International Conference on Particle Physics and Astrophysics,
25 October 2018, Moscow

Recent results on bottomonium(-like) states from Belle

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Outline:

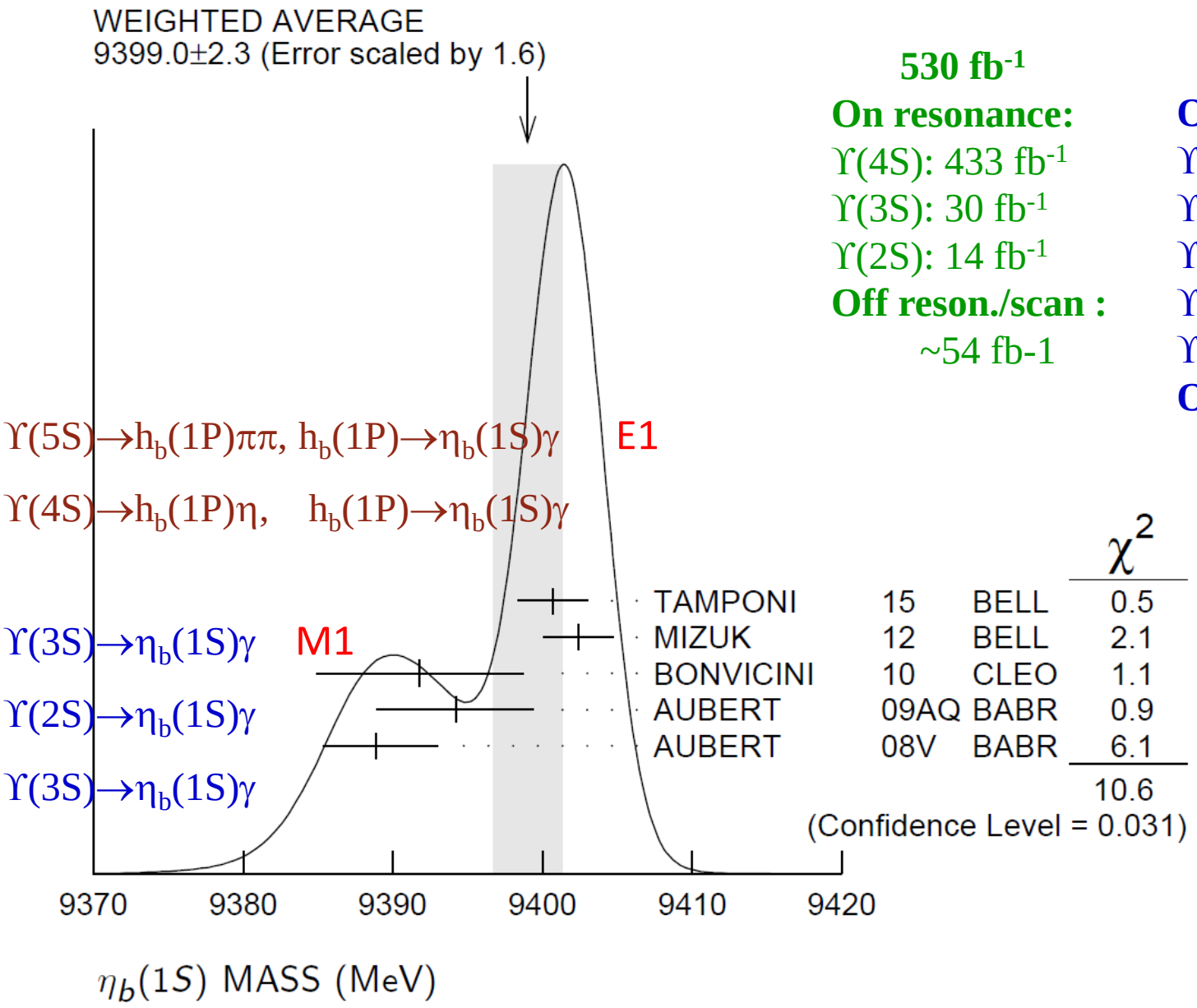
Observation of $\Upsilon(2S) \to \eta_b(1S)\,\gamma$ arXiv:1807.01201

Observation of $\Upsilon(4S) \to \Upsilon(1S)\,\eta'$ PRL 121,062001(2018)

Energy scan of $e^+e^- \to \chi_{bJ}(1P)\,\omega$ arXiv:1806.06203

Observation of $\Upsilon(2S) \to \eta_b(1S)\,\gamma$

Introduction



530 fb^{-1}

On resonance:

Υ(4S): 433 fb^{-1}

Υ(3S): 30 fb^{-1}

Υ(2S): 14 fb^{-1}

Off reson./scan :

~54 fb-1

> 1 ab^{-1}

On resonance:

Υ(5S): 121 fb^{-1}

Υ(4S): 711 fb^{-1}

Υ(3S): 3 fb^{-1}

Υ(2S): 24 fb^{-1}

Υ(1S): 6 fb^{-1}

Off reson./scan :

