Exotic quarkonium-like states and spectroscopy at

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INFN TORINO

PANIC 2017

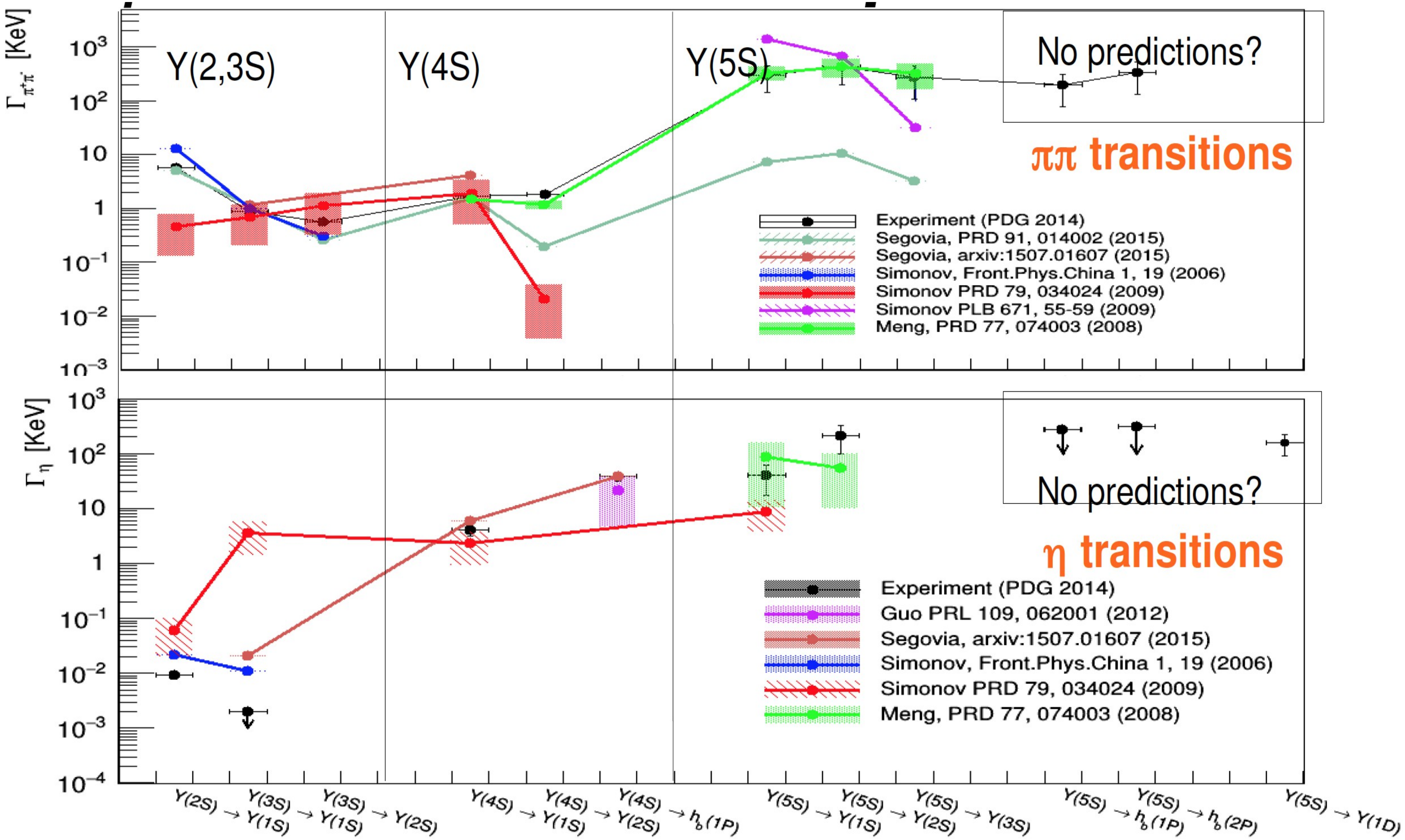
Production of $b\bar{b}$ above $B\bar{B}$ threshold

New $\chi_{c0}(2P)$ candidate

Searches for XYZ states in Υ decays

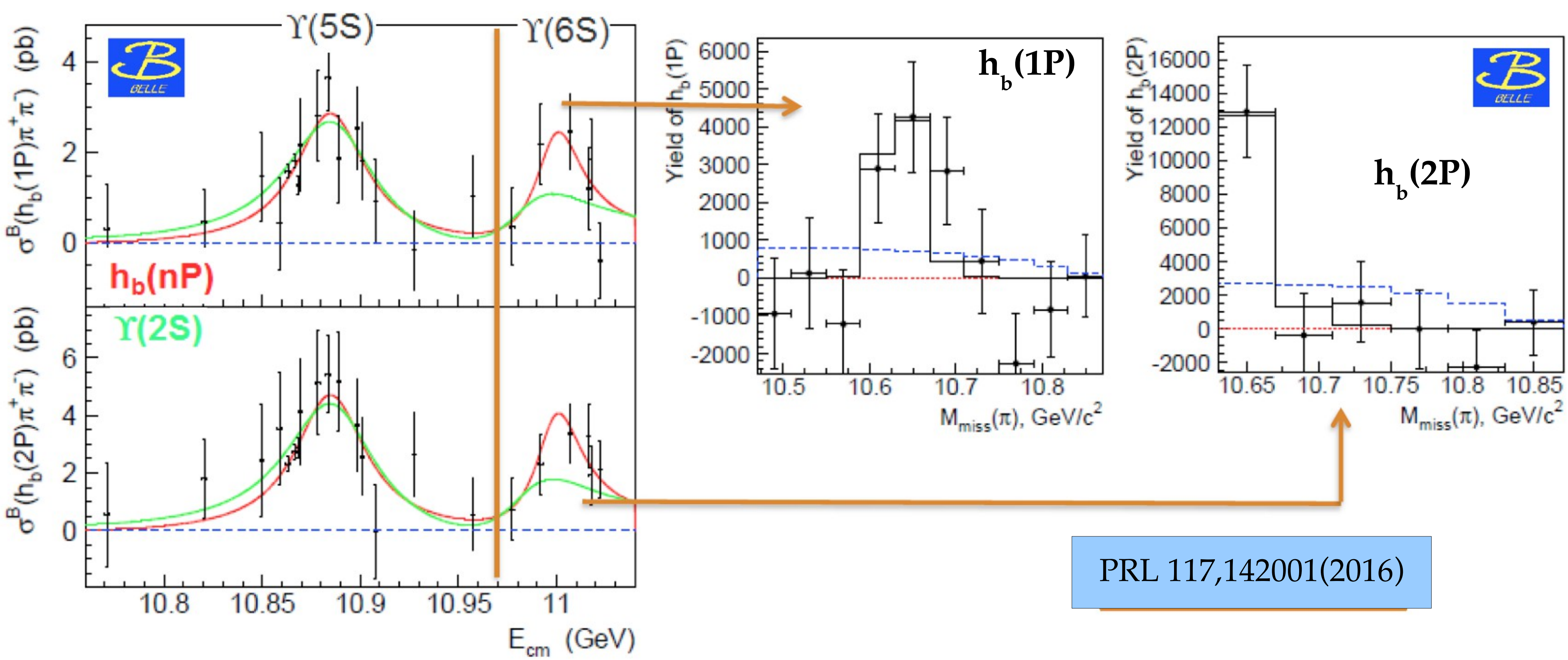
Searches for oddballs in Υ decays

The η vs ππ transitions from Υ(nS): theory vs exp



Belle: $e^+e^- \to h_b(1,2P)\,\pi\pi$

The analysis of the 6 points (1 fb^{-1} each) in the proximity of the Υ(6S) show a clear evidence of dipion transitions to both the h_b states. The small statistics does not allow to quantify the fractions decaying via Z_b(10610) and Z_b(10650) .



PRL 117,142001(2016)

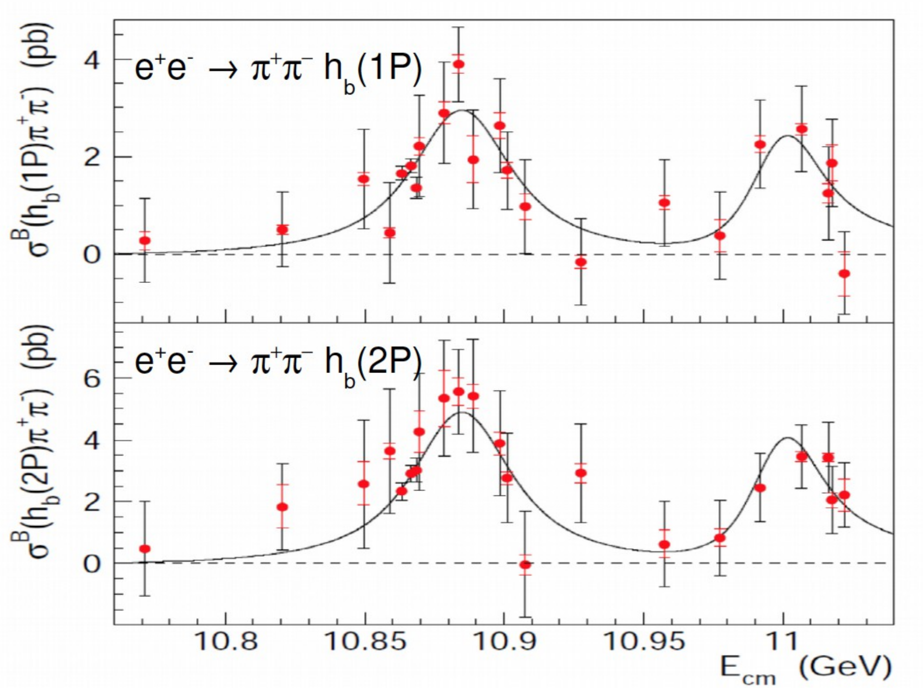
Belle-II is planning to take more data at Υ(6S) during the first or second year of data taking

The ππ transitions: energy dependence

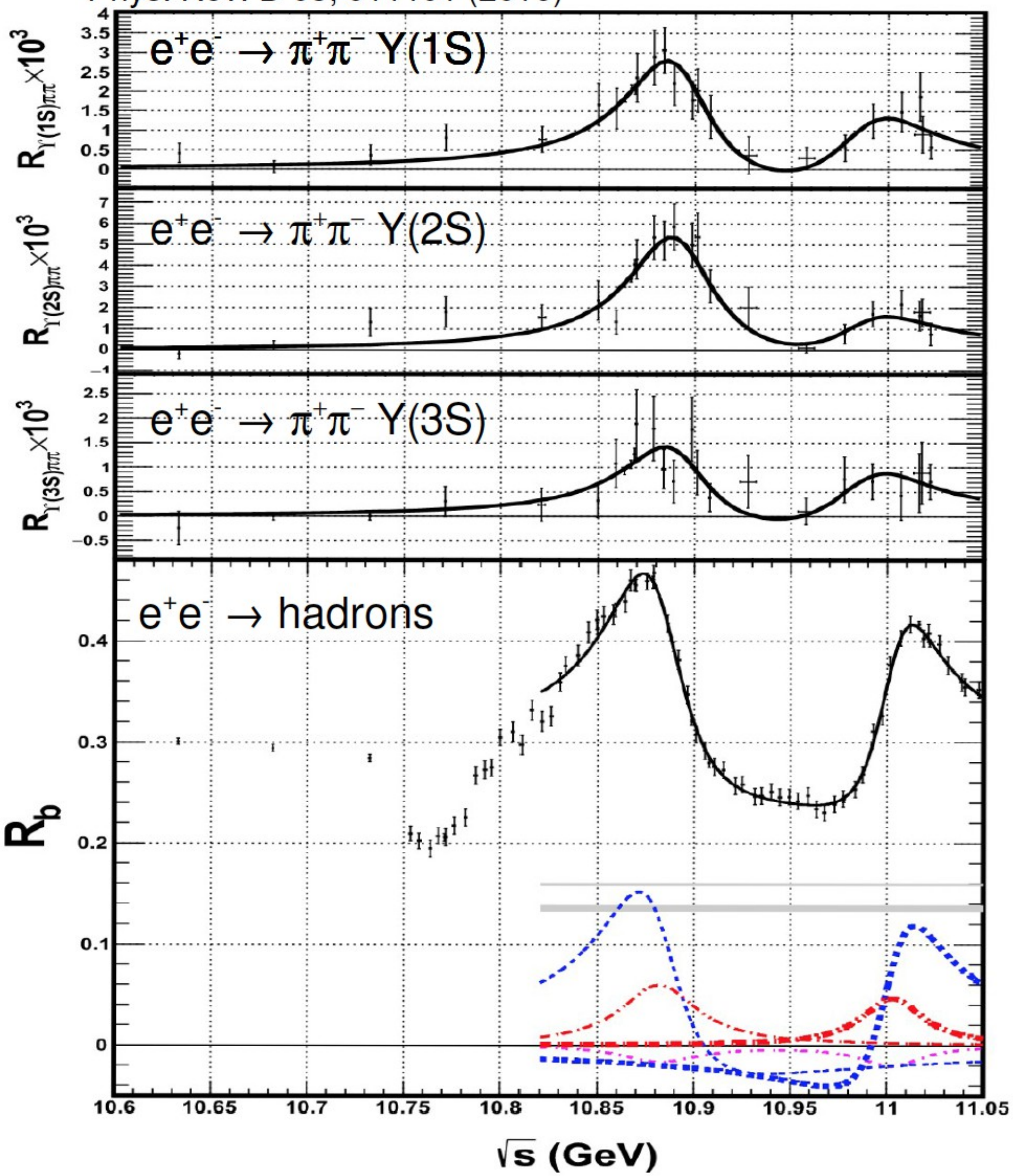
The energy dependence of the $b\bar{b}$ cross section in the resonance region exhibits a different behaviour, if compared with the cross sections for exclusive final states

