Quarkonium Working Group
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Decays of bottomonium states at BELLE

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(on behalf of the BELLE Collaboration)

Outline of contents

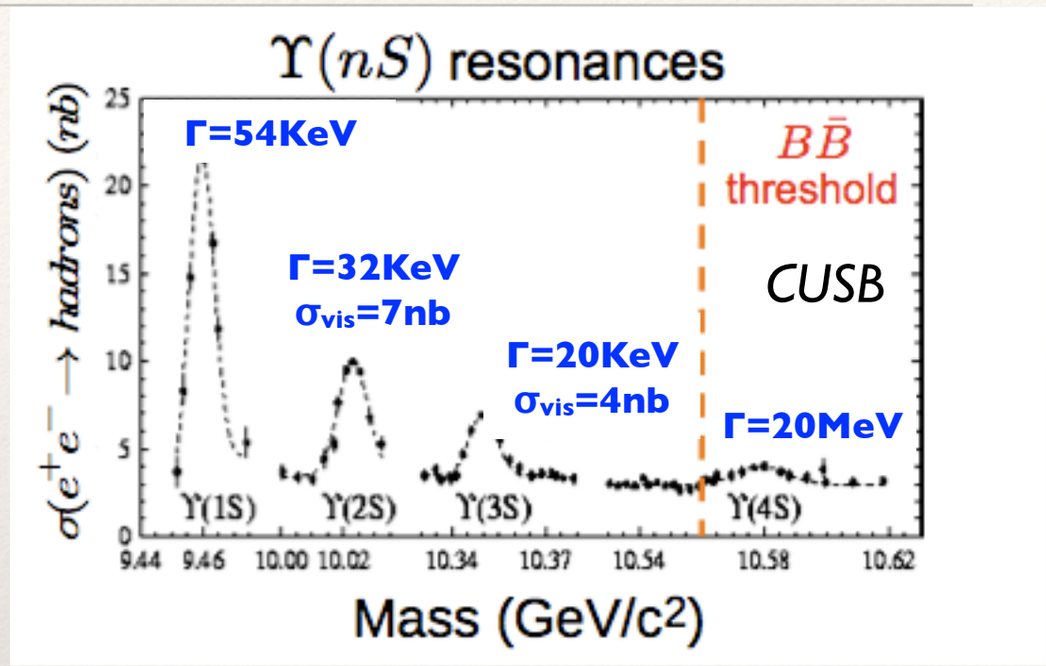
- Study of $\chi_{bJ}(1P)$ states in radiative $\Upsilon(2S)$ decays (Preliminary, **NEW!**, arXiv: 1606.01276)
- $\Upsilon(1S, 2S) \longrightarrow \Lambda\overline{\Lambda} + X$ (Preliminary)
- $\Upsilon(4S) \longrightarrow \eta h_b(1P)$ (PRL 115 (2015) 142001)

See K. Chilikin's talk this afternoon

- $\Upsilon(1S) \longrightarrow$ charmonium (and search for X,Y,Z) (arXiv:1605.00990)

The BELLE experiment

- Operated at **KEKB** asymmetric e^+e^- collider, run at the energies of the different Υ resonances (below and above $B\bar{B}$ threshold)
- Collected the largest data samples at almost all of these energies (the only exception being $\Upsilon(3S)$)

