QWG8, GSI, 5 October 2011

Observation of $h_b(1P) \to \eta_b(1S)\,\gamma$

Roman Mizuk
ITEP, Moscow

for the BELLE Collaboration

Introduction

Belle recently observed $h_b(1P)$ and $h_b(2P)$ in $\Upsilon(5S) \to h_b(mP)\pi^+\pi^-$:

$$N[h_b(1P)] = (50.4 \pm 7.8\ ^{+4.5}_{-1.9}) \times 10^3\ ,\ \sim 6\sigma \text{ significance}$$

$$N[h_b(2P)] = (84.4 \pm 6.8\ ^{+23}_{-10}) \times 10^3\ ,\ \sim 12\sigma \text{ significance}$$

arXiv:1103.3411

arXiv:1105.4583

Expected decays of h_b

$h_b(1P) \to ggg$ (57%), $\eta_b(1S)\gamma$ (41%), γgg (2%)

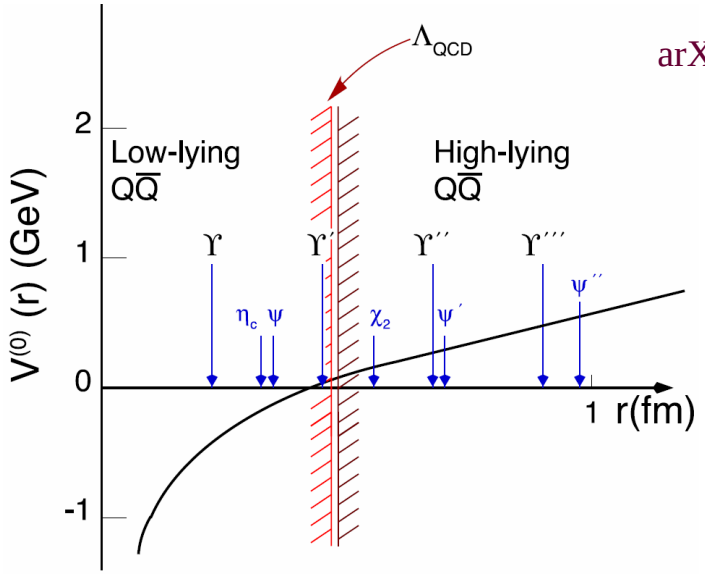
$h_b(2P) \to ggg$ (63%), $\eta_b(1S)\gamma$ (13%), $\eta_b(2S)\gamma$ (19%), γgg (2%)

Godfrey & Rosner, PRD66 014012 (2002)

Large $h_b(mP)$ samples give opportunity to study $\eta_b(nS)$ states.

Introduction to $\eta_b(1S)$

$\eta_b(1S)$ – small radius system, precision calculation of mass



arXiv:1010.5827

Experimental status of η_b

$M[\eta_b(1S)] = 9390.9 \pm 2.8$ MeV (BaBar + CLEO)
$M[\Upsilon(1S)] - M[\eta_b(1S)] = 69.3 \pm 2.8$ MeV

pNRQCD: 41±14 MeV Lattice: 60±8 MeV

Kniehl et al., PRL92,242001(2004) Meinel, PRD82,114502(2010)

