Recent XYZ results from Belle

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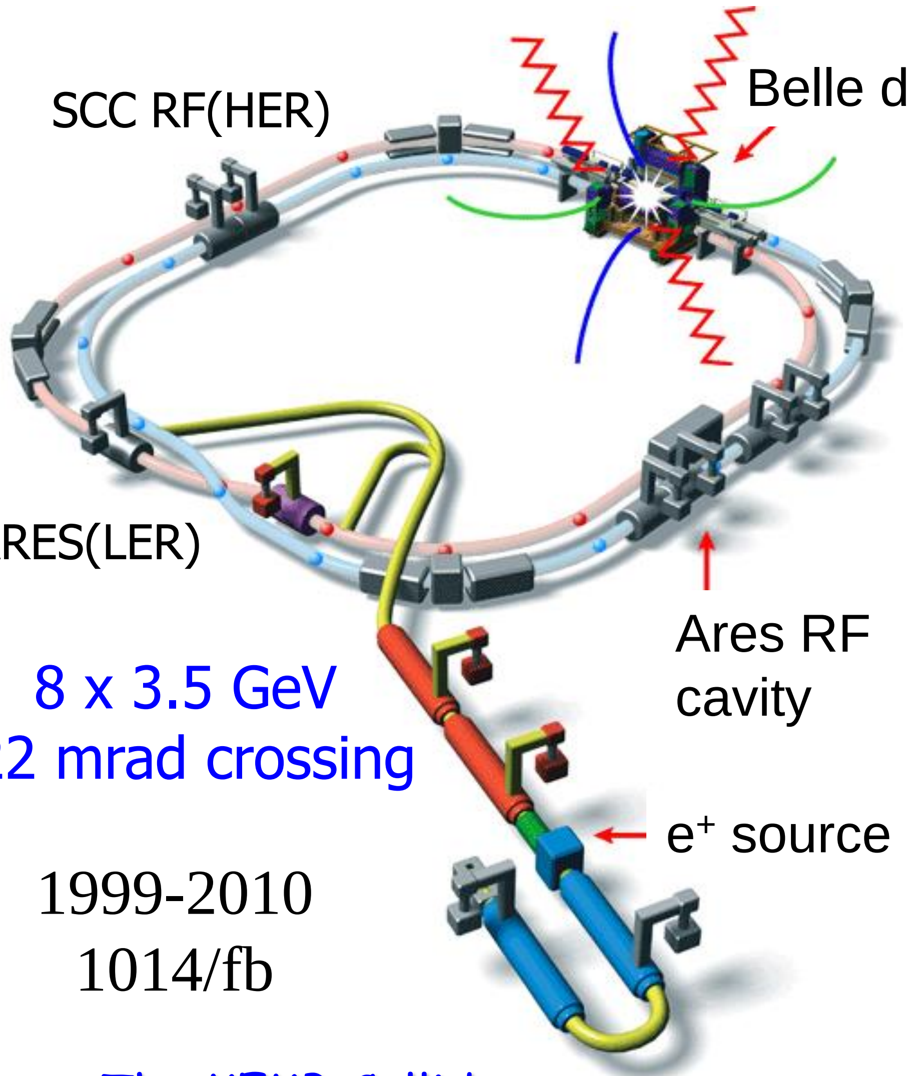
The Belle experiment



8 x 3.5 GeV
22 mrad crossing

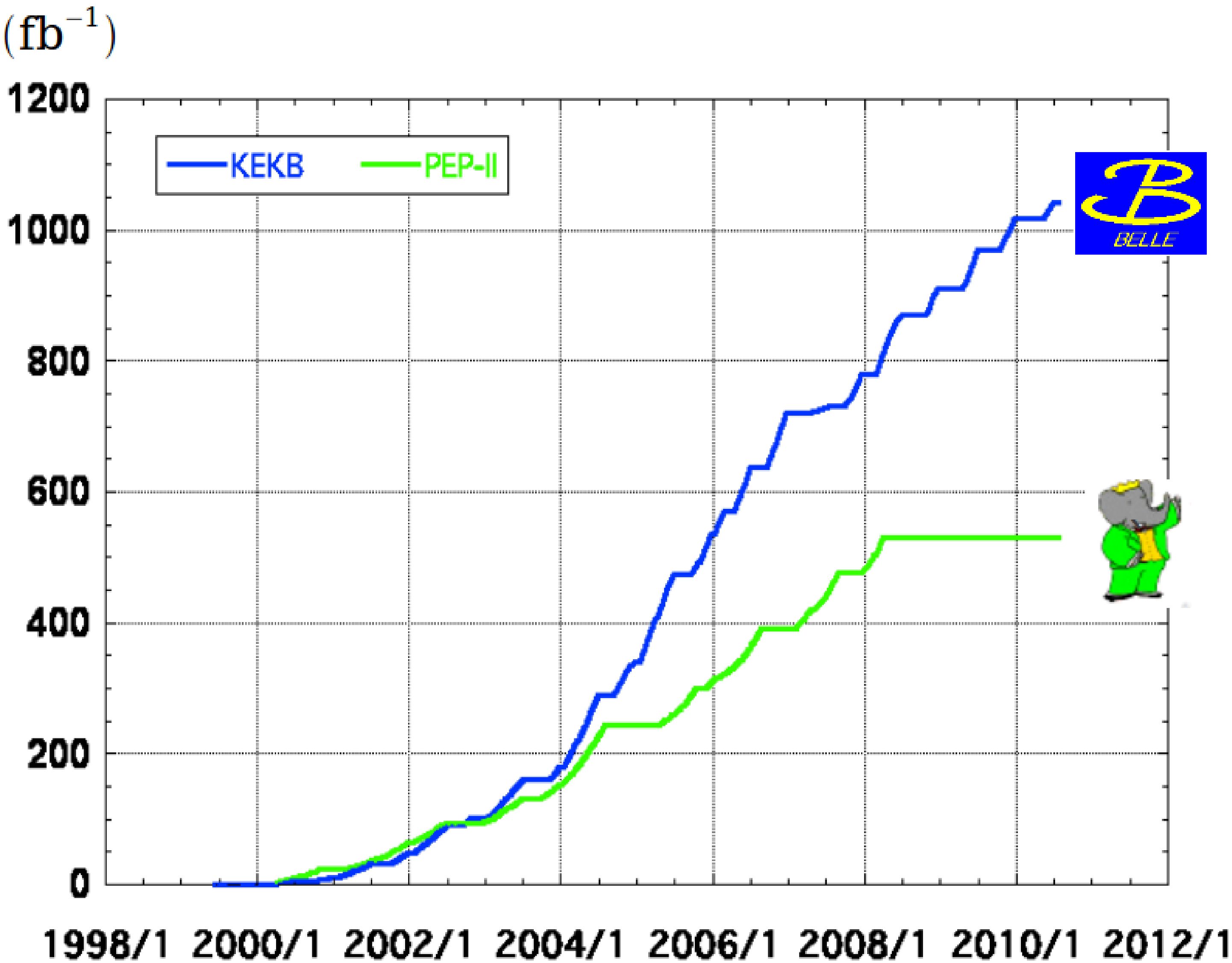
1999-2010
1014/fb

The KEKB Collider

World record:

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

Integrated luminosity of B factories



> 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:

$\sim$ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

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

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

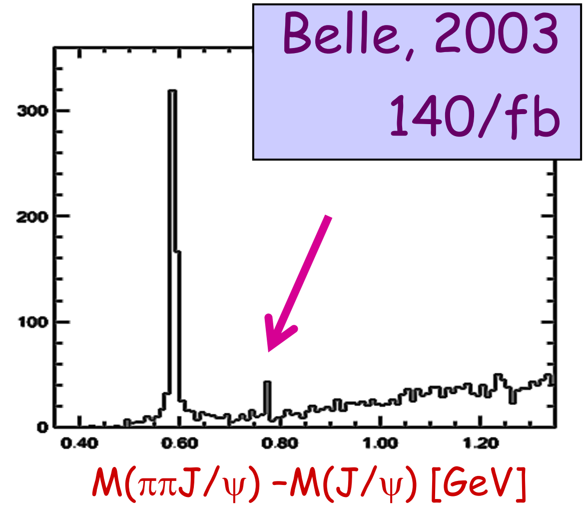
Off resonance:

$\sim$ 54 fb^{-1}

outline

- Recently released XYZ results
- Ongoing analyses on XYZ
- Prospects at Belle II
- Summary

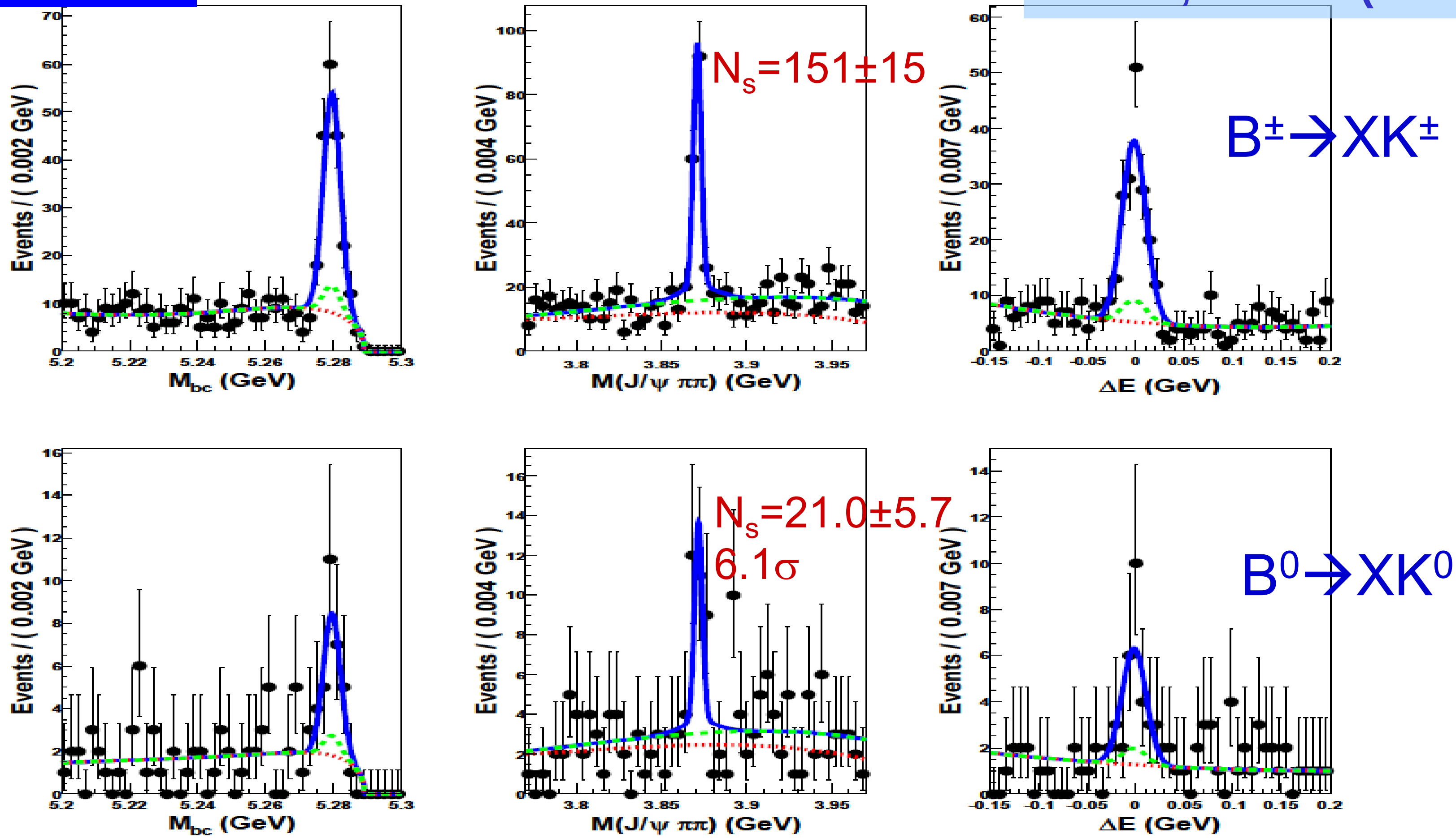
The X(3872)



- Mass: Very close to $\bar{D}^0 D^{*0}$ threshold
- Width: Very narrow, < 1.2 MeV
- $J^{PC}=1^{++}$
- Production
  - in $\bar{p}p$/pp collison – rate similar to charmonia
  - In B decays – KX / K*X vs. charmonium [Belle, next pages]
  - Y(4260)→γ+X(3872) [from BESIII]
- Decay BR: open charm ~ 50%, charmonium~O(%)
- 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}?)

$B \to X(3872)K$

PRD84, 052004 (2011) 711 fb^{-1}



$$\mathcal{B}(B^+ \to K^+X(3872)) \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$$
$$(8.61 \pm 0.82\ (\mathrm{stat}) \pm 0.52\ (\mathrm{syst})) \times 10^{-6},$$

$$\frac{\mathcal{B}(B^0 \to K^0X(3872))}{\mathcal{B}(B^+ \to K^+X(3872))} = 0.50 \pm 0.14\ (\mathrm{stat}) \pm 0.04\ (\mathrm{syst})$$

More information on X(3872)

Belle observed $B^0 \rightarrow X(3872)K^+\pi^-$ with smaller data sample (605 fb^{-1})

BELLE-CONF-0849

$$\mathbf{BR(B^0 \rightarrow X(K^+\pi^-)_{non\_res})\ BR(X\rightarrow J/\psi\pi^+\pi^-) = (8.1\pm2.0^{+1.1}_{-1.4})10^{-6}}$$

dominates ! unlike $B\rightarrow(c\bar{c})K\pi$

$$\mathbf{BR(B^0 \rightarrow XK^{*0})BR(X\rightarrow J/\psi\pi^+\pi^-) < 3.4x10^{-6}\ 90\%\ CL}$$

arXiv:0809.1224 (Never published !)

With full data sample (711fb^{-1}) and reprocessed data, one expect more sensitivity to this decay mode. It's crucial to investigate further the X(3872)'s properties by adding more B decay modes involving X(3872) like $X(3872)K^+\pi^-$, $X(3872)K_S\pi^+$ and $X(3872)K^+\pi^0$, and taking advantage of a B-factory environment.

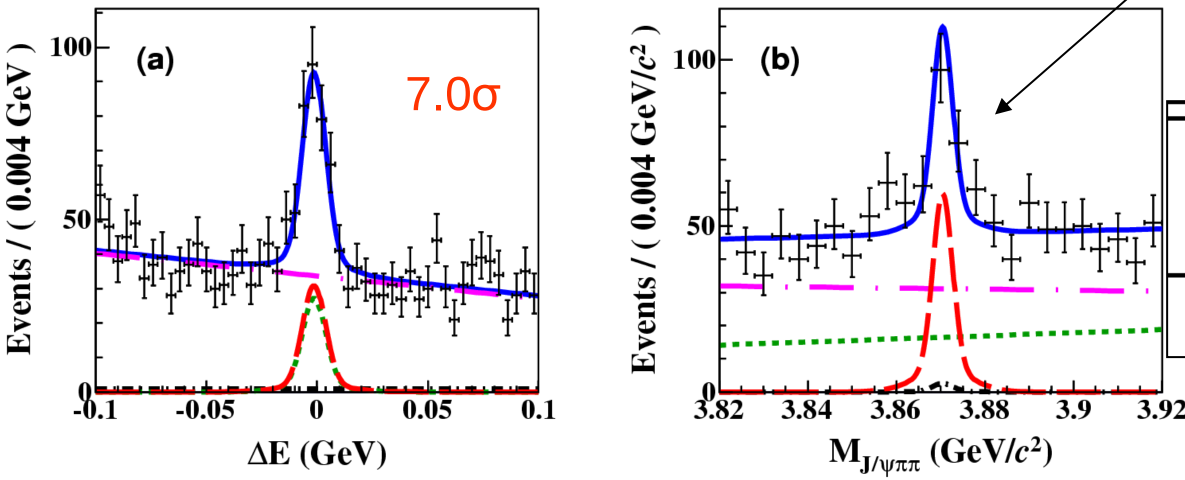
PRD91,051101(R) (2015)

B→X(3872)Kπ

2D-fit to ΔE and M($J/\psi\pi^+\pi^-$) **PRD91,051101(R) (2015)**

$B^0 \to X(3872)K^+\pi^-$

116±19 X(3872)

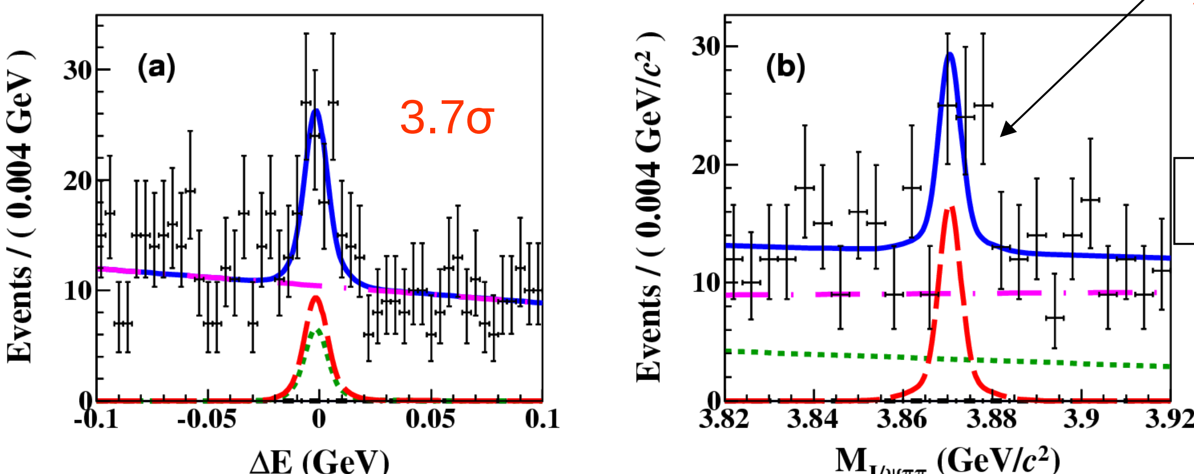


$$\mathcal{B}(B \to X(3872)K\pi) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-)$$

$$(7.9 \pm 1.3 \pm 0.4) \times 10^{-6}$$

$B^+ \to X(3872)K_S\pi^+$

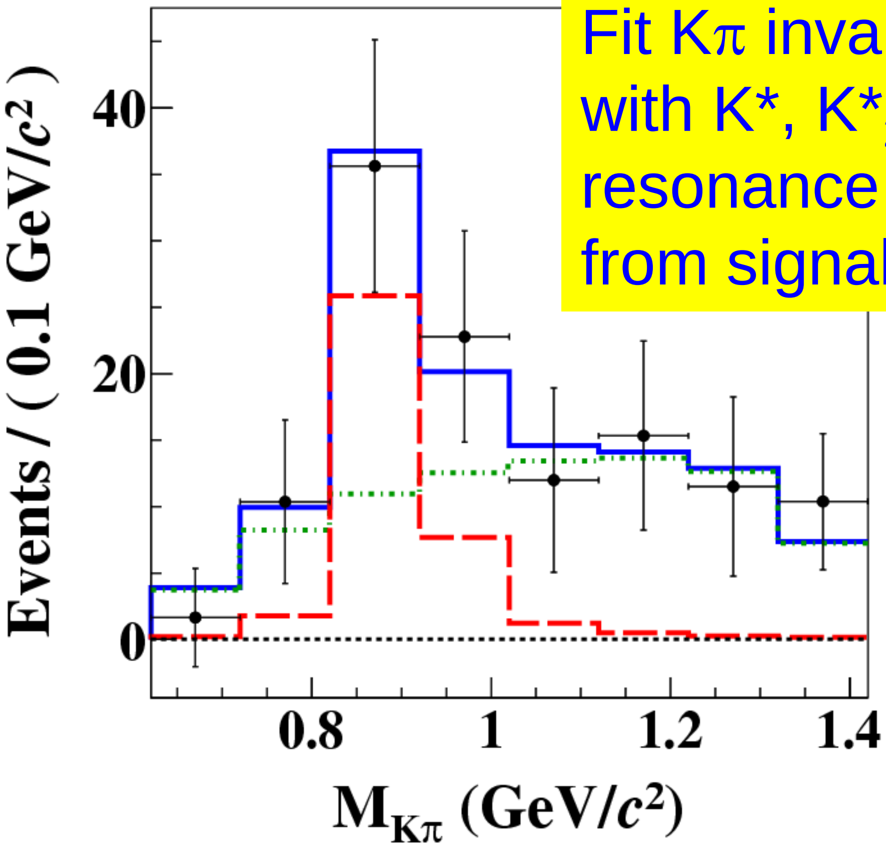
35±10 X(3872)



