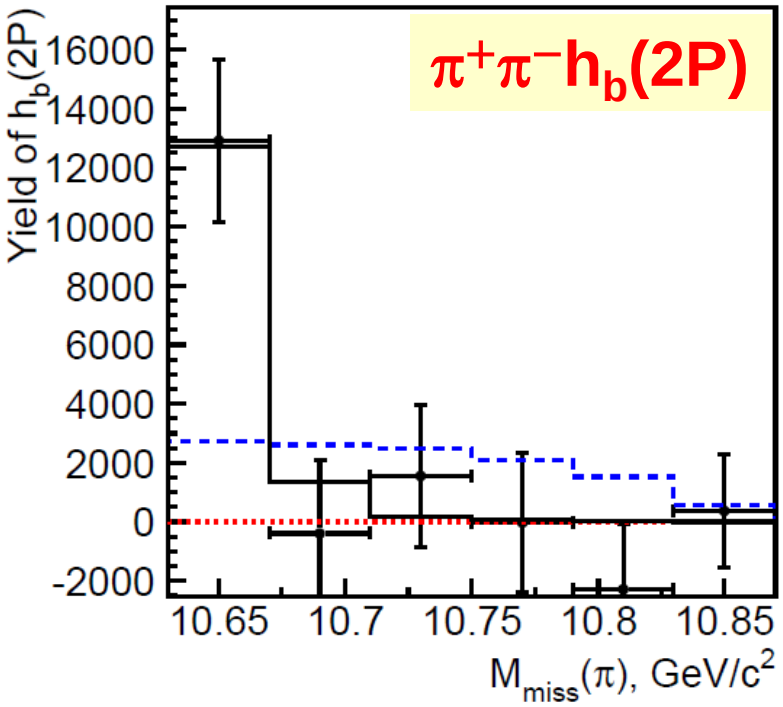


Belle: arXiv:1508.06562

Z_b in $\Upsilon(6S) \rightarrow \pi^+\pi^- h_b(nP)$

- Events mainly from Z_b intermediate states
  not clear if only one Z_b or both.
- Belle II will tell us.



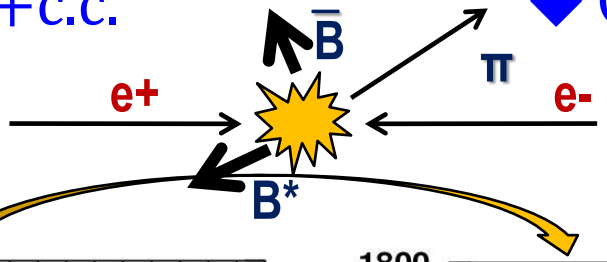


Belle: arXiv:1508.06562

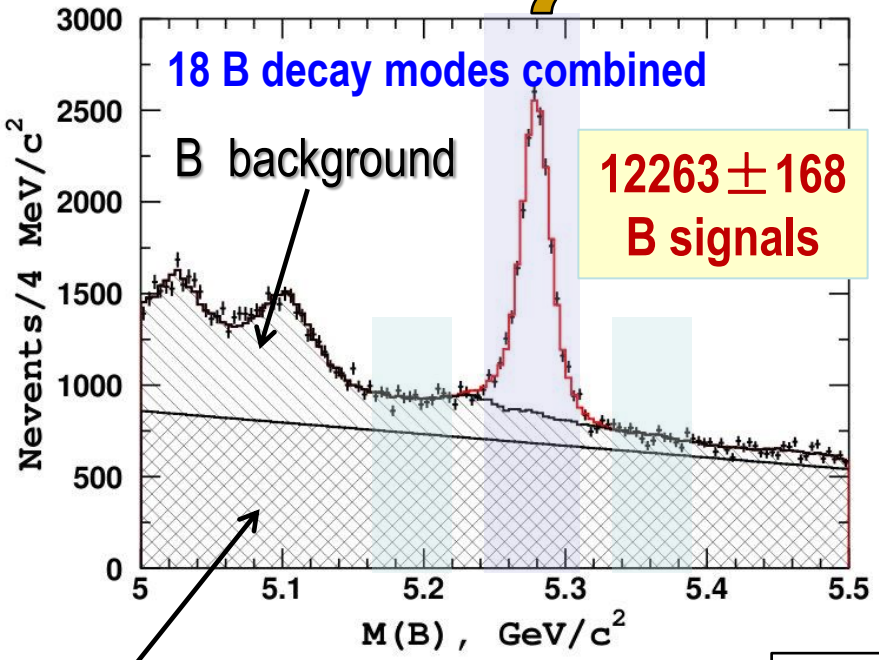
Z_b in $\Upsilon(5S) \rightarrow [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

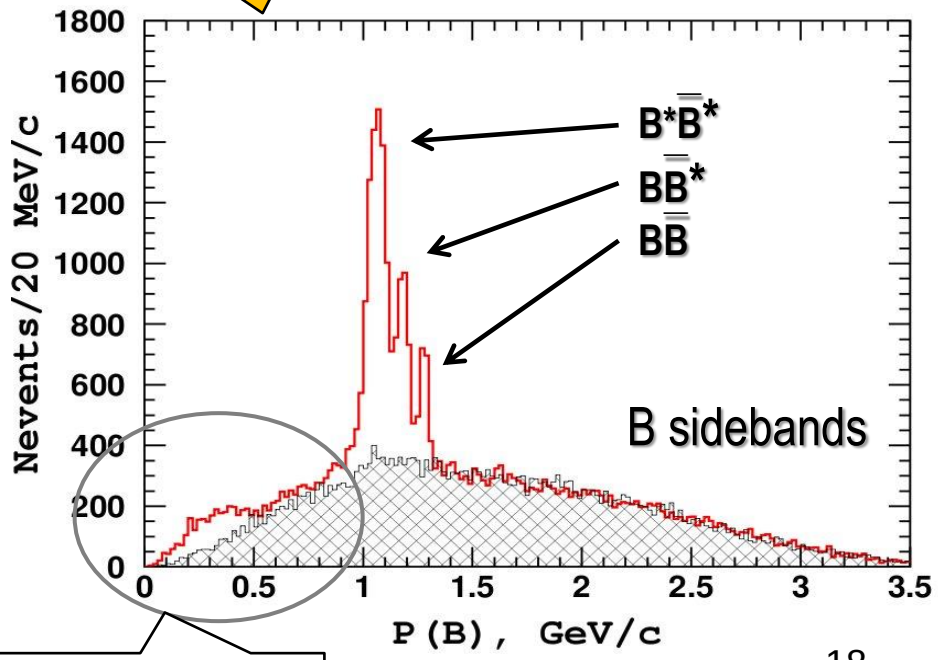
- $BB\pi = \bar{B}^0 B^+ \pi^- + c.c.$
- $BB^*\pi = \bar{B}^{*0} B^+ \pi^- + c.c. / \bar{B}^0 B^{*+} \pi^- + c.c.$
- $B^*B^*\pi = \bar{B}^{*0} B^{*+} \pi^- + c.c.$

- One B is reconstructed
- Select a bachelor $\pi^\pm$
- Check $B\pi$ recoil mass