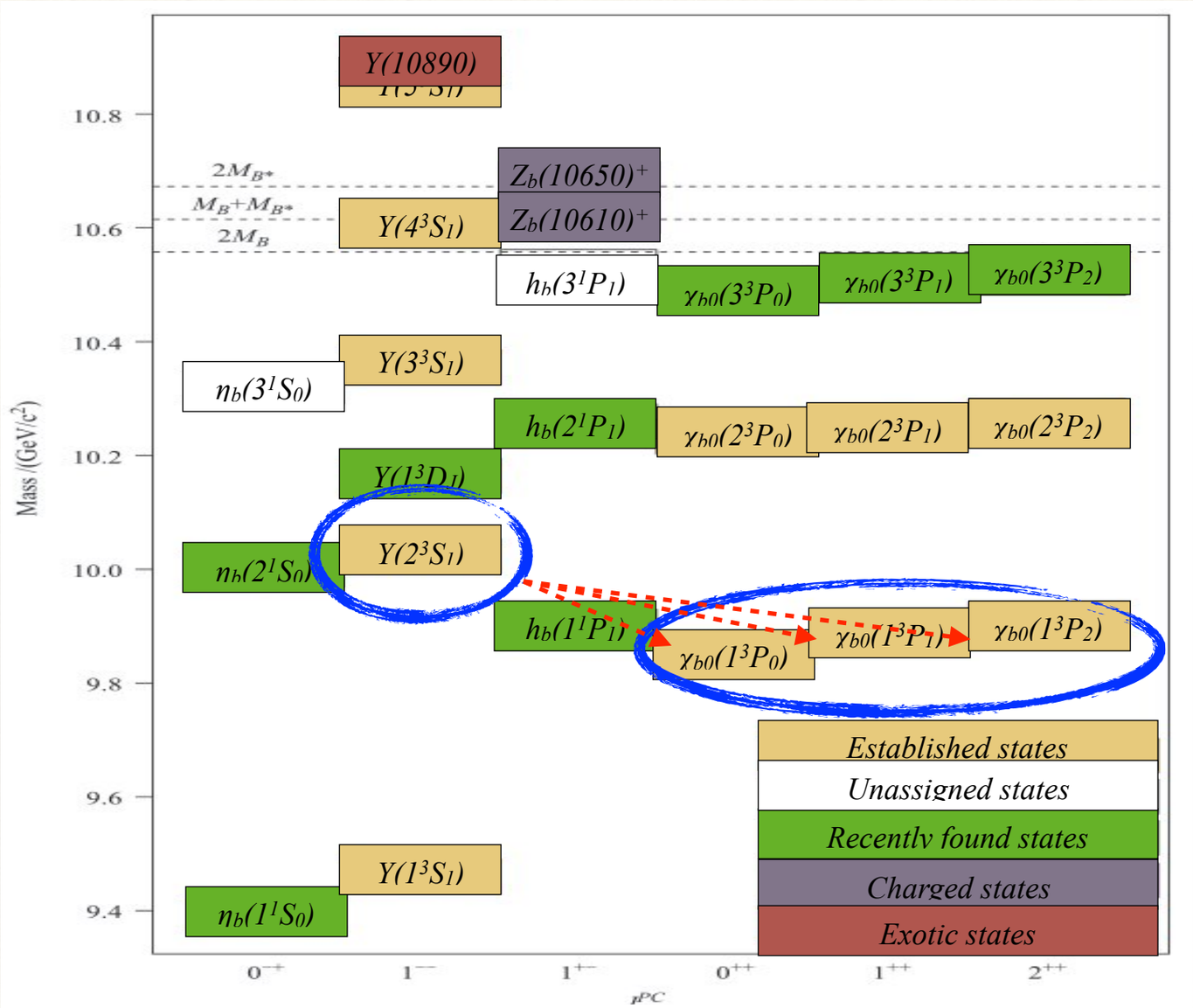


- **711 fb^{-1}** at $\Upsilon(4S)$
- **3 fb^{-1}** at $\Upsilon(3S)$
- **24 fb^{-1}** at $\Upsilon(2S)$
- **6 fb^{-1}** at $\Upsilon(1S)$
- **~100 fb^{-1}** off resonance/scan above threshold
- **121 fb^{-1}** at $\Upsilon(5S)$

arXiv:1606.01276

$\Upsilon(2S) \longrightarrow \gamma\chi_{bJ}(1P)$

- $\chi_{bJ}(1P)$ accessed through electric dipole radiative transitions from the $\Upsilon(2S)$
- $\chi_{b0}(1P)$ and $\chi_{b2}(1P)$ —> 2γ or 2 gluons
  - various theoretical predictions assuming $\Gamma_{tot} \sim \Gamma_{2g}$
  - all predict $\chi_{b0}(1P)$ to be wider than $\chi_{b2}(1P)$
- $\chi_{b1}(1P)$ —> 2g allowed if one of the gluons is virtual (—> $q\bar{q}$ pair)



- Analysing: **$\Upsilon(2S) \longrightarrow \gamma\chi_{bJ}(1P)$, $\chi_{bj}(1P) \longrightarrow h_i$**
- h_i is a light ($\pi^{\pm}$,$K^{\pm}$,K^0_S,p + 1,2 π^0) hadronic state

arXiv:1606.01276

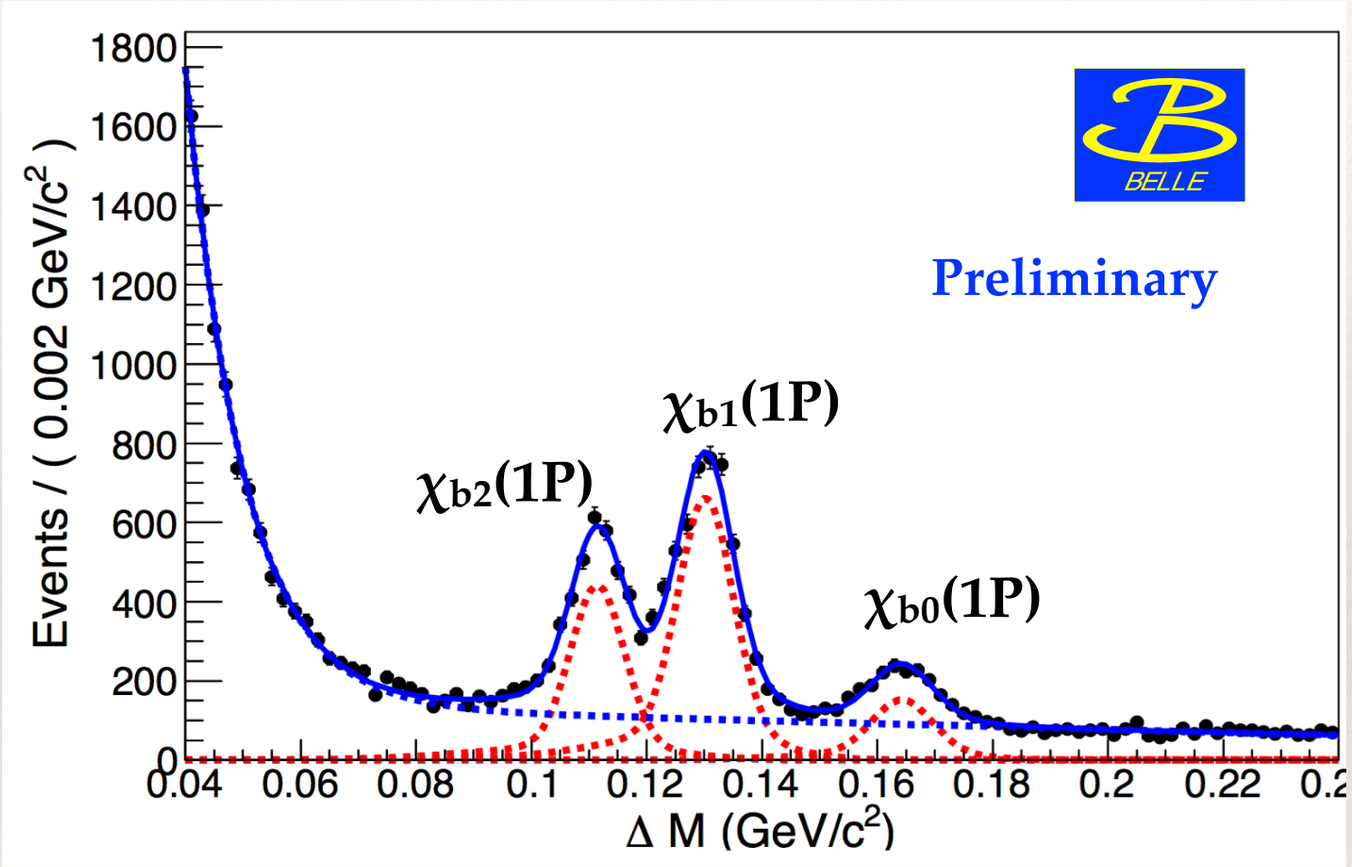
$\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$