$e^+e^- \to \pi^+\pi^- \Upsilon(1,2,3S), \pi^+\pi^- \; h_b(1,2P)$

We need to further study the exclusive two-body $B^{(*)}\bar{B}^{(*)}$ and three body $B^{(*)}\bar{B}^{(*)}\pi$ final states, to fully understand the $b\bar{b}$ hadronization and the nature of the $\Upsilon(4,5S)$ resonances



Phys. Rev. D 93, 011101 (2016)



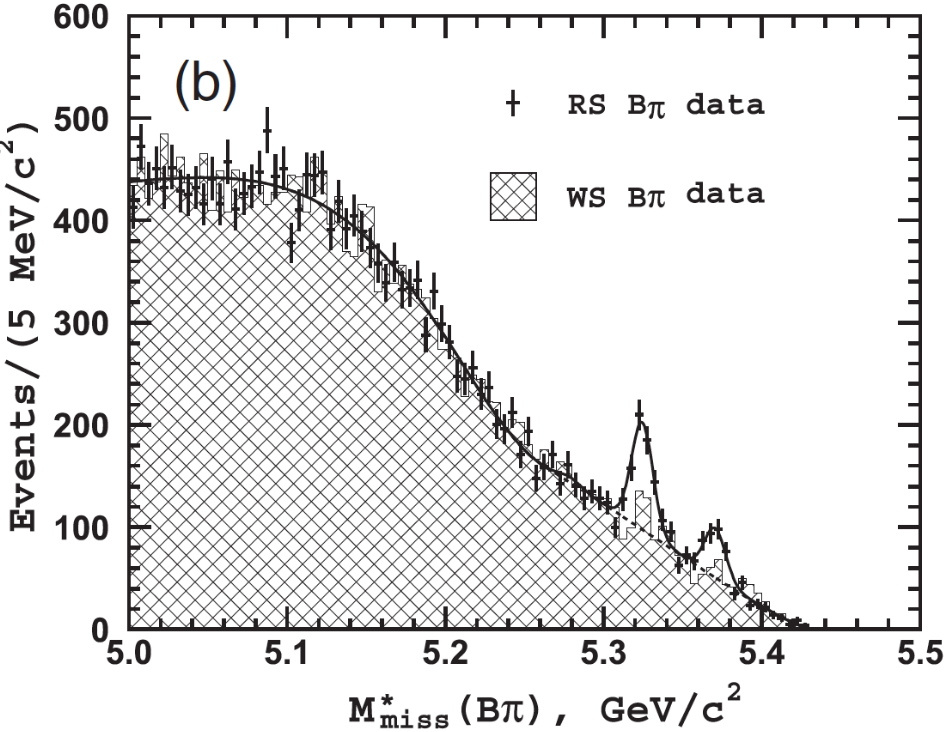
Z_b, Z_b ' Branching Ratios

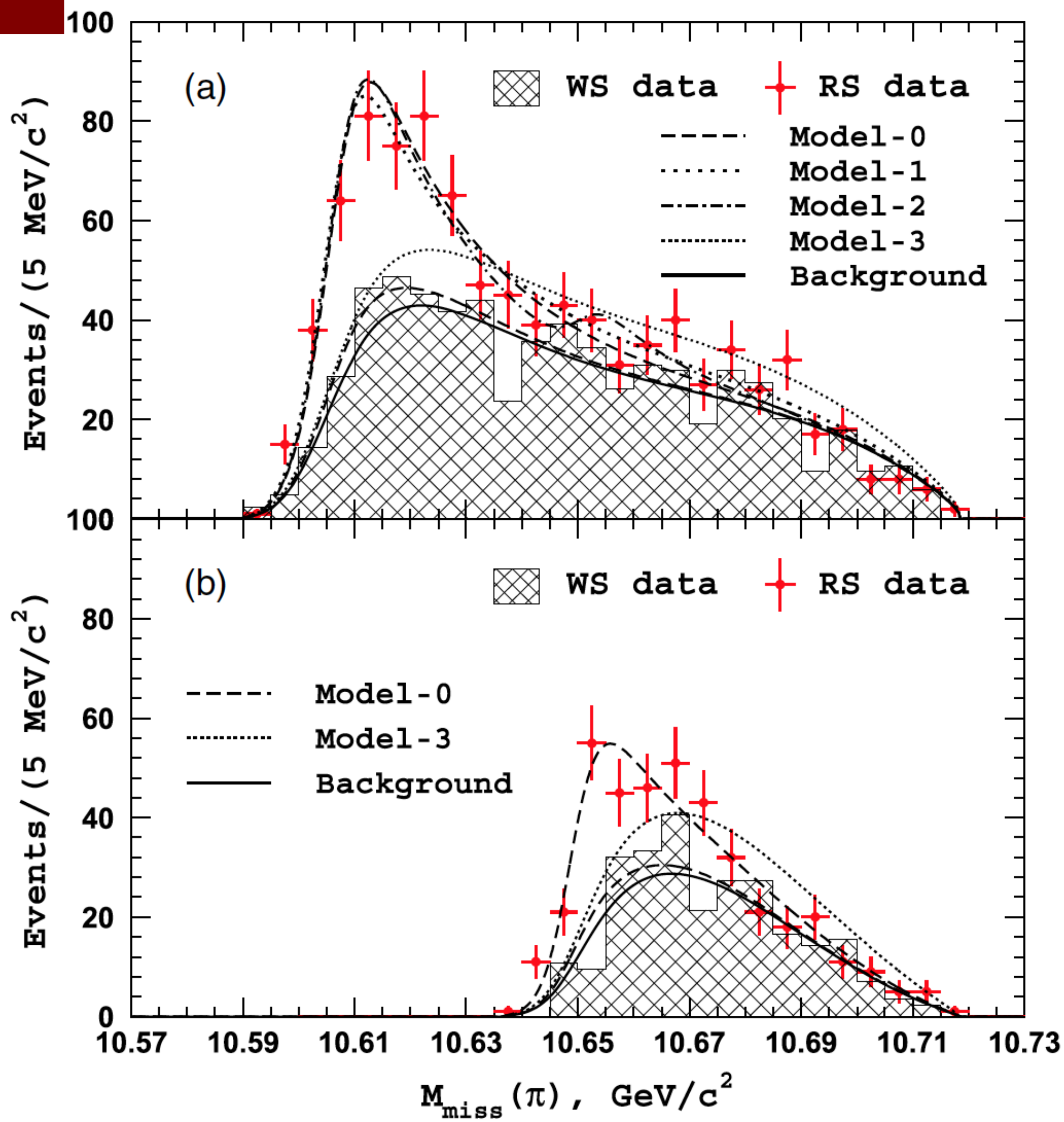
PRL 116,212001 (2016)

$$S(m) = |\mathcal{A}_{Z_b(10610)} + \mathcal{A}_{Z_b(10650)} + \mathcal{A}_{\rm nr}|^2$$

Simultaneous fit to both the BB*π and B*B*π signals with different assumptions:

- Model-0: Z_b for BB*π and Z_b' for B*B*π
- Model-1: adding A_{nr} to both
- Model-2: allowing Zb+Zb' for BB*π
- Model-3: only A_{nr}





(*) WS: wrong sign RS: right sign

Z_b, Z_b' Branching Ratios

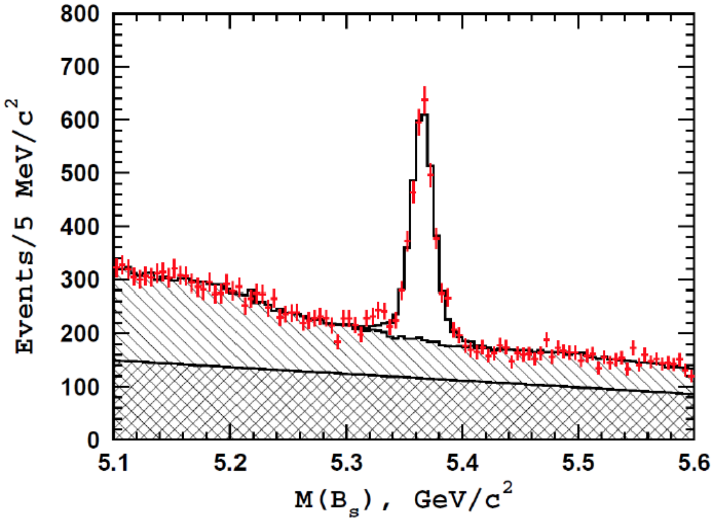
PRL 116,212001 (2016)

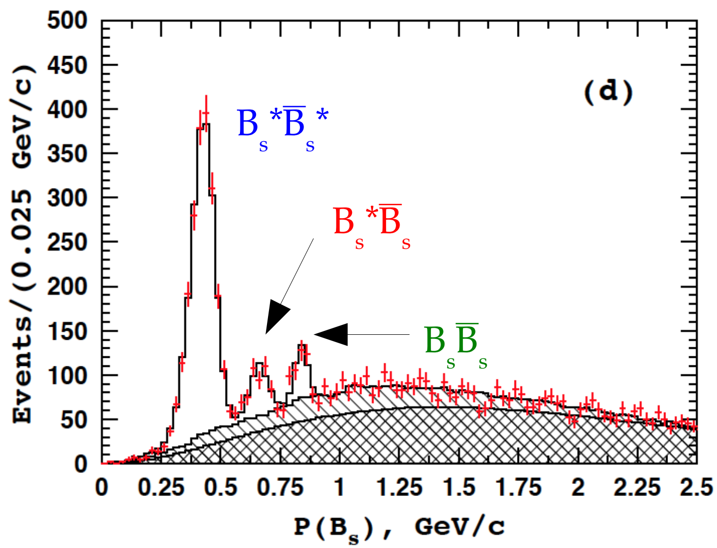
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.54^{+0.16+0.11}_{-0.13-0.08}$	$0.17^{+0.07+0.03}_{-0.06-0.02}$
$\Upsilon(2S)\pi^+$	$3.62^{+0.76+0.79}_{-0.59-0.53}$	$1.39^{+0.48+0.34}_{-0.38-0.23}$
$\Upsilon(3S)\pi^+$	$2.15^{+0.55+0.60}_{-0.42-0.43}$	$1.63^{+0.53+0.39}_{-0.42-0.28}$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