Belle preliminary



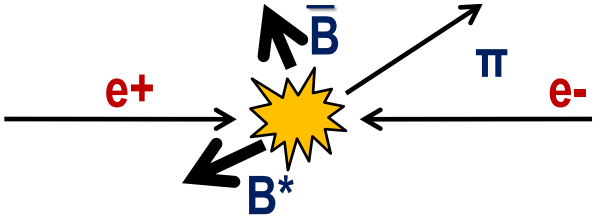


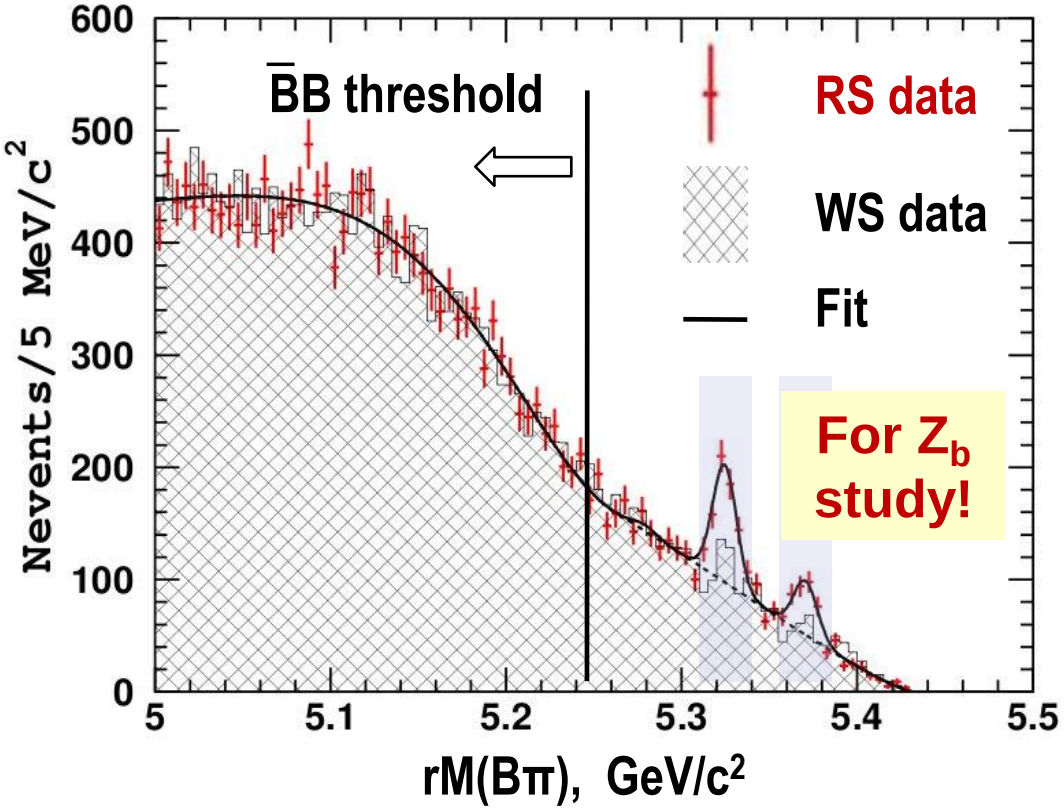
$B^{(*)}B^{(*)}\pi + \bar{B}B\gamma$

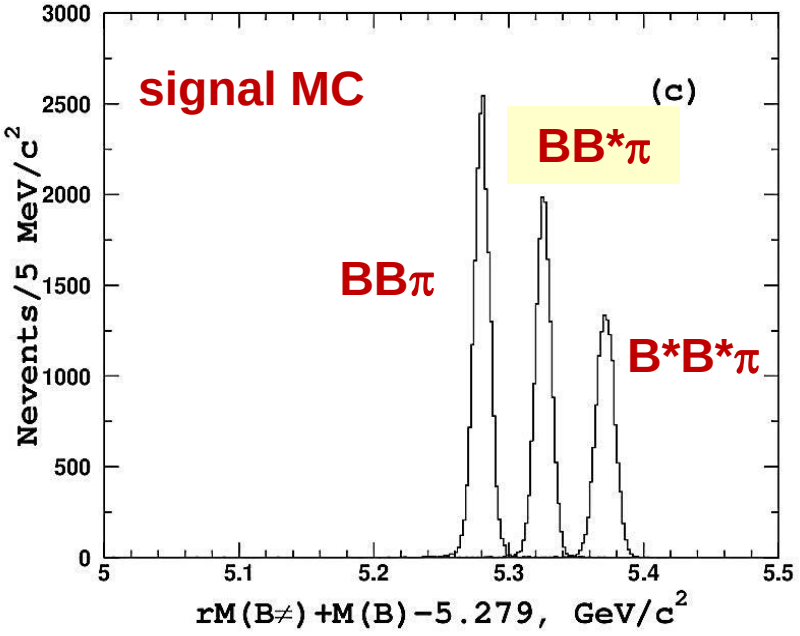
Z_b in $\Upsilon(5S) \rightarrow [B^{(*)}B^{(*)}]^+\pi^- + c.c.$

Combine the B with a charged pion

➔ calculate recoil mass of $B\pi$







$N(BB\pi) = 13 \pm 25$ $N(BB^*\pi) = 357 \pm 30$ $N(B^*B^*\pi) = 161 \pm 21$

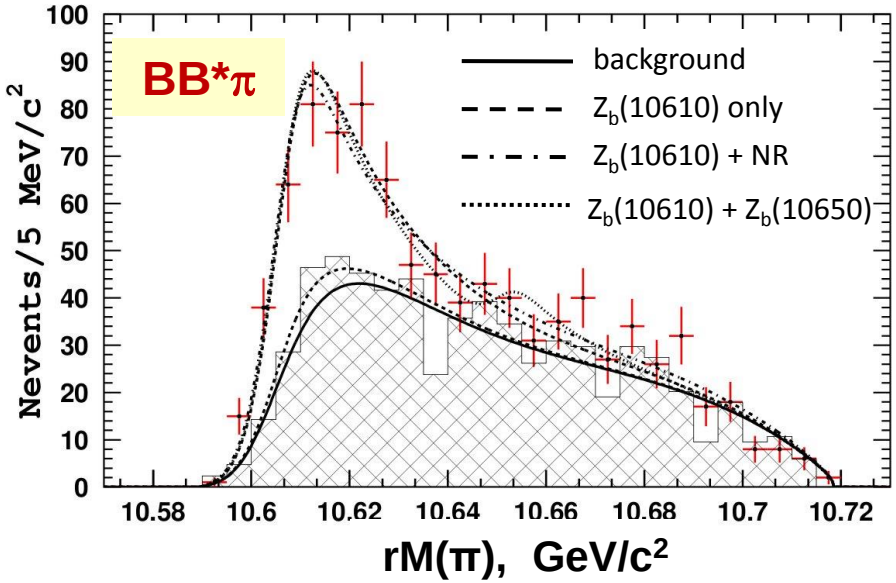
Cross sections are not available yet!

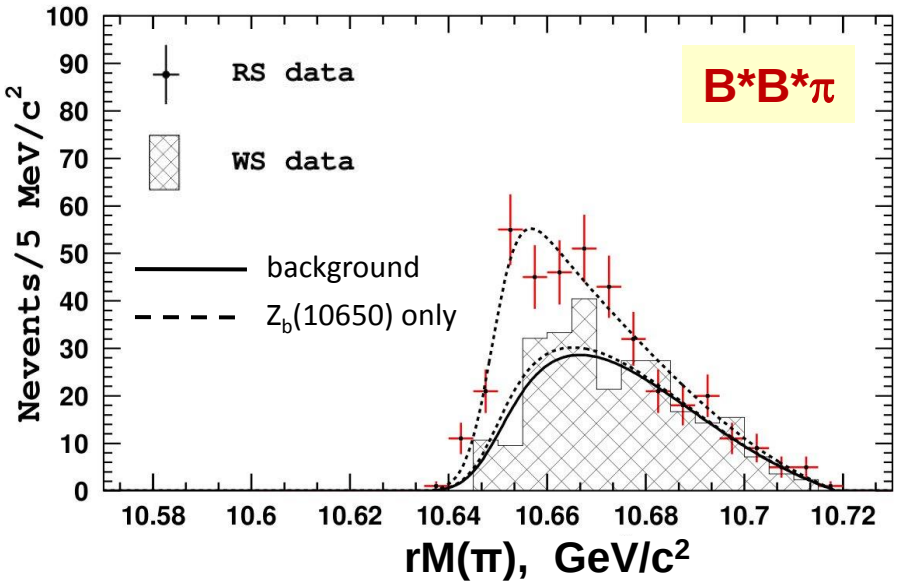
Belle preliminary

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

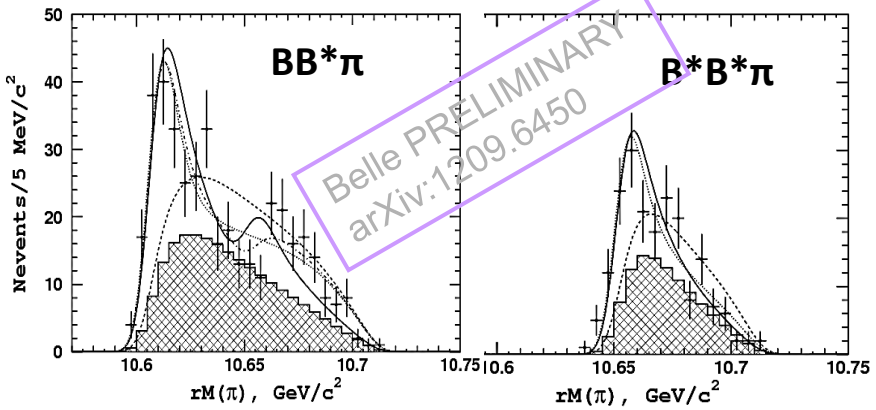
Check recoil mass of bachelor $\pi^\pm$

Belle preliminary



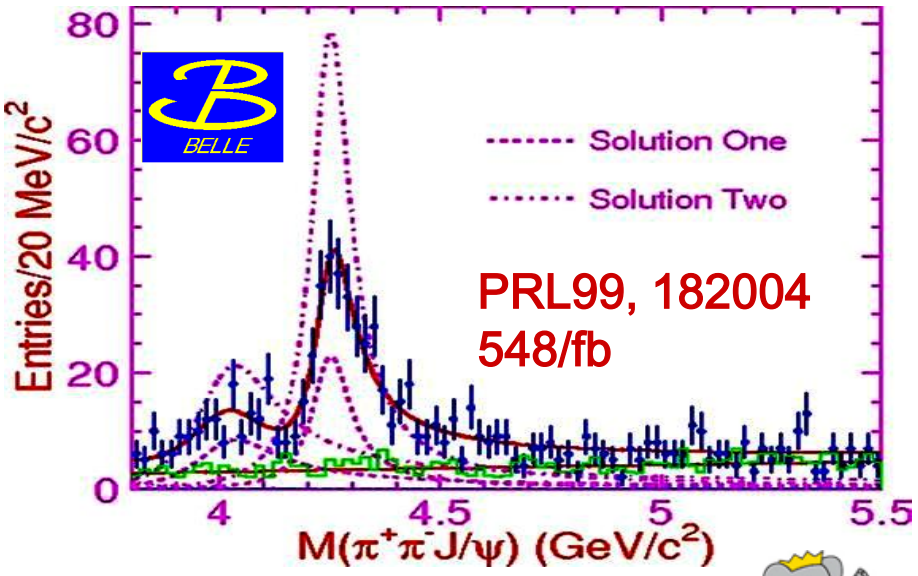


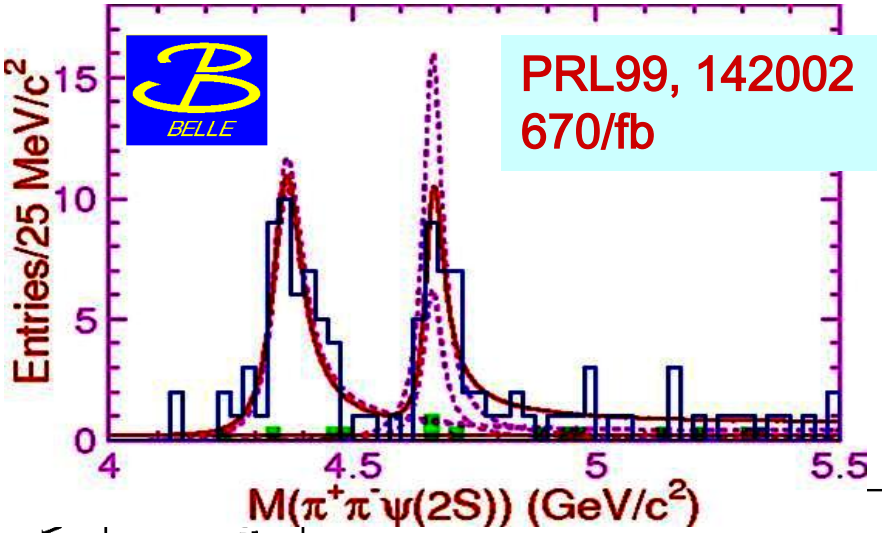
$Z_b(10610)$ saturates $BB^*\pi$ and $Z_b(10650)$ saturates $B^*B^*\pi$