Width of $\eta_b(1S)$: no information

Method

Decay chain

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

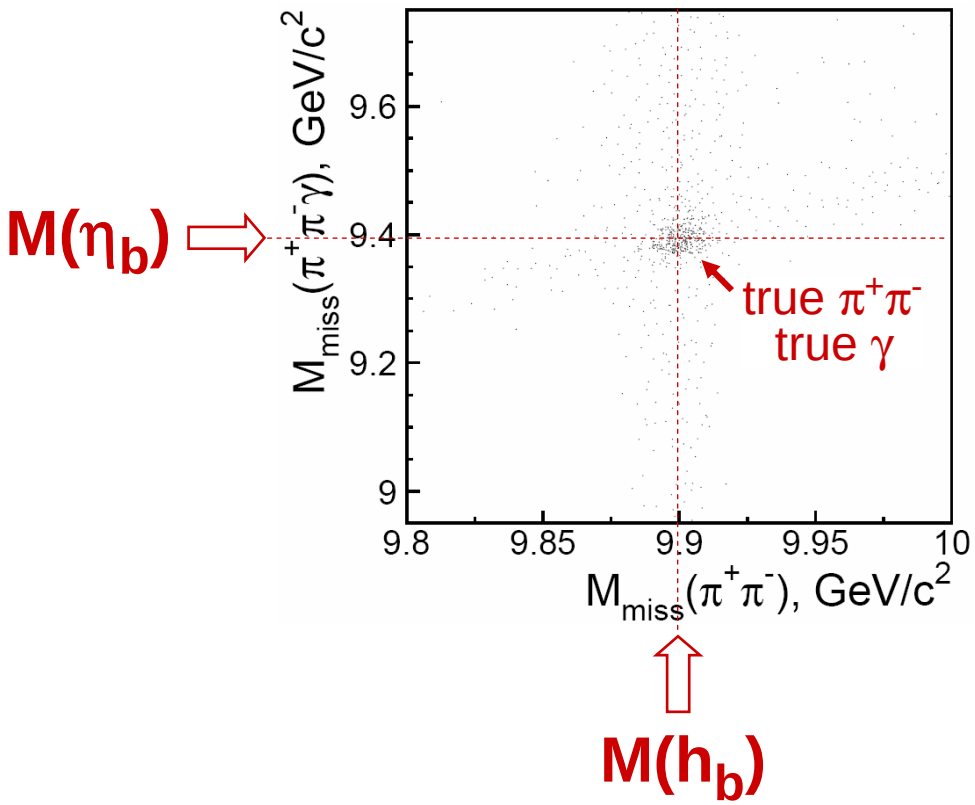
$\hookrightarrow h_b\,(nP)\ \pi^+$

$\hookrightarrow \eta_b(mS)\ \gamma$

reconstruct

Use missing mass to identify signals

MC simulation



Method

Decay chain

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

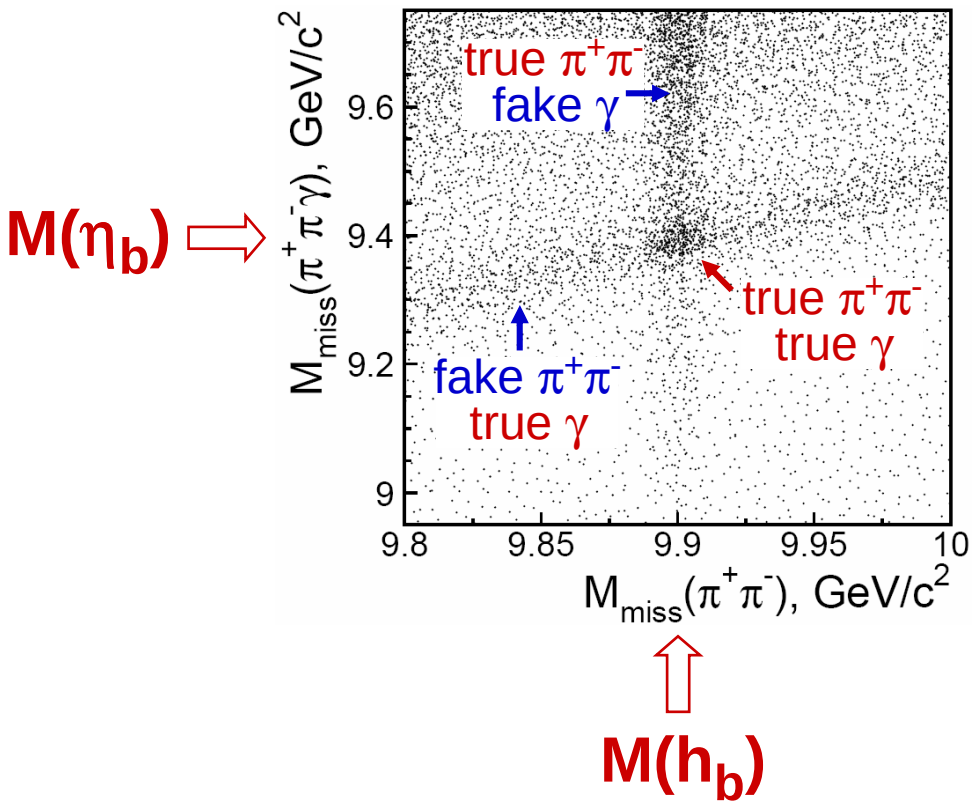
$\hookrightarrow h_b\,(nP)\ \pi^+$

$\hookrightarrow \eta_b(mS)\ \gamma$

reconstruct

Use missing mass to identify signals

MC simulation



Method

Decay chain

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

$\hookrightarrow h_b\,(nP)\ \pi^+$

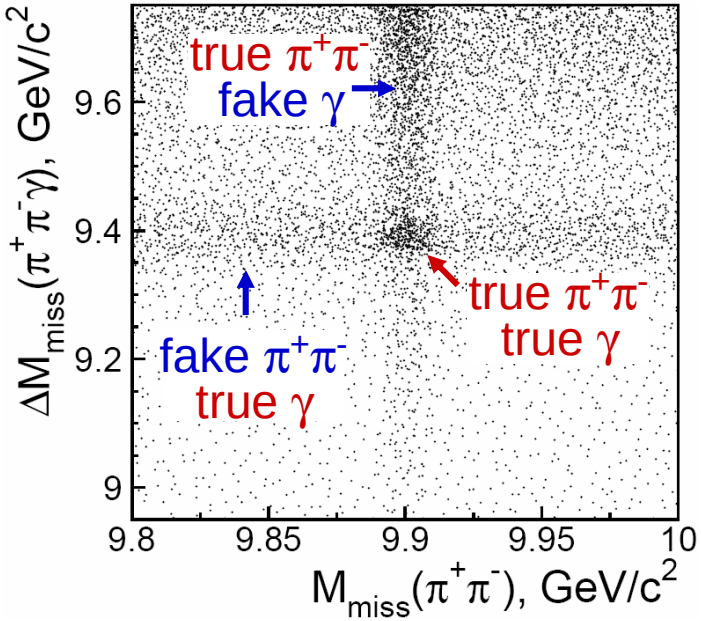