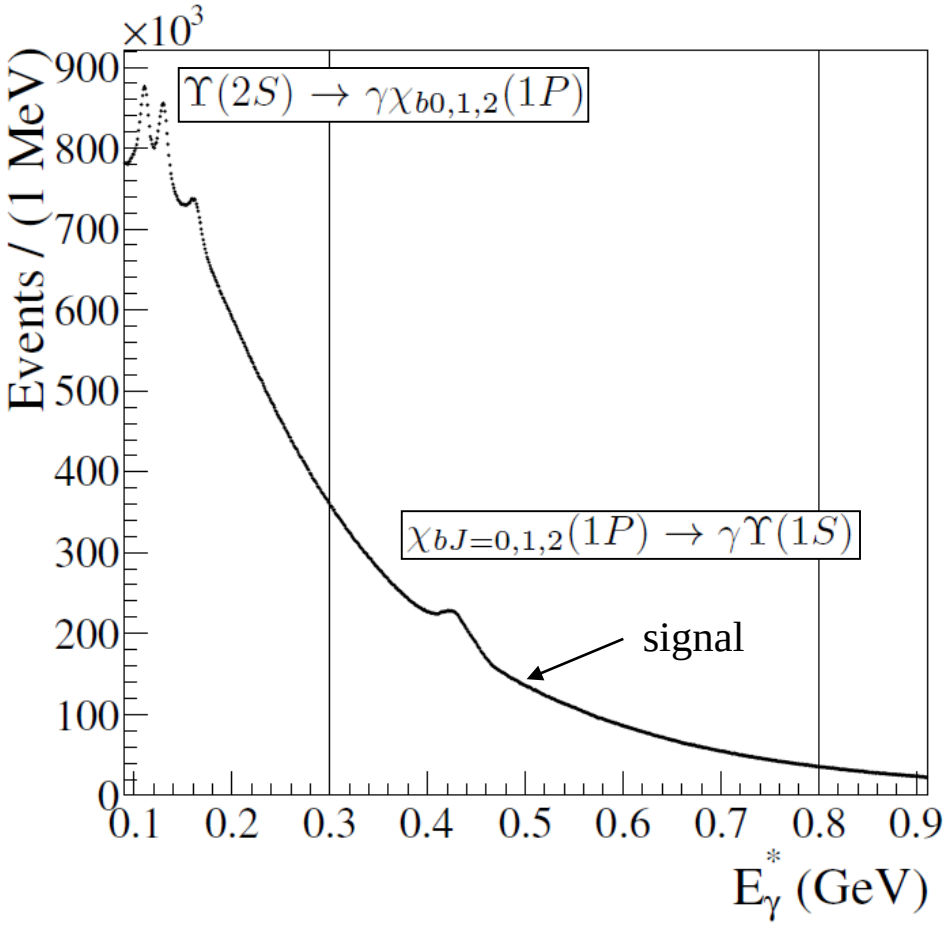
~100 fb-1

Method

Use data collected at $\Upsilon(2S)$.
To search for $\Upsilon(2S) \to \eta_b(1S)\,\gamma$ plot energy spectrum of ALL photons.

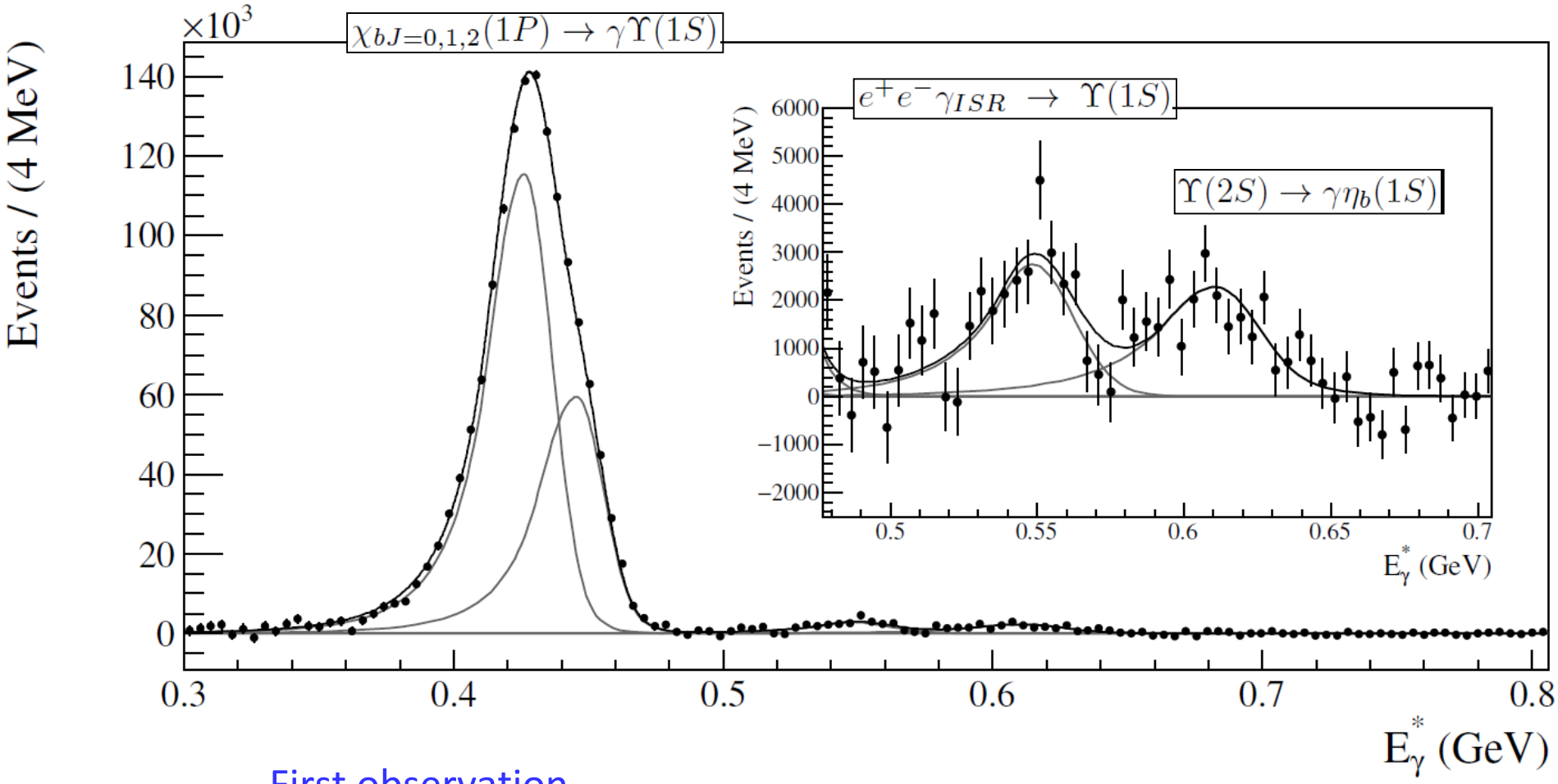
Selection:

good quality of cluster
barrel ECL only
π^0 veto
continuum suppr. via thrust



Result

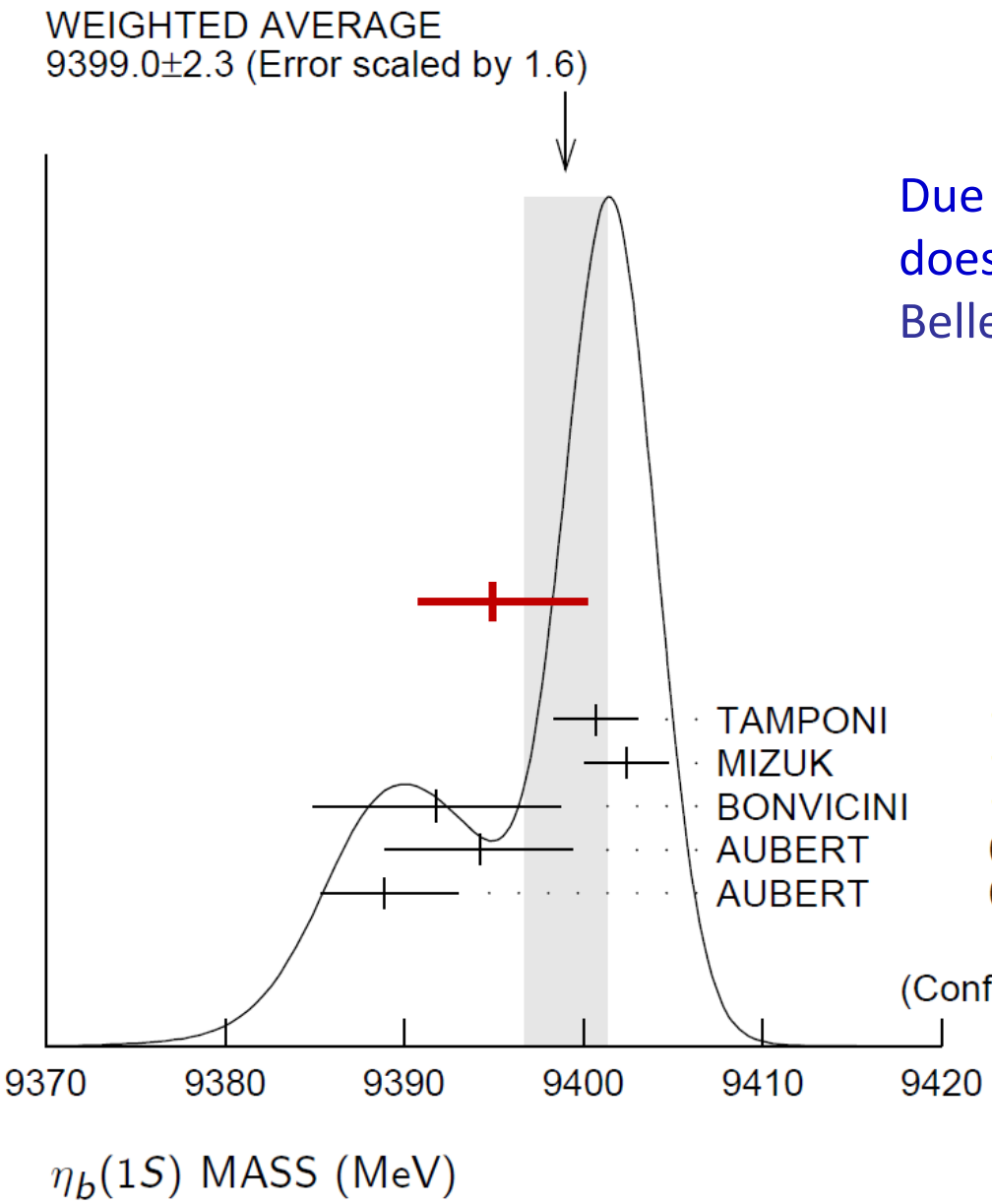
arXiv:1807.01201



First observation

$$m_{\eta_b(1S)} = 9394.8^{+2.7+4.5}_{-3.1-2.7}\ \mathrm{MeV}/c^2$$

Result



			χ^2
TAMPONI	15	BELL	0.5
MIZUK	12	BELL	2.1
BONVICINI	10	CLEO	1.1
AUBERT	09AQ	BABR	0.9
AUBERT	08V	BABR	6.1
			10.6

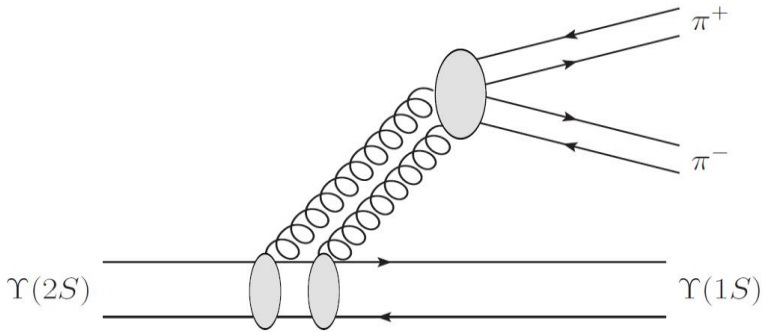
(Confidence Level = 0.031)

Due to large uncertainty Belle result does not settle the puzzle.
Belle-II should study this.

Observation of $\Upsilon(4S) \to \Upsilon(1S)\,\eta'$

Transition	Partial width (keV)
$\Upsilon(2S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	5.7 ± 0.5
$\Upsilon(1S)\,\eta$	$(9.3 \pm 1.5) \times 10^{-3}$
$\Upsilon(3S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	0.89 ± 0.08
$\Upsilon(1S)\,\eta$	$< 2 \times 10^{-3}$
$\Upsilon(2S)\,\pi^+\pi^-$	0.57 ± 0.06
$\Upsilon(4S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	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
$\Upsilon(5S) \to$	
$\Upsilon(1S)\,\pi^+\pi^-$	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

In bottomonium hadronic transitions are OZI suppressed:



$\Upsilon(5S)$, $\Upsilon(6S)$ – violation of OZI-rule.

$\pi^+\pi^-$ transitions: E1E1 gluons,

η transitions: E1M2 gluons

– Heavy Quark Spin Symmetry suppressed

$\Upsilon(4S)$, $\Upsilon(5S)$ – violation of HQSS.

$\Upsilon\eta$ / $\Upsilon\pi^+\pi^-$, $\chi_{b1}\omega$ / $\chi_{b2}\omega$

Bondar, RM, Voloshin
MPLA32,1750025(2017)