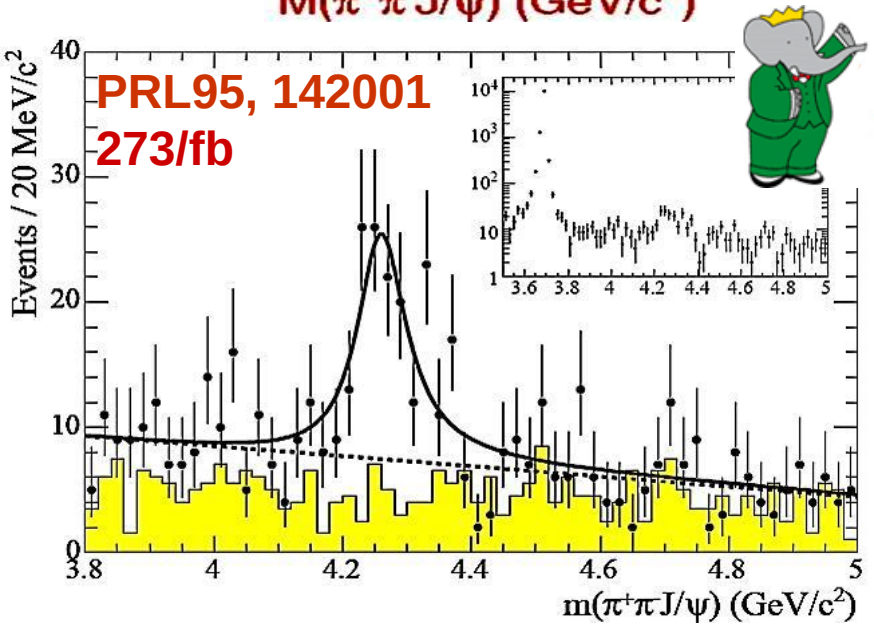


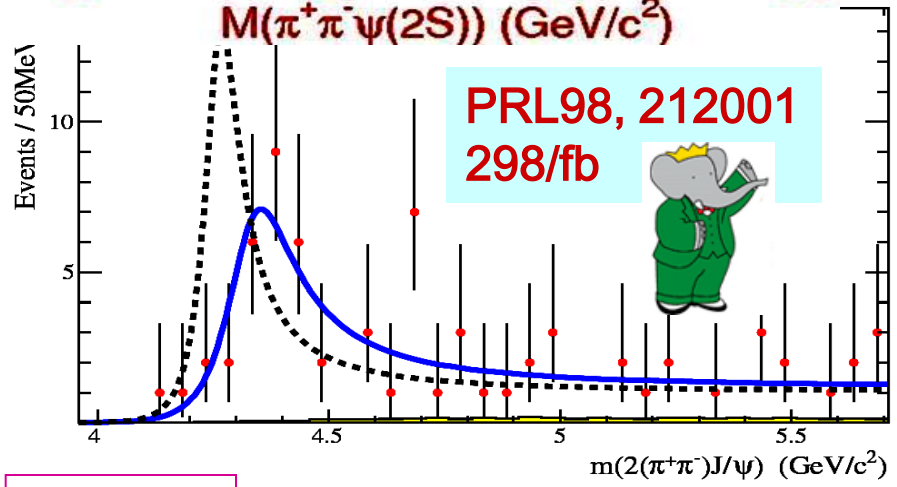
Assuming Z_b decays are saturated by observed channels, $B^{(*)}B^*$ channels dominate the Z_b decays

The Y states

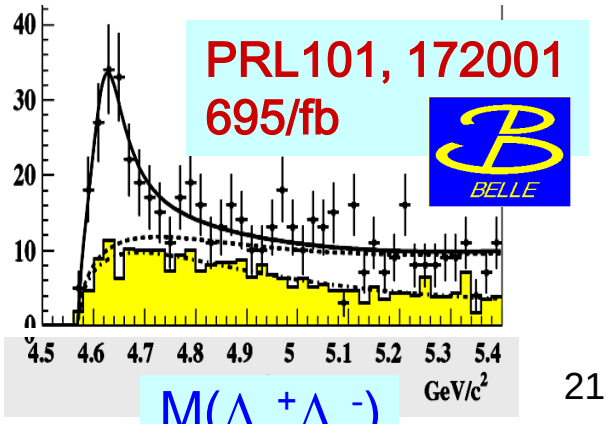








Y(4008)
Y(4260)
Y(4360)
Y(4660)
Y(4630)



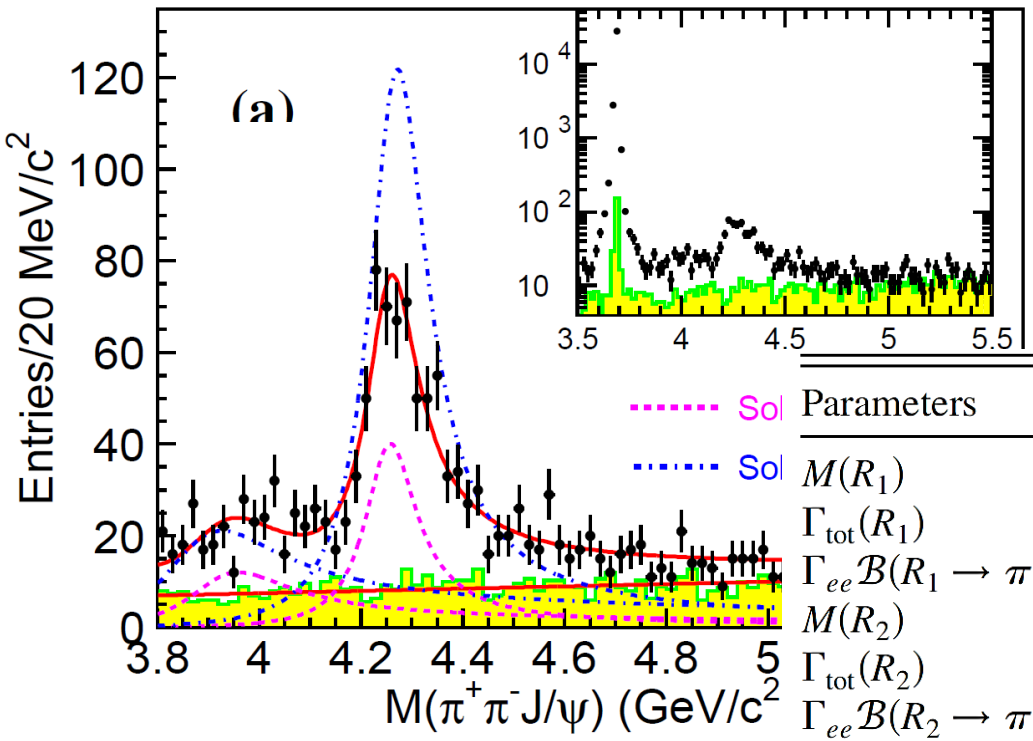
Update with full Belle data

$e^+e^- \to \pi^+\pi^- J/\psi$ from ISR

PRL110, 252002 (2013)

Still observed two resonances, Y(4008) and Y(4260), agrees with Belle's previous results.

R_1=Y(4008)
R_2=Y(4260)



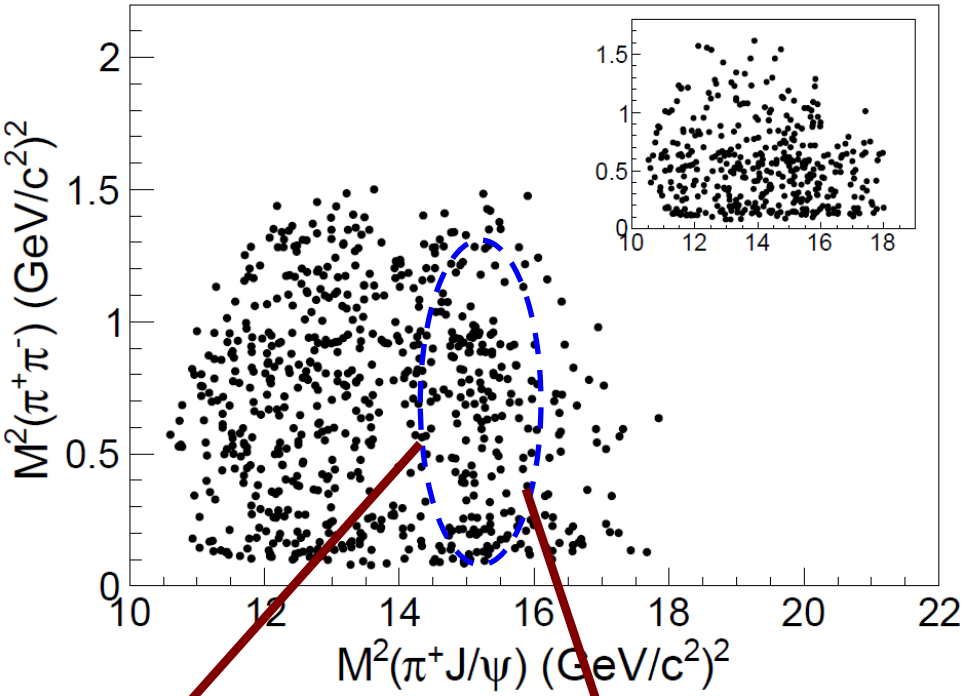
Parameters	Solution I	Solution II
$M(R_1)$	$3890.8 \pm 40.5 \pm 11.5$	
$\Gamma_{\rm tot}(R_1)$	$254.5 \pm 39.5 \pm 13.6$	
$\Gamma_{ee}\mathcal{B}(R_1 \to \pi^+\pi^- J/\psi)$	$(3.8 \pm 0.6 \pm 0.4)$	$(8.4 \pm 1.2 \pm 1.1)$
$M(R_2)$	$4258.6 \pm 8.3 \pm 12.1$	
$\Gamma_{\rm tot}(R_2)$	$134.1 \pm 16.4 \pm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