$$(10.6 \pm 3.0 \pm 0.9) \times 10^{-6}$$

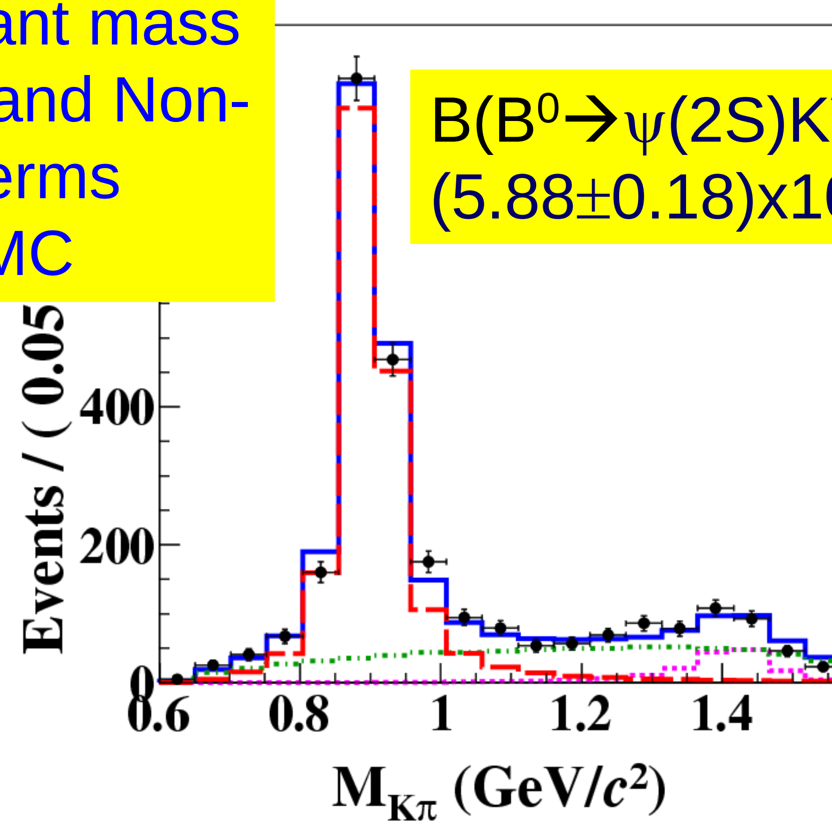
B→X(3872)Kπ

$B^0 \to X(3872)K^+\pi^-$



Fit Kπ invariant mass with K*, K^*_2 and Non-resonance terms from signal MC

$B^0 \to \psi(2S)K^+\pi^-$



$\mathcal{B}(B^0 \to \psi(2S)K^*) = (5.88 \pm 0.18) \times 10^{-4}$

$$\frac{\mathcal{B}(B^0 \to X(3872)K^*(892)^0) \times \mathcal{B}(K^*(892)^0 \to K^+\pi^-)}{\mathcal{B}(B^0 \to X(3872)K^+\pi^-)} = 0.34 \pm 0.09(\text{stat.}) \pm 0.02(\text{syst.}).$$

X-like states decaying to η_c modes

- **Motivation**

arXiv:1501.06351, JHEP06(2015)13

  - X(3872) was first observed by Belle in $B \to K(J/\psi\pi^+\pi^-)$. Angular analysis of this mode performed by LHCb determined all quantum numbers: 1^{++}.
  - If X(3872) is a $D^0\bar{D}^{*0}$ molecule, there may be other "X-like" particles with different quantum numbers, that are also bound states of $D^{(*)}$ mesons.

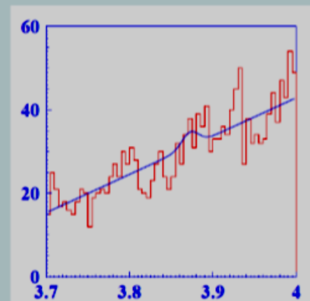
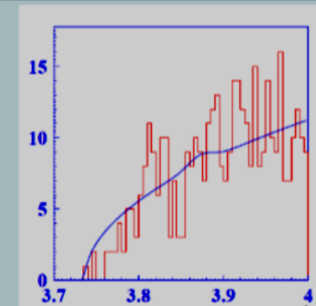
- **Assumption**

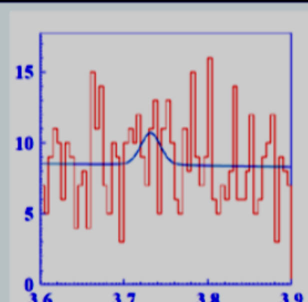
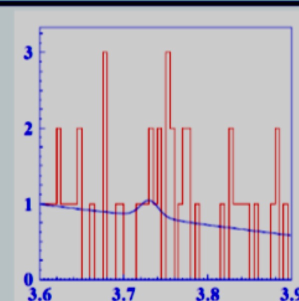
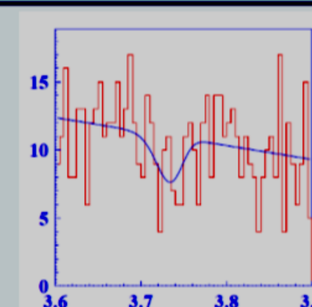
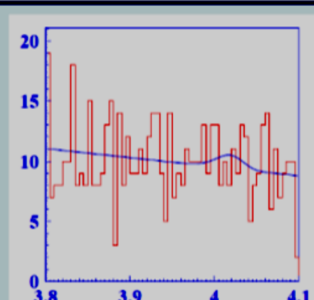
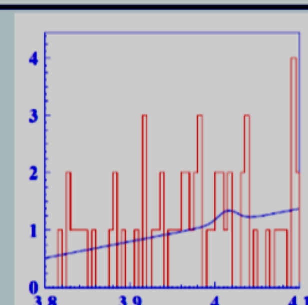
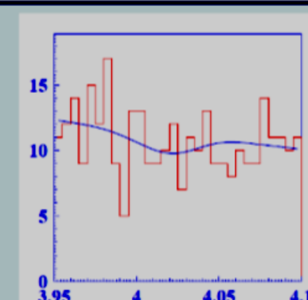
candidate	combination	quantum number J^{PC}	decay mode
$X_1(3872)$	$D^0\bar{D}^{*0} - \bar{D}^0D^{*0}$	1^{+-}	$X \to \eta_c\omega$, $X \to \eta_c\rho$
X(3730)	$D^0\bar{D}^0 + \bar{D}^0D^0$	0^{++}	$X \to \eta_c\eta$, $X \to \eta_c\pi^0$
X(4014)	$D^{*0}\bar{D}^{*0} + \bar{D}^{*0}D^{*0}$	0^{++}	$X \to \eta_c\eta$, $X \to \eta_c\pi^0$

$X_1(3872)$: C-odd partner candidate of X(3872)

- **Analysis features**
  - X is produced in charged B decays: $B^\pm \to K^\pm X$ ($\eta_c \to K_sK\pi$, $K_s \to \pi^+\pi^-$)
  - combined fit of 2 decay modes of η ($\gamma\gamma$ and $\pi^+\pi^-\pi^0$)
  - test mode $B^\pm \to K^\pm\psi(2S)$, $\psi(2S) \to J/\psi\,\pi^+\pi^-$ gives results consistent with PDG
  - $B^\pm$ decays into the same final states, but without intermediate X are studied.

X-like states decaying to η_c modes

	$X \to \eta_c \pi^+ \pi^-$	$X \to \eta_c \omega$
$X_1(3872)$		

	$X \to \eta_c \eta$		$X \to \eta_c \pi^0$
	$\eta \to \gamma\gamma$	$\eta \to \pi^+\pi^-\pi^0$	
X(3730)			
X(4014)			

M(X) GeV/c^2 - Y: N events

arXiv:1501.06351, JHEP06(2015)13

X-like states decaying to η_c modes

- No signal was observed in any of the studied decay channels.

- Upper limits on the branching products for

$B^{\pm} \to K^{\pm}X,\ X \to \eta_c h$ for $h = \pi^+\pi^-, \omega, \eta, \pi^0$

	Decay mode $B^{\pm} \to K^{\pm}X$		Yield	U (90% C.L.)
$X_1(3872)$	$X \to \eta_c\pi^+\pi^-$		17.9 ± 16.5	3.0×10^{-5}
	$X \to \eta_c\omega$		6.0 ± 12.5	6.9×10^{-5}
$X(3730)$	$X \to \eta_c\eta$	$\eta \to \gamma\gamma$	13.8 ± 9.9	4.6×10^{-5}
		$\eta \to \pi^+\pi^-\pi^0$	1.4 ± 1.0	
	$X \to \eta_c\pi^0$		-25.6 ± 10.4	5.7×10^{-5}
$X(4014)$	$X \to \eta_c\eta,\ \eta \to \gamma\gamma$		8.9 ± 11.0	3.9×10^{-5}
	$X \to \eta_c\eta,\ \eta \to \pi^+\pi^-\pi^0$		1.3 ± 1.6	
	$X \to \eta_c\pi^0$		-8.1 ± 13.2	1.2×10^{-5}

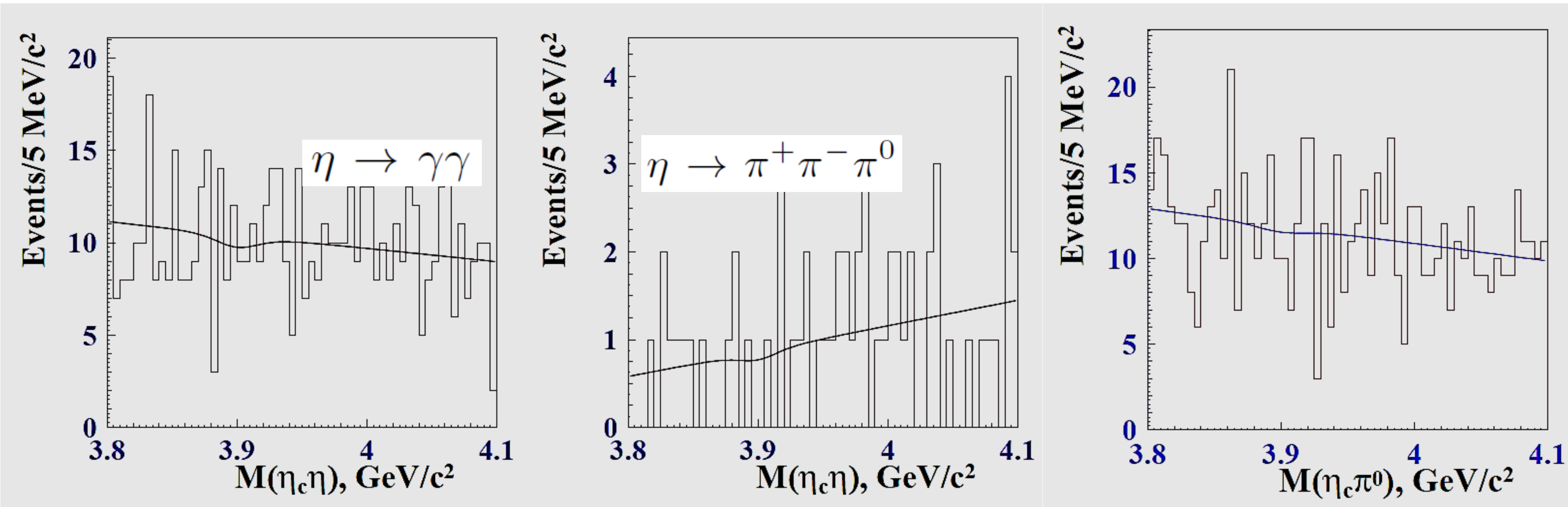
- Upper limits on the branching products for

$B^{\pm} \to K^{\pm}\eta_c h$ for $h = \pi^+\pi^-, \omega, \eta, \pi^0$

Decay mode $B^{\pm} \to K^{\pm}X$		Yield	U (90% C.L.)
$B^{\pm} \to K^{\pm}\eta_c\pi^+\pi^-$		155 ± 72	3.9×10^{-4}
$B^{\pm} \to K^{\pm}\eta_c\omega$		-41 ± 27	5.3×10^{-4}
$B^{\pm} \to K^{\pm}\eta_c\eta$	$\eta \to \gamma\gamma$	-14.1 ± 26.1	2.2×10^{-5}
	$\eta \to \pi^+\pi^-\pi^0$	-1.8 ± 3.4	
$B^{\pm} \to K^{\pm}\eta_c\pi^0$		-1.9 ± 12.1	6.2×10^{-5}

arXiv:1501.06351, JHEP06(2015)13

$Z(3900)^0$ / $Z(4020)^0$ / $X(3915)$ → η_c modes



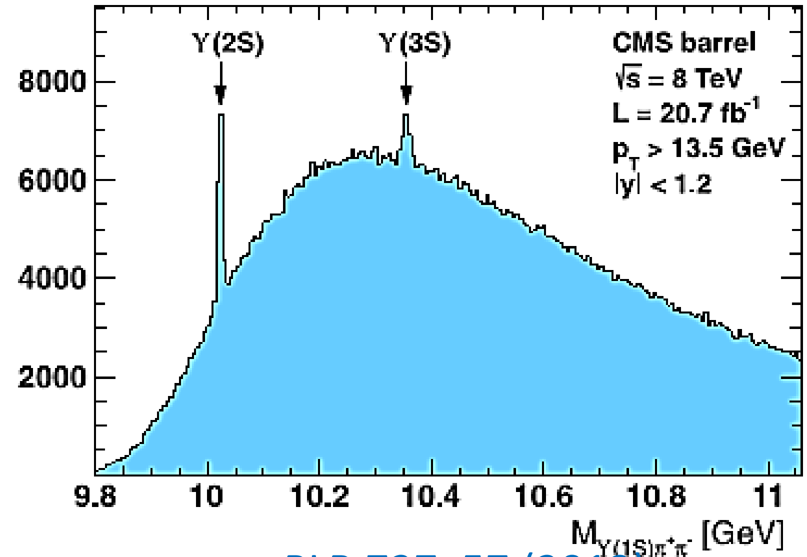
Resonance	Decay mode	U (90% C.L.)
$Z(3900)^0$	$\eta_c\pi^+\pi^-$	4.7×10^{-5}
$Z(4020)^0$		1.6×10^{-5}
$X(3915)$	$\eta_c\eta$	3.3×10^{-5}
	$\eta_c\pi^0$	1.8×10^{-5}

arXiv:1501.06351
JHEP06(2015)13

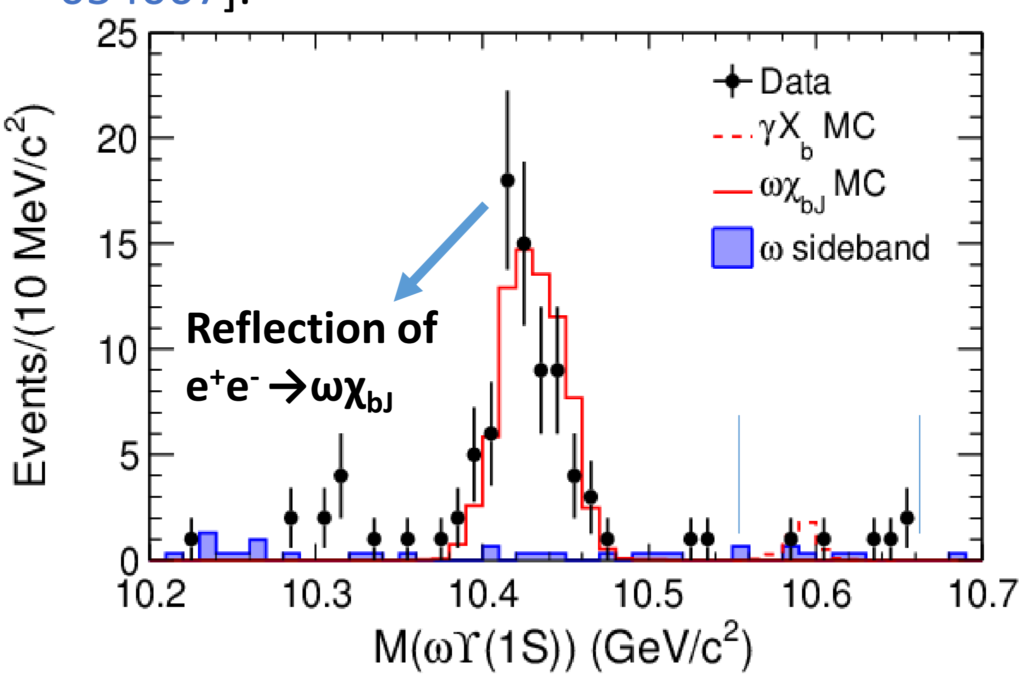
$e^+e^- \to \gamma X_b \to \gamma\omega\Upsilon(1S)$

PRL 113, 142001 (2014)

- **The X(3872) counterpart in the bottomonium sector X_b, NOT observed decay channel $\pi^+\pi^-\Upsilon(1S)$.**
- **As X_b is above $\omega\Upsilon(1S)$ threshold, this Isospin-conserving process should be more promising.** [PRD88, 054007].



PLB 727, 57 (2013) .



Assuming X_b narrow, the product branching fraction : **$Br(\Upsilon(5S) \to \gamma X_b) Br(X_b \to \omega\Upsilon(1S))$** varies from **$2.6 \times 10^{-5}$ to 3.8×10^{-5} between 10.55 and 10.65 GeV/c^2**.

$e^+e^- \to \pi^+\pi^-\pi^0\,\chi_{bJ}$ at 10.867 GeV

Motivations:

Heavy quarkonia hadronic transition :

QCD multipole expansion (QCDME) model. [Y. P Kuang, Front Phys. China 1, 19 (2006)]

For $\Upsilon(5S)$ resonance peak:

- The anomalously large width : $e^+e^- \to \pi^+\pi^-\Upsilon(ns)$ [Belle PRL 100, 112001] and $e^+e^- \to \pi^+\pi^- h_b(ns)$ [PRL 108, 032001] .
- $Z_b(10610)^{\pm}$ and $Z_b(10650)^{\pm}$ [PRL 108, 122001].

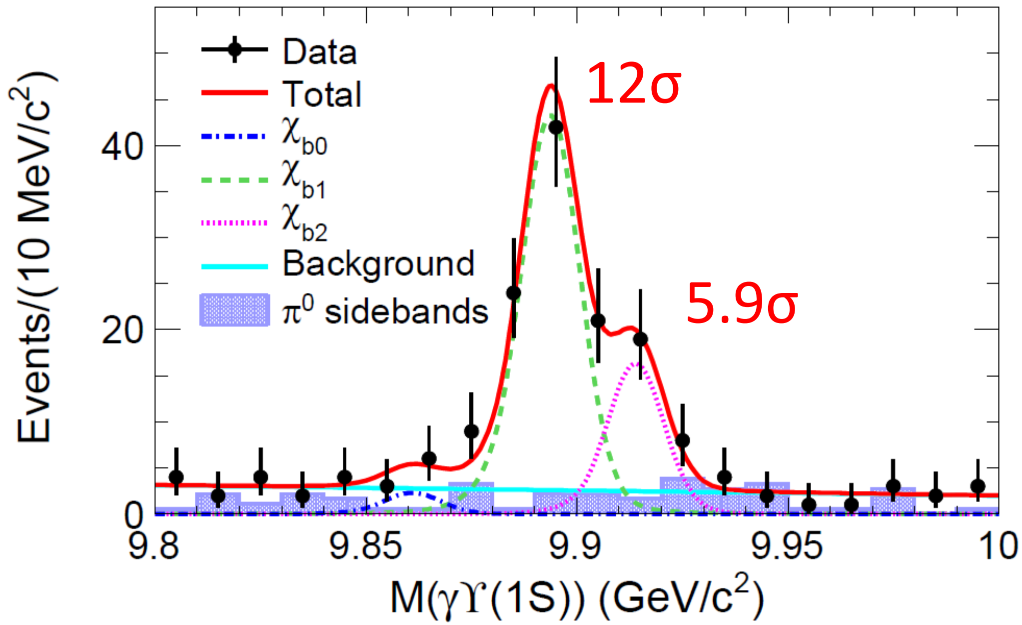
- Search for **hadronic transition** : **$\Upsilon(5S) \to \pi^+\pi^-\pi^0\,\chi_{bJ}$**

$e^+e^- \rightarrow \pi^+\pi^-\pi^0 \chi_{bJ}$

PRL 113, 142001 (2014)

118 fb^{-1} Υ(5S) data sample

$\chi_{bJ} \rightarrow \gamma\Upsilon(1S)$



- **The same order as $e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)$.** [PRL 100, 112001].
- **Hadronic loop effect?** [arXiv:1406.6763]

Assuming all events decay from ϒ(5S).