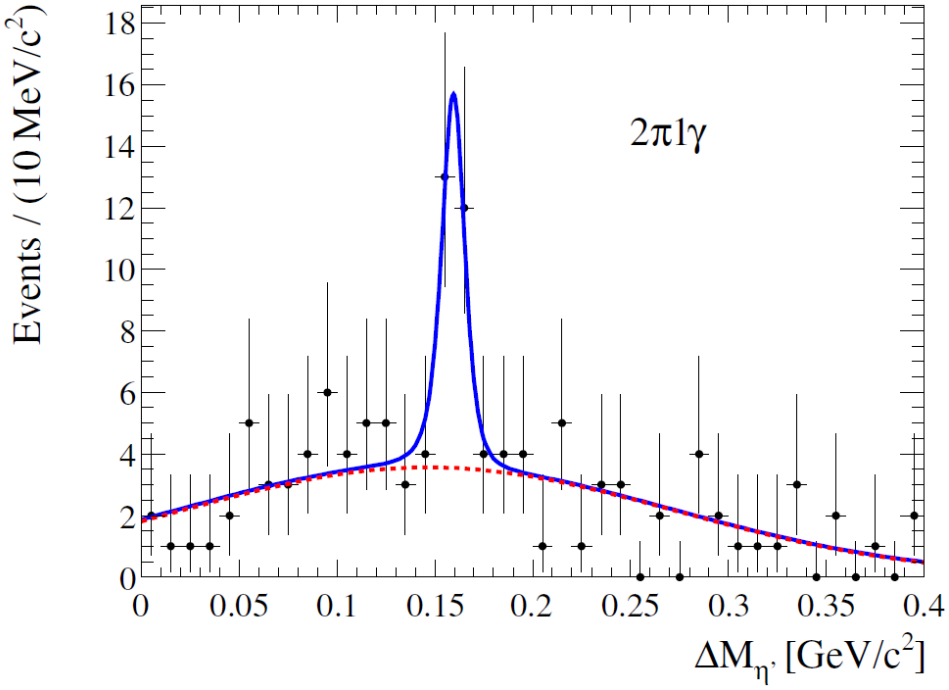
⇐ B meson loops

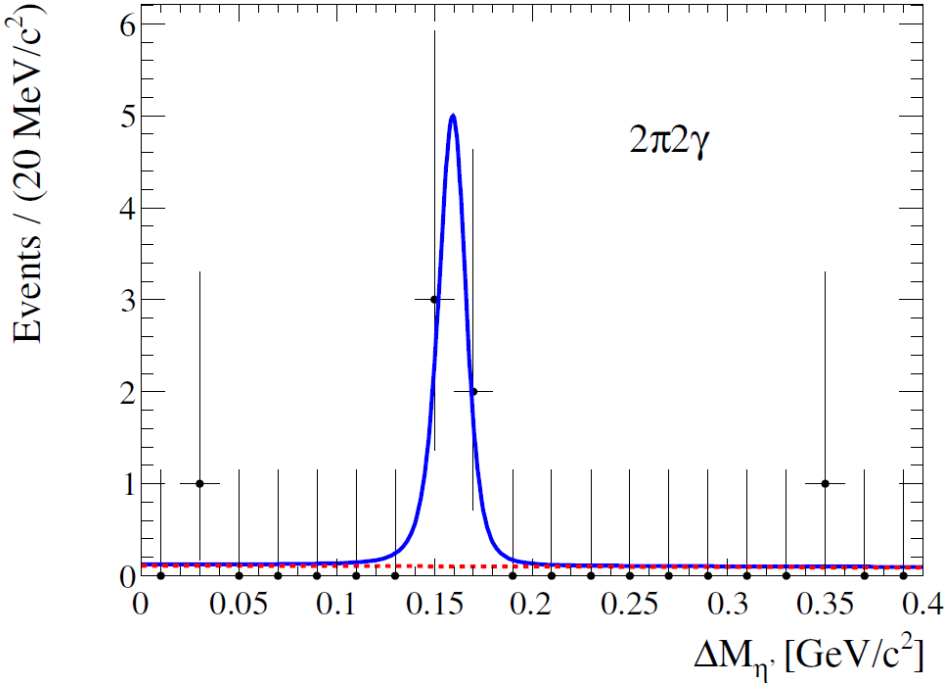
Method

$\Upsilon(4S) \to \Upsilon(1S)\,\eta'$ $\quad \Upsilon(1S) \to \mu^+\mu^-$ $\quad \eta' \to \rho\,\gamma \to \pi^+\pi^-\,\gamma$

$\to \pi^+\pi^-\,\eta \to \pi^+\pi^-\,\gamma\gamma$

PRL 121,062001(2018)





$$\Delta M_{\eta'} = M(\Upsilon(4S)) - M(\Upsilon(1S)) - M(\eta')$$

Results

Transition	Partial width (keV)
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$\Upsilon(4S) \to \Upsilon(1S)\,\eta'$ 0.70 ± 0.18

$$\mathcal{B}(\Upsilon(4S) \to \eta'\Upsilon(1S)) =$$
$$(3.43 \pm 0.88(\text{stat.}) \pm 0.21(\text{syst.})) \times 10^{-5}$$