- **74** $\chi_{bJ}(1P)$ hadronic decay modes are reconstructed, using charged particles ($\pi^{\pm}$,$K^{\pm}$,$p/\bar{p}$), K^0_S and π^0
- Selection on:
  - impact parameter, number of charged tracks, likelihood ratios for particle identification;
  - good-quality photons with E_γ>30 MeV, in the barrel region, not matched with charged tracks' trajectories, and not coming from a π^0 decay
- **Kinematic fit** (4C) improving mass resolution —> χ^2/NDF used as further selection and to select the best candidate if multiple ones are present

arXiv:1606.01276

$\Upsilon(2S) \to \gamma \chi_{bJ}(1P)$

- Fit to data on **$\Delta M = M(\Upsilon(2S)) - M(\chi_{bJ}(1P))$**
- Sum over all the final states:



Signal	Yield	Mass in MeV/c^2
$\chi_{b0}(1P)$	1197 ± 58	9858.98 ± 0.33
$\chi_{b1}(1P)$	4747 ± 94	9893.05 ± 0.12
$\chi_{b2}(1P)$	3064 ± 87	9911.81 ± 0.16

- **41 modes** (out of 74 analysed) have a significance of at least **5 standard deviations** in at least 1 of the $\chi_{bJ}(1P)$ states
- 85 decay modes (27, 28, 30 for J = 0, 1, 2)
- Results consistent and more precise than previous CLEO's measurement of 26 decay modes

CLEO Coll., PRD 78, 091103(2008)

- Product branching fractions:
  - precision of the measurement dominated by the effect of possible intermediate decays (ρ,ϕ,ω,K*…)

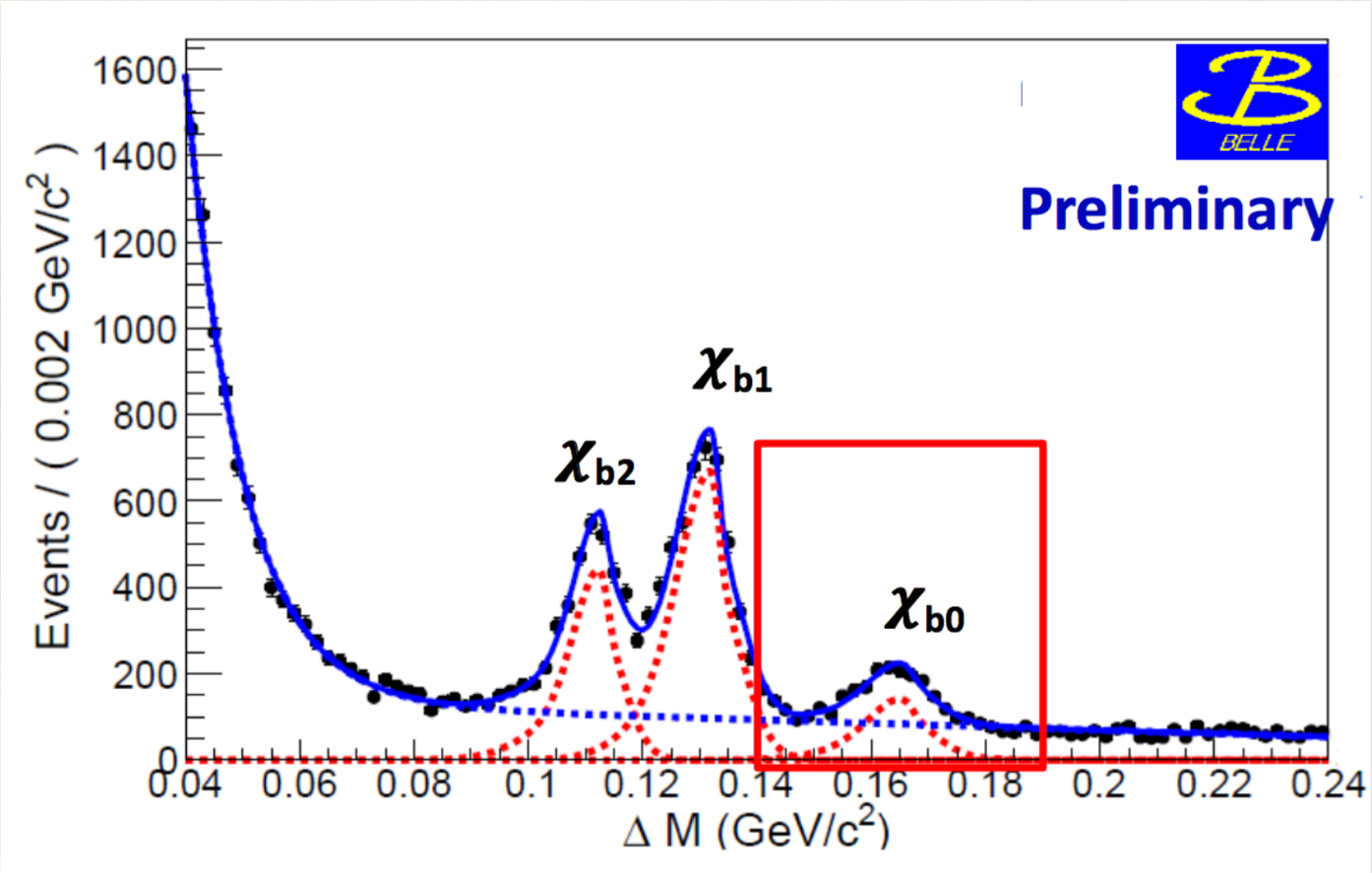
arXiv:1606.01276

$\chi_{b0}(1P)$ width

- Various predictions for $\chi_{b0}(1P)$ width: the largest among the $\chi_{bJ}(1P)$ states, width may be above 2 MeV

$\Gamma[\chi_{b0}(1P)]$	$\Gamma[\chi_{b2}(1P)]$	Theoretical approach used
431^{+45}_{-49}	214^{+1}_{-0}	Covariant light-front approach
887	220	Relativistic (Salpeter method) corrections
960(2740)	330(250)	Perturbative (nonperturabtive) calculations
653	109	Relativistic quark model
2150(2290)	220(330)	QCD potential (alternative treatment)
672	123	Relativistic quark model