Born cross section:

$\sigma(e^+e^- \rightarrow \pi^0\pi^+\pi^- \chi_{b0})$ < 3.4 (pb) at 90% C.L.

$\sigma(e^+e^- \rightarrow \pi^0\pi^+\pi^-\chi_{b1}) = 0.98 \pm 0.12 \pm 0.12$ (pb)

$\sigma(e^+e^- \rightarrow \pi^0\pi^+\pi^- \chi_{b2}) = 0.62 \pm 0.14 \pm 0.08$ (pb)

Product BF :

BF(Υ(5S) $\rightarrow \pi^0\pi^+\pi^- \chi_{b0}$) < 6.9×10^{-3} at 90% C.L.

BF(Υ(5S) $\rightarrow \pi^0\pi^+\pi^-\chi_{b1}$) = $(2.02 \pm 0.25 \pm 0.25) \times 10^{-3}$

BF(Υ(5S) $\rightarrow \pi^0\pi^+\pi^- \chi_{b2}$) = $(1.27 \pm 0.29 \pm 0.16) \times 10^{-3}$

$e^+e^- \to \pi^+\pi^-\pi^0 \chi_{bJ}$

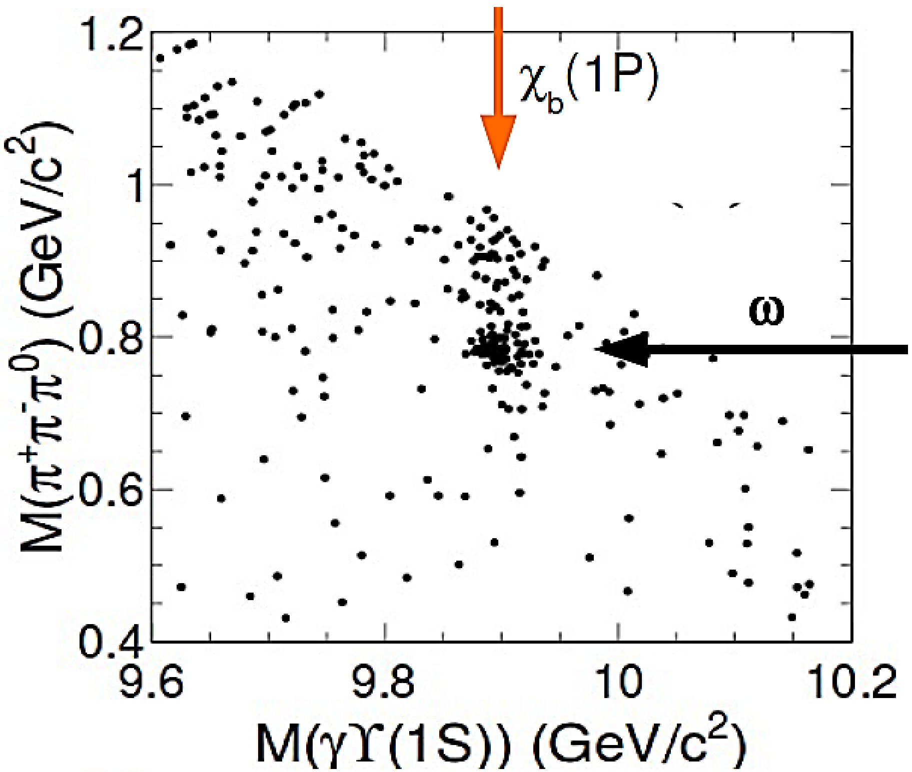
PRL 113, 142001 (2014)

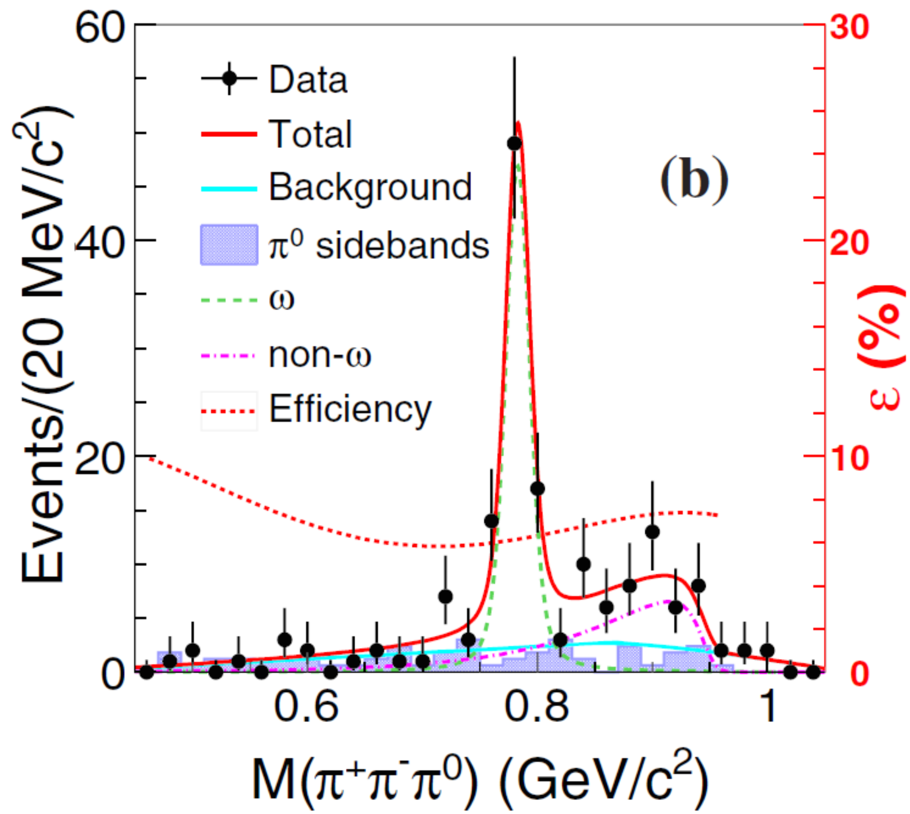
2D fit to scatter plot of

$M(\pi^+\pi^-\pi^0)$ vs $M(\gamma\Upsilon(1S))$.

$\pi^+\pi^-\pi^0$ invariant mass distribution:

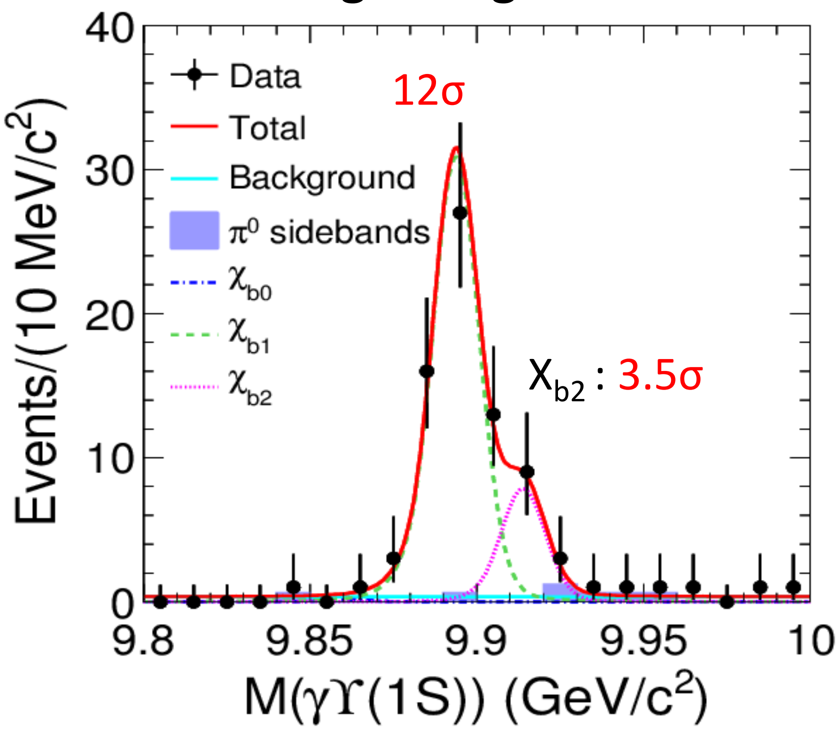
- **ω signal**
- **An enhancement in higher $M(\pi^+\pi^-\pi^0)$**

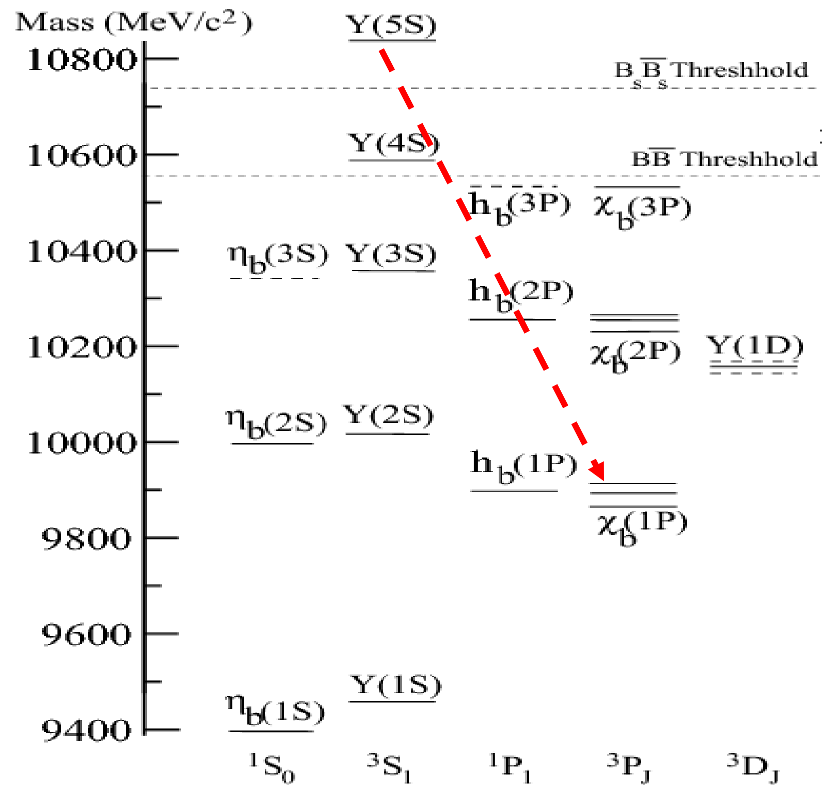




$e^+e^- \to \omega\chi_{bJ}$

ω signal region.





Born cross section:

$\sigma(e^+e^- \to \omega\chi_{b0}) < 1.9$ (pb) at 90% C.L.

$\sigma(e^+e^- \to \omega\chi_{b1}) = 0.76 \pm 0.11 \pm 0.11$ (pb)

$\sigma(e^+e^- \to \omega\chi_{b2}) = 0.29 \pm 0.11 \pm 0.08$ (pb)

The $\frac{Br(\Upsilon(5S) \to \omega\chi_{b2})}{Br(\Upsilon(5S) \to \omega\chi_{b1})}$ higher than **expectation from quark symmetry**. [PLB 346, 129 (1995)].

→ **a molecular component in** ϒ(5S) [arXiv: 1406.0082]

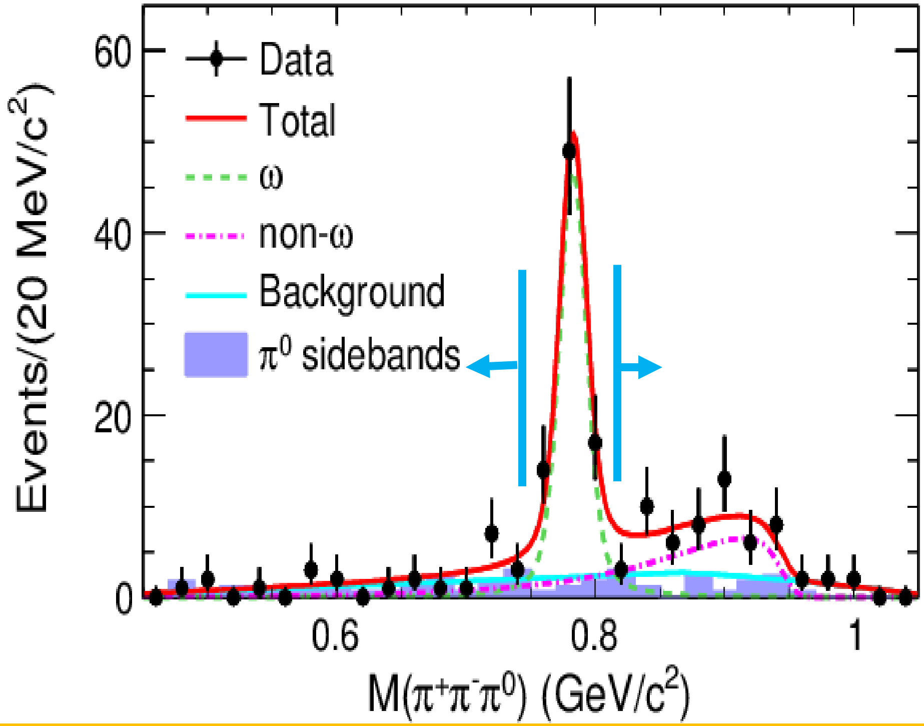
→ **S- and D- wave mixing** [arXiv:1406.6543]

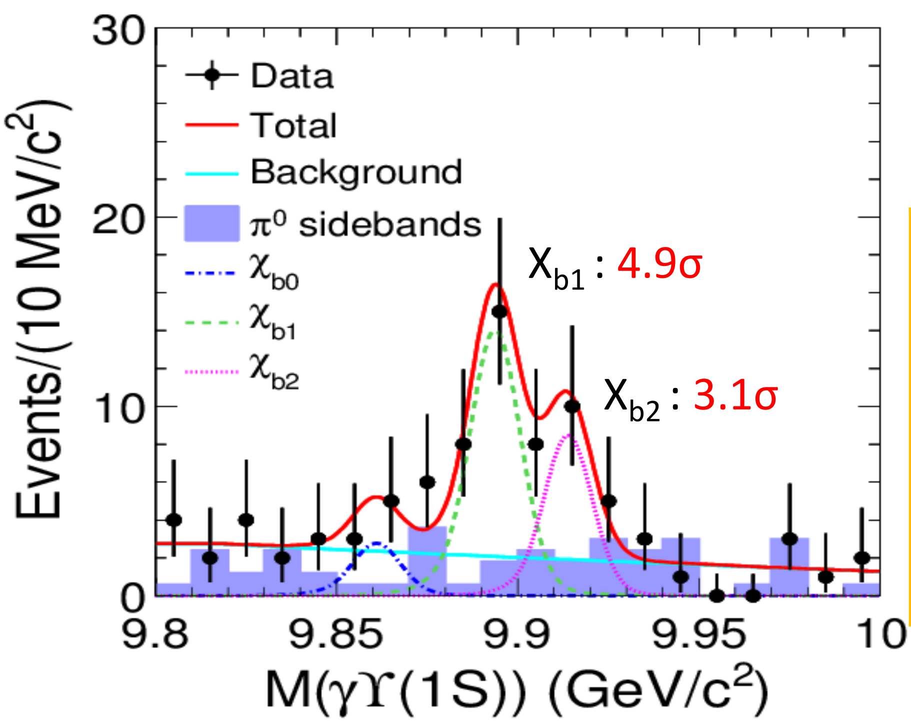
$e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{bJ}$

PRL 113, 142001 (2014)

- The χ_{bJ} candidates out of ω signal region.
- Possible cascade decay from

  $\Upsilon(5S) \to \pi Z_b \to \pi\rho\chi_{bJ}$ [arXiv:1406.0082]
- **The interpretation is currently limited.**





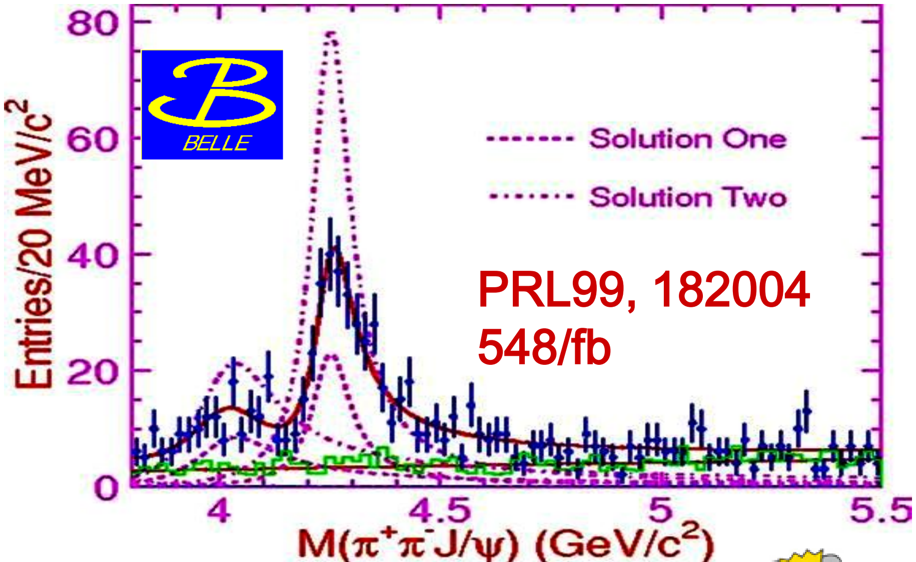
Born cross section:

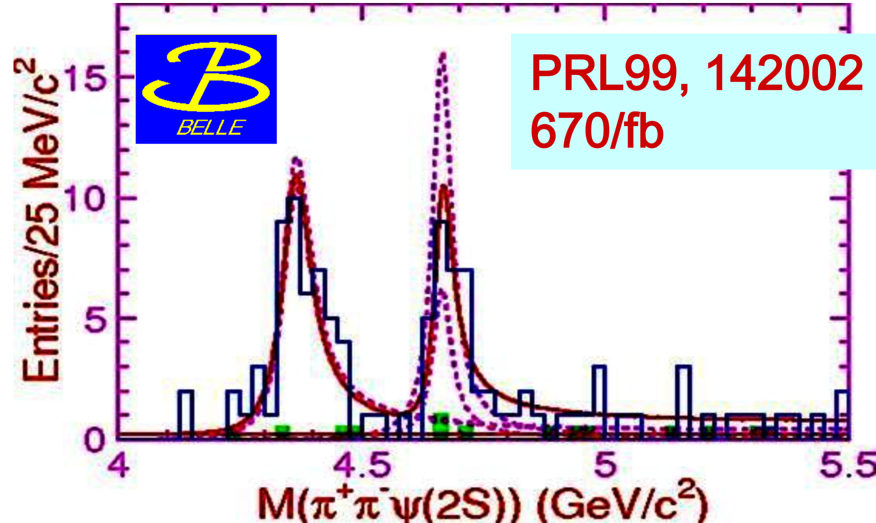
$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b0}) < 2.3$ (pb) at 90% C.L.