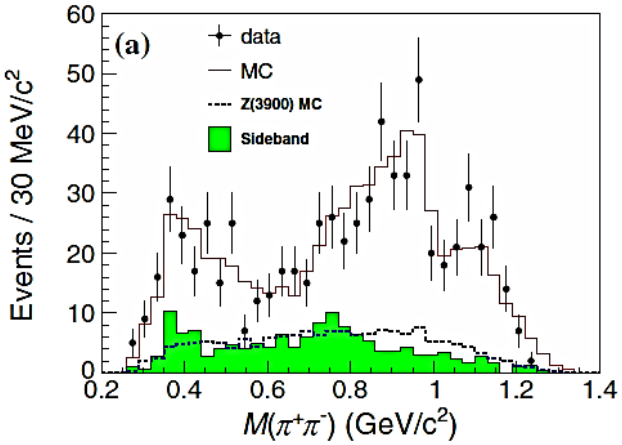
1. Fit with two coherent resonances $|BW_1+BW_2*\exp(i\phi)|^2$+bkg.
2. Mass of Y(4008) is lower than before
3. Fit quality: χ^2/ndf=101/84, confidence level is 9.3%

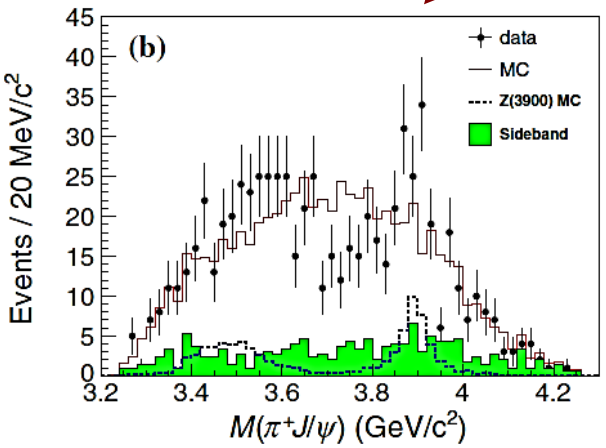
$e^+e^- \to \pi^+\pi^- J/\psi$ from ISR

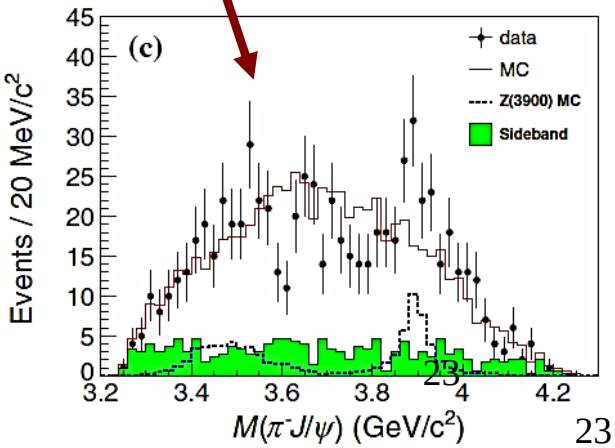
PRL110, 252002 (2013)

- $M^2(\pi\pi)$ vs. $M^2(\pi J/\psi)$ for $4.15 < M(\pi\pi J/\psi) < 4.45$ GeV
- (inset) Background events in J/ψ-mass sidebands
- Structures both in $\pi\pi$ and $\pi J/\psi$ systems
- 689 events in J/ψ signal region, purity~80%



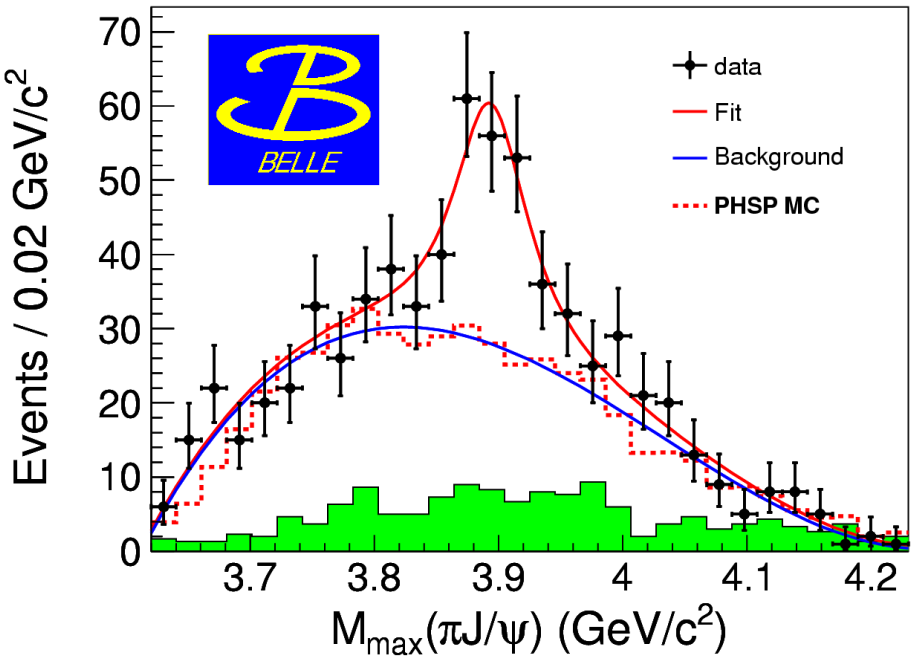






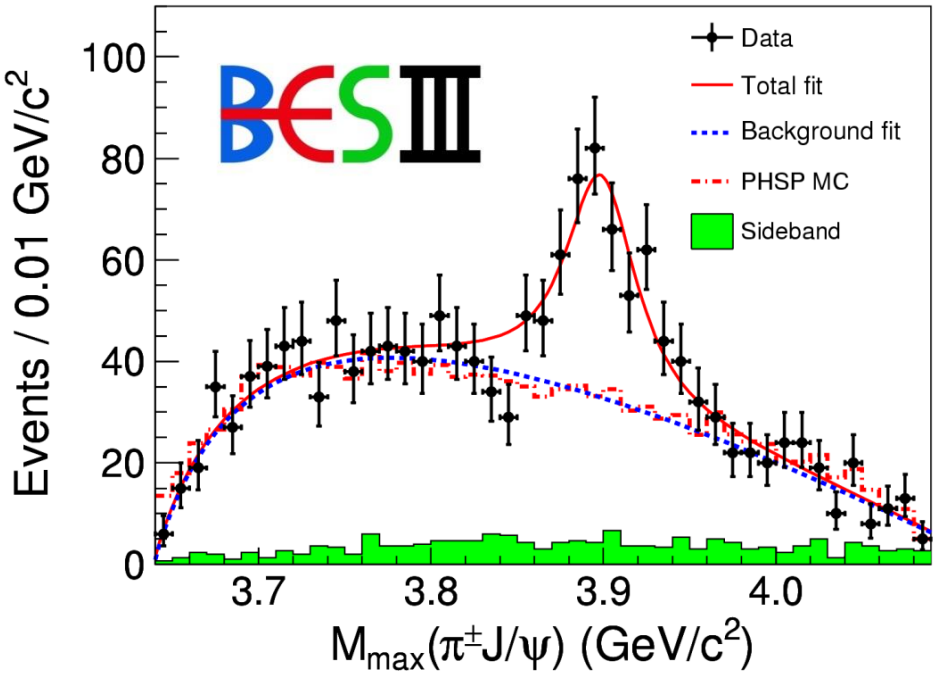
$Z(3900)^+$ observed in two experiments!