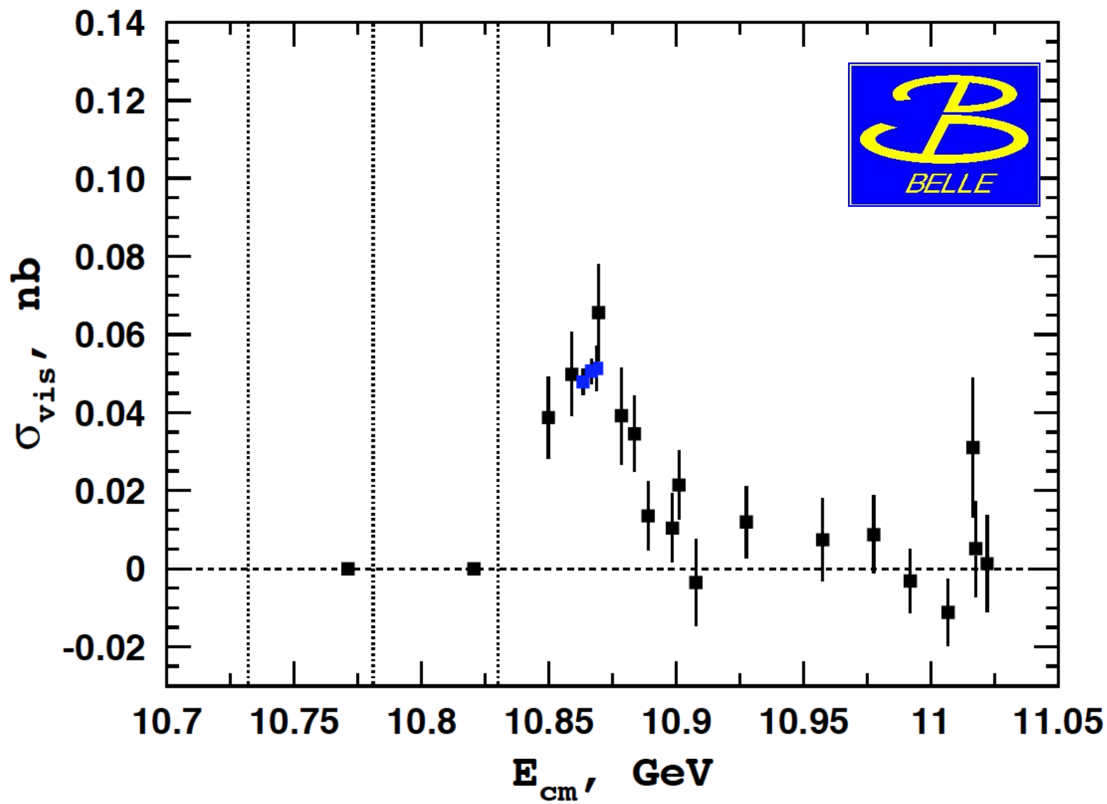
Study of $e^+e^- \to B_s^{(*)}\overline{B}_s^{(*)}$ from 10.77 to 11.02 GeV

ArXiV:1609.08749

Full reconstruction of these channels: $D_s^{(*)-}\pi^+$, $\pi^+\pi^- J/\psi$, $K^+K^- J/\psi$, $K^+K^- \psi'$







$B_s^*\overline{B}_s^*$: $B_s^*\overline{B}_s$ +c.c. : $B_s\overline{B}_s$ at 10.866 GeV

7 : 0.853 ± 0.106 ± 0.053 : 0.638 ± 0.094 ± 0.033

Strong tension with HQSS that predicts 7:4:1

More hadronic transitions

$\Upsilon(4S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	1.7 ± 0.2
$\Upsilon(1S)\,\eta$	4.0 ± 0.8
$\Upsilon(2S)\,\pi^+\pi^-$	1.8 ± 0.3
$h_b(1P)\,\eta$	45 ± 7

Limited by available channels

Limited by available statistics

$\Upsilon(6S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	137 ± 32
$\Upsilon(2S)\,\pi^+\pi^-$	183 ± 43
$\Upsilon(3S)\,\pi^+\pi^-$	77 ± 28
$Z_b(10610, 10650)^{\pm}\pi^{\mp}$	$1300 - 6600$

$\Upsilon(5S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	238 ± 41
$\Upsilon(1S)\,\eta$	39 ± 11
$\Upsilon(1S)\,K^+K^-$	33 ± 11
$\Upsilon(2S)\,\pi^+\pi^-$	428 ± 83
$\Upsilon(2S)\,\eta$	204 ± 44
$\Upsilon(3S)\,\pi^+\pi^-$	153 ± 31
$\chi_{b1}(1P)\,\omega$	84 ± 20
$\chi_{b1}(1P)\,(\pi^+\pi^-\pi^0)_{\text{non-}\omega}$	28 ± 11
$\chi_{b2}(1P)\,\omega$	32 ± 15
$\chi_{b2}(1P)\,(\pi^+\pi^-\pi^0)_{\text{non-}\omega}$	33 ± 20
$\Upsilon_J(1D)\,\pi^+\pi^-$	~ 60
$\Upsilon_J(1D)\,\eta$	150 ± 48
$Z_b(10610)^{\pm}\pi^{\mp}$	2070 ± 440
$Z_b(10650)^{\pm}\pi^{\mp}$	1200 ± 300

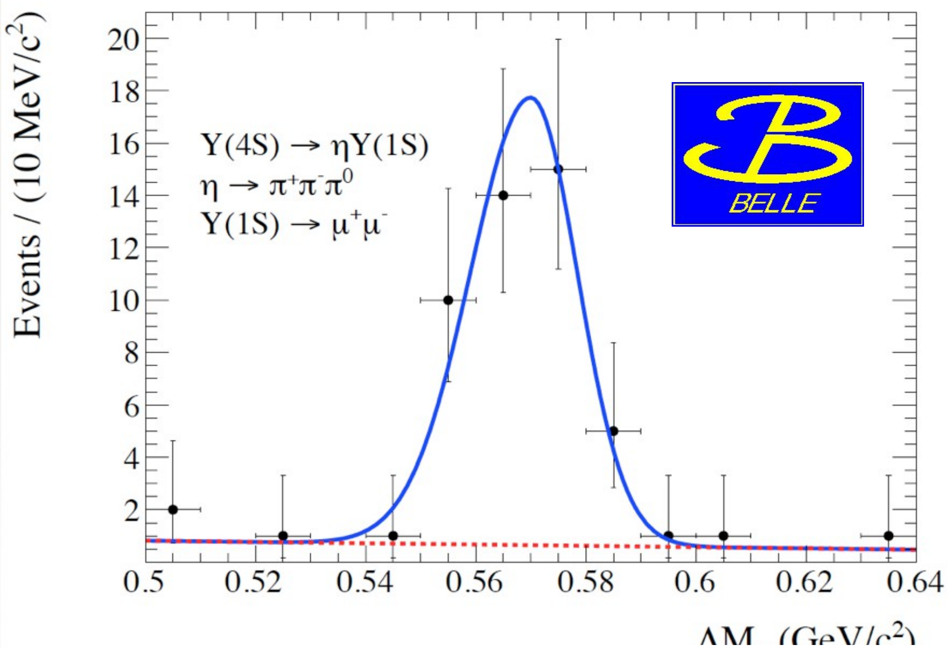
A full scan (1 MeV steps , Ldt = 10 fb^{-1}) from the $B\bar{B}$ threshold to the maximum available energy will give Belle II a unique opportunity to shed light on the hadronization mechanism

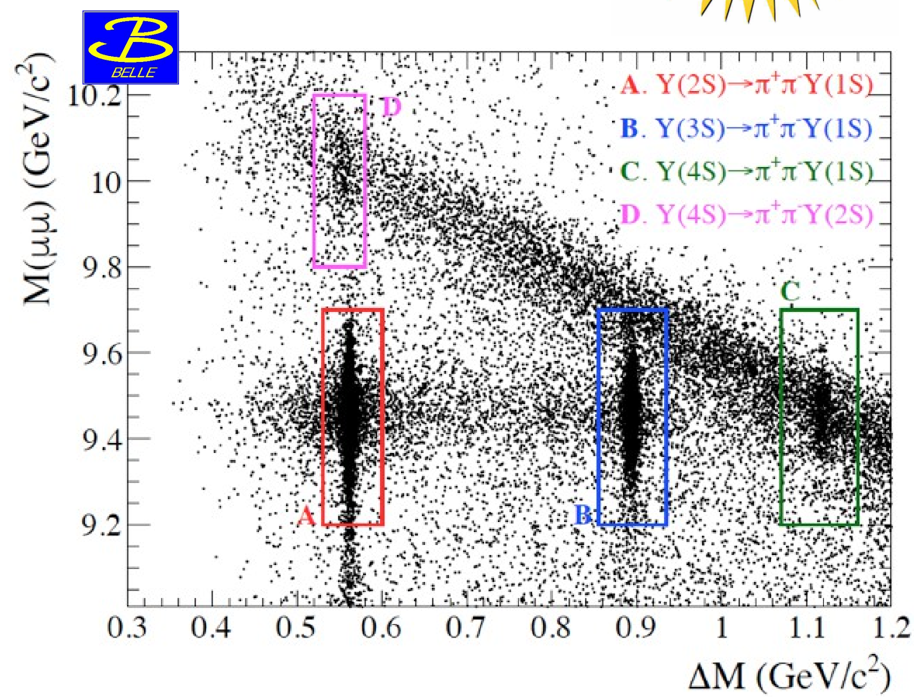
Bondar et al. **Mod.Phys.Lett. A32 (2017), 1750025**

The η and ππ transitions from Υ(4S)

ArXiV:1707.04973

Data sample: 500 fb^{-1} from Υ(4S), 58 from 10.52 GeV
Study of both dipion and eta transitions from the 4S
Search for the Υ(D) to Υ(1S) eta transition





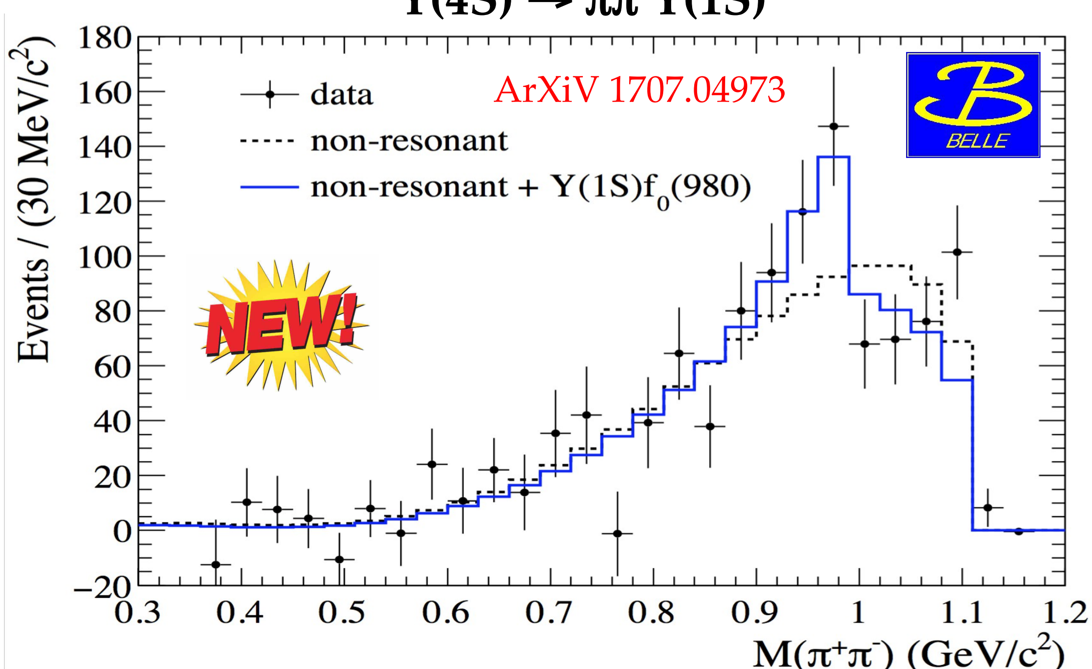
Measurement	Result	PDG value [17]
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(1S))$	$(8.2 \pm 0.5 \pm 0.4) \times 10^{-5}$	$(8.1 \pm 0.6) \times 10^{-5}$
$\mathcal{B}(\Upsilon(4S) \to \pi^+\pi^-\Upsilon(2S))$	$(7.9 \pm 1.0 \pm 0.4) \times 10^{-5}$	$(8.6 \pm 1.3) \times 10^{-5}$
$\mathcal{B}(\Upsilon(4S) \to \eta\Upsilon(1S))$	$(1.70 \pm 0.23 \pm 0.08) \times 10^{-4}$	$(1.96 \pm 0.28) \times 10^{-4}$
$\mathcal{R}$ as in Eq. 1	$2.07 \pm 0.30 \pm 0.11$	2.41 ± 0.42
Measurement	**Result**	**Expected value [12]**
$\sigma_{\text{ISR}}(\Upsilon(2S))$	$(17.36 \pm 0.19 \pm 0.69)$ pb	(17.1 ± 0.3) pb
$\sigma_{\text{ISR}}(\Upsilon(3S))$	$(28.9 \pm 0.5 \pm 1.3)$ pb	(28.6 ± 0.5) pb