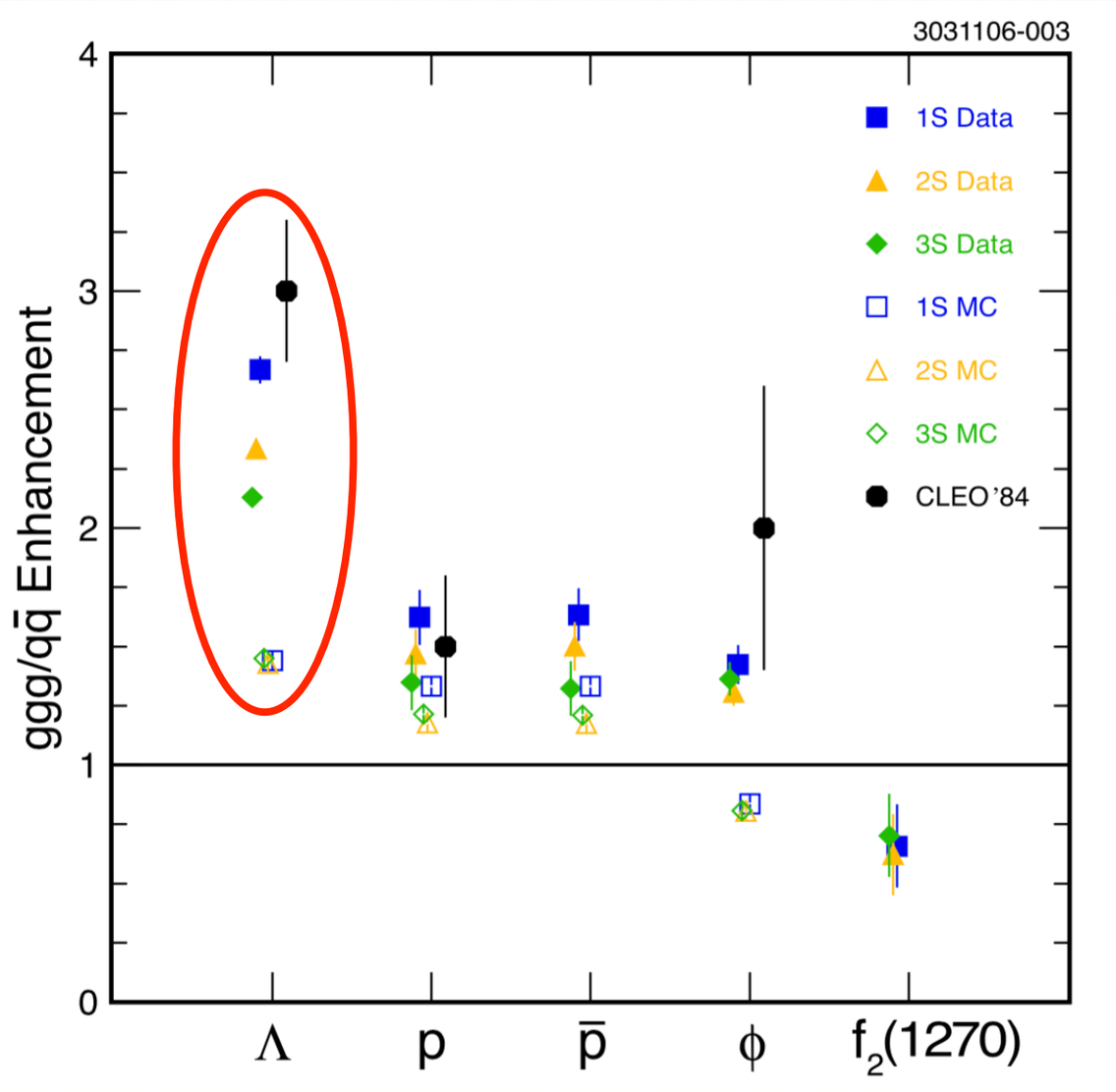
- Using the 41 modes with >5σ
- Detector resolution modeled with sum of an asymmetric Gaussian + a Gaussian function, convoluted with a Breit-Wigner function
- Absence of a statistically significant result
- **90% CL UL set at < 2.4 MeV**



BELLE Preliminary

$\Upsilon(1S,2S) \longrightarrow \Lambda\bar{\Lambda} + X$

- Enhancement (of a factor 3) of the inclusive production rate of Λ in the $\Upsilon(nS) \longrightarrow ggg$ decays with respect to the non resonant $e^+e^- \longrightarrow q\bar{q}$, at same center of mass energy
- Observed for Λ CM momentum < 2 GeV/c
- Enhancement qualitatively predicted by MC, but severely underestimated
- Using **Y(1S) and Y(2S) datasets**
- Reconstructing **48 modes** X made up with $\pi^{\pm}$, $K^{\pm}$, $p/\bar{p}$ and π^0



CLEO Coll., PRD 76, 012005 (2007)