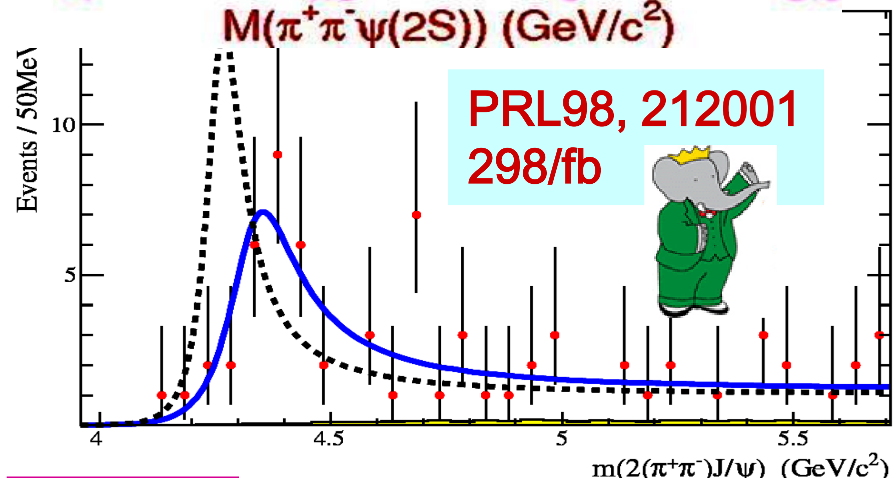
$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b1}) = 0.25 \pm 0.07 \pm 0.06$ (pb)

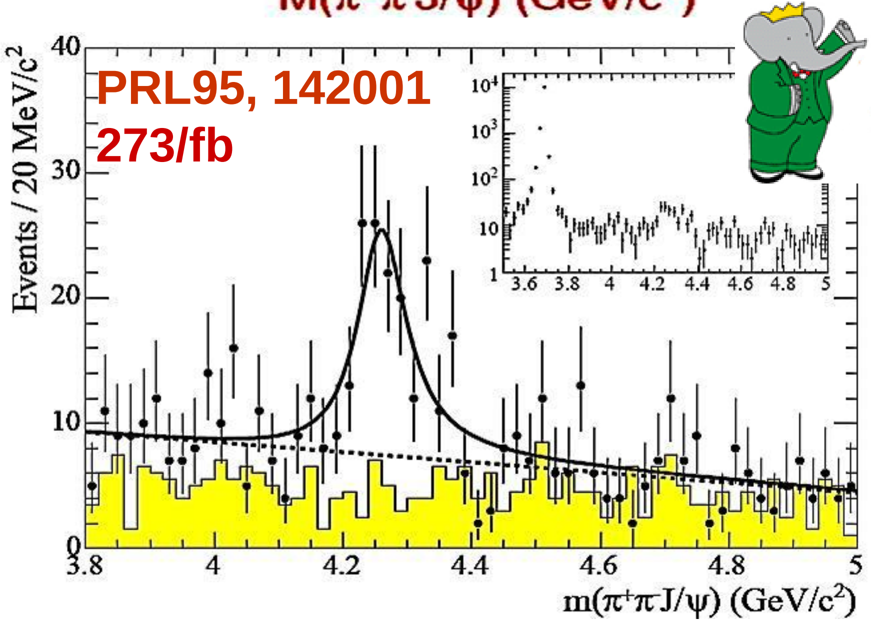
$\sigma(e^+e^- \to (\pi^+\pi^-\pi^0)_{non\text{-}\omega}\chi_{b2}) = 0.30 \pm 0.11 \pm 0.14$ (pb)

The Y states

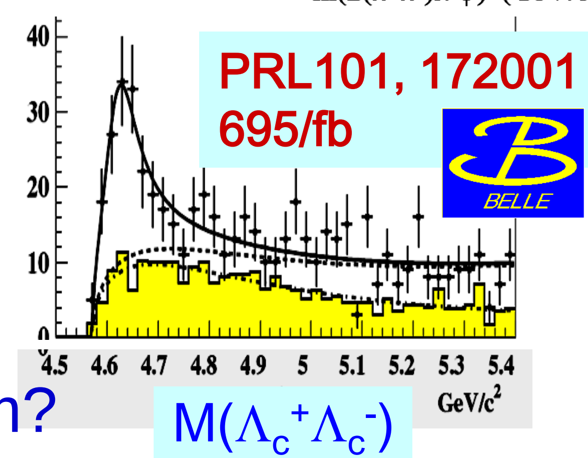








Y(4008)
Y(4260)
Y(4360)
Y(4660)
Y(4630)

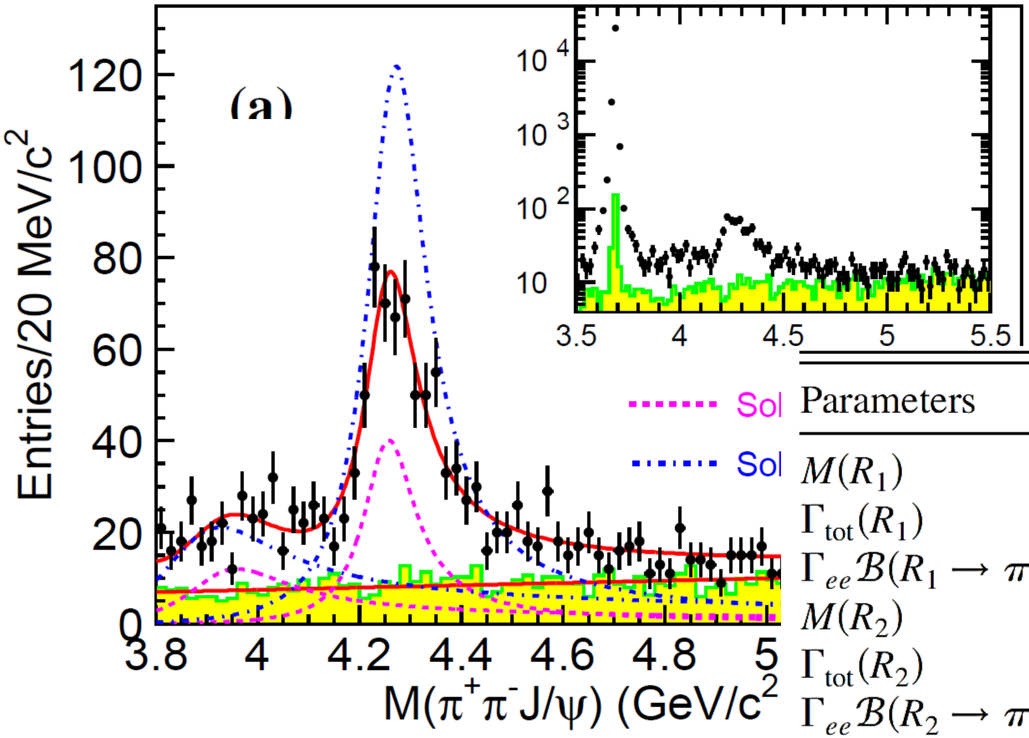


Above $\bar{D}D$ threshold, decay to open charm?

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

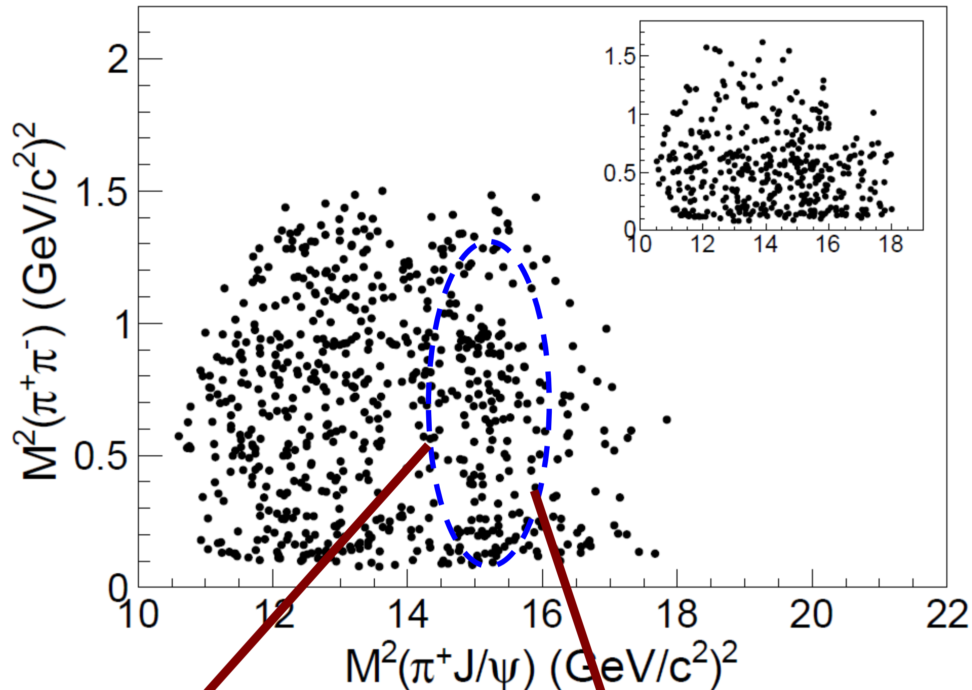
Parameters	Solution I	Solution II
$M(R_1)$	$3890.8 \pm 40.5 \pm 11.5$	
$\Gamma_{tot}(R_1)$	$254.5 \pm 39.5 \pm 13.6$	
$\Gamma_{ee}\mathcal{B}(R_1 \to \pi^+\pi^- J/\psi)$	$(3.8 \pm 0.6 \pm 0.4)$	$(8.4 \pm 1.2 \pm 1.1)$
$M(R_2)$	$4258.6 \pm 8.3 \pm 12.1$	
$\Gamma_{tot}(R_2)$	$134.1 \pm 16.4 \pm 5.5$	
$\Gamma_{ee}\mathcal{B}(R_2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

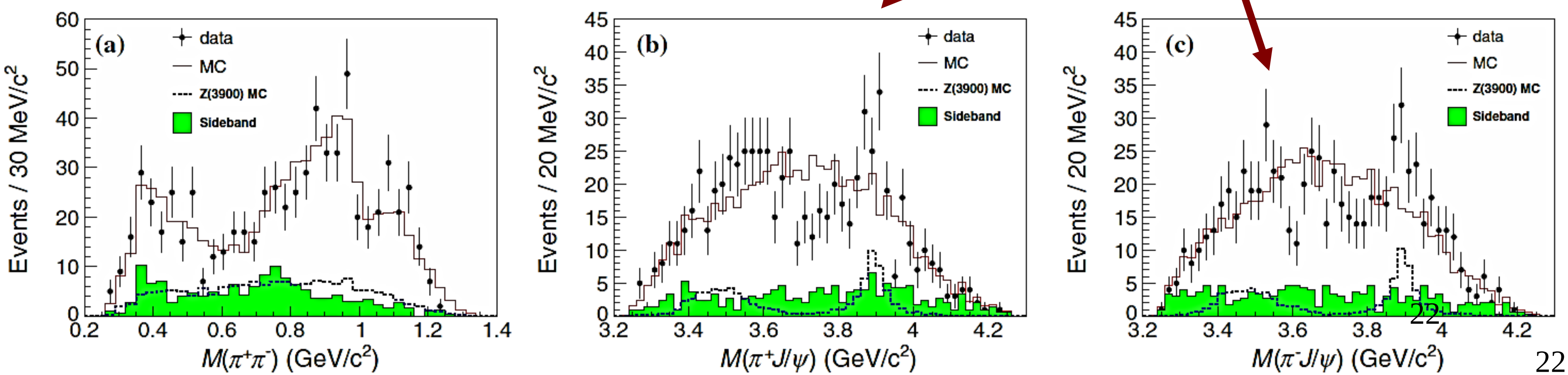
1. Fit with two coherent resonances $|BW_1+BW_2*\exp(i\phi)|^2$+bkg.
2. Mass of Y(4008) is lower than before
3. Fit quality: χ^2/ndf=101/84, confidence level is 9.3%

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

PRL110, 252002 (2013)

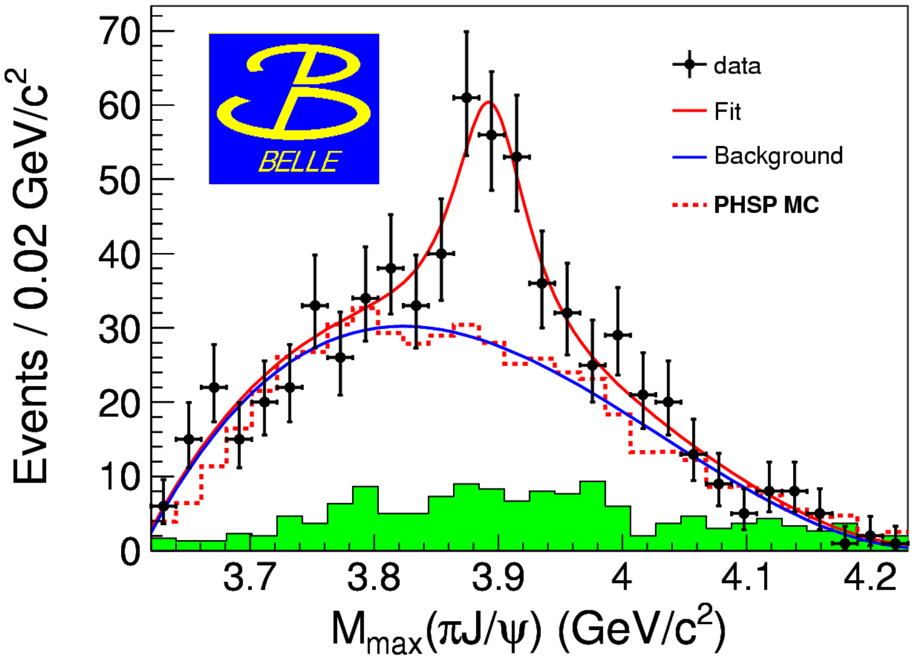
- $M^2(\pi\pi)$ vs. $M^2(\pi J/\psi)$ for $4.15 < M(\pi\pi J/\psi) < 4.45$ GeV
- (inset) Background events in J/ψ-mass sidebands
- Structures both in $\pi\pi$ and $\pi J/\psi$ systems
- 689 events in J/ψ signal region, purity~80%





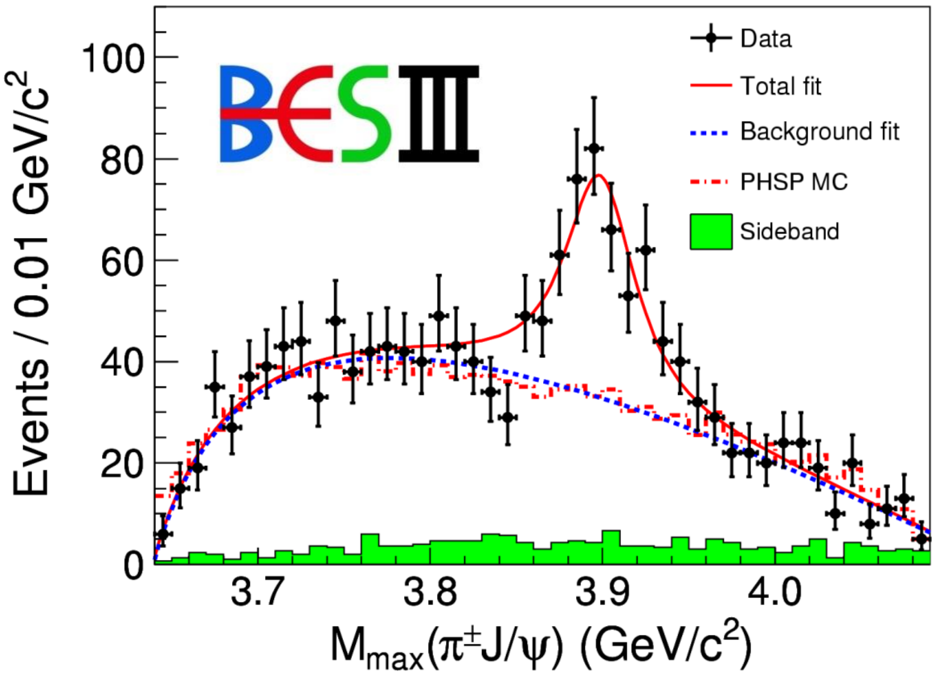
Z(3895)$^+$ observed in two experiments!

Belle with ISR: PRL110,252002



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

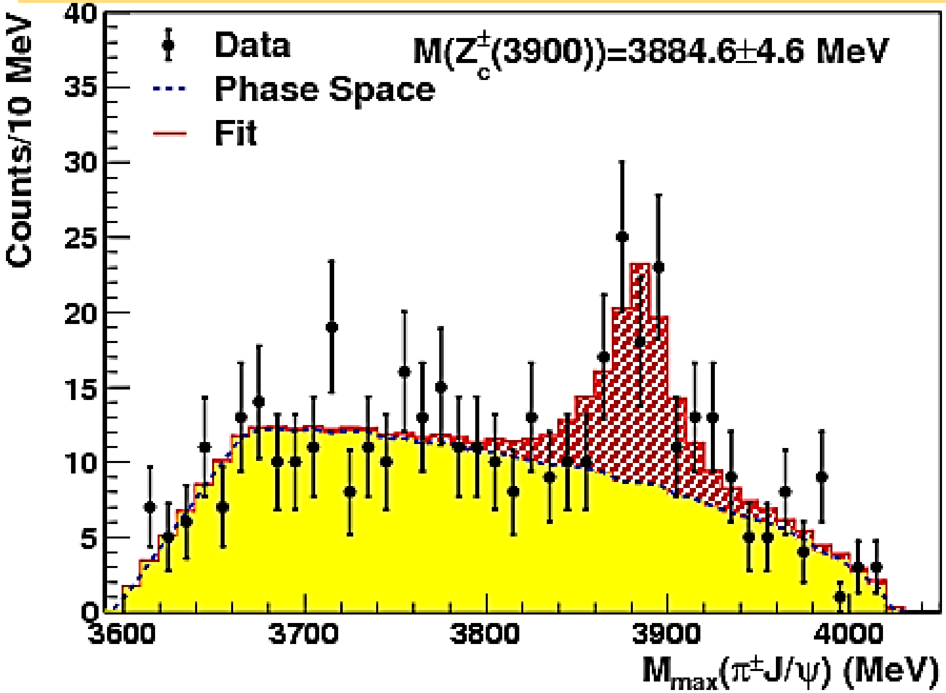
BESIII at 4.260 GeV: PRL110,252001

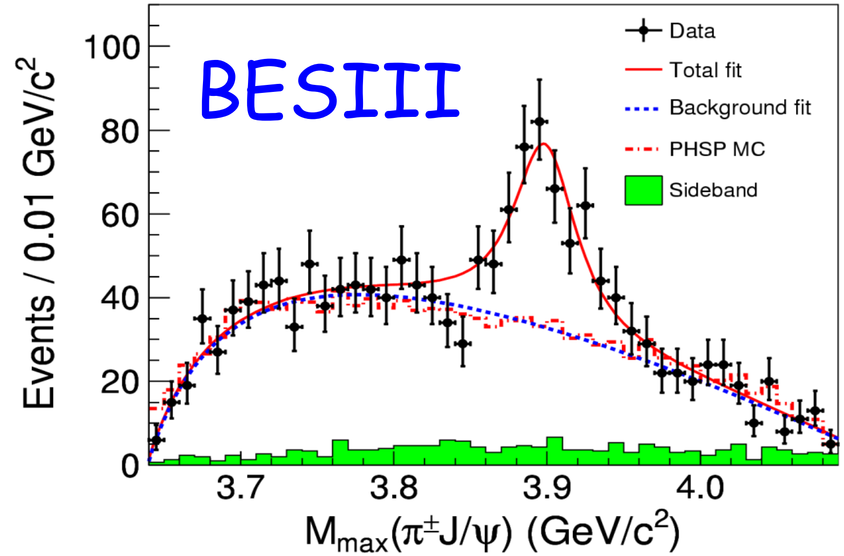


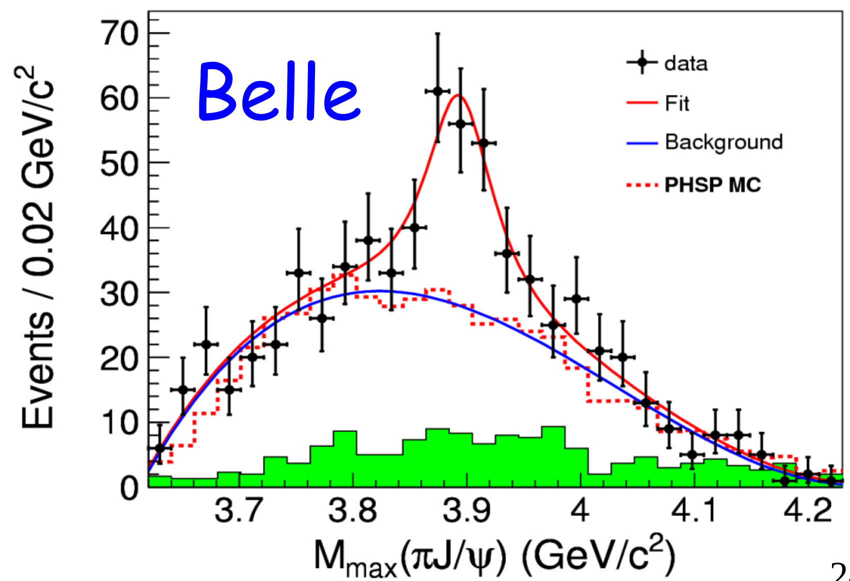
- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events
- >8σ

Confirmed with CLEOc data!