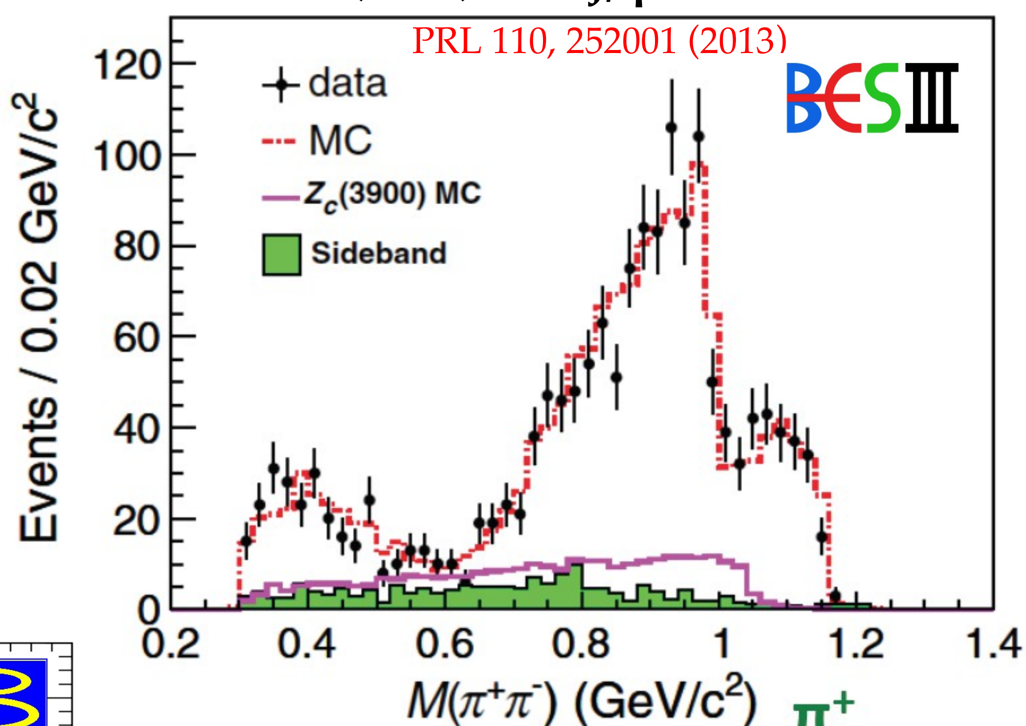
M(ππ) in Υ(4S) to ππ Υ(1S)

Similar to the one in charmonium(like):

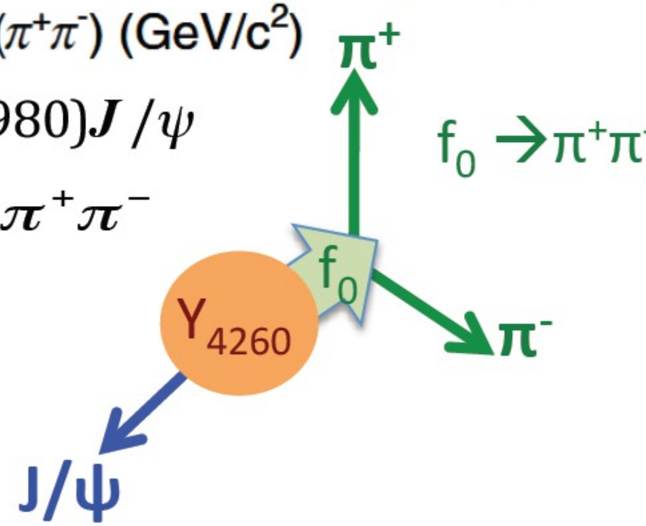
Y(4260) →ππ J/ψ

First evidence of the f_0(980) peak also at Υ(4S). The difference in Dalitz Plot is in the band produced by the Z_c(3900) : we need to go up 185 MeV (at 10745 MeV) to start seeing the impact of Z_b in Υππ .





$$Y(4260) \rightarrow f_0(980) J/\psi$$
$$\quad \llcorner\!\rightarrow \pi^+\pi^-$$

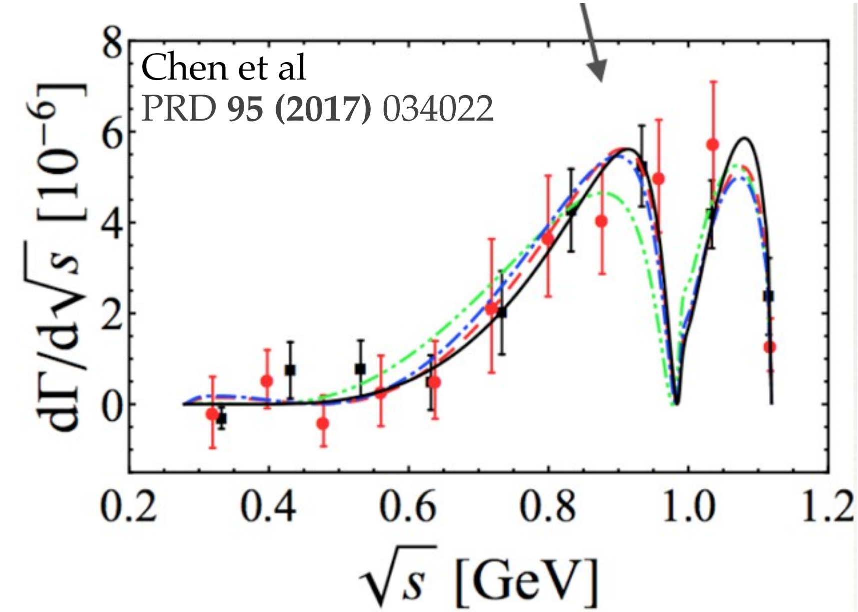


$M(\pi\pi)$ in Y(4S) to $\pi\pi$ Y(1S)

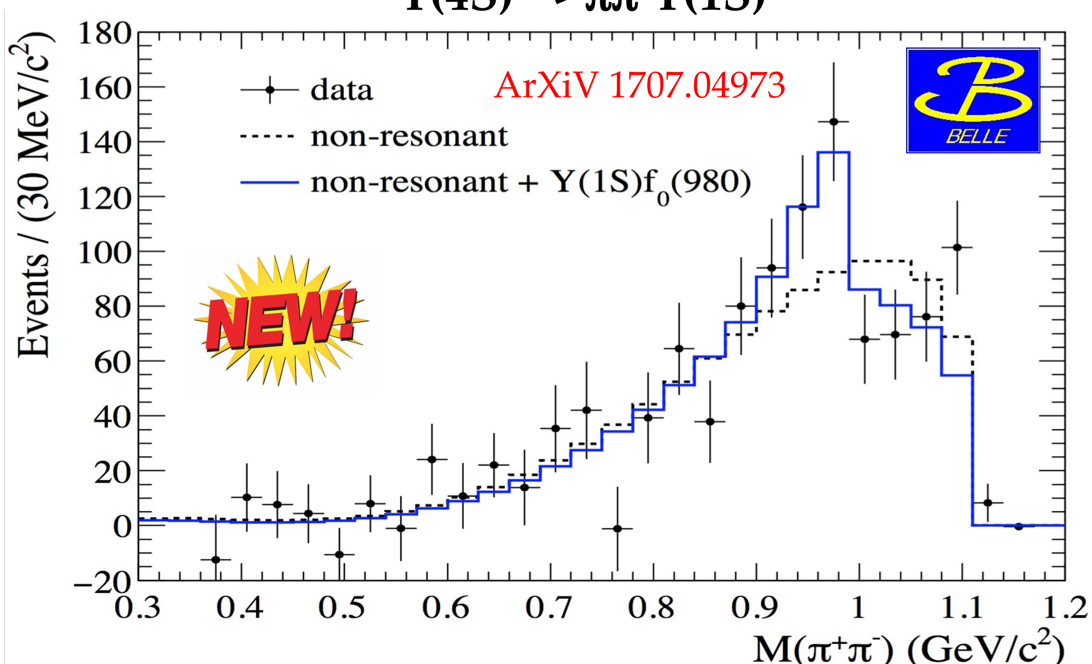
The $f_0(980)$ peak was not visible in the previous Belle and Babar papers at Y(4S), even if it appears quite clearly in the dipion mass distribution at the Y(5S).

A theory paper (Chen et al PRD **95 (2017)** 034022) predicted the $f_0(980)$ peak in the dipion mass distribution: we need a theory model able to describe these features through the whole energy range.

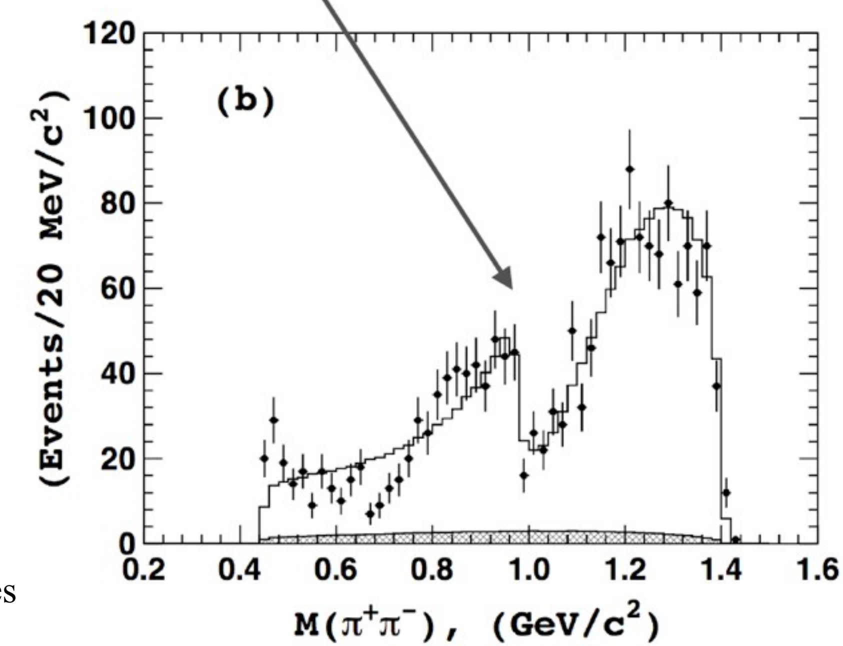
Recent theory prediction (Chen et al.) vs previous Belle and Babar data at Y(4S)