BELLE Preliminary

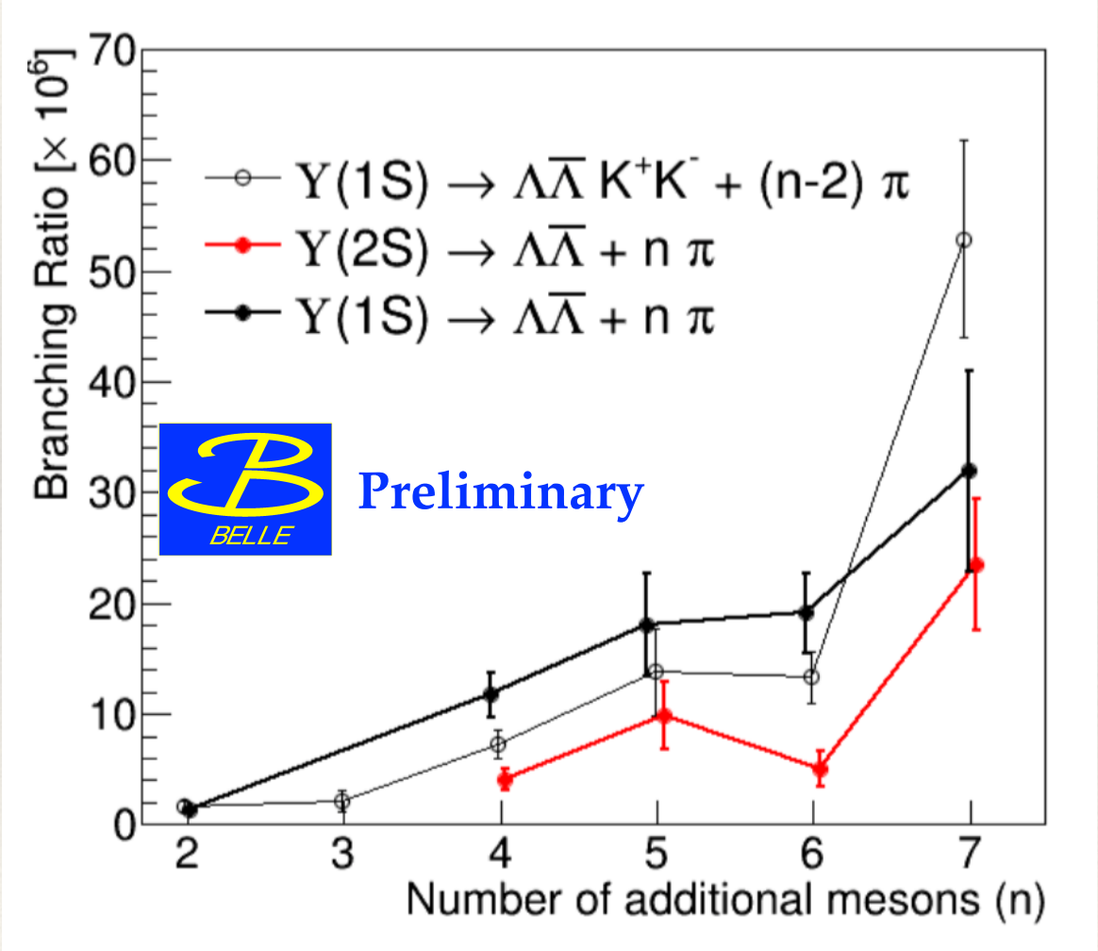
$\Upsilon(1S,2S) \longrightarrow \Lambda\bar{\Lambda} + X$

- Looking for deviations from the phase-space hypothesis in $M(\Lambda\bar{\Lambda})$
- Observing a signal >3σ in 15 Υ(1S) (7 Υ(2S)) modes

$$\mathcal{BR}[\Upsilon(1S) \to \Lambda\bar{\Lambda} + X] \sim 2 \times 10^{-4}$$

$$\mathcal{BR}[\Upsilon(2S) \to \Lambda\bar{\Lambda} + X] \sim 0.7 \times 10^{-4}$$

- Enhancement in the region $M(\Lambda\bar{\Lambda})$~$2M(\Lambda)$ in 6 channels (interpretation limited by statistics)
- No significant yield of $\chi_{bJ}(1P) \longrightarrow \Lambda\bar{\Lambda} + X$
- Tentative analysis of the global trend as a function of reconstructed mesons multiplicity
- Suggesting that the $\Lambda\bar{\Lambda}$ pairs are produced mainly in high multiplicity events



Belle Coll., PRL 115 (2015) 142001

$\Upsilon(4S) \longrightarrow \eta h_b(1P)$

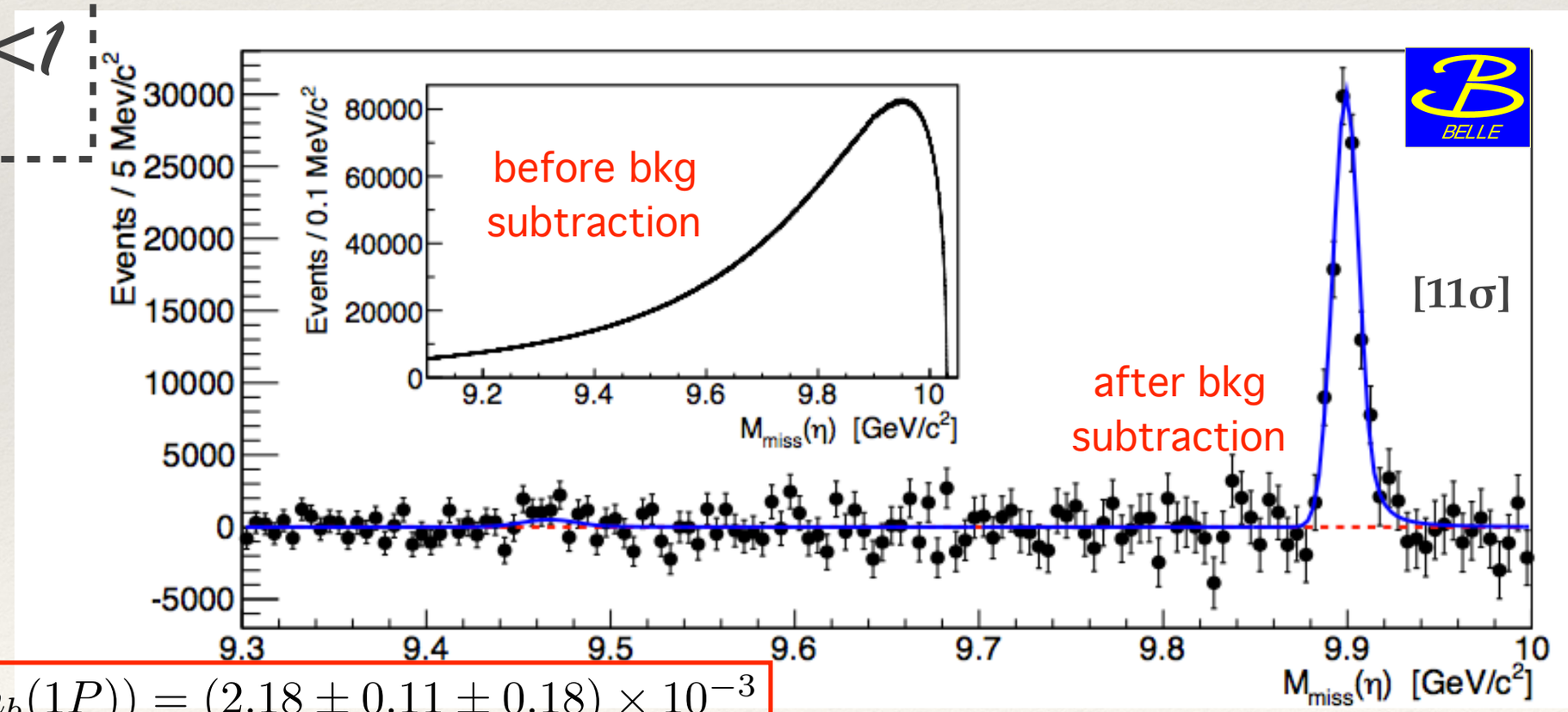
- Going inside the never-closed η transitions' puzzle…
- Following the same approach that led to the observation of the $h_b(1P,2P)$ from the $\Upsilon(5S)$