CLEOc data at 4.17 GeV:
arXiv:1304.3036, PLB727, 366 (2013)







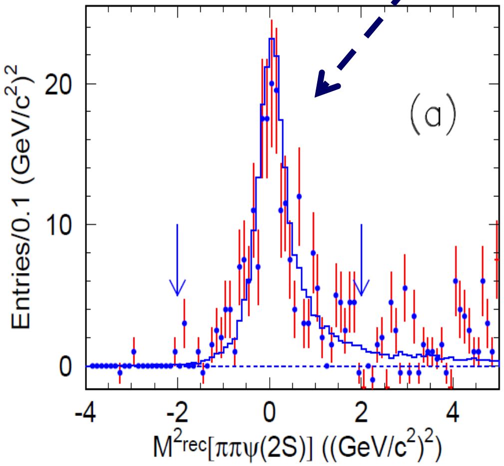
- $M = 3885 \pm 5 \pm 1$ MeV
- $\Gamma = 34 \pm 12 \pm 4$ MeV
- 81 ± 20 events 6.1σ

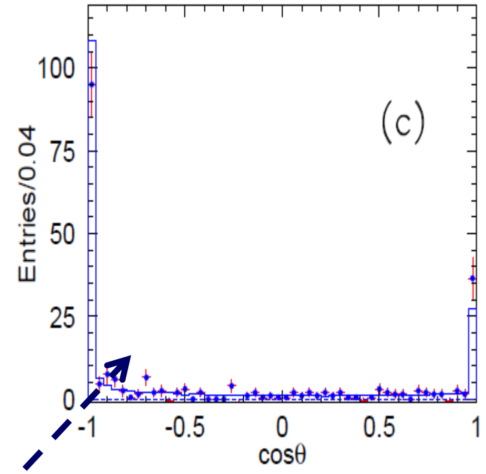
$e^+e^- \to \pi^+\pi^-\psi(2S)$ via ISR

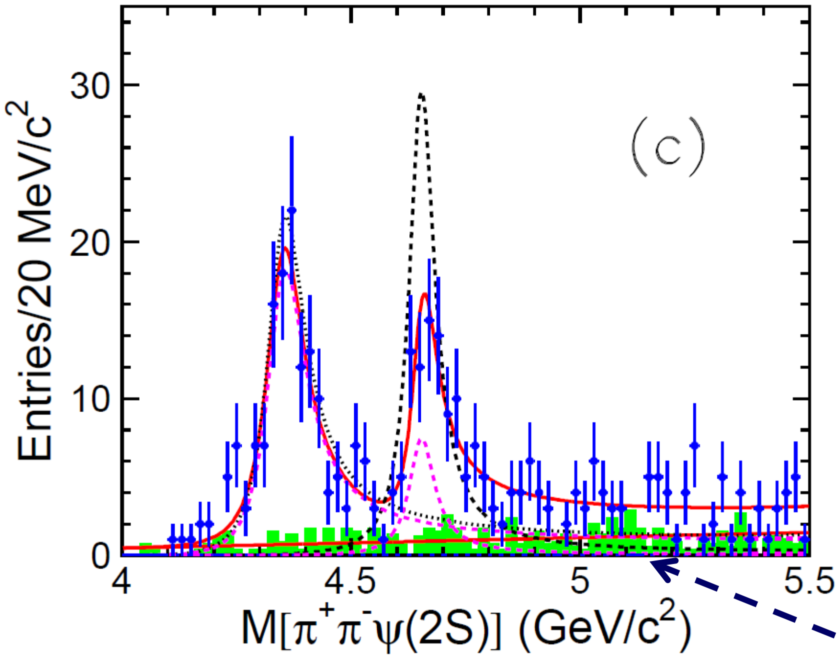
980 fb^{-1}

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

- **Clear signal of missed massless particle ($M_{rec}^2(\psi'\pi\pi)\sim 0$)**







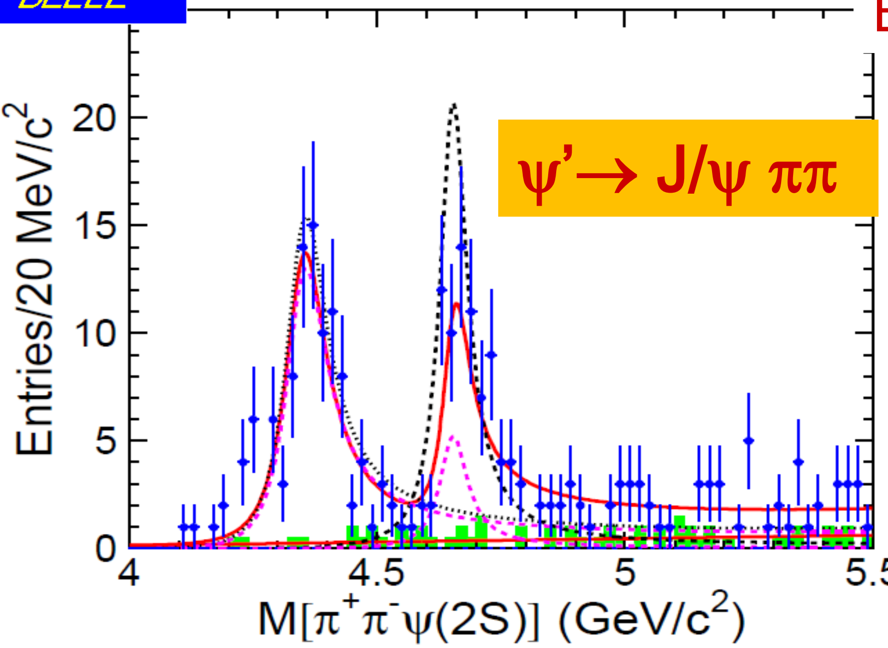
- **Polar angle distribution agrees well with ISR expectation**
- **Combinatorial background estimated by ψ' sidebands**
- **Bkgs from real $(\psi'\pi\pi)_{non\ ISR}$ or $\psi'\ X_{non\ \pi\pi}$ are negligibly small**

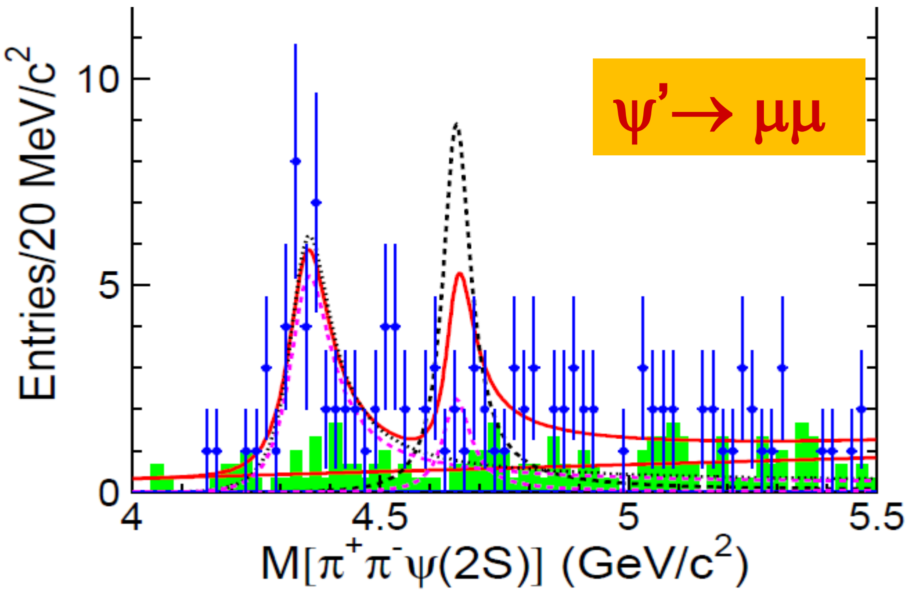
Two significant clusters:
Y(4360)+Y(4660);
a few events at Y(4260)

Belle: arXiv:1410.7641, PRD91_112007

Fit with Two BWs

Belle: arXiv:1410.7641, PRD91_112007



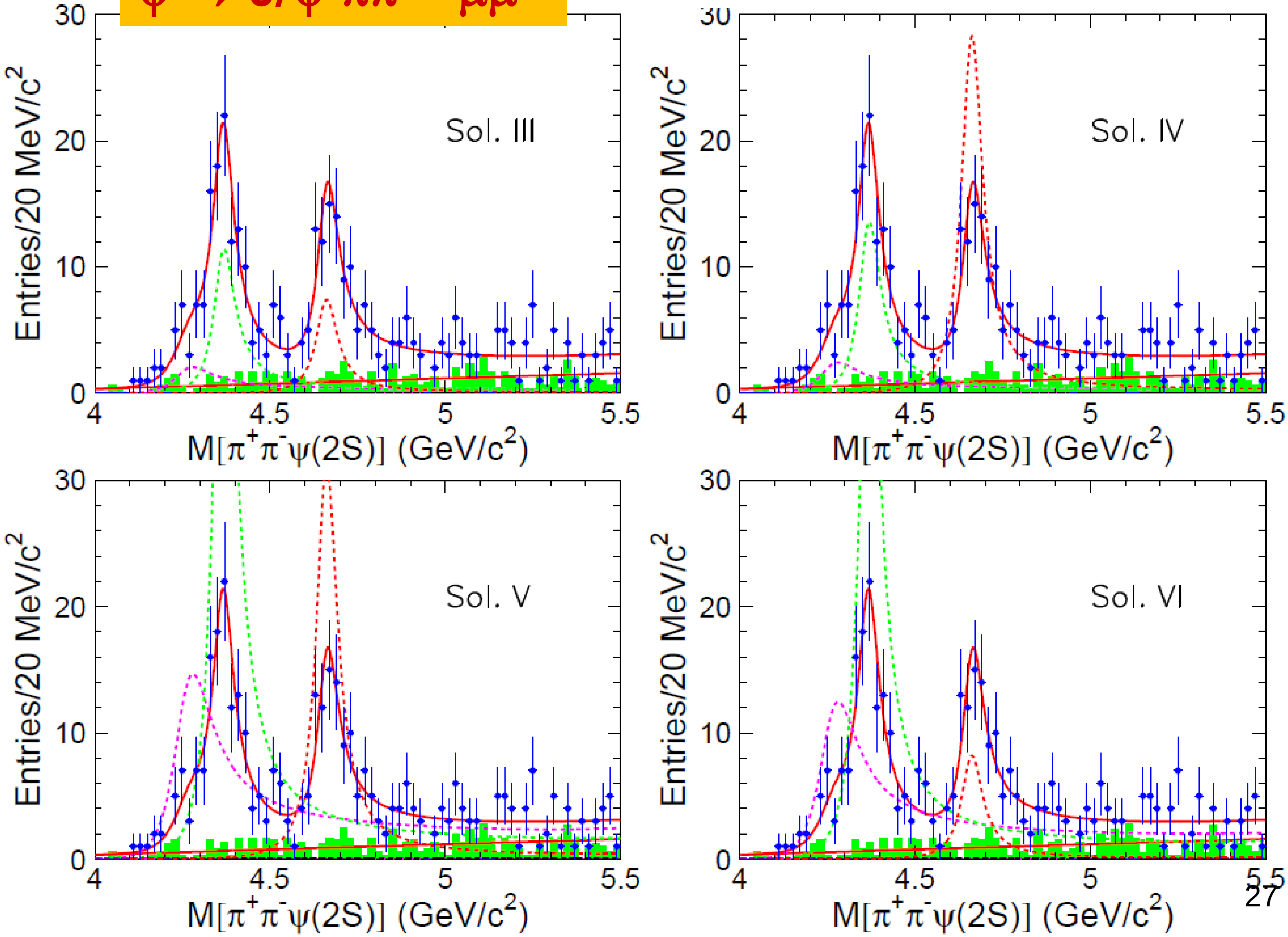


Parameters	Solution I	Solution II
$M_{Y(4360)}$	$4347 \pm 6 \pm 3$	
$\Gamma_{Y(4360)}$	$103 \pm 9 \pm 5$	
$\mathcal{B}[Y(4360) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4360)}$	$9.2 \pm 0.6 \pm 0.6$	$10.9 \pm 0.6 \pm 0.7$
$M_{Y(4660)}$	$4652 \pm 10 \pm 11$	
$\Gamma_{Y(4660)}$	$68 \pm 11 \pm 5$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

Fit with Three BWs

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

Belle: arXiv:1410.7641, PRD91_112007



Fit with Three BWs

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

Belle: arXiv:1410.7641, PRD91_112007

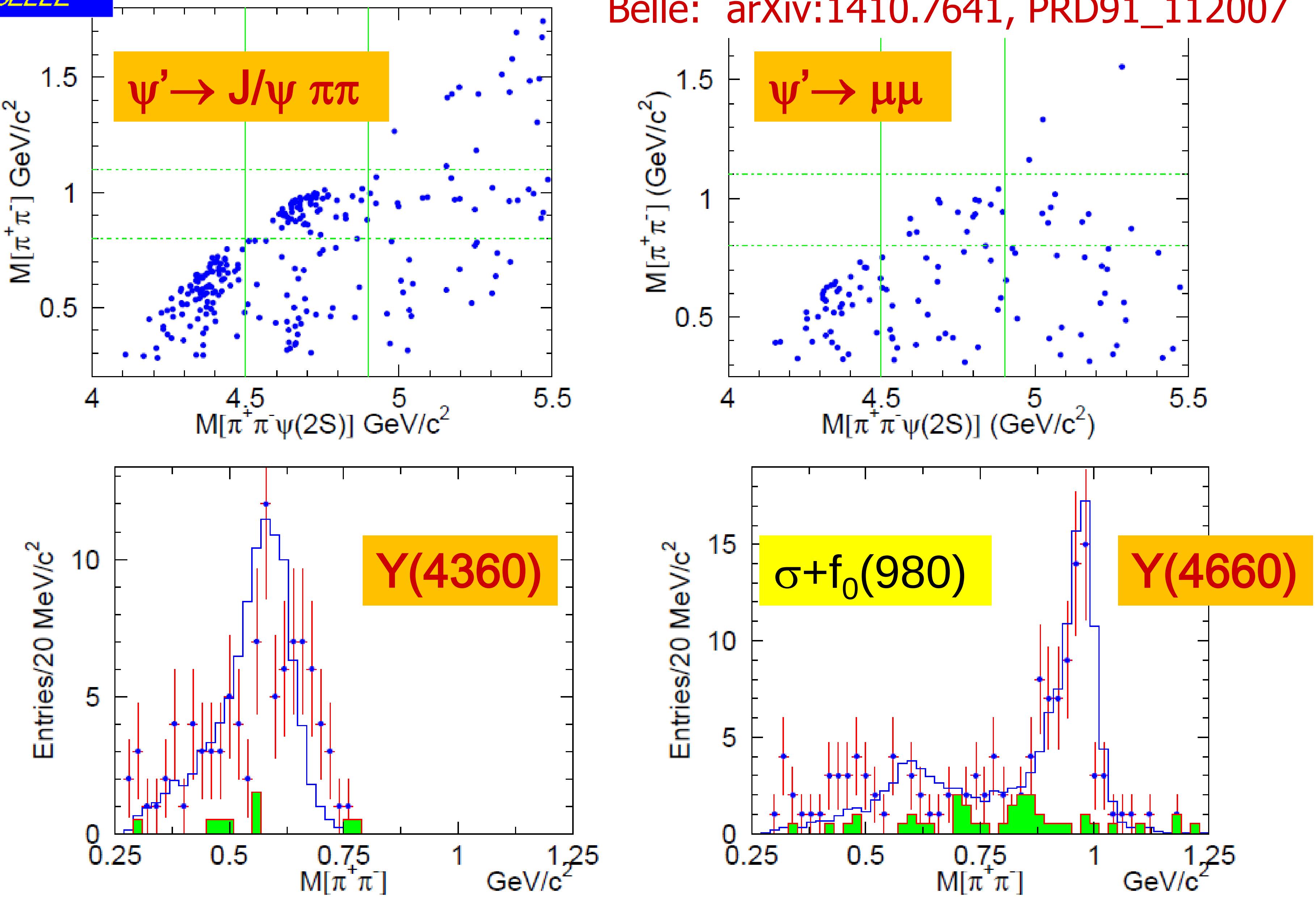
Parameters	Solution III	Solution IV	Solution V	Solution VI
$M_{Y(4260)}$	4259 (fixed)			
$\Gamma_{Y(4260)}$	134 (fixed)			
$\mathcal{B}[Y(4260) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4260)}$	$1.5 \pm 0.6 \pm 0.4$	$1.7 \pm 0.7 \pm 0.5$	$10.4 \pm 1.3 \pm 0.8$	$8.9 \pm 1.2 \pm 0.8$
$M_{Y(4360)}$	$4365 \pm 7 \pm 4$			
$\Gamma_{Y(4360)}$	$74 \pm 14 \pm 4$			
$\mathcal{B}[Y(4360) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4360)}$	$4.1 \pm 1.0 \pm 0.6$	$4.9 \pm 1.3 \pm 0.6$	$21.1 \pm 3.5 \pm 1.4$	$17.7 \pm 2.6 \pm 1.5$
$M_{Y(4660)}$	$4660 \pm 9 \pm 12$			
$\Gamma_{Y(4660)}$	$74 \pm 12 \pm 4$			
$\mathcal{B}[Y(4660) \to \pi^+\pi^-\psi(2S)] \cdot \Gamma^{e^+e^-}_{Y(4660)}$	$2.2 \pm 0.4 \pm 0.2$	$8.4 \pm 0.9 \pm 0.9$	$9.3 \pm 1.2 \pm 1.0$	$2.4 \pm 0.5 \pm 0.3$
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

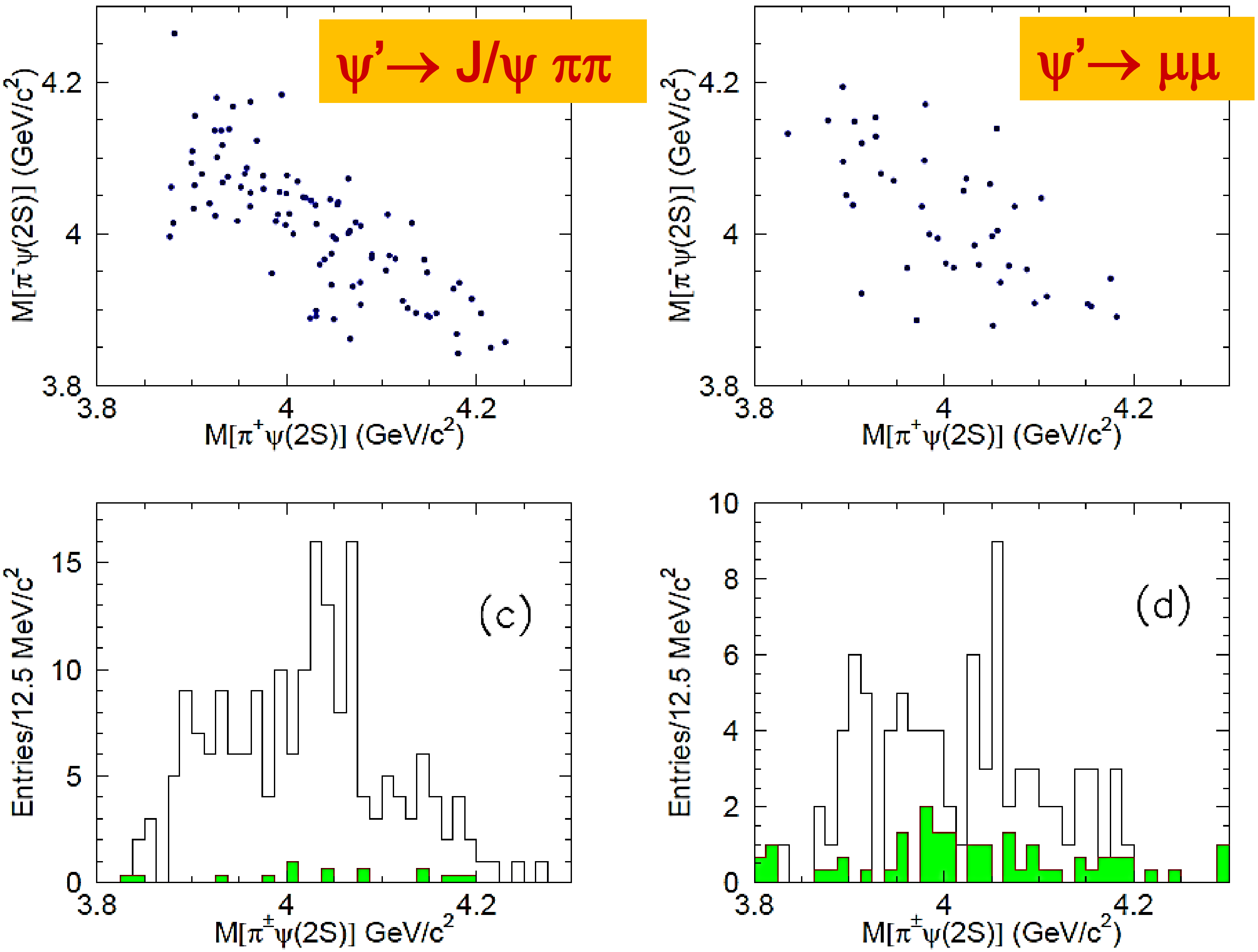
Affect the parameters of Y(4360) and Y(4660) significantly!