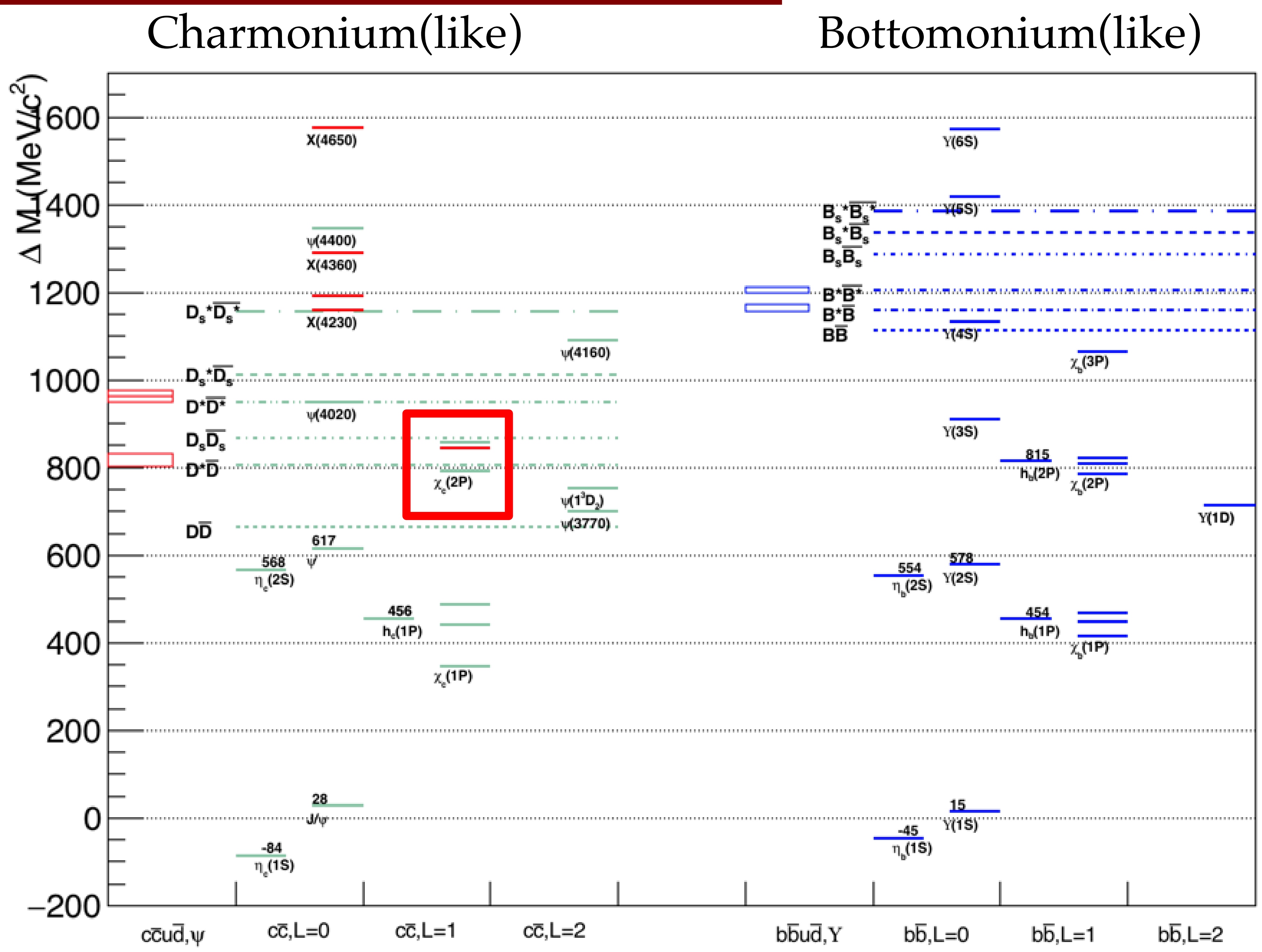
Y(4S) → ππ Y(1S)



BELLE Y(5S)



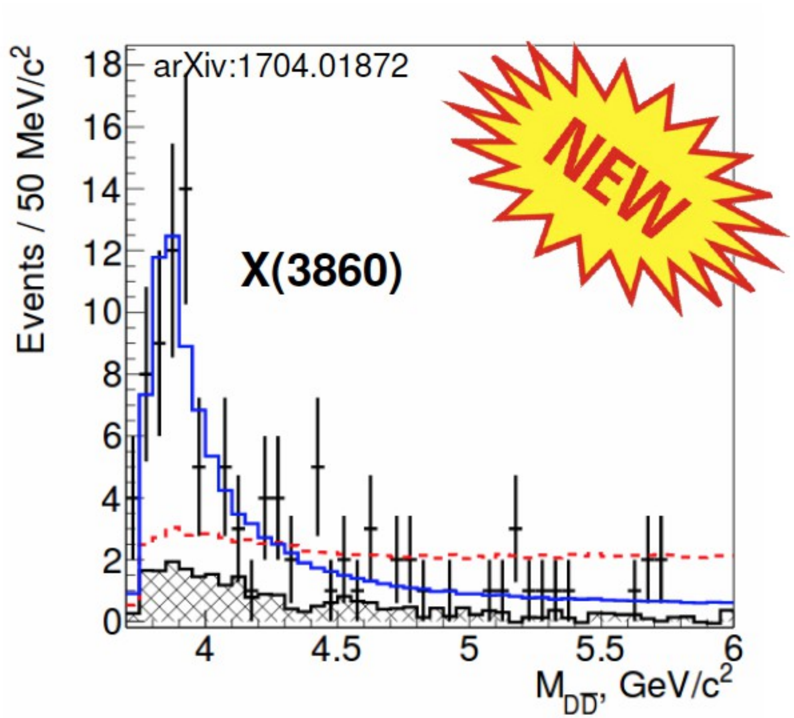
Progress on χ_c(2P) states

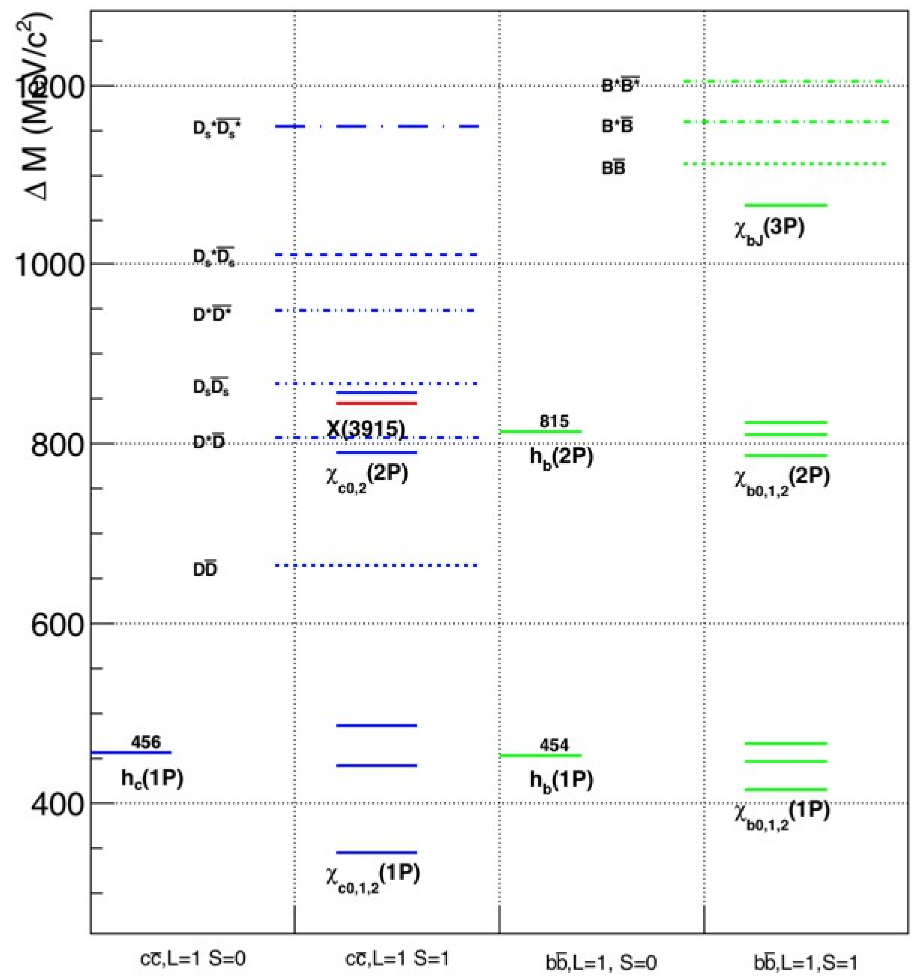


Observation of the 'real' χ_{c0}(2P)?

Phys.Rev. D95 (2017) 112003

Belle 2017: New analysis of $e^+e^- \to J/\psi\, D^0\overline{D}{}^0$: **X(3860)**



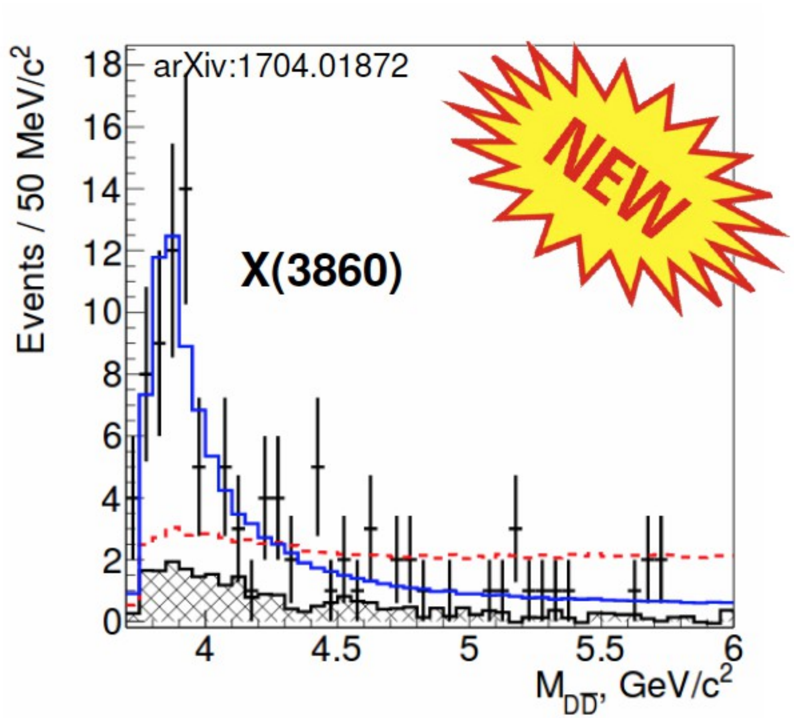


χ_{cJ0}(2P) should have:	X(3915)	X(3860)
1) Dominant decay to $D^0\overline{D}{}^0$	✗	✓
2) Be 80-120 MeV below χ_{cJ2}(2P)	✗	✓
3) $\mathcal{B}(\chi'_{c0} \to \omega J/\psi) < 7.8\%$.	✗	✓