Belle Coll. PRL 108 (2012) 032001

- First observation of $\boldsymbol{\Upsilon(4S) \longrightarrow \eta h_b(1P)}$
- **E1M1** transition predicted to have BR~10^{-3}

PRL 105 (2010) 162001

- η reconstructed in η—>γγ
- Analysing the η missing mass spectrum
- Measured BR:



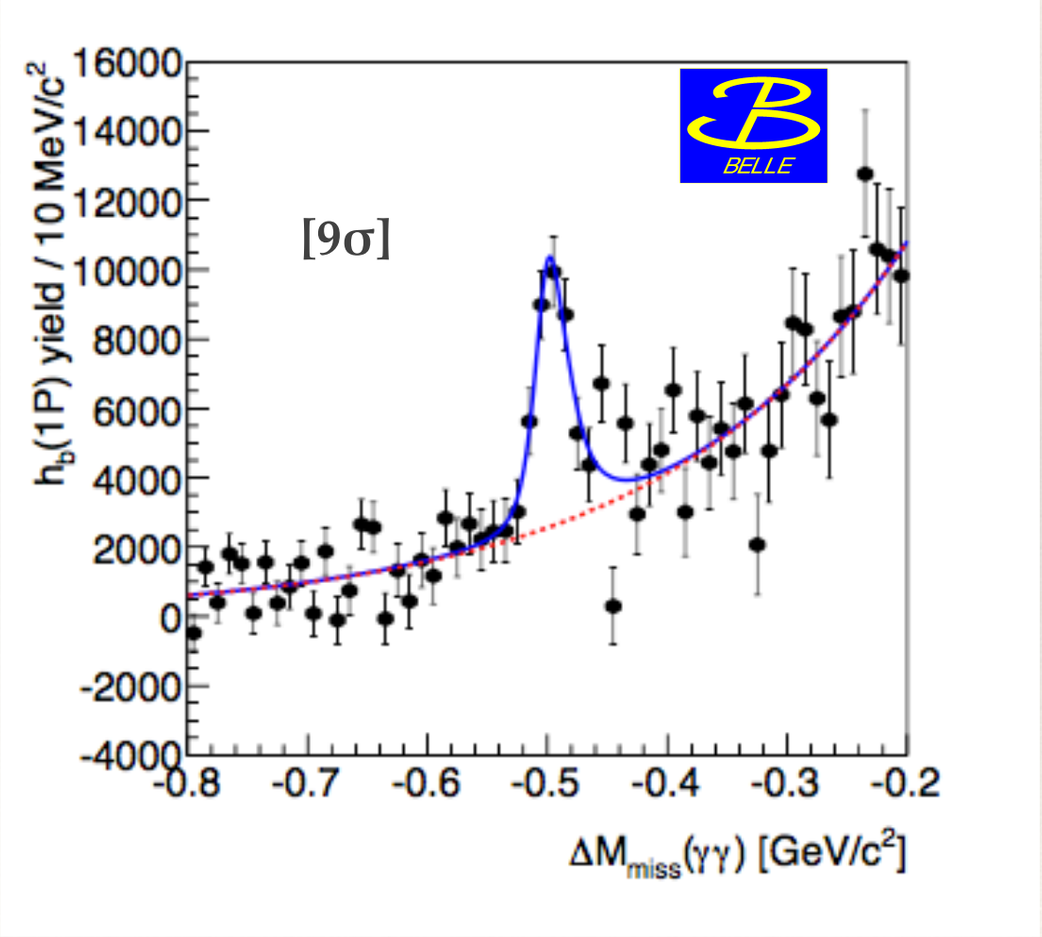
$$\mathcal{B}(\Upsilon(4S) \to \eta h_b(1P)) = (2.18 \pm 0.11 \pm 0.18) \times 10^{-3}$$

$\Upsilon(4S) \to \eta h_b(1P)$

- Large sample of $h_b(1P)$ reconstructed [O(100k)] —> possibility of:
  - measuring its mass
  - measuring $h_b(1P) \to \gamma\eta_b$, and η_b mass and width

- Mass measurements results:

$M_{h_b(1P)}$	$(9899.3 \pm 0.4 \pm 1.0)$ MeV/c^2
$M_{\eta_b(1S)} - M_{h_b(1P)}$	$(-498.6 \pm 1.7 \pm 1.2)$ MeV/c^2
$\Gamma_{\eta_b(1S)}$	$(8^{+6}_{-5} \pm 5)$ MeV/c^2
$M_{\eta_b(1S)}$	$(9400.7 \pm 1.7 \pm 1.6)$ MeV/c^2
$\Delta M_{HF}(1S)$	$(+59.6 \pm 1.7 \pm 1.6)$ MeV/c^2
$\Delta M_{HF}(1P)$	$(+0.6 \pm 0.4 \pm 1.0)$ MeV/c^2