$$R_{\eta'/\eta} = 0.20 \pm 0.06$$

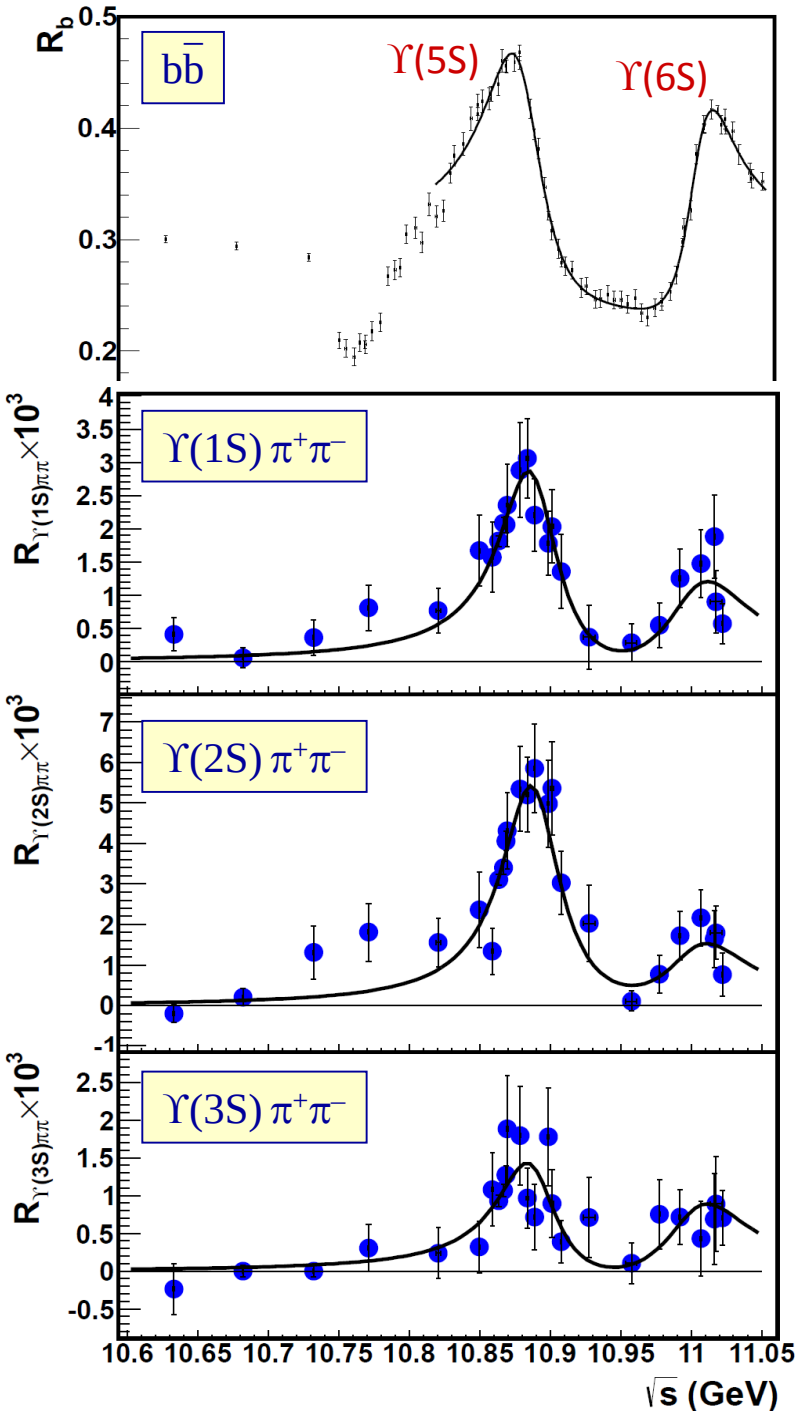
Predictions:

M. B. Voloshin, Mod. Phys. Lett. A **26**, 773 (2011)

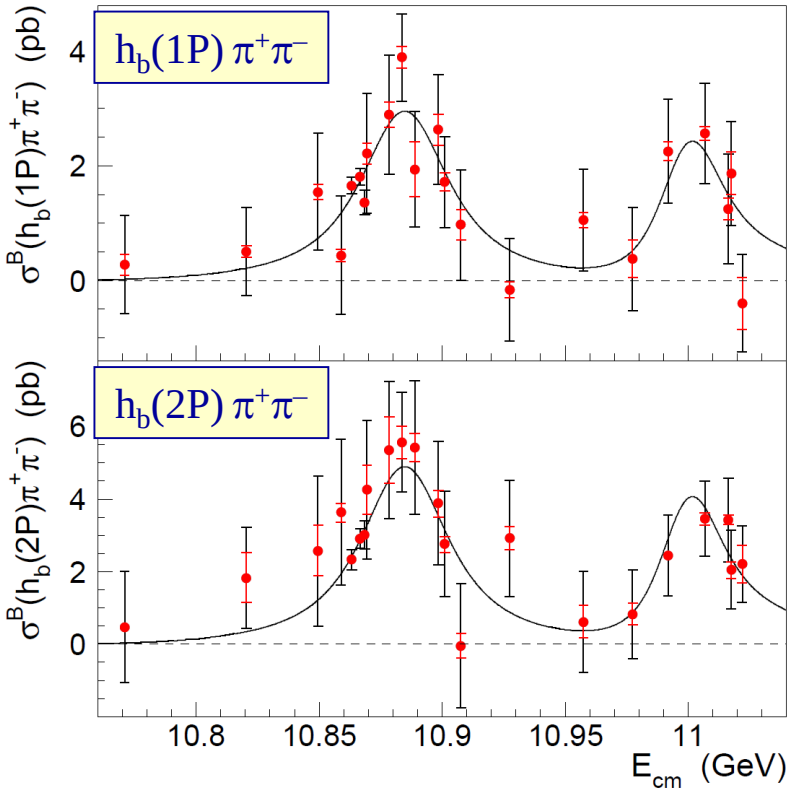
emission via hadron loops: $0.2 \le R_{\eta/\eta'} \le 0.6$
emission via gluons: enhanced by a factor 25