Belle with ISR: PRL110,252002



- M = 3894.5±6.6±4.5 MeV
- Γ = 63±24±26 MeV
- 159 ± 49 events
- >5.2σ

BESIII at 4.260 GeV: PRL110,252001

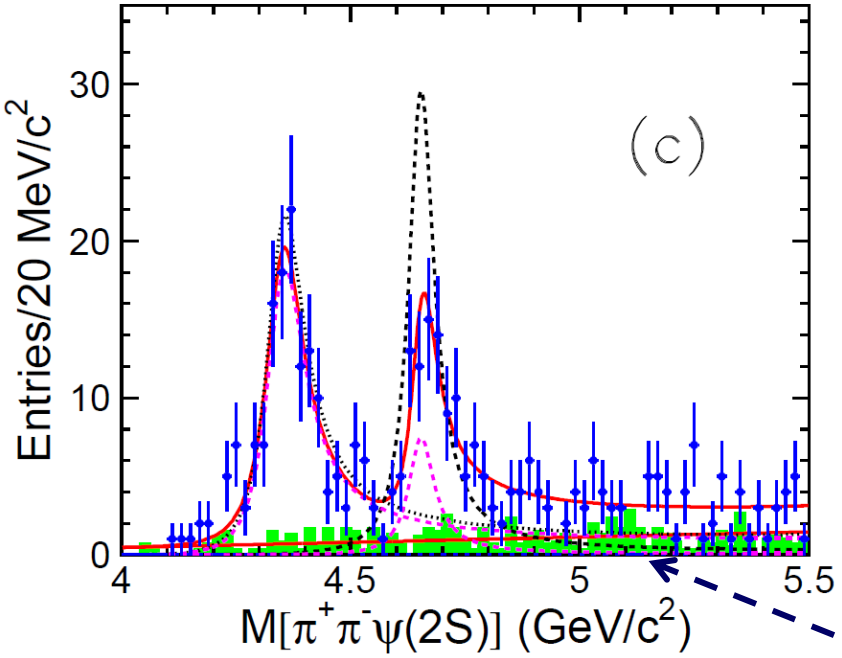


- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events
- >8σ

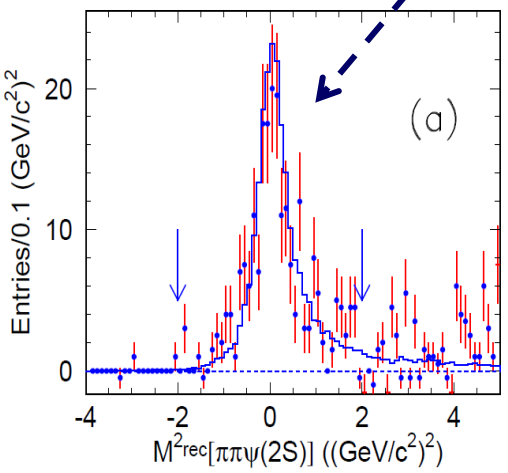
$e^+e^- \to \pi^+\pi^-\psi(2S)$ via ISR

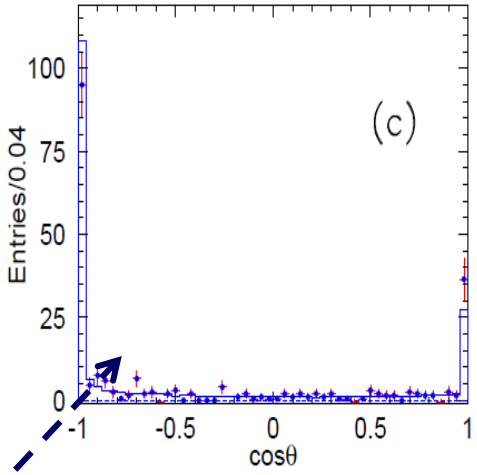
980 fb^{-1}

$\psi'(\to J/\psi\,\pi\pi$ or $\mu\mu) + \pi\pi$
no extra tracks
detection of γ_{ISR} is not required



- **Clear signal of missed massless particle ($M_{rec}^2(\psi'\pi\pi)\sim0$)**





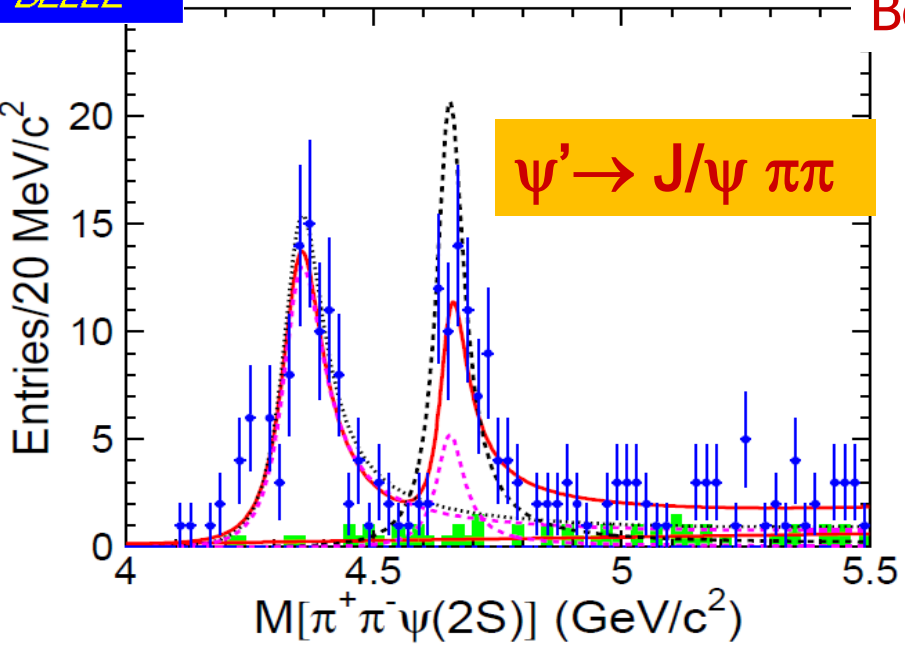
- **Polar angle distribution agrees well with ISR expectation**
- **Combinatorial background estimated by ψ' sidebands**
- **Bkgs from real $(\psi'\pi\pi)_{non\ ISR}$ or $\psi'\ X_{non\ \pi\pi}$ are negligibly small**

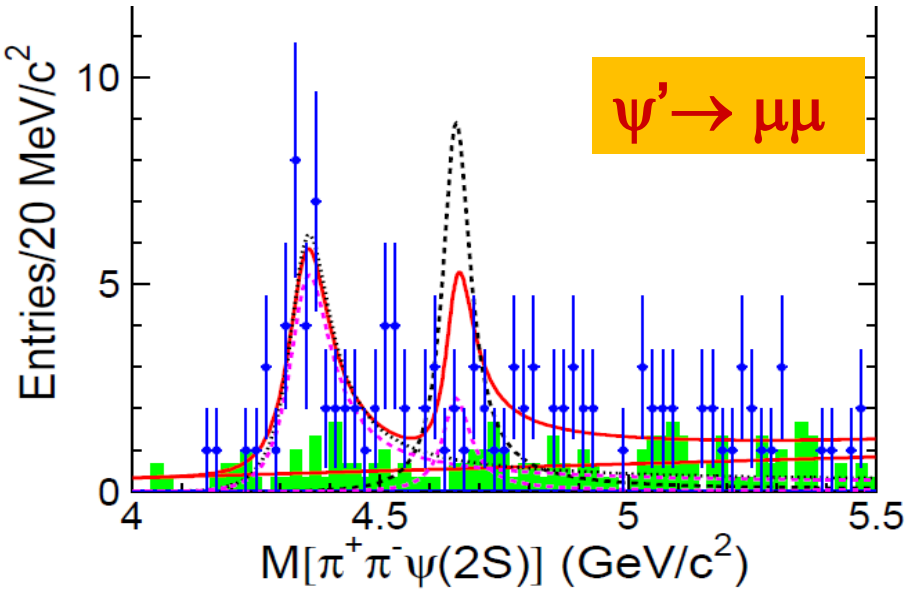
Two significant clusters:
Y(4360)+Y(4660);
a few events at Y(4260)