$\hookrightarrow \eta_b(mS)\ \gamma$

reconstruct

Use missing mass to identify signals

MC simulation

$M(\eta_b)$ ⇨



⇧

$M(h_b)$

$\Delta M_{miss}(\pi^+\pi^-\gamma) \equiv$

$M_{miss}(\pi^+\pi^-\gamma) - M_{miss}(\pi^+\pi^-) + M[h_b]$

- rectangular bg bands
- no correlation

Method

Decay chain

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

$\hookrightarrow h_b\,(nP)\ \pi^+$

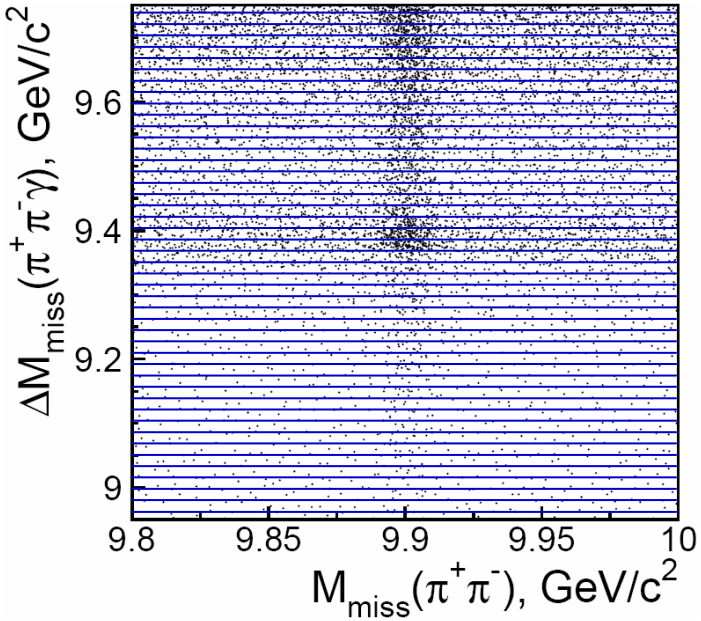
$\hookrightarrow \eta_b(mS)\ \gamma$

reconstruct

Use missing mass to identify signals

MC simulation

$M(\eta_b)$ ⇨



⇧

$M(h_b)$

$\Delta M_{miss}(\pi^+\pi^-\gamma) \equiv$

$M_{miss}(\pi^+\pi^-\gamma) - M_{miss}(\pi^+\pi^-) + M[h_b]$

- rectangular bg bands
- no correlation

Approach:

fit $M_{miss}(\pi^+\pi^-)$ spectra in $\Delta M_{miss}(\pi^+\pi^-\gamma)$ bins

Method

Decay chain

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

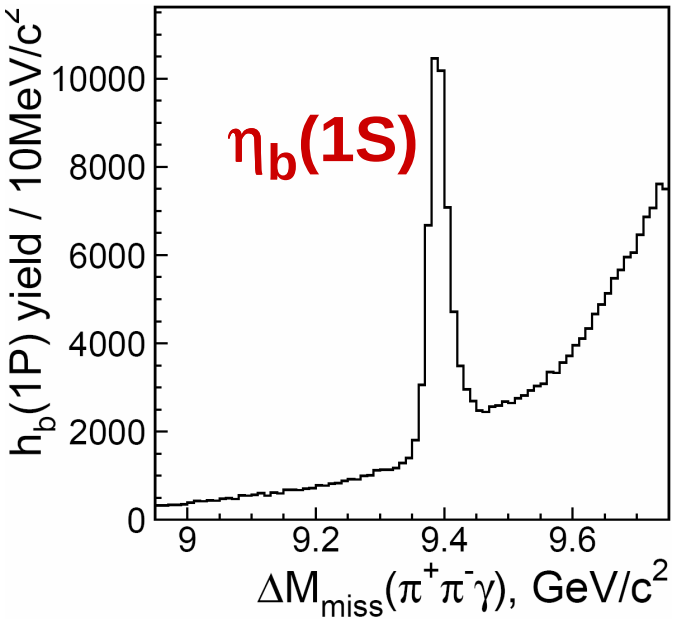
$\hookrightarrow h_b\,(nP)\ \pi^+$

$\hookrightarrow \eta_b(mS)\ \gamma$

reconstruct

Use missing mass to identify signals

MC simulation



$\Delta M_{miss}(\pi^+\pi^-\gamma) \equiv$
$M_{miss}(\pi^+\pi^-\gamma) - M_{miss}(\pi^+\pi^-) + M[h_b]$

- rectangular bg bands
- no correlation

Approach:

fit $M_{miss}(\pi^+\pi^-)$ spectra in $\Delta M_{miss}(\pi^+\pi^-\gamma)$ bins

$\Rightarrow$ $h_b(1P)$ yield vs. $\Delta M_{miss}(\pi^+\pi^-\gamma)$ $\Rightarrow$ signal of $\eta_b(1S)$

Selection

Decay chain $\Upsilon(5S) \to Z_b^+ \pi^-$

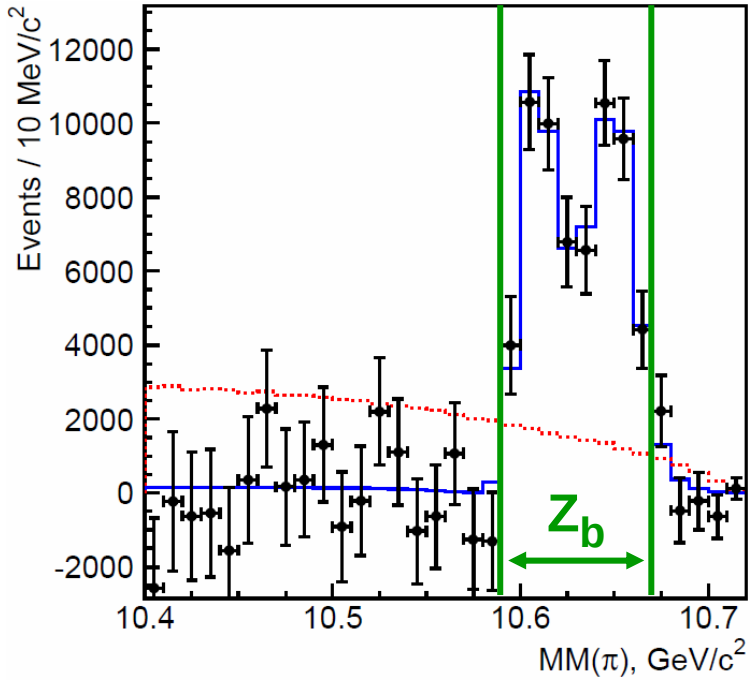
$\hookrightarrow h_b\,(nP)\,\pi^+$

$\hookrightarrow \eta_b(mS)\,\gamma$

reconstruct

Hadronic event selection; continuum suppression using event shape ($R_2<0.3$); π^0 veto.