Energy scan of $e^+e^- \to \chi_{bJ}(1P)\,\omega$

Belle energy scans



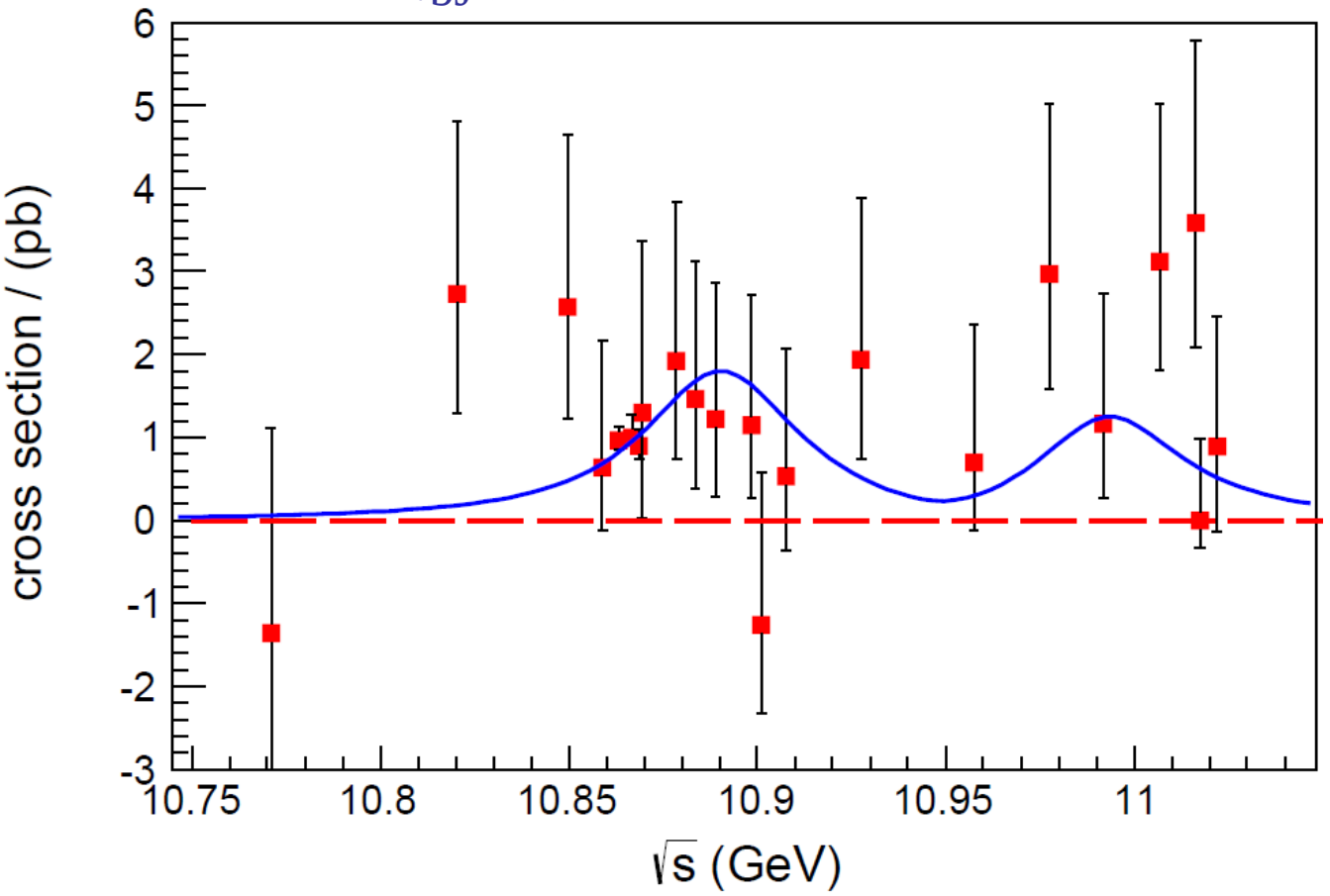
PRL117,142001(2016) PRD93,011101(2016)



$e^+e^- \to \Upsilon(nS)\,\pi^+\pi^-$ and
$e^+e^- \to h_b(mP)\,\pi^+\pi^-$
proceed via $\Upsilon(5S)$, $\Upsilon(6S)$