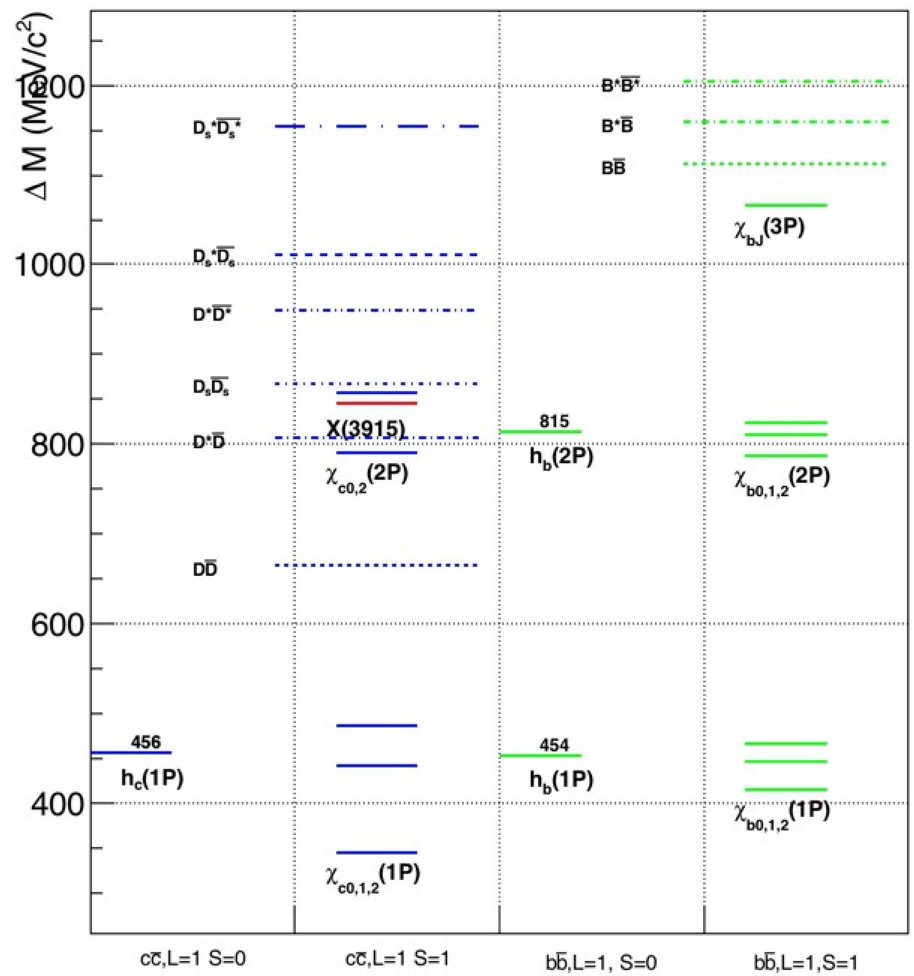
$\chi_{c0}(2P)$

Phys.Rev. D95 (2017) 112003

Belle 2017: New analysis of $e^+e^- \to J/\psi\, D^0\overline{D}^0$: **X(3860)**



$M = 3862^{+26+40}_{-32\ -13}\ MeV/c^2 \quad \Gamma = 201^{+154+88}_{-67\ -84}\ MeV$



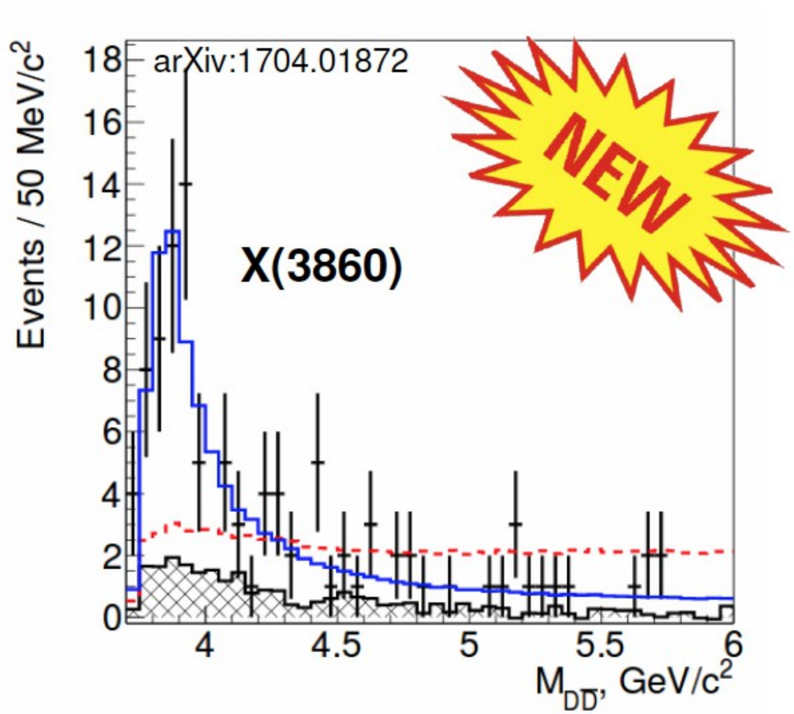
$$r_c = \frac{m_{\chi_{c2}(2P)} - m_{\chi_{c0}(2P)}}{m_{\chi_{c2}(1P)} - m_{\chi_{c0}(1P)}}$$

$r_c = 0.46^{+0.25}_{-0.34} \qquad r_b = 0.69 \pm 0.01$

$\chi_{c0}(2P)$

Phys.Rev. D95 (2017) 112003

Belle 2017: New analysis of $e^+e^- \rightarrow J/\psi\, D^0\bar{D}^0$: **X(3860)**



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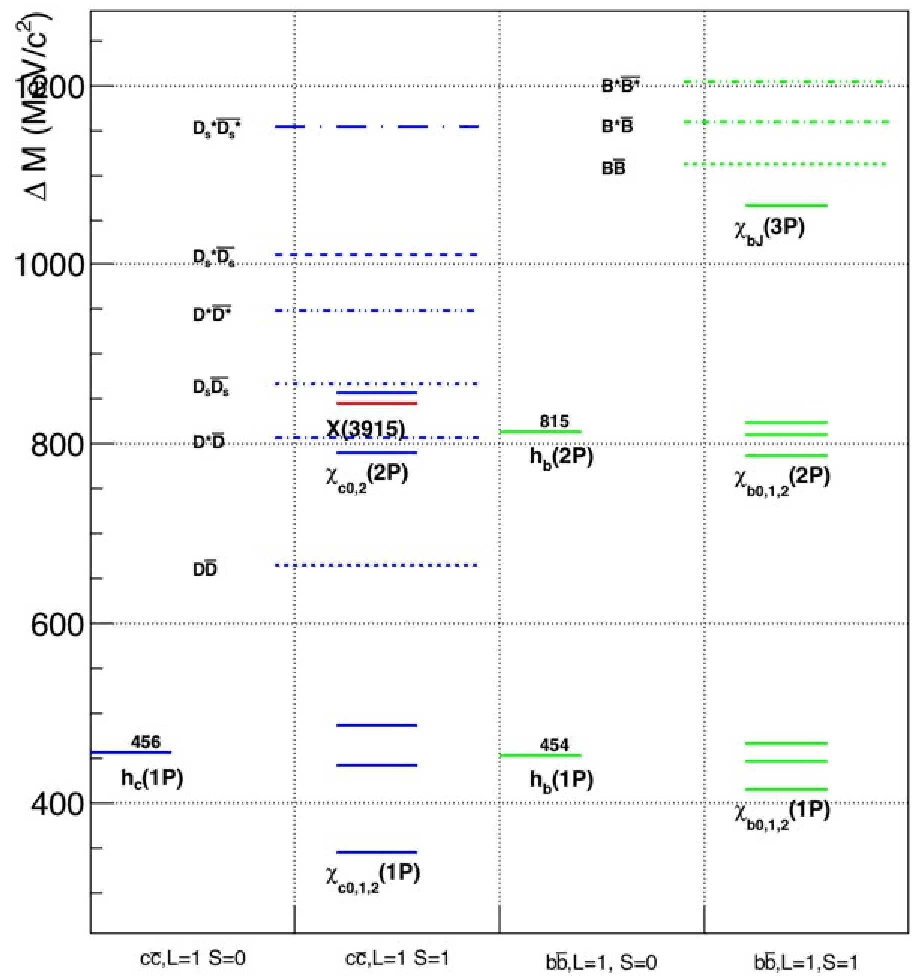


Open problems:
- **what is the X(3915) , then?**
- **where is the J=1 state?**

(X3872 is NOT a simple $c\bar{c}$)

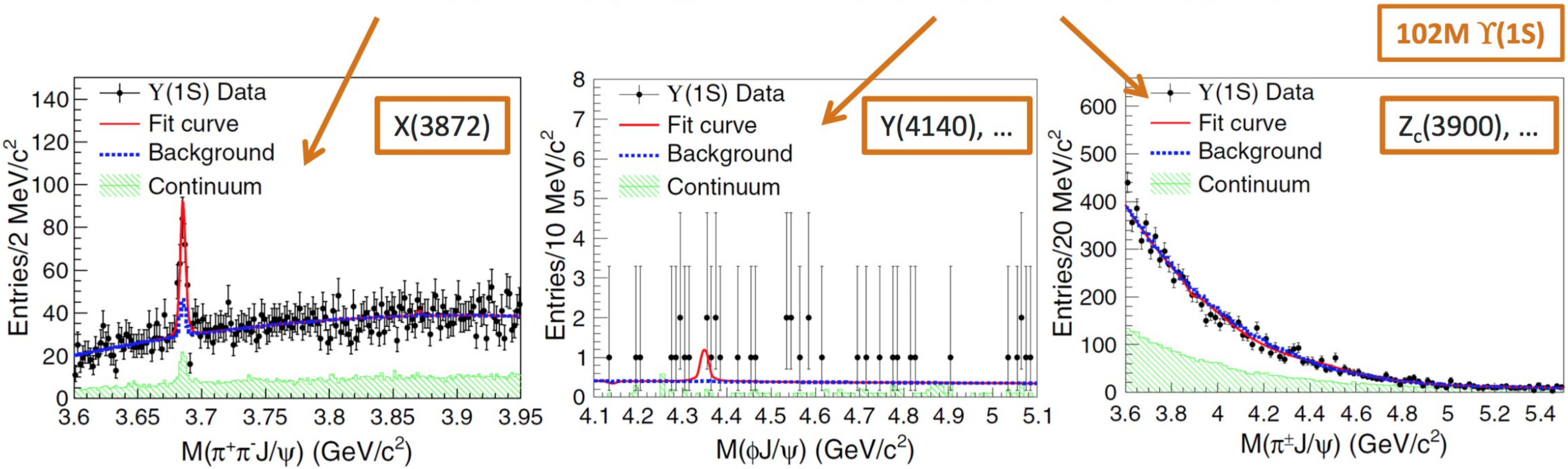
Search for XYZ states in Υ decays

*BELLE, PRD**93 (2016),112013***

Belle had already excluded XYZ production in two-body Y decays, here we extended the measurement to inclusive production

Best measurement of the spectrum of inclusive J/ψ and ψ+ production

Belle searched for : $\pi^+\pi^- J/\psi$, $\pi^+\pi^2\ \psi'$, $K^+K^- J/\psi$, $\phi J/\psi$, $\pi^\pm J/\psi$, $\pi^\pm \psi'$, $K^\pm J/\psi$



Search for XYZ states in Υ decays

*BELLE, PRD**93** **(2016),112013***

We set 90% CL Upper Limits for charmonium-like states at O(10^{-6}) to O(10^{-4}) level

X	N_{fit}	N_{up}	$\varepsilon(\%)$	$\sigma_{syst}(\%)$	$\Sigma(\sigma)$	$\mathcal{B}_R$
$X(3872) \to \pi^+\pi^- J/\psi$	8.8±6.5	18.6	0.89	7.1	1.6	$< 2.1 \times 10^{-5}$
$Y(4260) \to \pi^+\pi^- J/\psi$	−2.1±37.3	47.8	1.02	38.4	–	$< 4.6 \times 10^{-5}$
$Y(4260) \to \pi^+\pi^- \psi(2S)$	11.5±11.3	27.4	0.13	30.4	1.2	$< 2.1 \times 10^{-4}$
$Y(4360) \to \pi^+\pi^- \psi(2S)$	−4.8±10.4	14.7	0.16	39.7	–	$< 9.1 \times 10^{-5}$
$Y(4660) \to \pi^+\pi^- \psi(2S)$	−19.3±9.0	14.4	0.24	40.9	–	$< 5.9 \times 10^{-5}$
$Y(4260) \to K^+K^- J/\psi$	−16.0±9.6	5.8	1.43	28.7	–	$< 4.0 \times 10^{-6}$
$Y(4140) \to \phi J/\psi$	0.2±1.2	3.6	0.49	20.1	0.2	$< 7.3 \times 10^{-6}$
$X(4350) \to \phi J/\psi$	1.2±2.3	6.1	0.70	33.0	0.6	$< 8.6 \times 10^{-6}$
$Z_c(3900)^\pm \to \pi^\pm J/\psi$	9.2±18.7	35.4	1.44	27.0	0.4	$< 2.5 \times 10^{-5}$
$Z_c(4200)^\pm \to \pi^\pm J/\psi$	67.1±73.8	125.3	1.29	43.3	2.0	$< 9.9 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm J/\psi$	45.5±33.9	84.1	1.29	46.2	2.4	$< 6.6 \times 10^{-5}$
$Z_c(4050)^\pm \to \pi^\pm \psi(2S)$	−8.4±20.3	23.1	0.31	45.8	–	$< 7.4 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm \psi(2S)$	11.7±18.5	36.6	0.40	67.9	0.6	$< 9.0 \times 10^{-5}$
$Z_{cs}^\pm \to K^\pm J/\psi$	−31.3±13.7	30.5	2.95	68.7	–	$< 1.1 \times 10^{-5}$