Belle: arXiv:1410.7641, PRD91_112007

Fit with Two BWs

Belle: arXiv:1410.7641, PRD91_112007



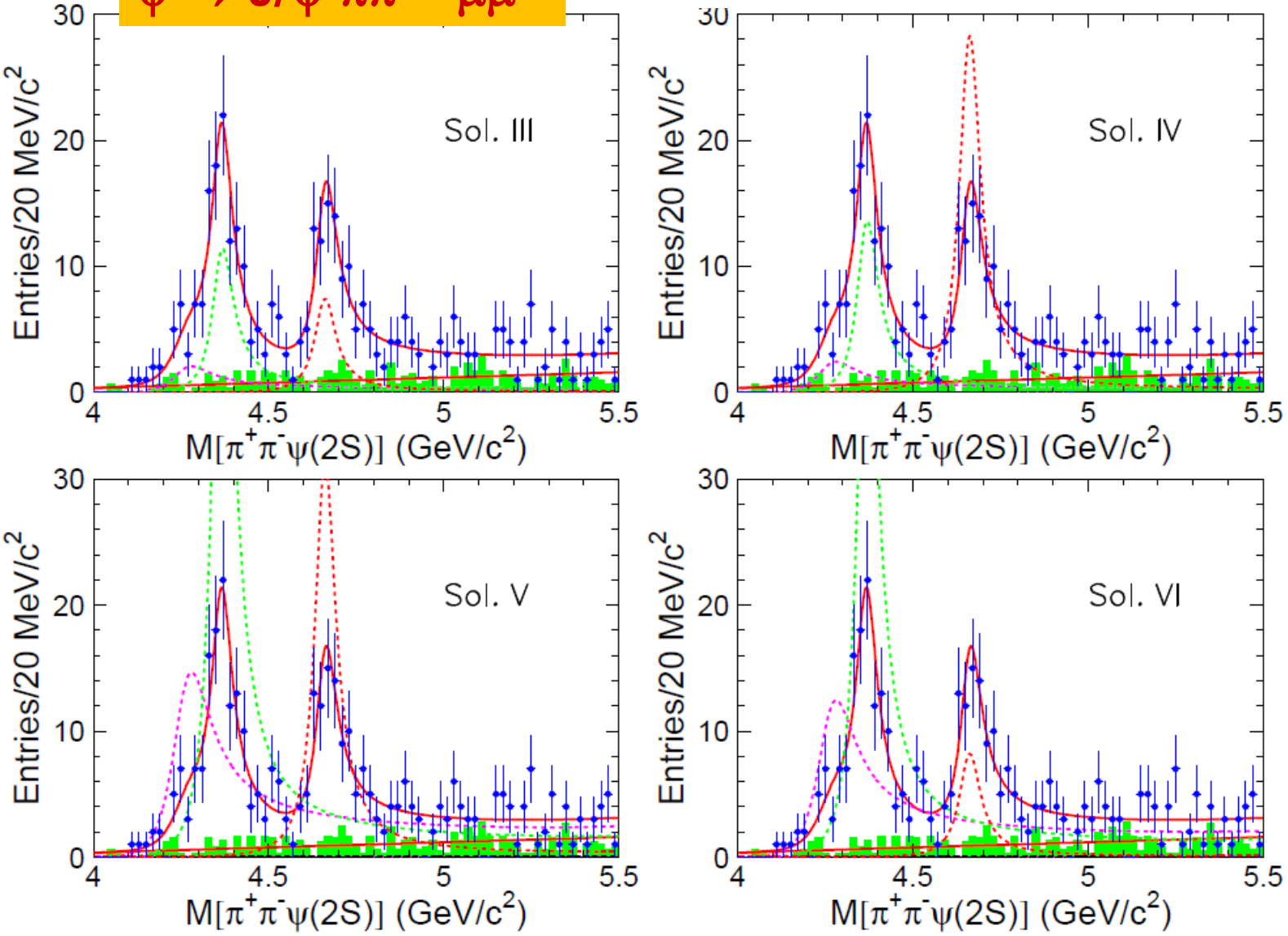


Parameters	Solution I	Solution II
$M_{Y(4360)}$	$4347 \pm 6 \pm 3$	
$\Gamma_{Y(4360)}$	$103 \pm 9 \pm 5$	
$\mathcal{B}[Y(4360) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4360)}$	$9.2 \pm 0.6 \pm 0.6$	$10.9 \pm 0.6 \pm 0.7$
$M_{Y(4660)}$	$4652 \pm 10 \pm 11$	
$\Gamma_{Y(4660)}$	$68 \pm 11 \pm 5$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

Fit with Three BWs

$\psi' \to J/\psi\,\pi\pi + \mu\mu$

Belle: arXiv:1410.7641, PRD91_112007



Fit with Three BWs

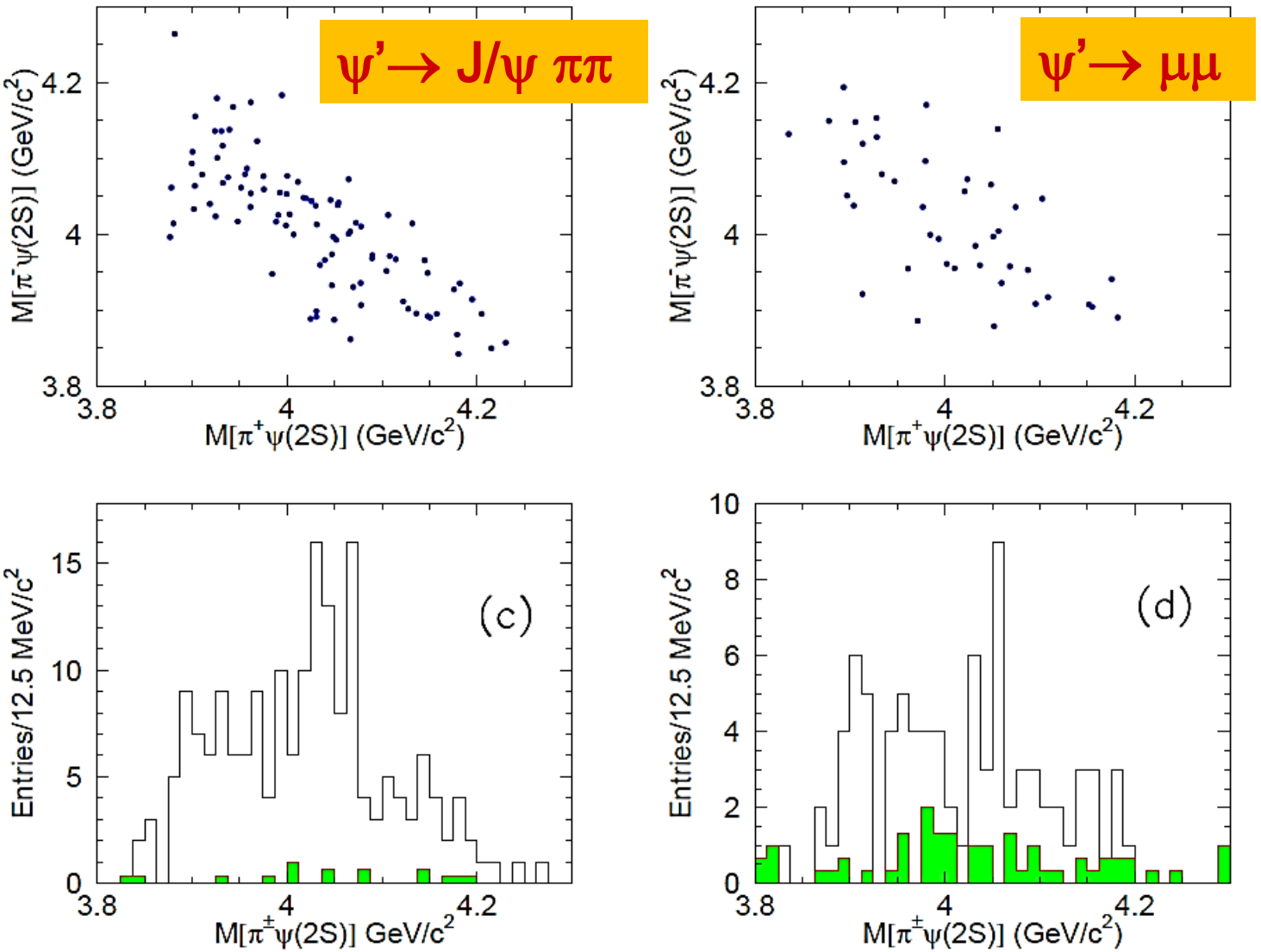
$\psi' \to J/\psi\,\pi\pi + \mu\mu$ Belle: arXiv:1410.7641, PRD91_112007

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	$26 \pm 19 \pm 10$	$238 \pm 14 \pm 21$	$329 \pm 8 \pm 5$	$117 \pm 23 \pm 25$

Significance of Y(4260) is 2.4σ

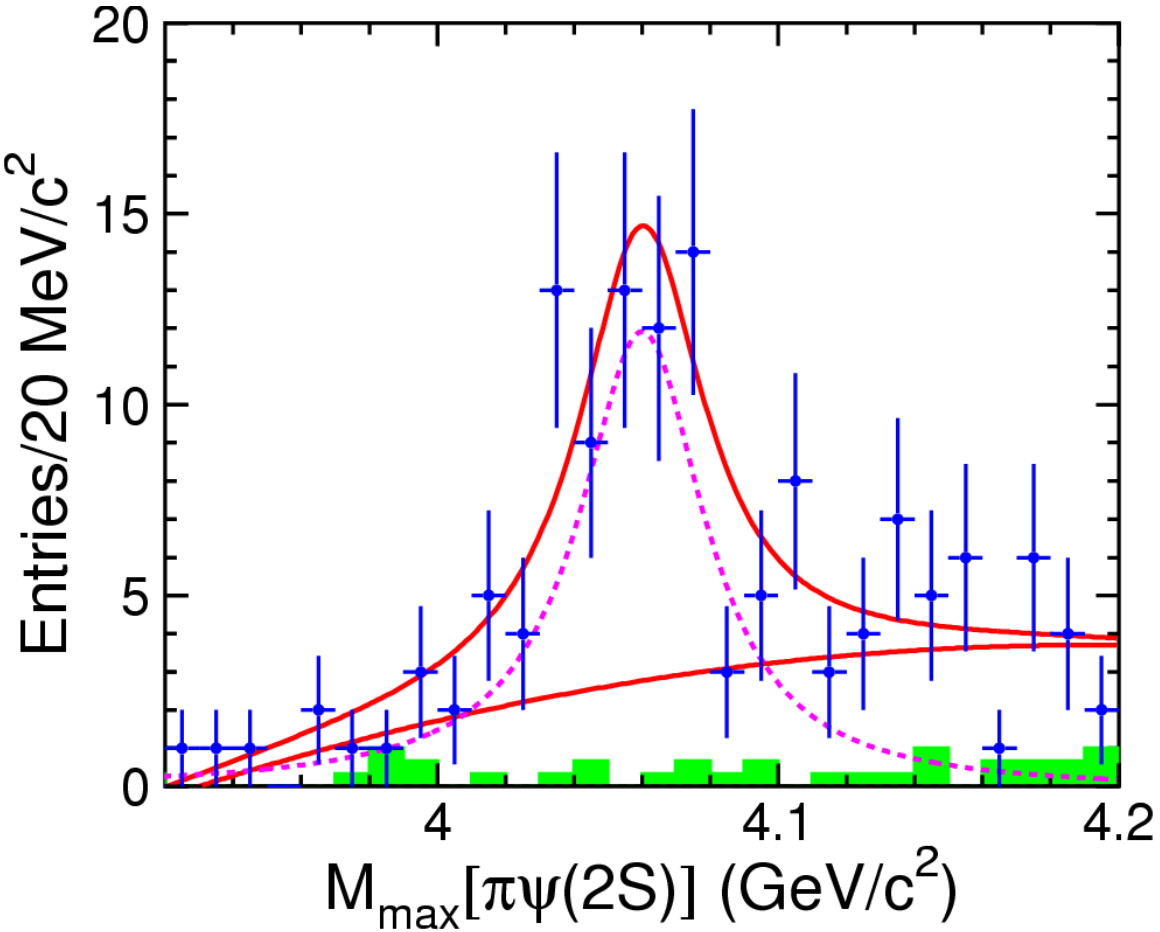
Affect the parameters of Y(4360) and Y(4660) significantly!

Z_c states from Y(4360) decays?