M(π⁺π⁻) distributions

Belle: arXiv:1410.7641, PRD91_112007

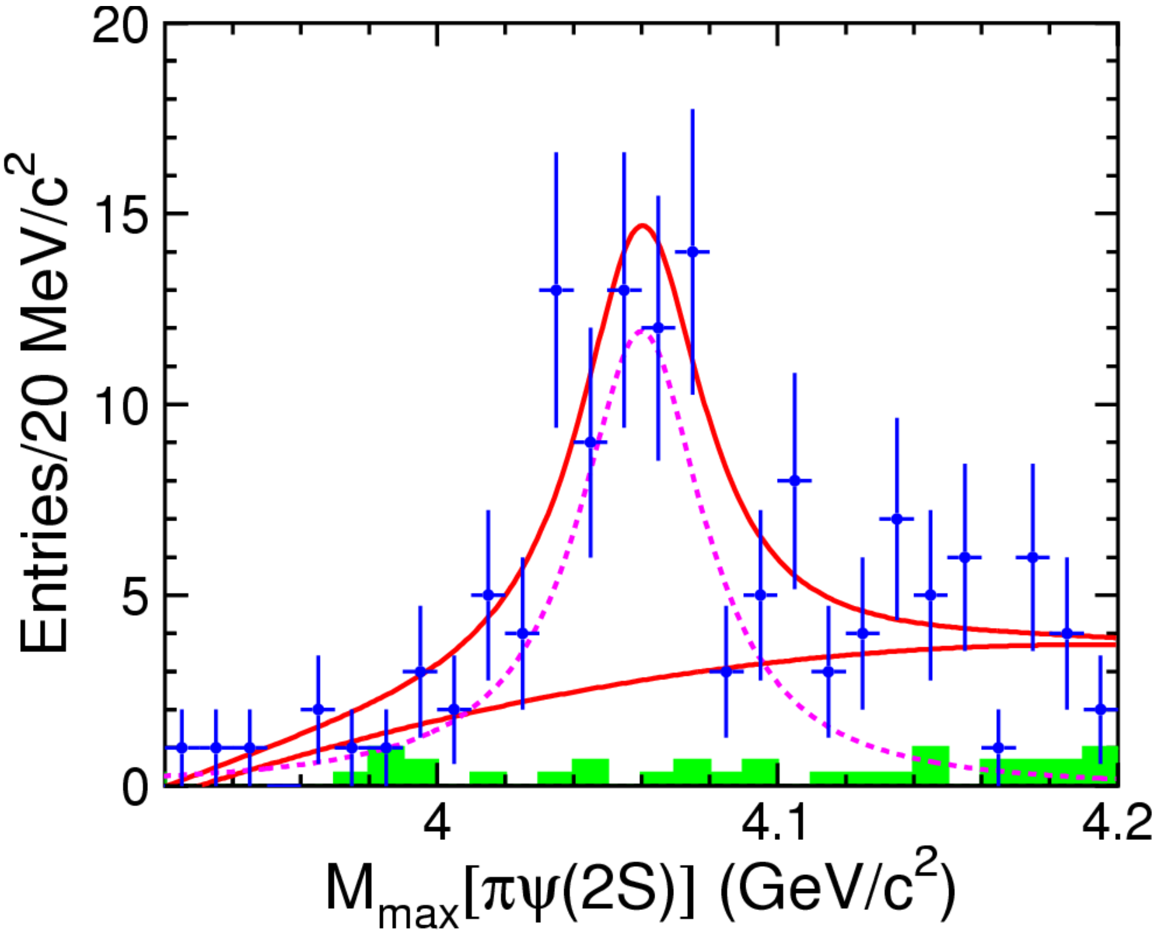


Zc states from Y(4360) decays?



Belle: arXiv:1410.7641, PRD91_112007

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

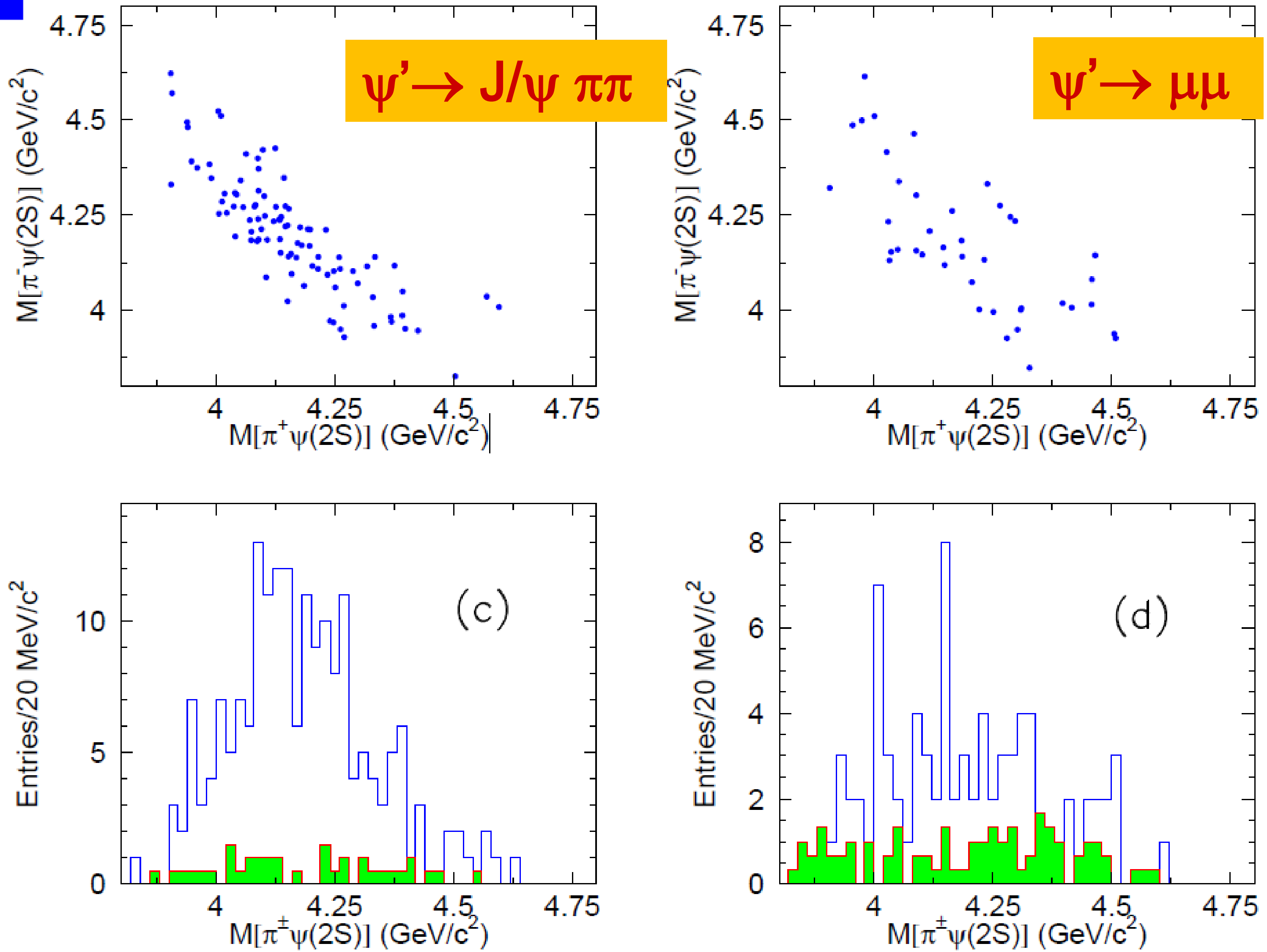


- $M(Z_c) = 4054 \pm 3 \pm 1$ MeV/c^2
- $\Gamma = 45 \pm 11 \pm 6$ MeV
- Significance: >**3.5σ**

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.

No significant Zc in Y(4660) decays!

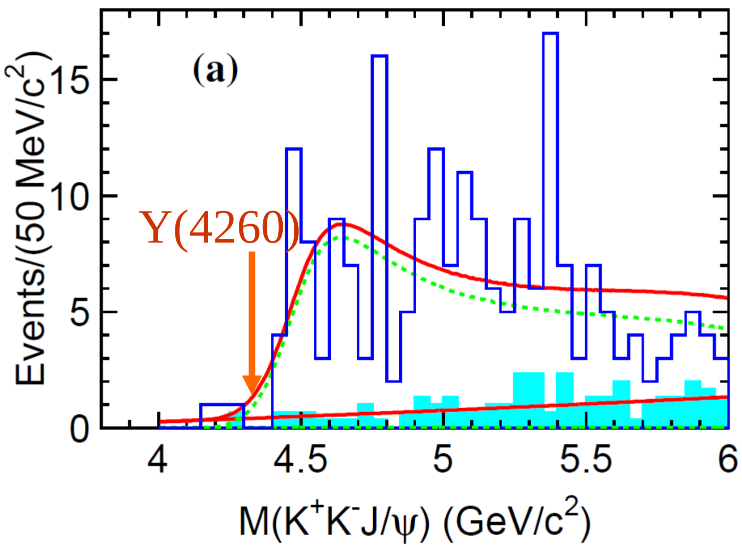


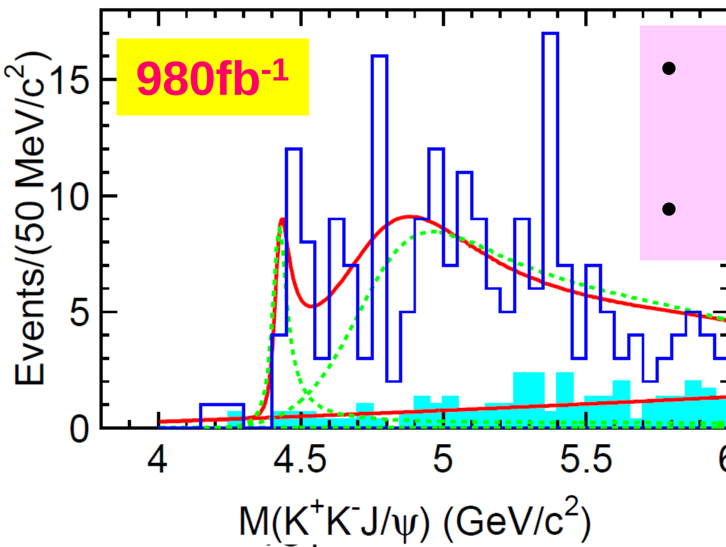
Belle: arXiv:1410.7641, PRD91_112007

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

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

Shaded hist.: J/ψ mass sidebands



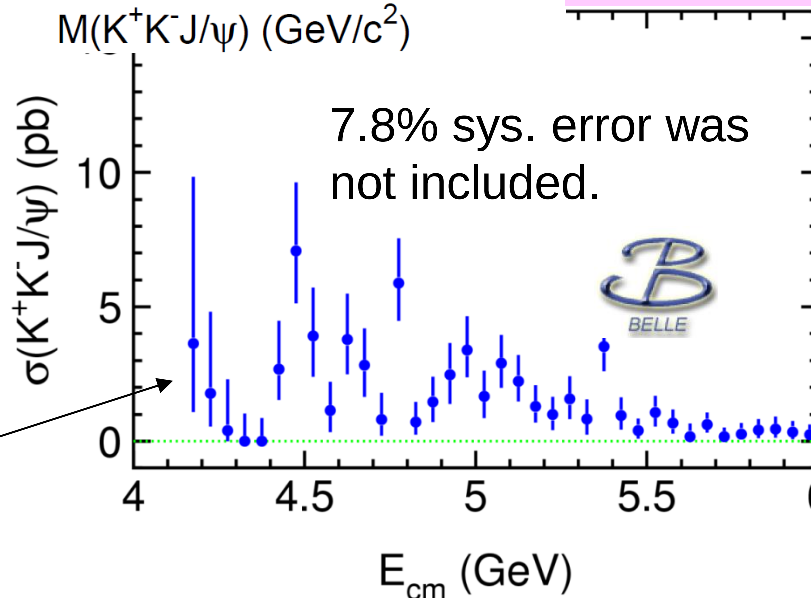


- +one resonance.
- Fit with $\psi(4415)$

$\chi^2/ndf=30/11$
- ➢ M=4747±117MeV
- ➢ Γ=671±86 MeV

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

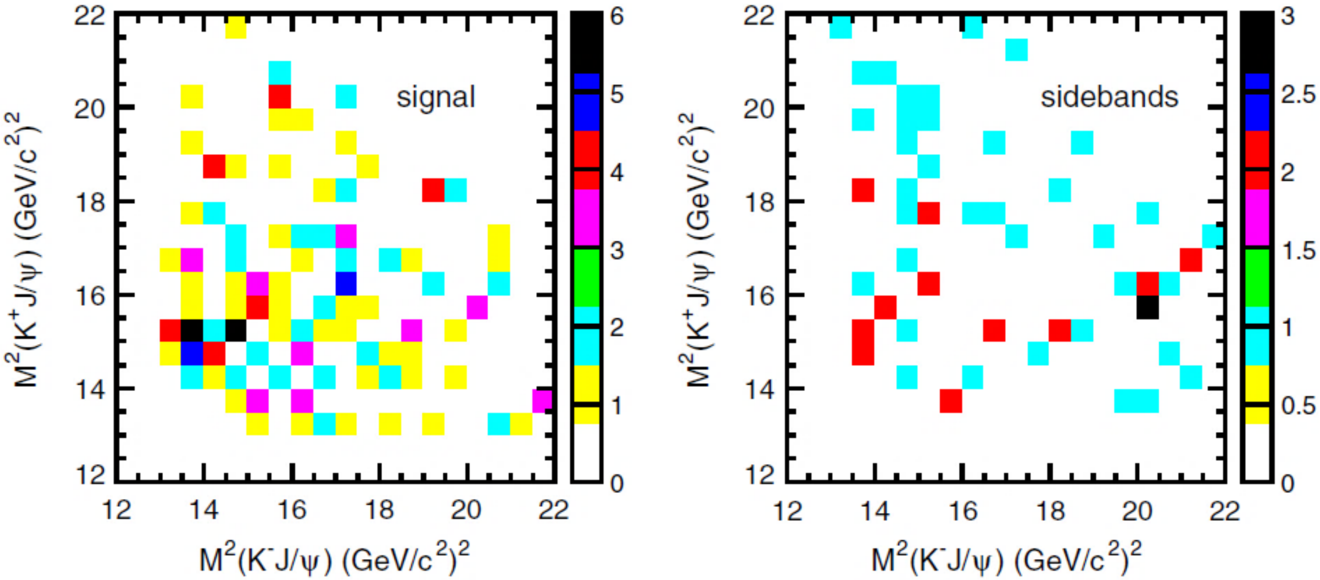
$$\sigma_i = \frac{n_i^{obs} - f \times n_i^{bkg}}{\mathcal{L}_i \cdot \epsilon_i \cdot \mathcal{B}(J/\psi \to \ell^+\ell^-)}$$



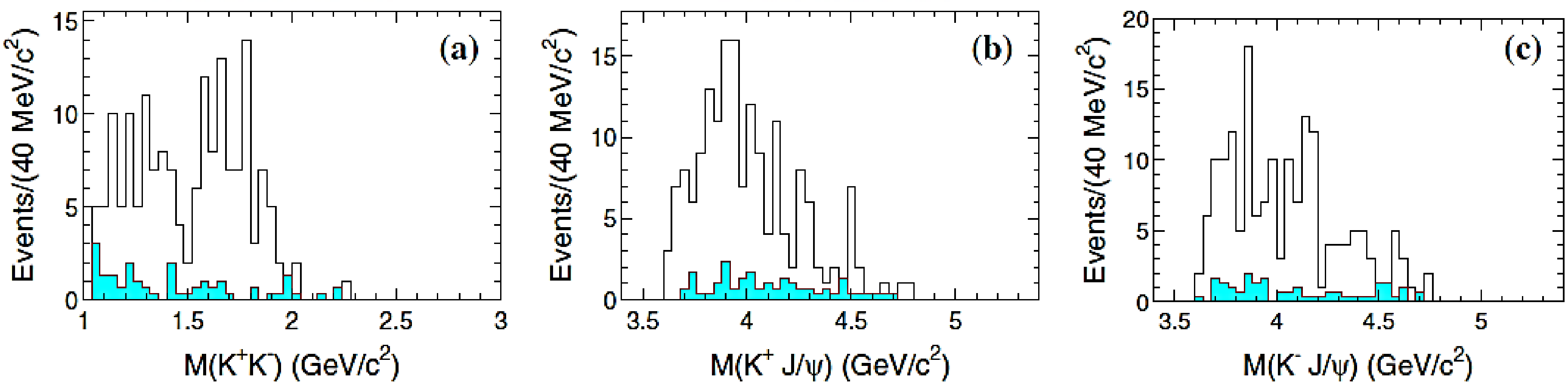
PRD 89,072015(2014)

Search for $Z_{cs} \to KJ/\psi$ states

PRD 89,072015(2014)

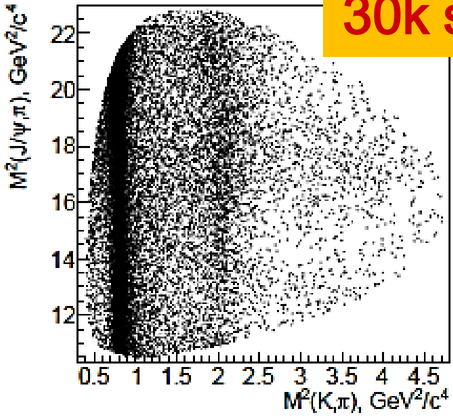


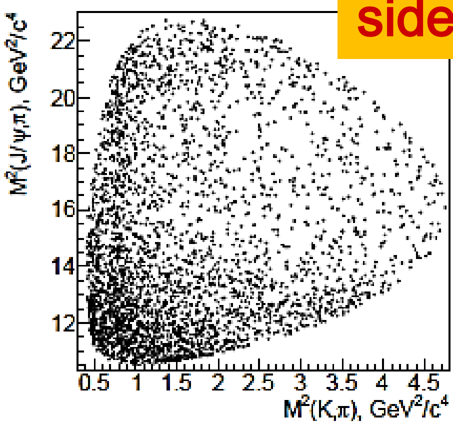
Large data samples at BelleII are needed to understand KJ/ψ and KKJ/ψ structures !