Search for XYZ states in Υ decays

BELLE, PRD93 (2016),112013

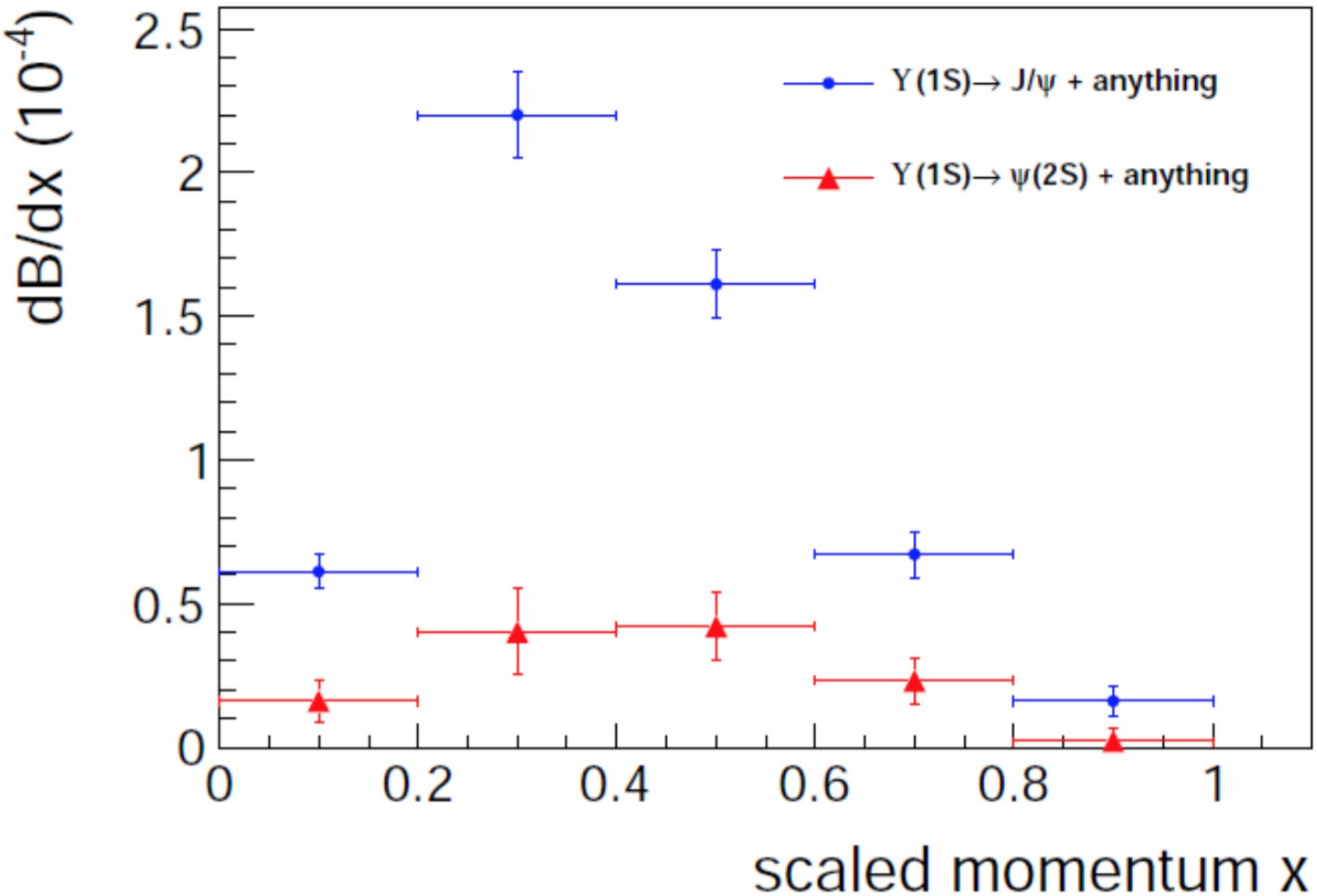
Inclusive production of J/ψ and ψ' from Υ(1S) decays: measurements

B(Υ(1S) → J/ψ +anything)

Belle: (5.25±0.13±0.25) x 10^{-4}
(PDG: (6.5±0.7) x 10^{-4})

B(Υ(1S) → ψ'+anything):

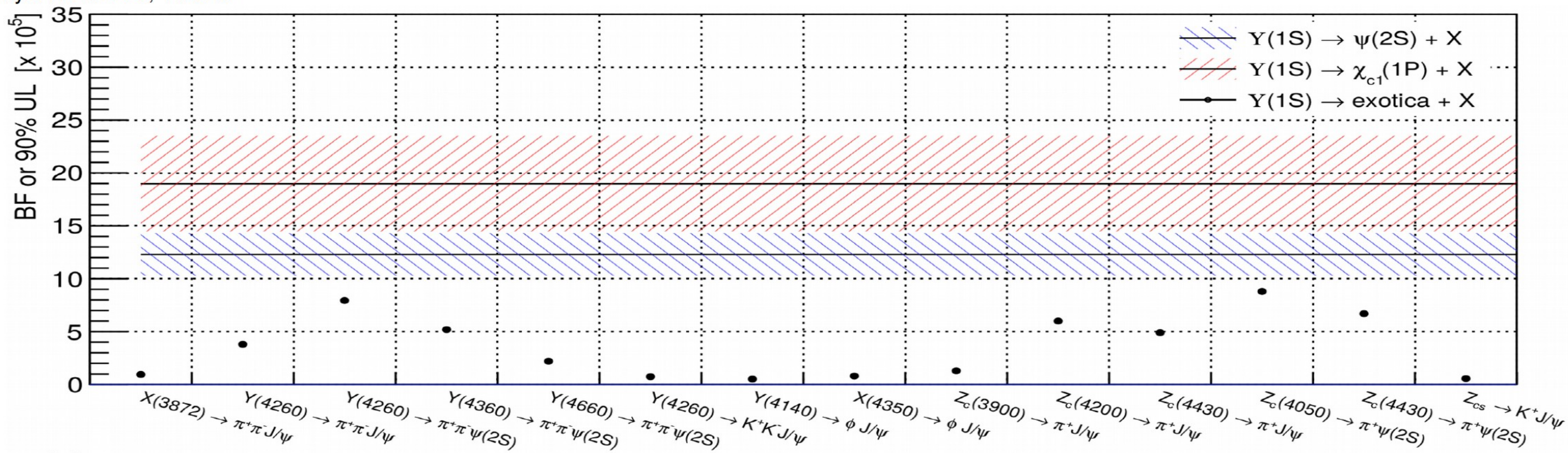
Belle: (5.25±0.13±0.25) x 10^{-4}
(PDG: (2.7±0.9) x 10^{-4}

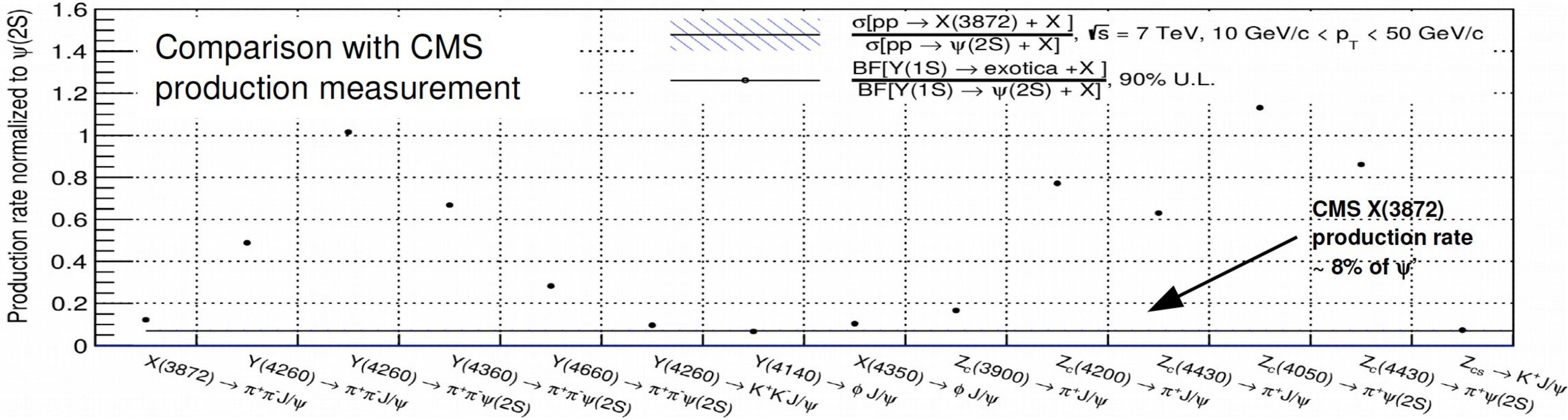


Search for XYZ states in Υ decays

We can compare these upper limits with our measured inclusive rates for production of known resonances, and link them to ψ' production rate in CMS: more statistics is needed.