Belle: arXiv:1410.7641, PRD91_112007

$Z_c(4050)^{\pm} \rightarrow \pi\psi'$

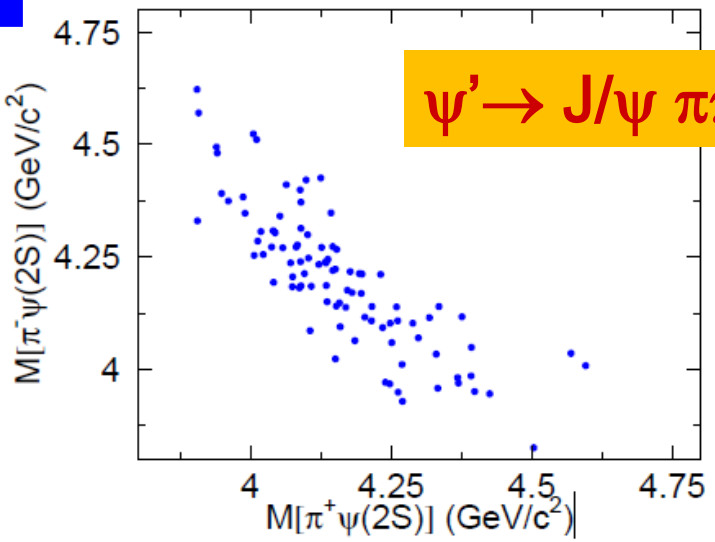


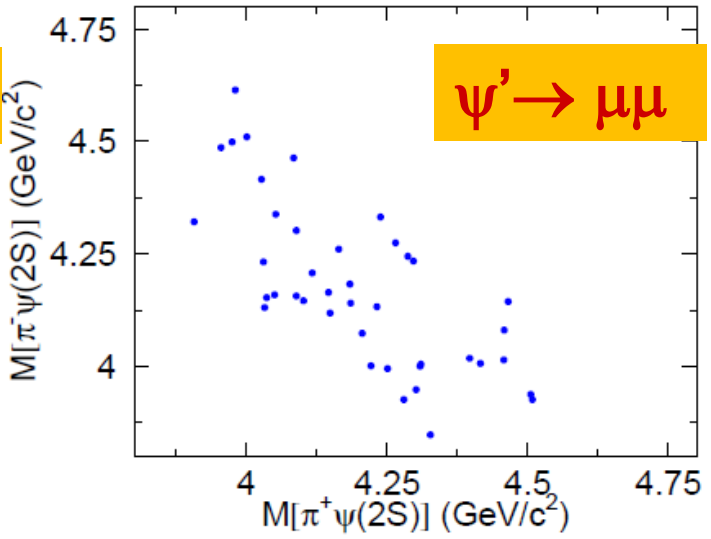
arXiv:1410.7641
PRD91_112007

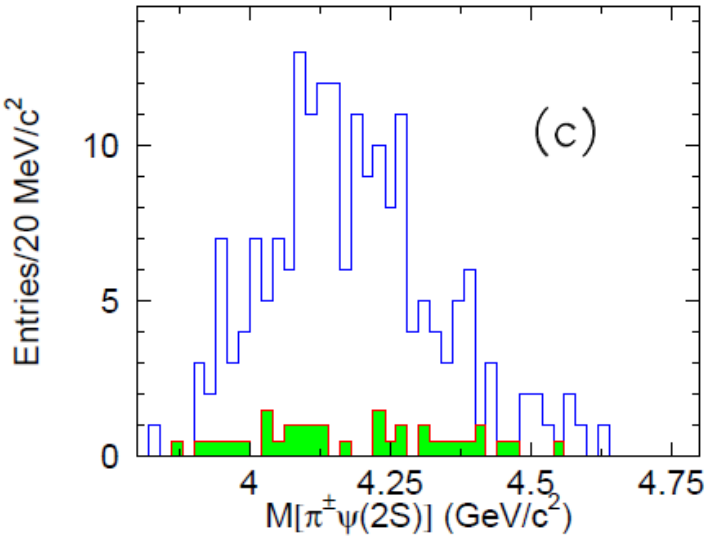
An unbinned maximum-likelihood fit is performed on the distribution of $M_{max}(\pi^{\pm}\psi(2S))$, the maximum of $M(\pi^{+}\psi(2S))$ and $M(\pi^{-}\psi(2S))$, simultaneously with both modes.

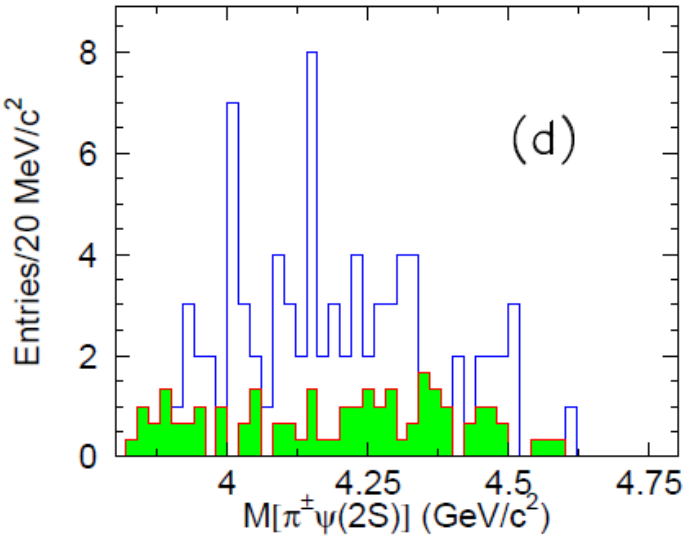
- $M(Z_c) = 4054 \pm 3 \pm 1$ MeV/c^2
- $\Gamma = 45 \pm 11 \pm 6$ MeV
- Significance: **>3.5σ**

No significant Z_c in Y(4660) decays!







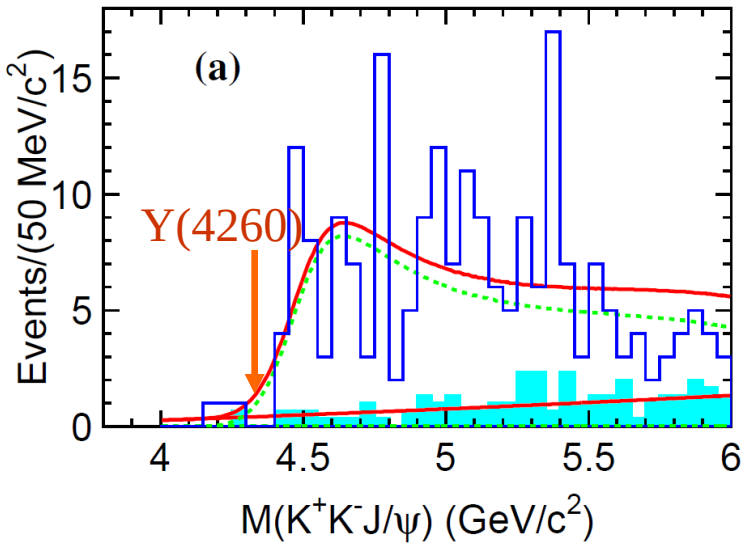


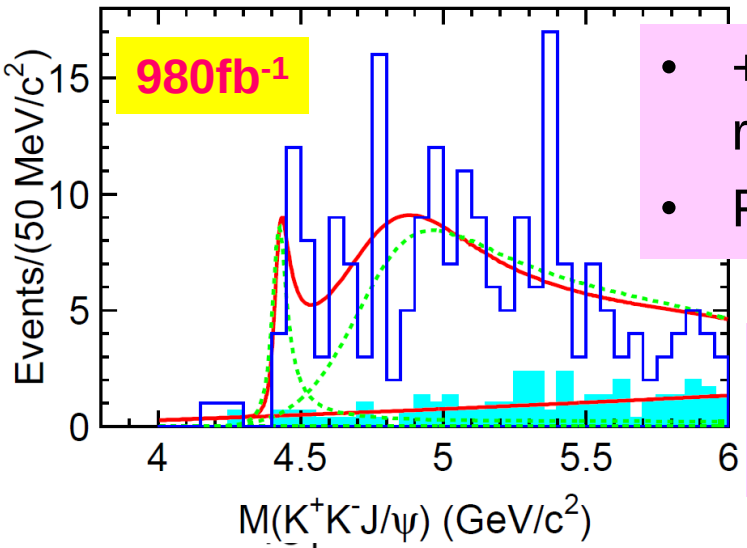
Belle: arXiv:1410.7641, PRD91, 112007

$e^+e^- \to K^+K^-J/\psi$ via ISR

Event selections are almost the same as in Phys. Rev. D 77, 011105(R) (2008)