- Hyperfine mass splitting:

$$\Delta M_{HF}(1S) = m(\Upsilon(1S)) - M(\eta_b(1S))$$

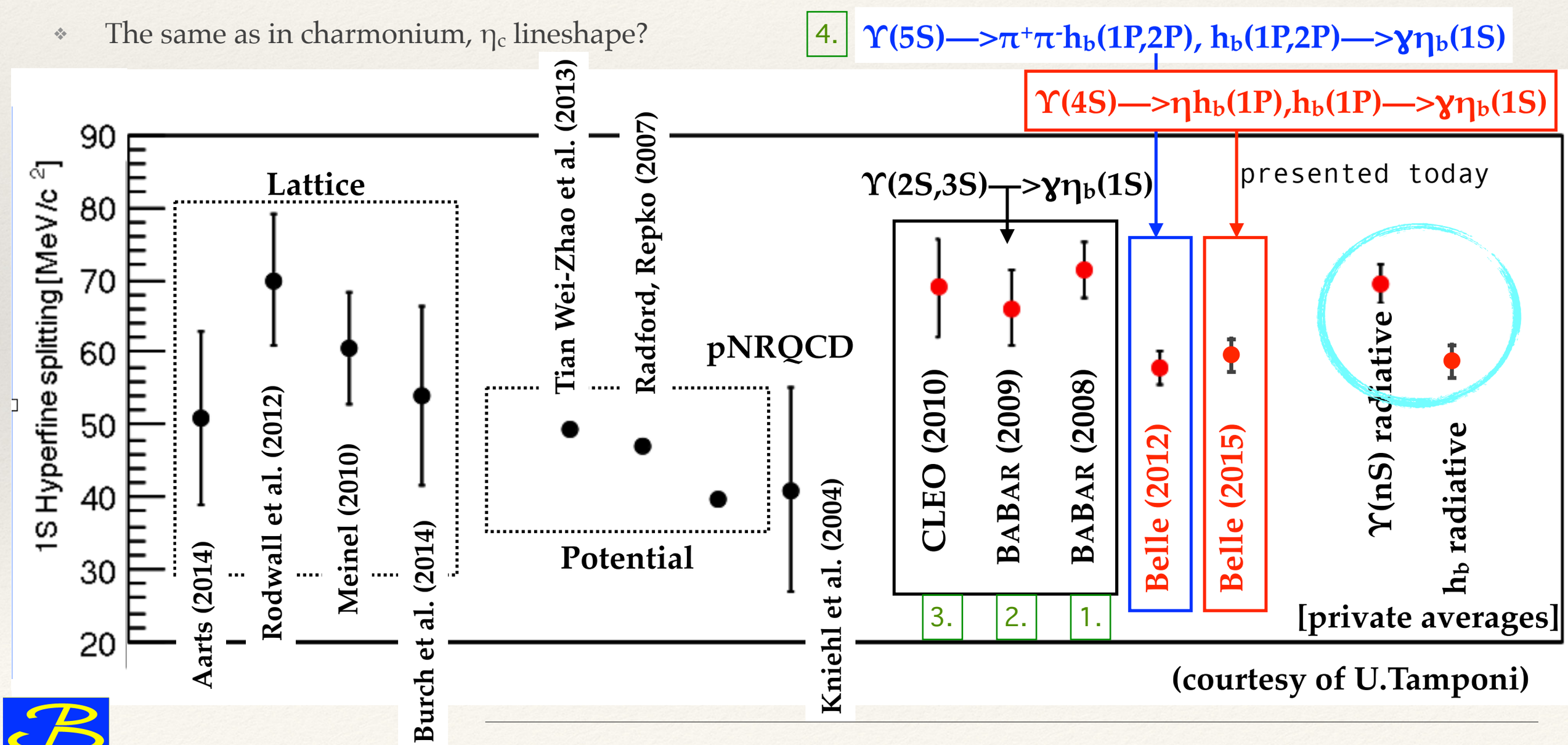
$$\Delta M_{miss} = M_{miss}(\eta\gamma) - M_{miss}(\eta)$$

1. BaBar Coll. PRL 101 (2008) 071801
2. BaBar Coll. PRL 103 (2009) 161801

3. CLEO Coll. PRD 81 (2010) 031104
4. Belle Coll. PRL 108 (2012) 032001

Hyperfine mass splitting

- Hyperfine mass-splitting of singlet-triplet states related to the spin structure of the resonances
- A discrepancy of >3σ for the 1S-HF splitting between measurements from **E1** and **M1** transitions
- The same as in charmonium, η_c lineshape?