Belle, Phys. Rev. D 93, 112013



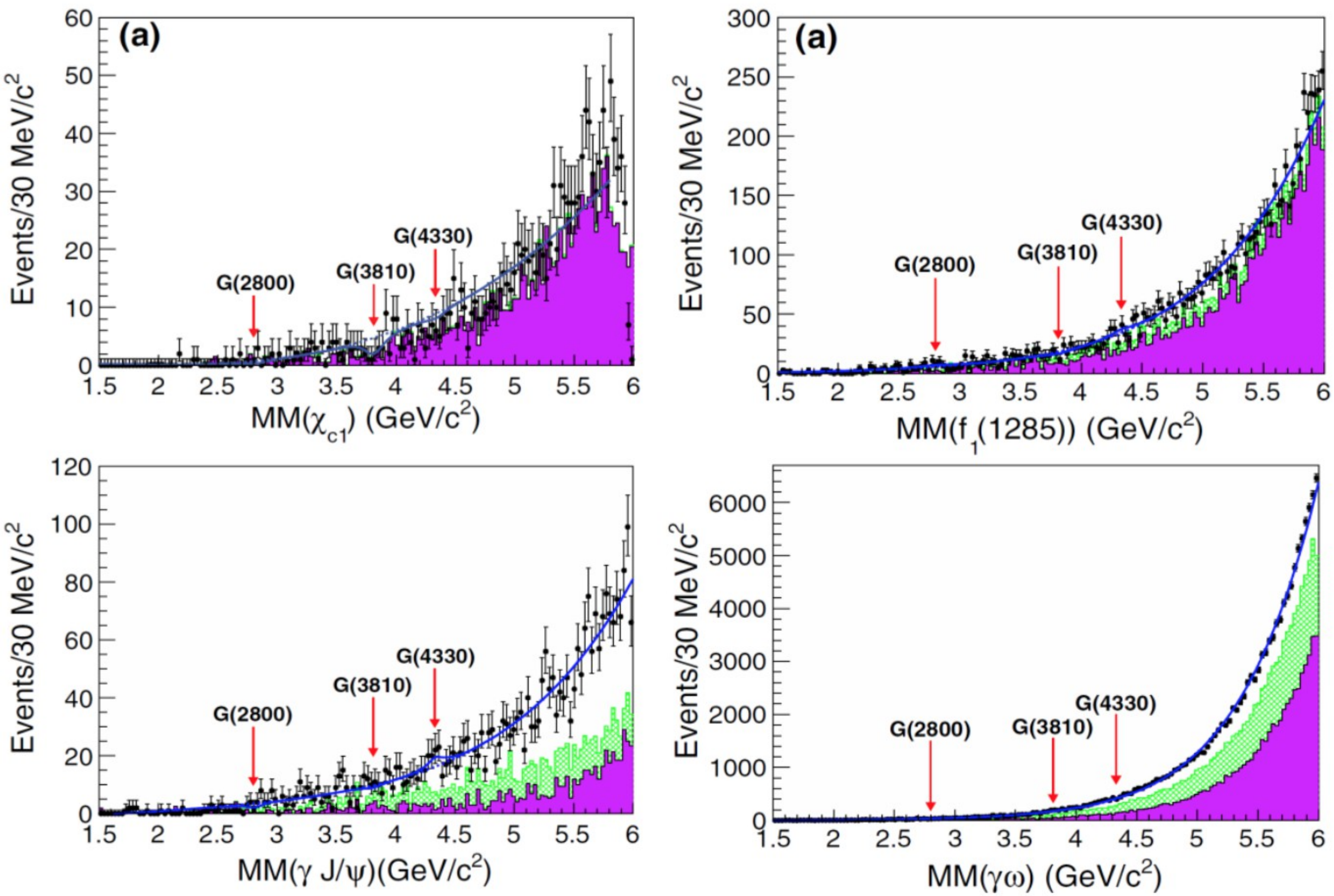


Search for Oddballs in Υ(1,2S) decays

PRD95 (2017),012001

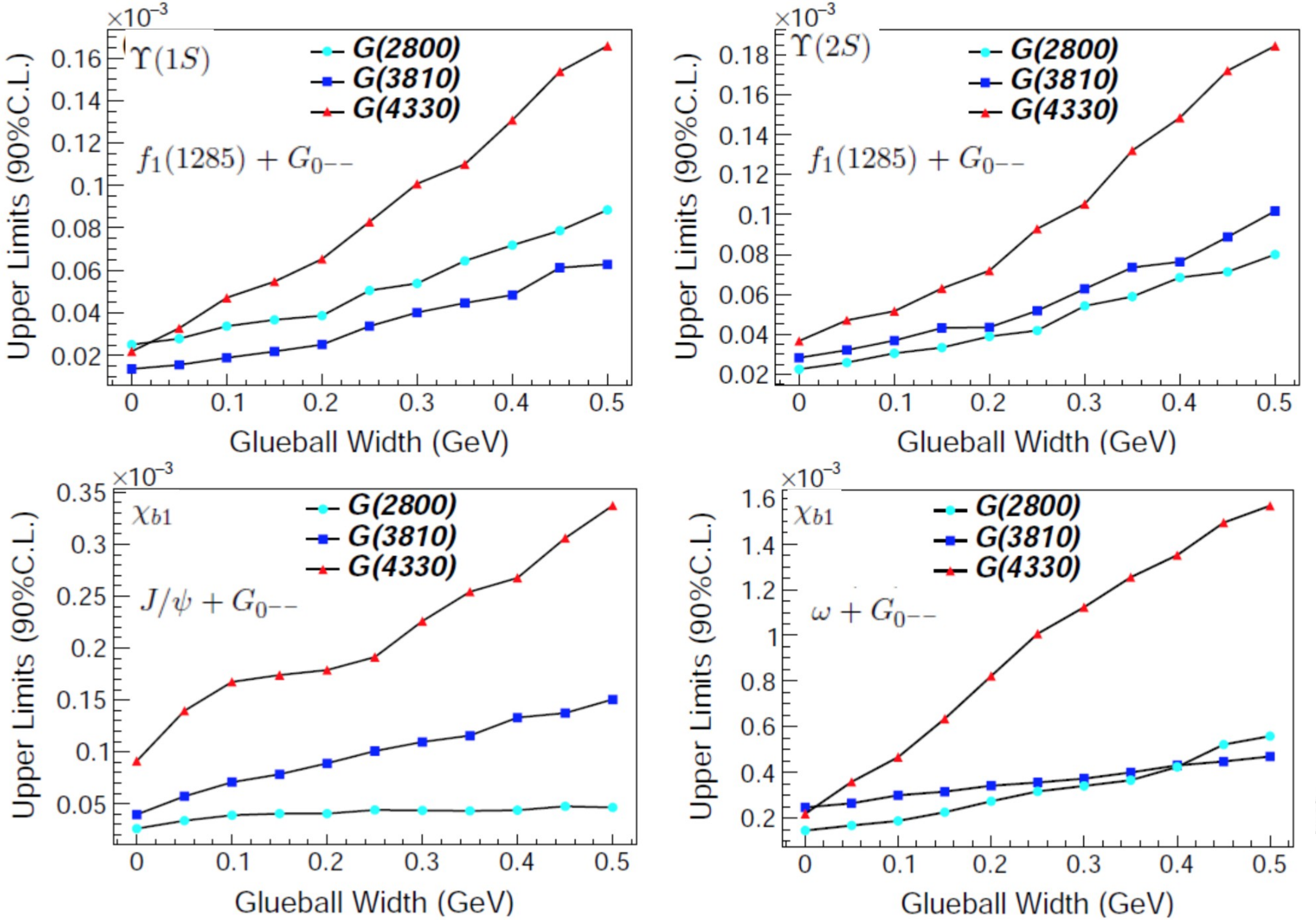
0^{--} glueballs (oddballs) are predicted by theory (PRL113, 221601 (2014), JHEP 1510 (2015) 137)
Belle has searched for them inclusively :

- in Υ(1,2S) decays, recoiling against χ_{c1} and $f_1(1285)$
- in $\chi_{bJ}(1P)$ decays , recoiling against J/ψ and ω



Search for Oddballs in Υ(1,2S) decays

PRD95 (2017),012001



Inclusive production of χ_{c1} in Υ(1,2S) decays

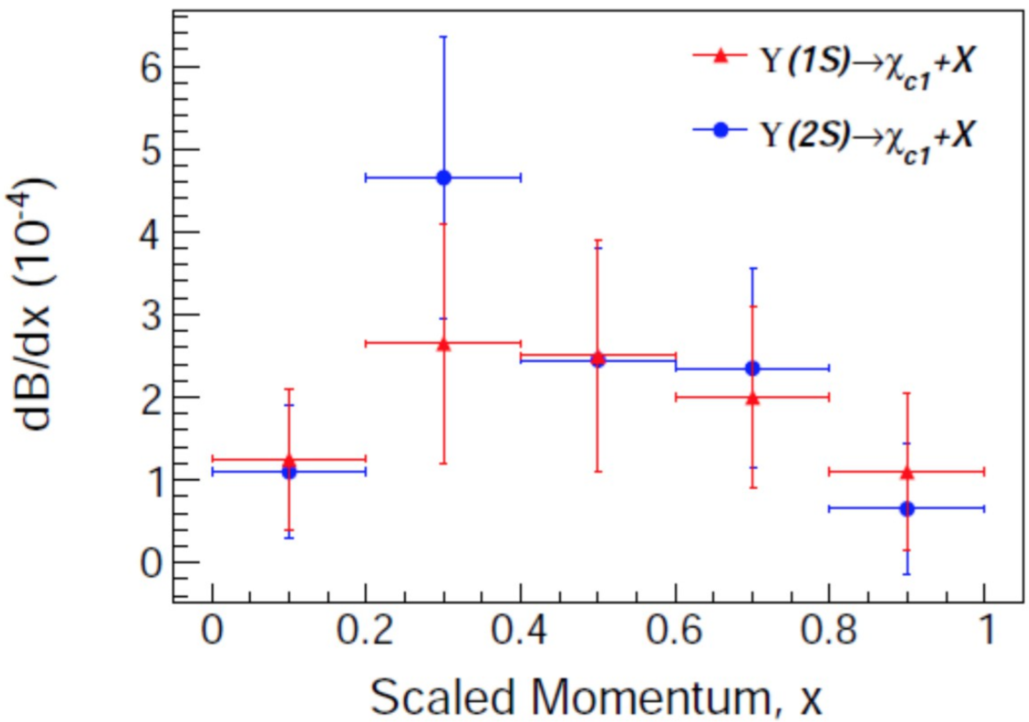
PRD95 (2017),012001

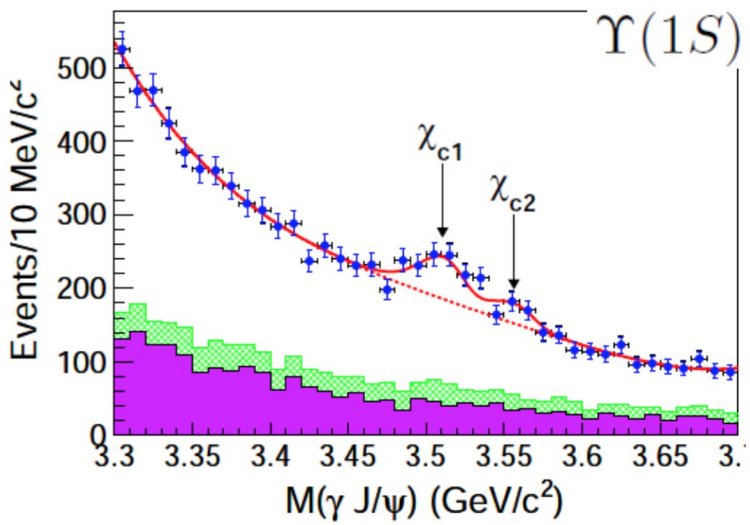
$$\mathcal{B}(\Upsilon(1S) \to \chi_{c1} + anything) = (1.90 \pm 0.43(stat.) \pm 0.14(syst.)) \times 10^{-4}$$

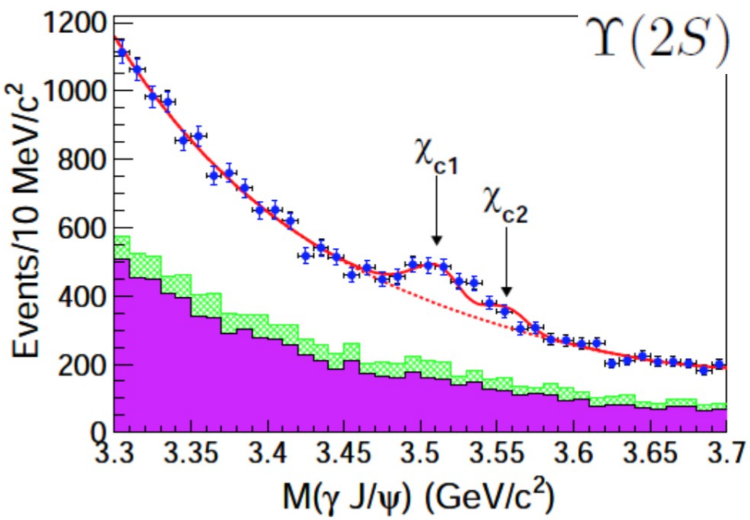
Best measurement

$$\mathcal{B}(\Upsilon(2S) \to \chi_{c1} + anything) = (2.24 \pm 0.44(stat.) \pm 0.20(syst.)) \times 10^{-4}$$

First measurement







In conclusion …

B-Factories largely contributed to a revolution in our understanding of the mechanisms of $c\bar{c}$ and $b\bar{b}$ production in the proximity of the double meson thresholds. This has led to the discovery of a new class of mesonic states made of four quarks : the Zc's and Zb's.

In addition, violation of the heavy quark spin symmetry (HQSS) has given us unexpected pathways to access heavy paraquarkonia from the broad resonances above open flavor thresholds : Y(4S) to ηh_b being the most striking case.

Belle has recently observed a significant HQSS violation at the Y(5S) energy, mainly in the $B_s{}^*B_s$ channel. Belle's unique datasets are still yielding many unexpected results.

The B-factories have also discovered a large number of exotic states, together with many missing parts of the charmonium and bottomonium spectra. Recently, Belle has probably found the J=0 member of the charmonium 2P multiplet, casting light in the very intriguing region in the proximity of the X(3872) resonance, whose nature is still not understood. This opens though new questions on the nature of the X(3915) charmonium like state.

Finally, Belle is continuously searching other processes to produce for the newly discovered XYZ states . In narrow Upsilon decays , we set a large number of upper limits on inclusive production of XYZ states and improved the BR's for inclusive production of conventional charmonia. Furthermore, Belle set limits on production of 0^{--} glueballs from Y(1,2S).

谢谢

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