Shaded hist.: J/ψ mass sidebands



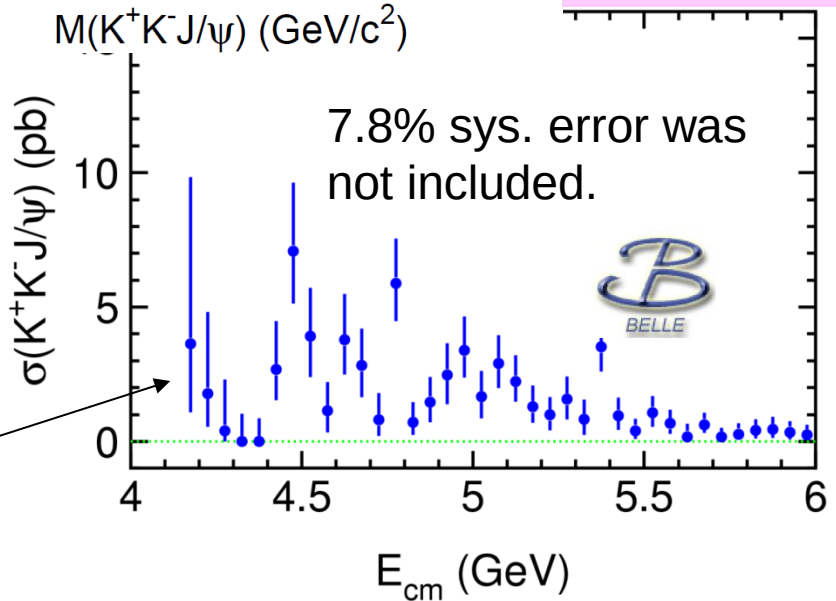


- +one resonance.
- Fit with $\psi(4415)$

χ^2/ndf=30/11
- M=4747±117MeV
- Γ=671±86 MeV

4-6 GeV: 213 events
35 bkg, 178±16 signal

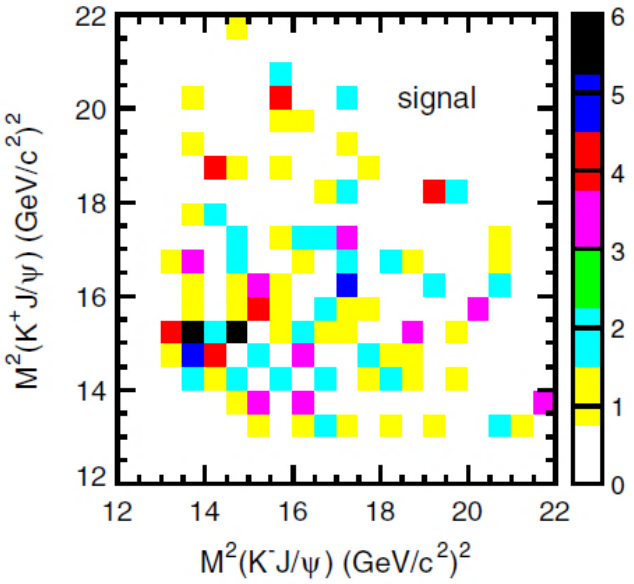
$$\sigma_i = \frac{n_i^{\rm obs} - f \times n_i^{\rm bkg}}{\mathcal{L}_i \cdot \epsilon_i \cdot \mathcal{B}(J/\psi \to \ell^+\ell^-)}$$

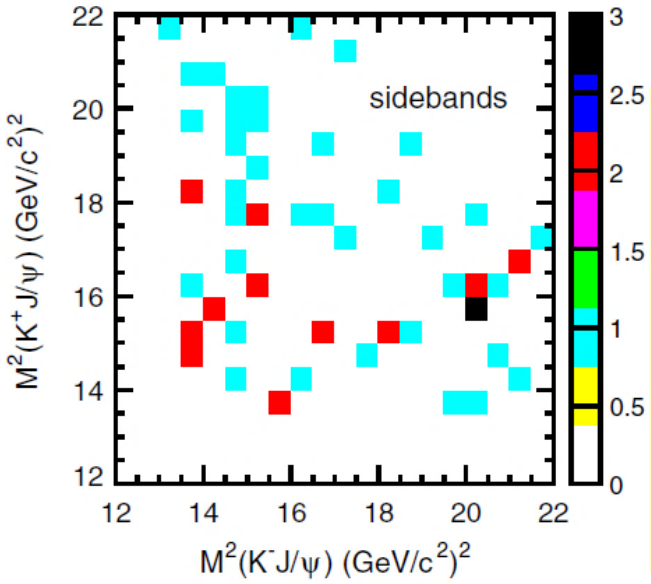


PRD 89,072015(2014)

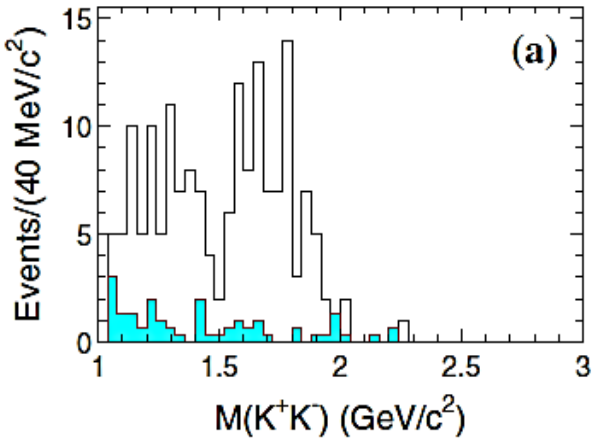
Search for Z_{cs}→KJ/ψ states

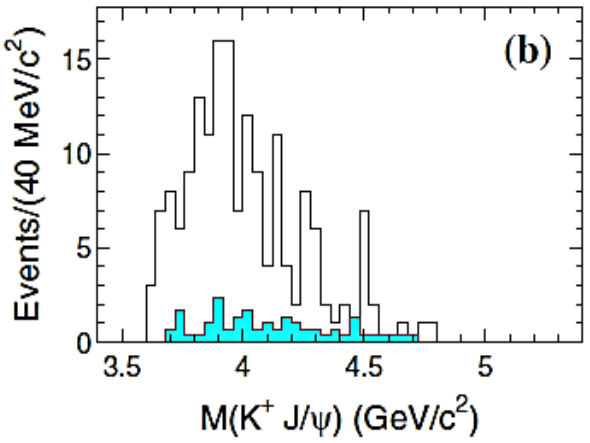
PRD 89, 072015(2014)

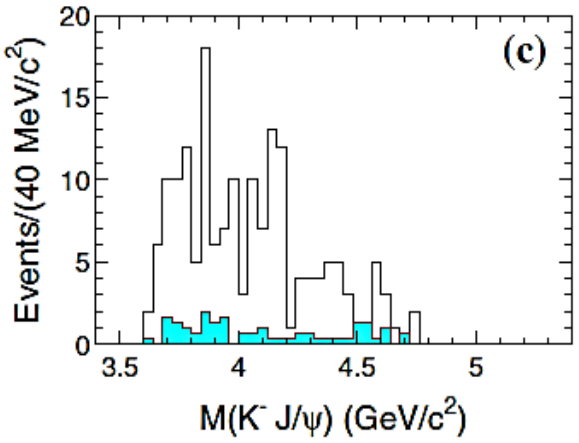




Large data samples at BelleII are needed to understand KJ/ψ and KKJ/ψ structures !



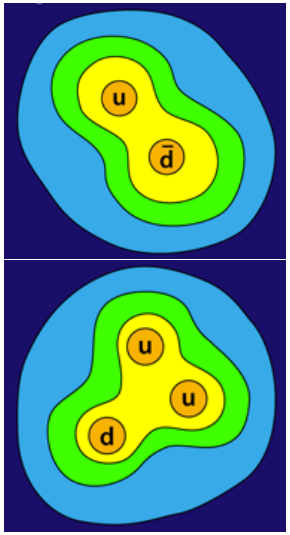




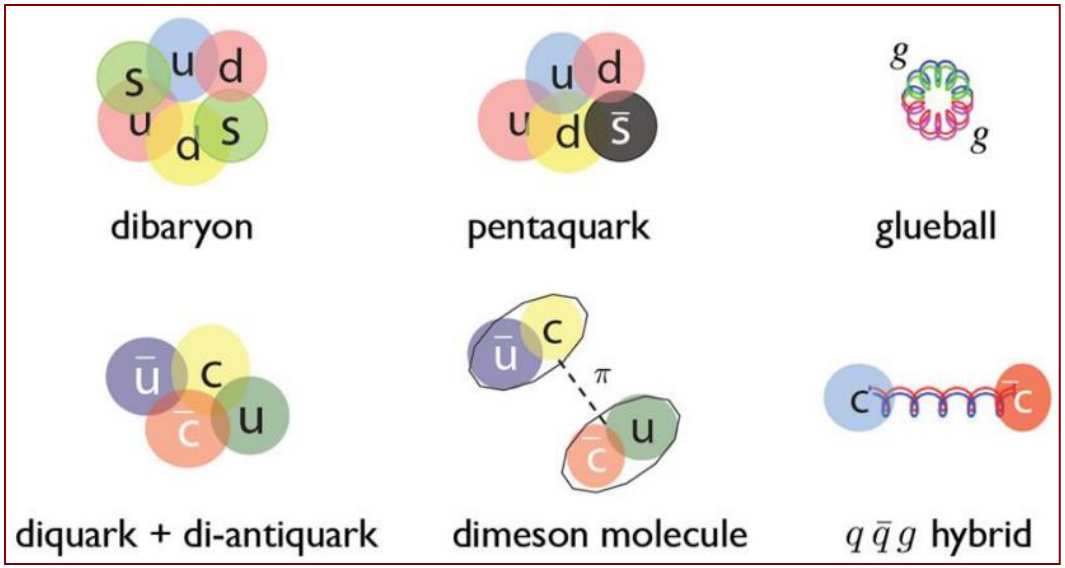
No evident structure in $K^{\pm}J/\psi$ mass distribution under current statistics

What are these states?

- Quark model: hadrons are composed from 2 (meson) quarks or 3 (baryon) quarks



Normal vs. Exotic



- QCD does not forbid hadrons with $N_{quarks} \neq 2, 3$
  - Glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - Hybrid : $N_{quarks} = 2$ (or more) + excited gluon
  - Multiquark state : $N_{quarks} > 3$
  - Molecule : bound state of more than 2 hadrons
  - …

Summary

- With the world's largest data samples in bottomonium energy region Belle achieved a lot
  - improved knowledge on $\Upsilon(5S)$ and $\Upsilon(6S)$
  - New results on the Z_b states
- With ISR events, Belle studied charmoniumlike states
  - Improved measurement of Y(4360) & Y(4660)
  - Evidence for $Z_c(4050) \rightarrow \pi\psi'$ but no Z_{cs} yet
- Still lots of analyses on going, results soon
- Belle II is coming ……

Thanks a lot!

The end

$M(\pi^+\pi^-)$ distributions

Belle: arXiv:1410.7641, PRD91_112007