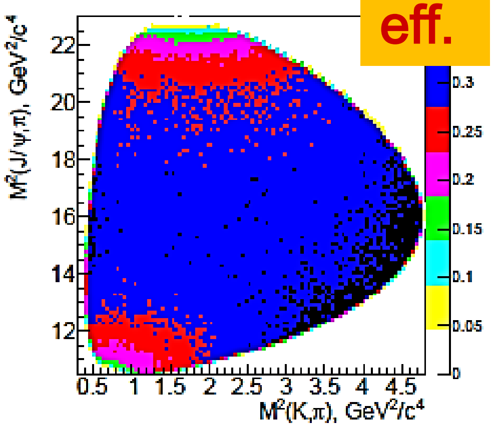


No evident structure in $K^{\pm}J/\psi$ mass distribution under current statistics

PWA of B→J/ψKπ







- 4D PWA $\Phi = (M^2_{K\pi}, M^2_{J/\psi\pi}, \theta_{J/\psi}, \varphi).$
- Resonances: all K*s and Zc(4430)
- Search for additional Zc states

Resonance	Fit fraction	Significance (Wilks)
$K_0^*(800)$	$(7.1^{+0.7}_{-0.5})\%$	22.5σ
$K^*(892)$	$(69.0^{+0.6}_{-0.5})\%$	166.4σ
$K^*(1410)$	$(0.3^{+0.2}_{-0.1})\%$	4.1σ
$K_0^*(1430)$	$(5.9^{+0.6}_{-0.4})\%$	22.0σ
$K_2^*(1430)$	$(6.3^{+0.3}_{-0.4})\%$	23.5σ
$K^*(1680)$	$(0.3^{+0.2}_{-0.1})\%$	2.7σ
$K_3^*(1780)$	$(0.2^{+0.1}_{-0.1})\%$	3.8σ
$K_0^*(1950)$	$(0.1^{+0.1}_{-0.1})\%$	1.2σ
$K_2^*(1980)$	$(0.4^{+0.1}_{-0.1})\%$	5.3σ
$K_4^*(2045)$	$(0.2^{+0.1}_{-0.1})\%$	3.8σ
$Z_c(4430)^+$	$(0.5^{+0.4}_{-0.1})\%$	5.1σ
$Z_c(4200)^+$	$(1.9^{+0.7}_{-0.5})\%$	8.2σ

Belle: PRD 90, 112009 (2014)

PWA of B→J/ψKπ

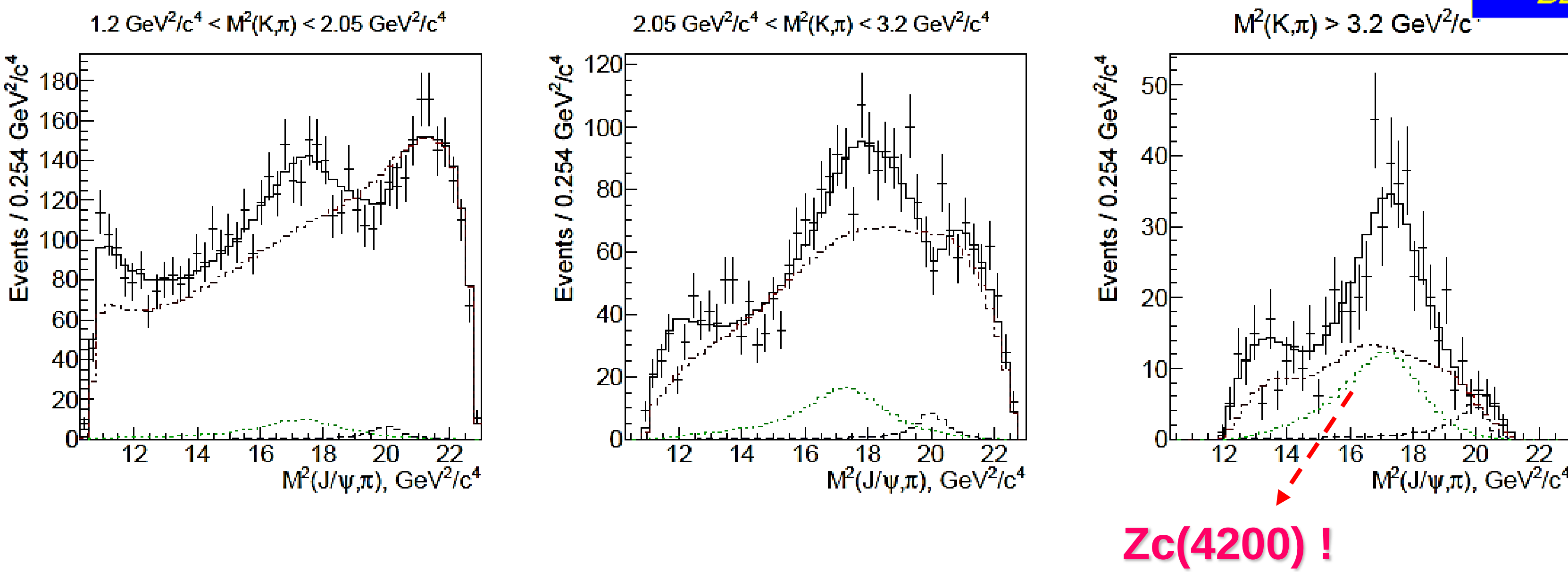


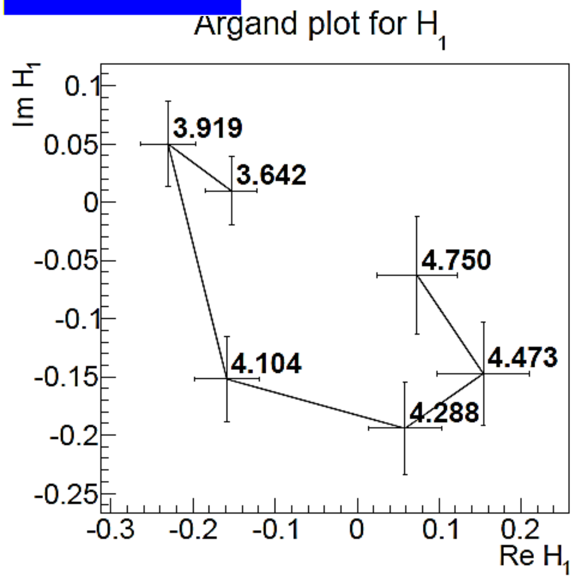
FIG. 8. The fit results with the $Z_c(4200)^+$ ($J^P = 1^+$) in the default model. The points with error bars are data; the solid histograms are fit results, the dashed histograms are the $Z_c(4430)^+$ contributions, the dotted histograms are the $Z_c(4200)^+$ contributions and the dash-dotted histograms are contributions of all K^* resonances. The slices are defined in Fig. 4.

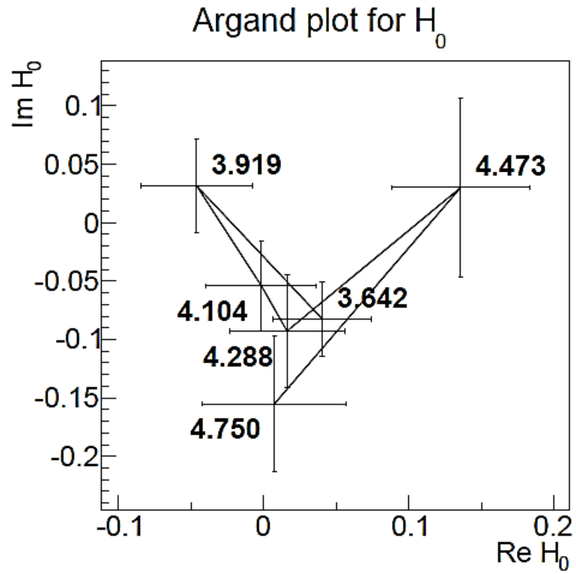
TABLE I. Fit results in the default model. Errors are statistical only.

J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV/c^2	4318 ± 48	4315 ± 40	4196^{+31}_{-29}	4209 ± 14	4203 ± 24
Width, MeV	720 ± 254	220 ± 80	370 ± 70	64 ± 18	121 ± 53
Significance (Wilks)	3.9σ	2.3σ	8.2σ	3.9σ	1.9σ

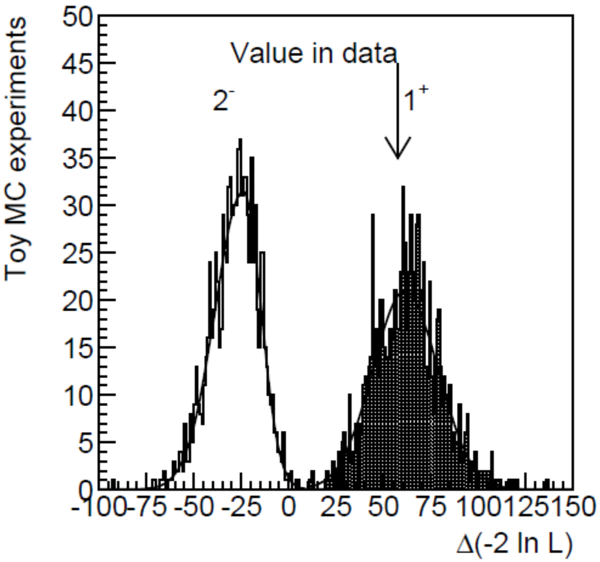
Belle: , PRD 90, 112009 (2014)

PWA of B→J/ψKπ





A JP=1+ charged charmoniumlike state Zc(4200) is observed in its decay to πJ/ψ!



$$M = 4196^{+31+17}_{-29-13}\ \mathrm{MeV}/c^2,$$

$$\Gamma = 370^{+70+70}_{-70-132}\ \mathrm{MeV}.$$

Belle: , PRD 90, 112009 (2014)

PWA of B→J/ψKπ

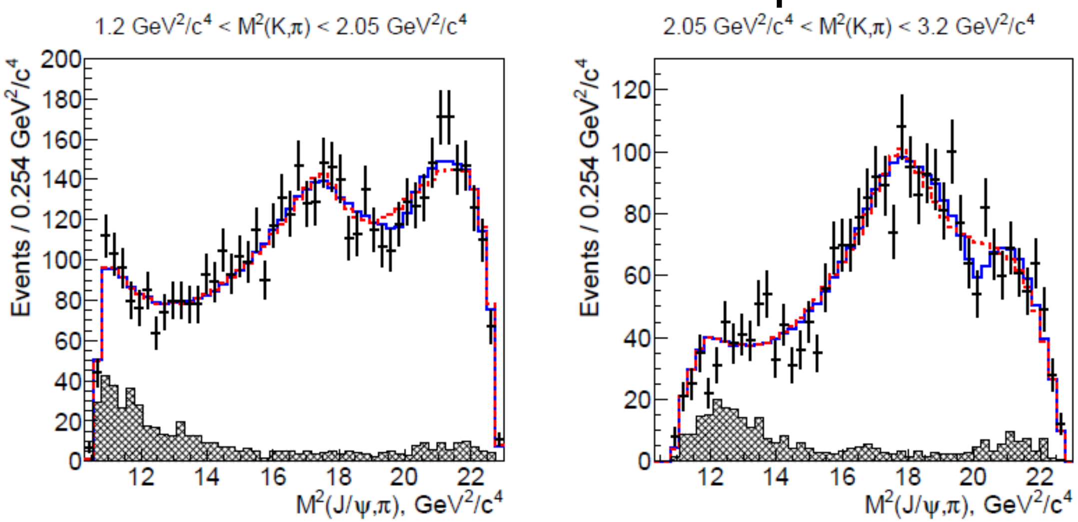


FIG. 10. The fit results with (solid line) and without (dashed line) the $Z_c(4430)^+$ (the $Z_c(4200)^+$ is included in the model) for the second and third vertical slices that are defined in Fig. 4.

- 4.0σ evidence for $Z_c(4430)\to\pi J/\psi$!
- No significant $B\to Z_c(3900)K$ signal observed!

TABLE X. Fit results with addition of the $Z_c(3900)^+$ in the default model. Errors are statistical only.

J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV$/c^2$	3889.8 ± 3.3	3890.3 ± 3.1	3890.6 ± 3.3	3891.1 ± 3.2	3891.5 ± 3.3
Width, MeV	43.2 ± 6.5	37.8 ± 7.9	39.2 ± 8.1	39.4 ± 8.5	41.2 ± 7.7
Significance	2.4σ	1.1σ	0.1σ	$< 0.1\sigma$	0.2σ

Belle: , PRD 90, 112009 (2014)

PWA of B→J/ψKπ

- New state $Z_c(4200)$! Very wide!
- 4.0σ evidence for $Z_c(4430) \to \pi J/\psi$!
- No significant $B \to Z_c(3900)K$ signal observed!

$$\mathcal{B}(\bar{B}^0 \to J/\psi K^-\pi^+) = (1.15 \pm 0.01 \pm 0.05) \times 10^{-3},$$
$$\mathcal{B}(\bar{B}^0 \to J/\psi K^*(892)) = (1.19 \pm 0.01 \pm 0.08) \times 10^{-3},$$
$$\mathcal{B}(\bar{B}^0 \to Z_c(4430)^+K^-) \times \mathcal{B}(Z_c(4430)^+ \to J/\psi\pi^+) = (5.4^{+4.0+1.1}_{-1.0-0.9}) \times 10^{-6},$$
$$\mathcal{B}(\bar{B}^0 \to Z_c(4200)^+K^-) \times \mathcal{B}(Z_c(4200)^+ \to J/\psi\pi^+) = (2.2^{+0.7+1.1}_{-0.5-0.6}) \times 10^{-5},$$
$$\mathcal{B}(\bar{B}^0 \to Z_c(3900)^+K^-) \times \mathcal{B}(Z_c(3900)^+ \to J/\psi\pi^+) < 9 \times 10^{-7} \ (90\% \ \mathrm{CL}).$$

Belle: , PRD 90, 112009 (2014)

IJMPA 29, 1430046 (2014)

Many $Z_c^{\pm}$ states now

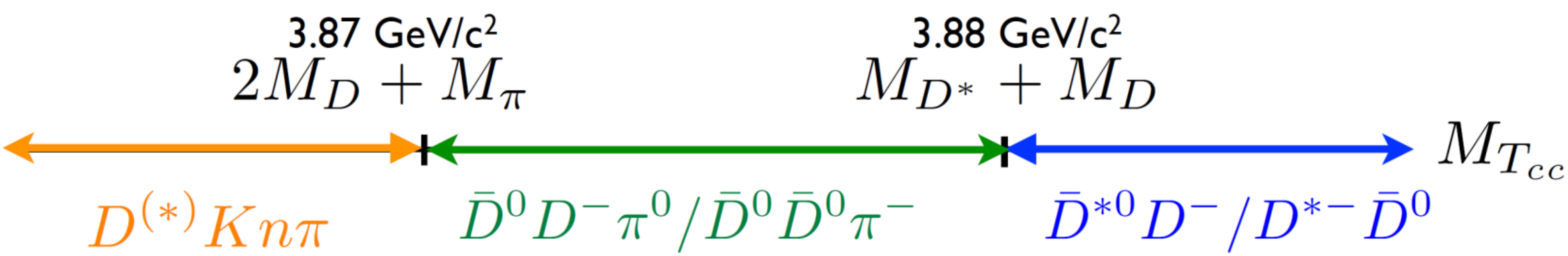
State	Mass (MeV/c^2)	Width (MeV)
$Z_c(3900)^-$	3888.6 ± 2.7	34.7 ± 6.6
$Z_c(4020)^-$	4023.9 ± 2.4	10.2 ± 3.5
$Z(4050)^-$	4051^{+24}_{-43}	82^{+51}_{-28}
$Z(4200)^-$	4196^{+35}_{-30}	370^{+99}_{-110}
$Z(4250)^-$	4248^{+185}_{-45}	177^{+321}_{-72}
$Z(4430)^-$	4478 ± 20	181 ± 33

We are eager to know their nature!

2. Ongoing analyses on XYZ

Doubly charmed tetraquark

- **Tcc+($cc\bar{u}\bar{d}$)**
  - One of the tetraquarks including two charm quarks (cc) and two light quarks ($\bar{u}$ and $\bar{d}$),
  - Explicitly exotic hadron (not a hidden charm state)
  - Bound state is expected [1]
  - But we want to check all possible scenarios



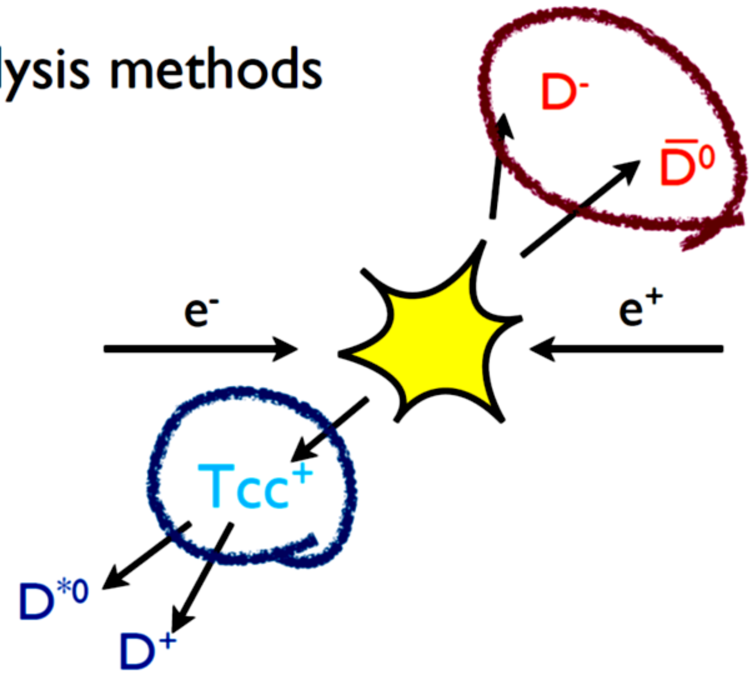
  - 11580 events could be generated at BELLE with 772fb^{-1} on-resonance data assuming 0.015pb cross-section [2]

[1] Eur. Phys. J. C 54, 259 (2008)), Eur. Phys. J. C 64, 283 (2009)

[2] Phys. Atom. Nucl. 67, 757 (2004), Phys. Rev. Lett. 84, 1663 (2003), Phys. Lett. B 551, 296 (2003),

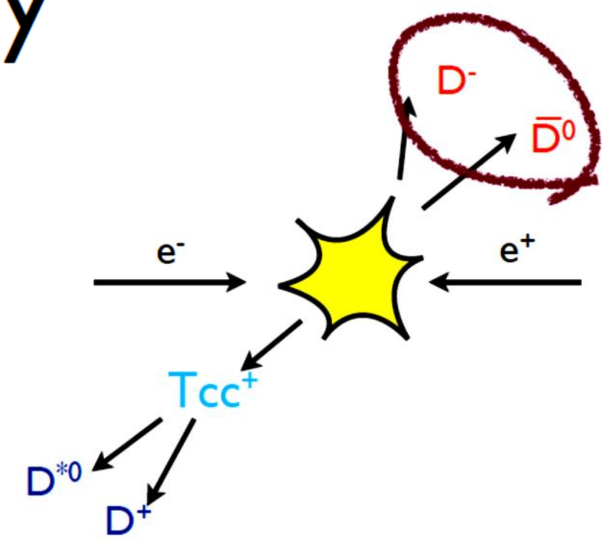
Strategy of analysis

- Two independent analysis methods
- Recoil mass
- Invariant mass

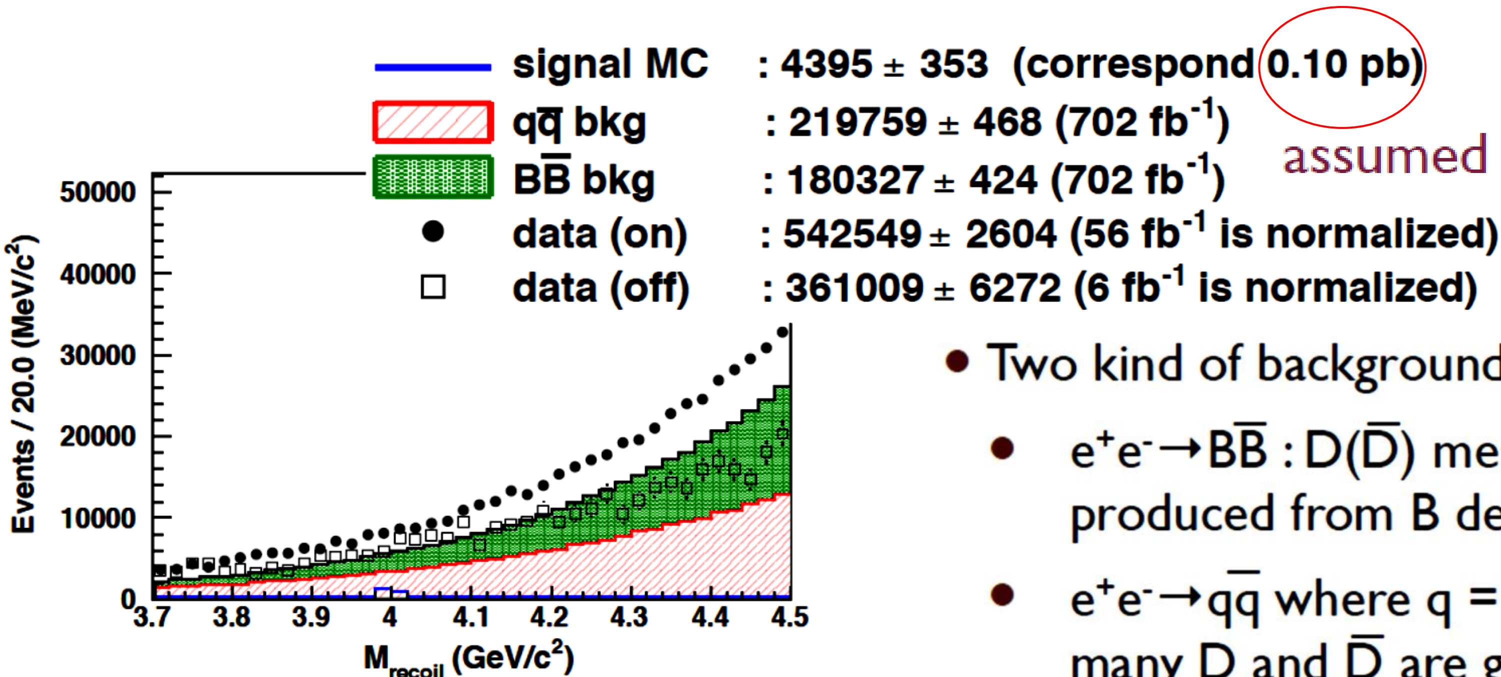


- In this analysis, we reconstruct D^0 and D to check recoil mass.
- In this analysis, we reconstruct Tcc by D^*D (expected for Tcc > 3.88 GeV/c^2).
- In this presentation, we only show the status for $D^{*0}(\rightarrow D^0\pi^0)D^+$ (status similar for $D^{*0}(\rightarrow D^0\gamma)D^+$ and $D^{*+}(\rightarrow D^0\pi^+, D^+\pi^0)D^0$).