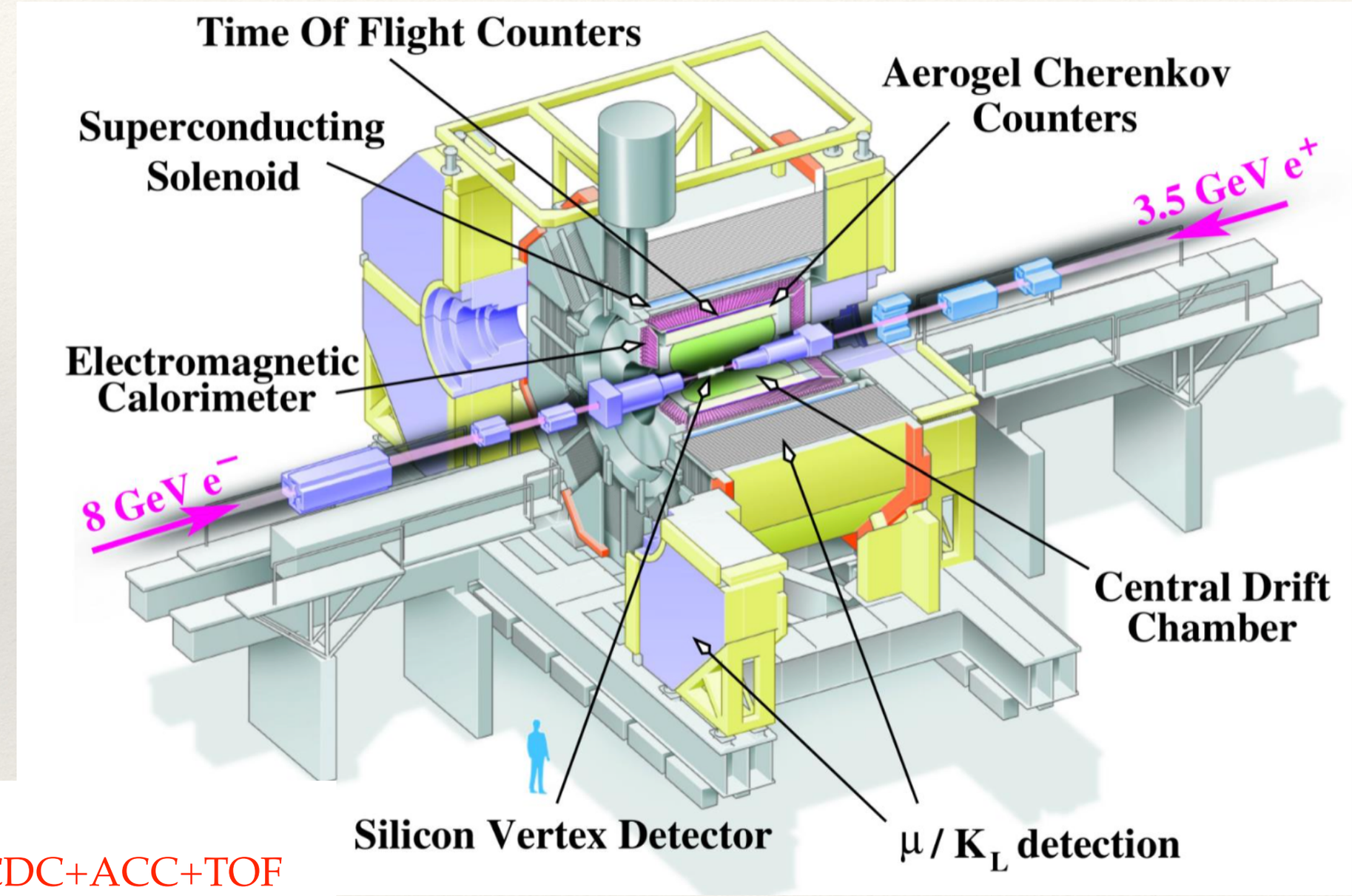


Summary

- Bottomonium decays are still a rich harvest in BELLE physics program (and its future of course…)
- Some examples of recent results:
  - $\Upsilon(2S) \to \gamma \chi_{bJ}(1P)$ with UL on $\chi_{b0}(1P)$ width **Preliminary, NEW!**
  - $\Upsilon(1S,2S) \to \Lambda\bar{\Lambda} + X$ **Preliminary**
  - $\Upsilon(4S) \to \eta h_b(1P)$ ($h_b(1P) \to \gamma \eta_b$) with η_b mass (and HF splitting) measurement
- Many more to come, stay tuned!

Backup

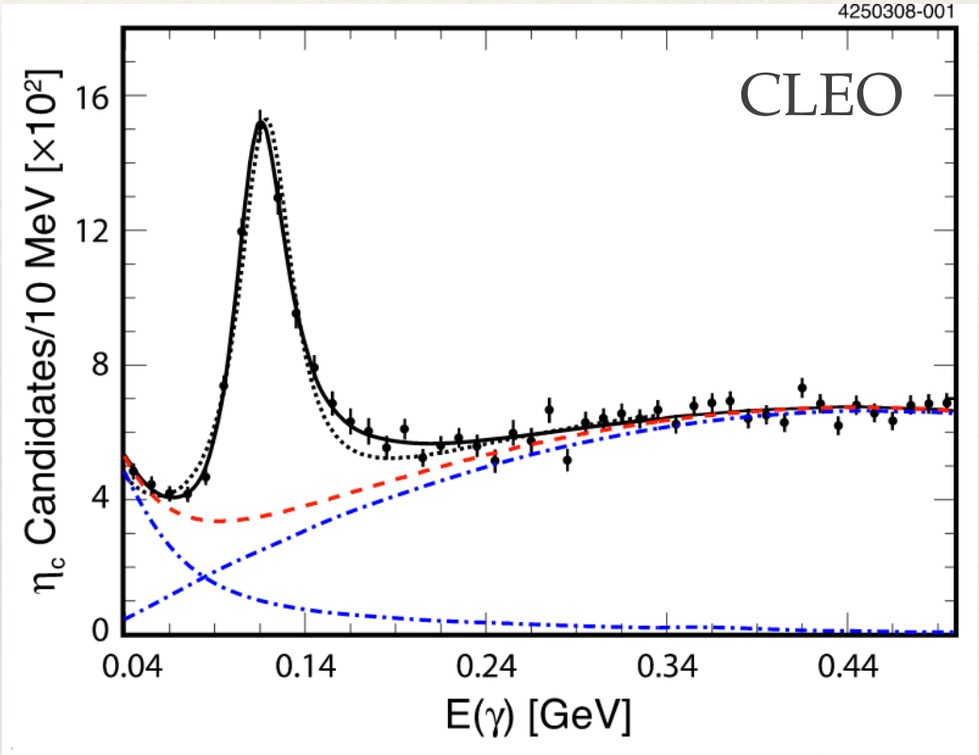
The BELLE detector



- Tracking : SVD+CDC
- Particle Identification: CDC+ACC+TOF
- Calorimetry: (CsI(Tl) crystal)

Analogy with η_c lineshape?

- CLEO (2009) observed a distortion in the η_c line shape due to the photon-energy dependence of the magnetic dipole transition rate ($J/\psi \to \gamma\, \eta_c$ and $\psi(2S) \to \gamma\, \eta_c$)
- Background that decreases with $E(\gamma)$ from $J/\psi \to X_i$, where a spurious cluster is found in the calorimeter + a rising background from both $J/\psi \to \pi^0 X_i$ and non-signal $J/\psi \to \gamma X_i$
- Taking into account this, a mass value (2982.2 ± 0.6 MeV/c^2) compatible with the result from $\gamma\gamma$ fusion and $p\bar{p}$ annihilation; without ~7 MeV lower
- A similar factor for η_b?



CLEO Coll. PRL 102 (2009) 011801
Erratum ibid. 106 (2011) 159903