Results

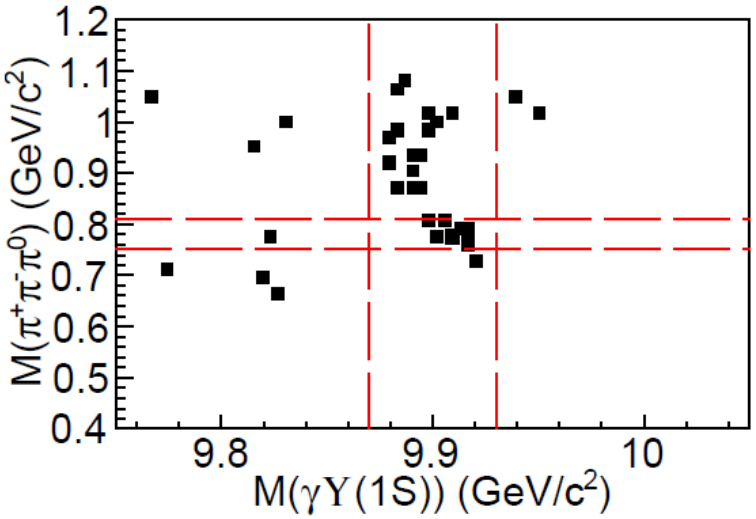
$e^+e^- \to \chi_{bJ}(1P)\,\omega$

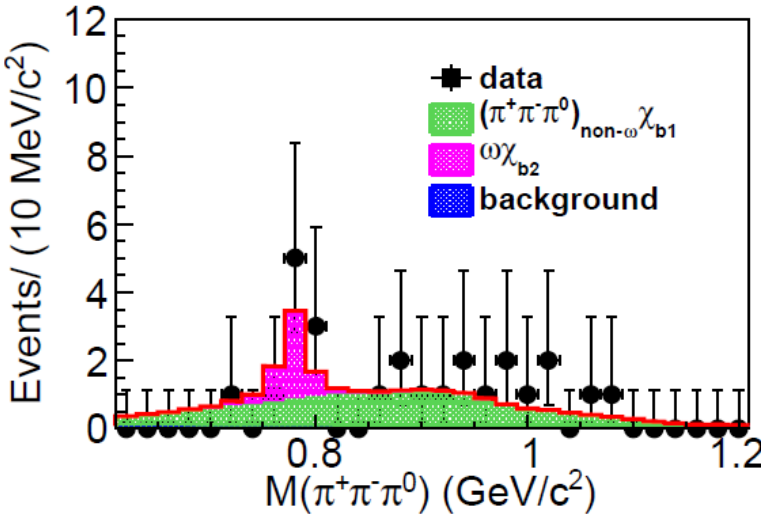


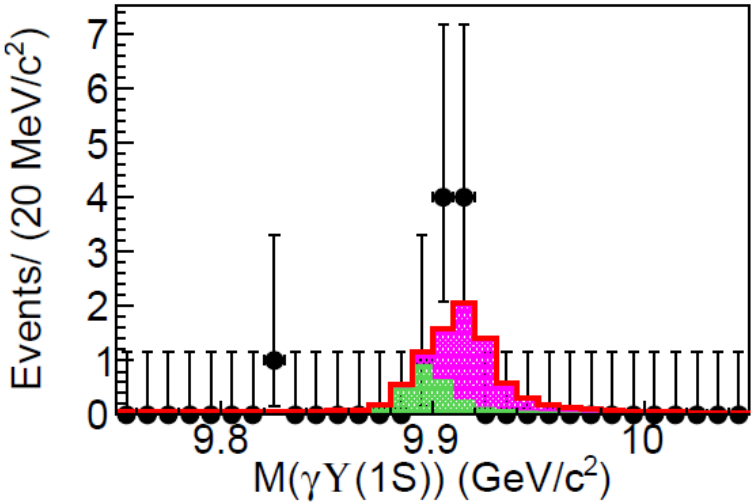
Production mechanism remains unestablished.

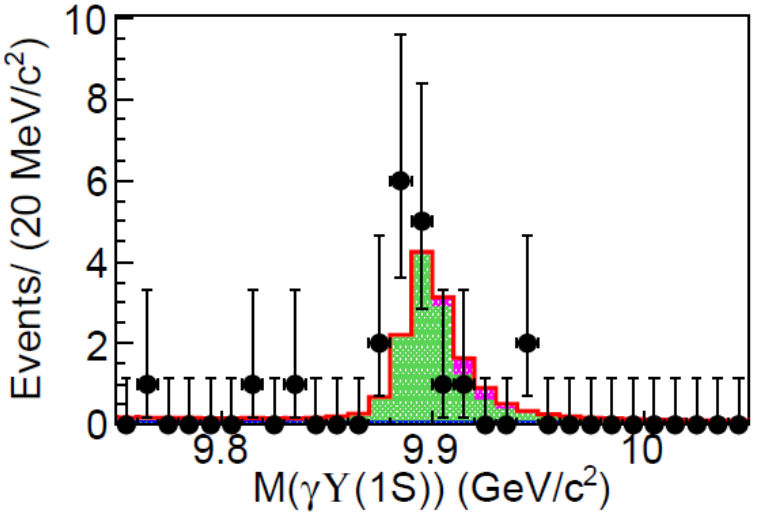
Results

Combined data in the $\Upsilon(6S)$ region









observation of $(\pi^+\pi^-\pi^0)_{\mathrm{non}-\omega}\chi_{b1}$ evidence for $\omega\chi_{bJ}$

Conclusions

Analysis of Belle data on bottomonium is on-going

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Observation of $\Upsilon(4S) \to \Upsilon(1S)\,\eta'$ PRL 121,062001(2018)

Energy scan of $e^+e^- \to \chi_{bJ}(1P)\,\omega$ arXiv:1806.06203

On-going Belle analyses (to be reported soon):

Energy scan of BB, BB*, B*B*,.. cross sections

Update on line shape of Z_b states in elastic channels

Search for $\Upsilon(5S) \to W_{bJ}\,\gamma \to (\Upsilon(1S)\pi^+\pi^-)\,\gamma$

Search for $\Upsilon(4S,5S) \to \eta_b(1S,2S)\,\omega$ …

Your wishes on what should be (still) studied at Belle ?