Recoil mass study



- Blind analysis is on going
- Check the expectation before open the signal window in data
- Using two (anti-)charmed mesons, we calculate recoil mass

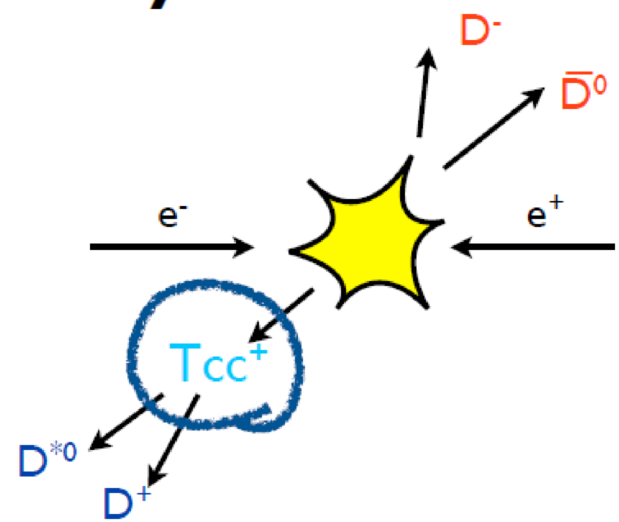


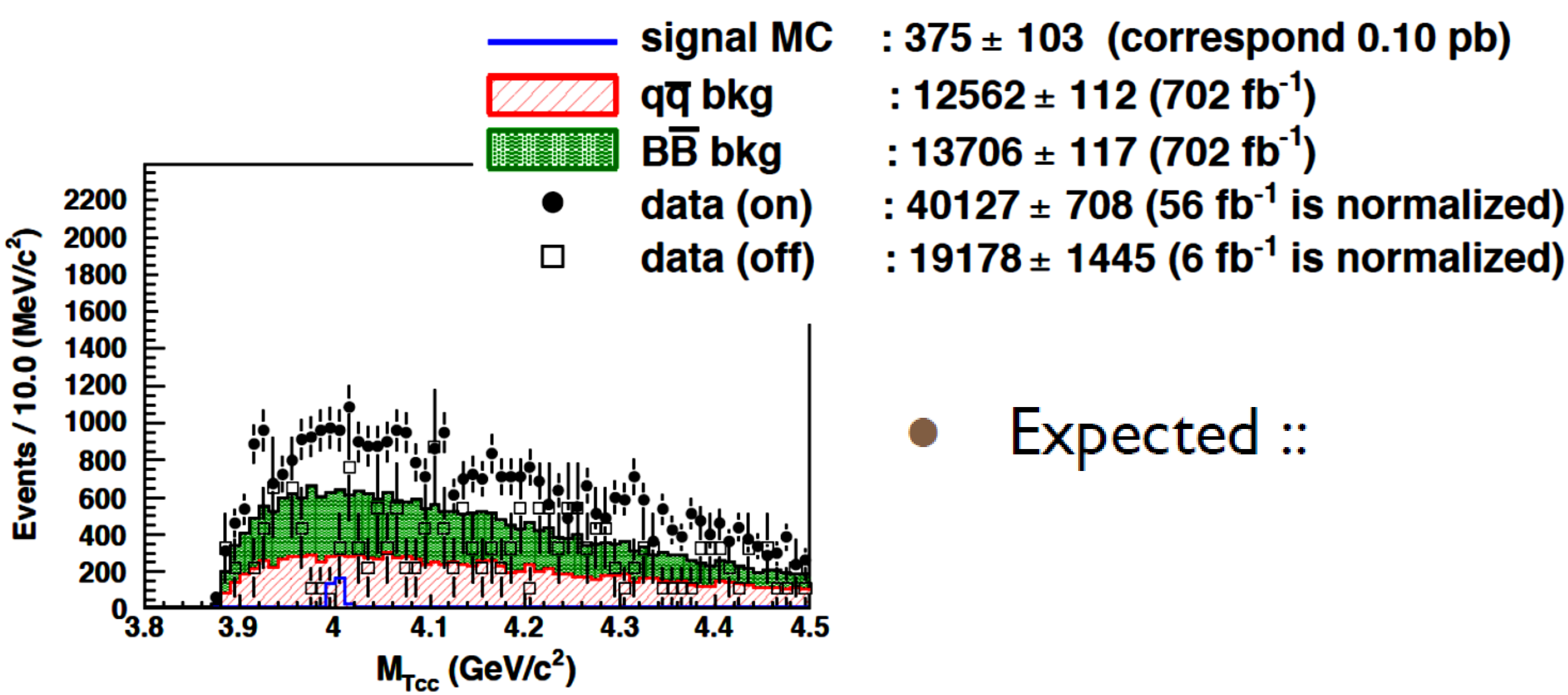
assumed cross-section

- Two kind of background:
  - $e^+e^- \to B\bar{B}$: $D(\bar{D})$ mesons are produced from B decays
  - $e^+e^- \to q\bar{q}$ where q = u,d,s and c: many D and $\bar{D}$ are generated and mis-reconstructed D

Invariant mass study

- T_{cc}^{+} is reconstructed by $D^{*0}(\rightarrow D^0\pi^0)\ D^+$
- Signal extraction by using $M_{Tcc} = \sqrt{((E_{D^*} + E_D)^2 - |\vec{p}_{D^*} + \vec{p}_D|^2)}$.

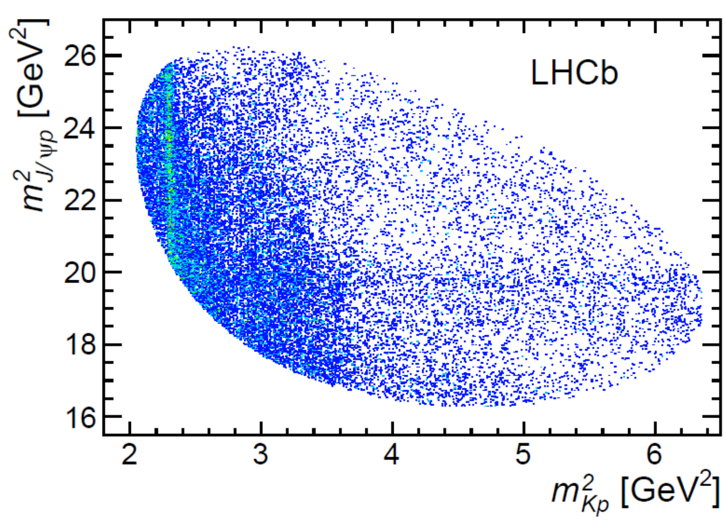


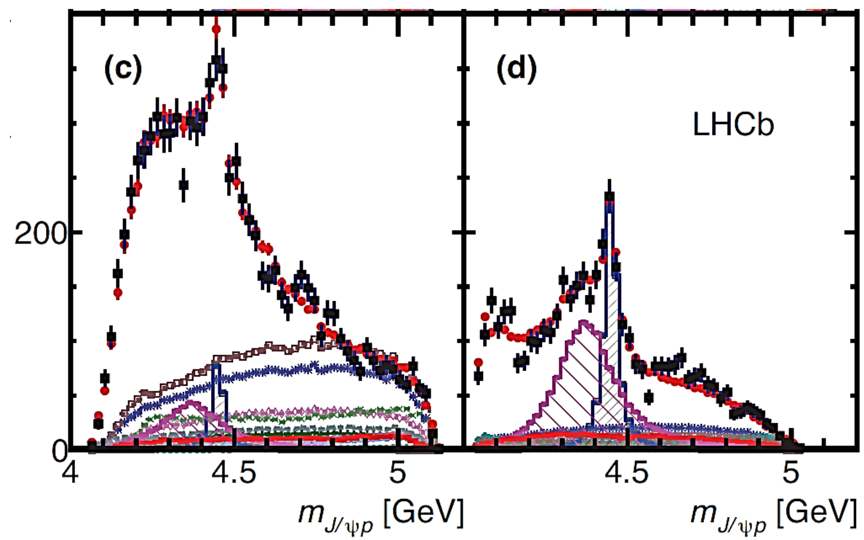


- Expected ::

Pc at Belle?

- Recent observation of two Pc states at LHCb

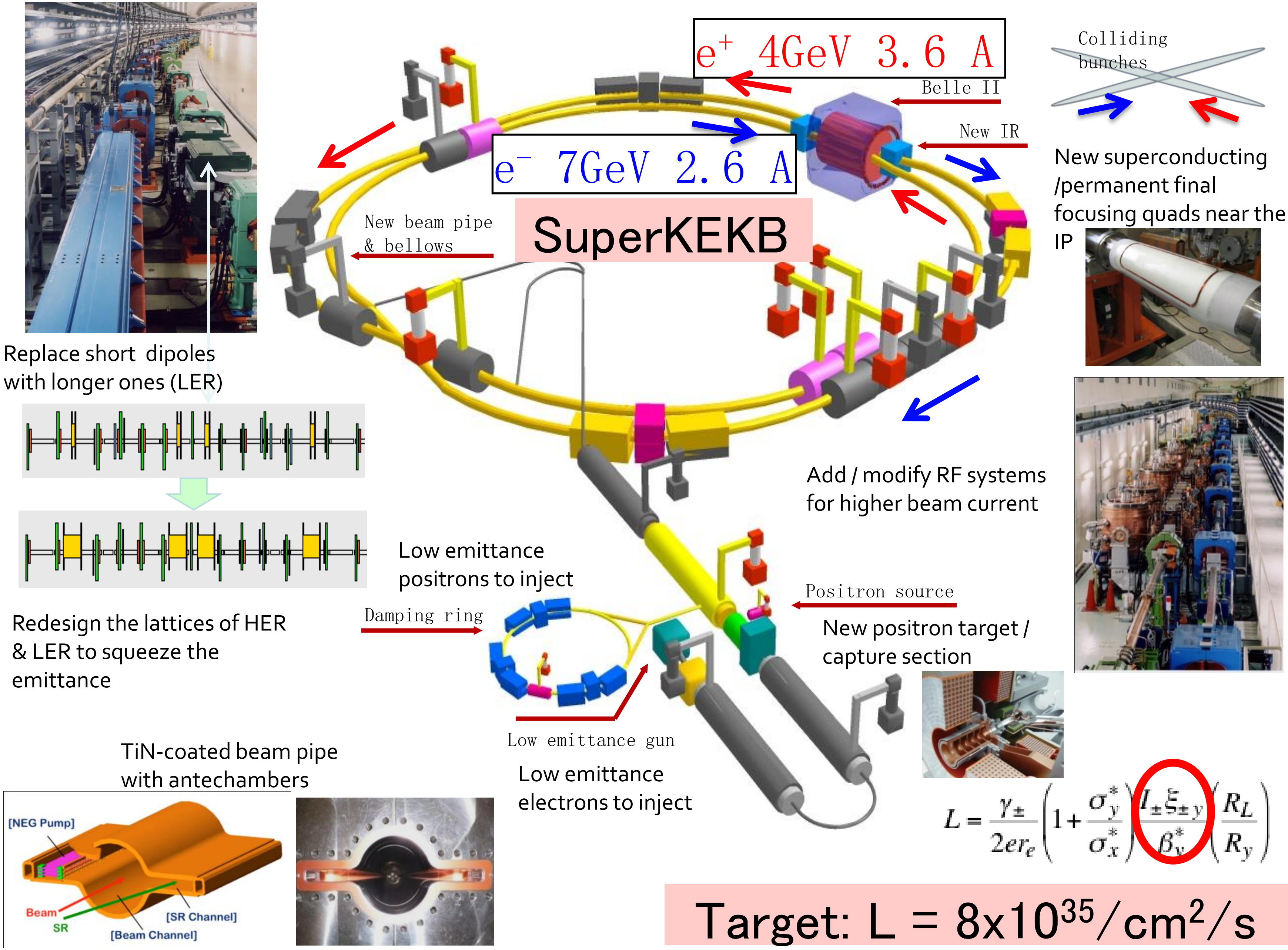




- Can we observe them with Belle data?
  - B decays: B→Pc+pbar (no signal!)
  - Continuum production: e^+e^-→Pc+X (in progress)
  - Υ(1S)、 Υ(2S)→Pc+X (in progress, better than continuum?)
  - Other pentaquark states? (in progress)
- May theorists calculate the rates?

3. Prospects at BelleII

SuperKEKB collider

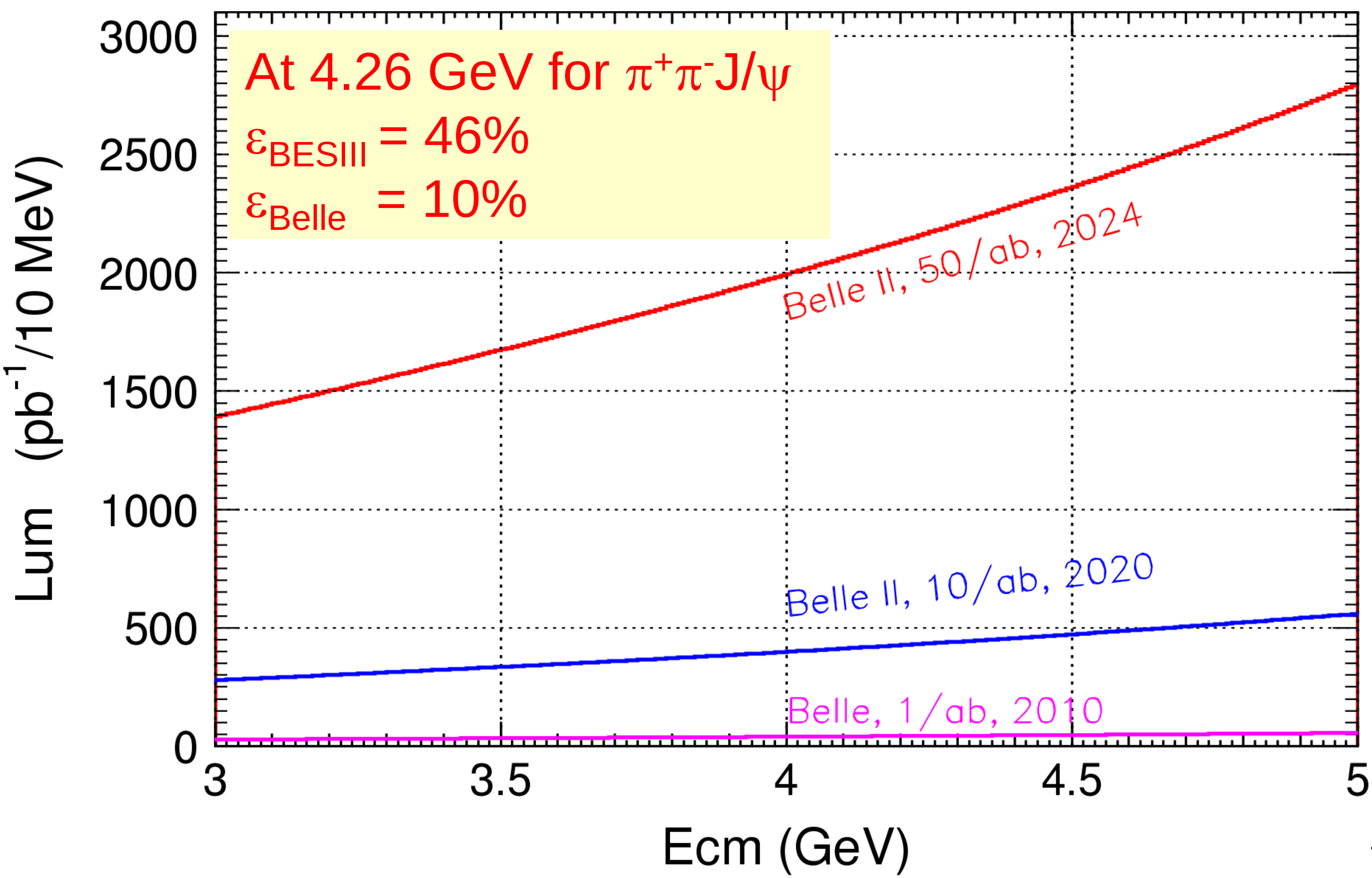


$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

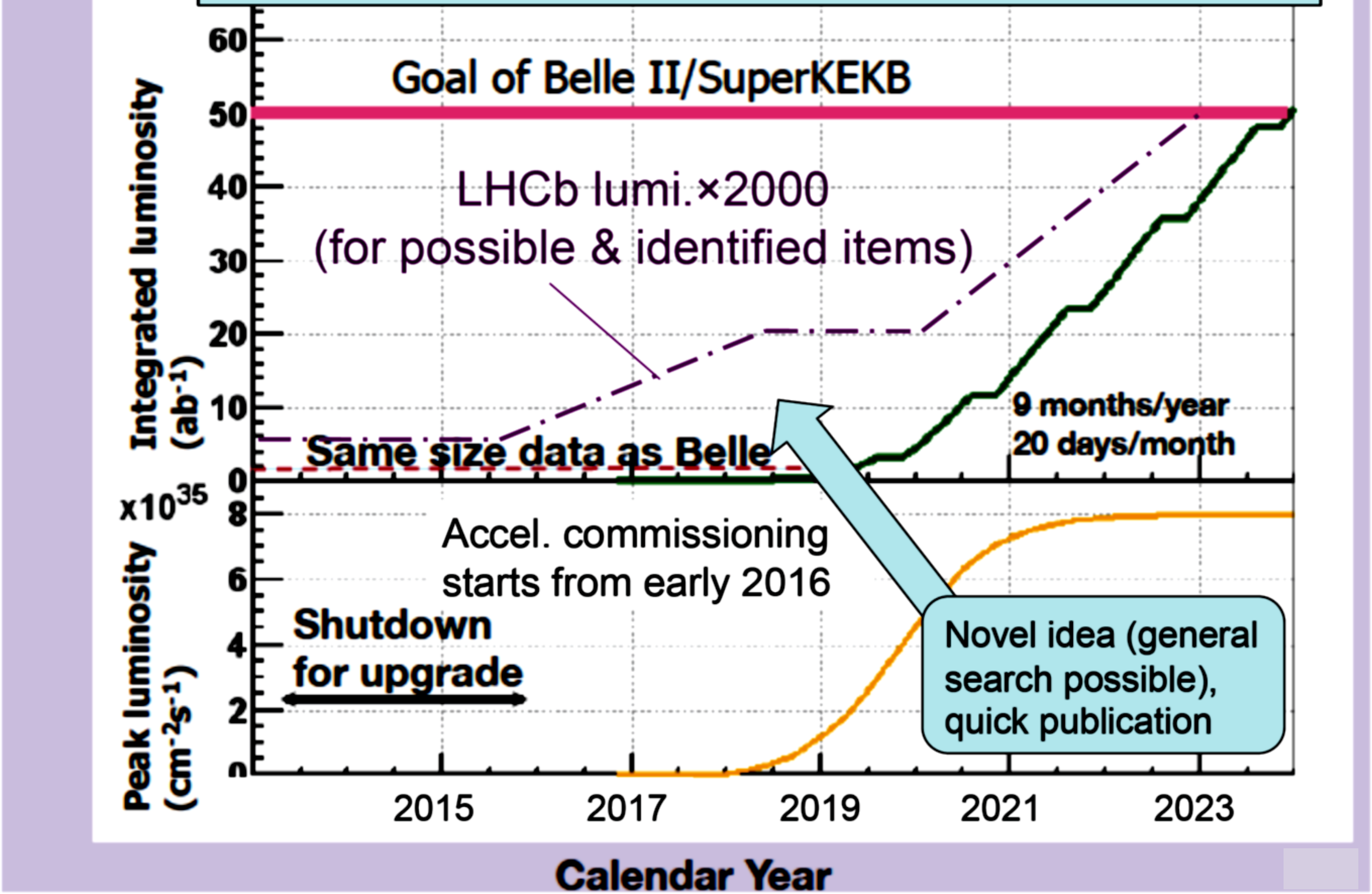
Target: L = 8×10^{35}/cm^2/s

Belle II is coming

ISR produces events at all CM energies BESIII can reach



Competition with LHCb



Summary

- Lots of results on XYZ states
- Nature yet to understand
- Belle is still producing results with 1/ab data
- Belle II will collect 50/ab data to improve the analyses

Thanks a lot!

The end