Require intermediate Z_b : **$10.59 < MM(\pi) < 10.67$ GeV**

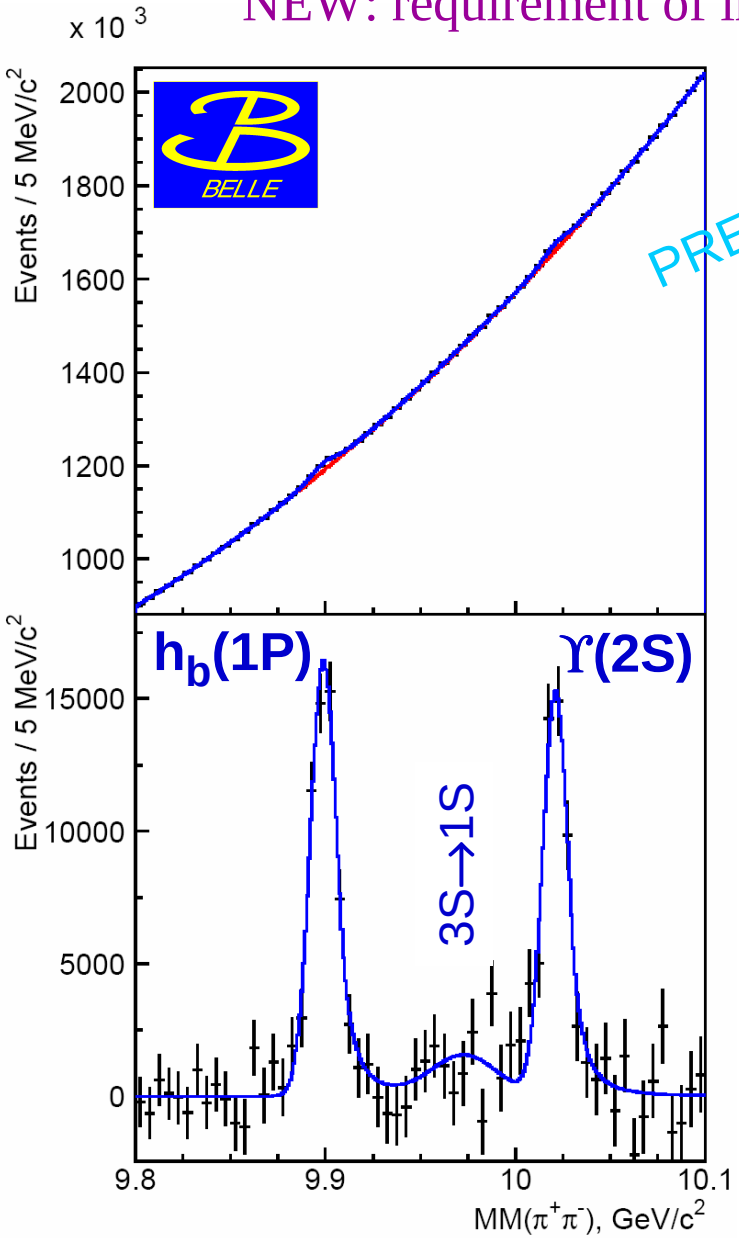


bg. suppression ×5.2

$M_{miss}(\pi^+\pi^-)$ spectrum

NEW: requirement of intermediate Z_b

121.4 fb^{-1}



Update of M [h_b(1P)] :

$$(9899.0 \pm 0.4 \pm 1.0)\ \mathrm{MeV}/c^2$$

$$\Delta M_{HF}\ [h_b(1P)] = (+0.8 \pm 1.1)\mathrm{MeV}/c^2$$

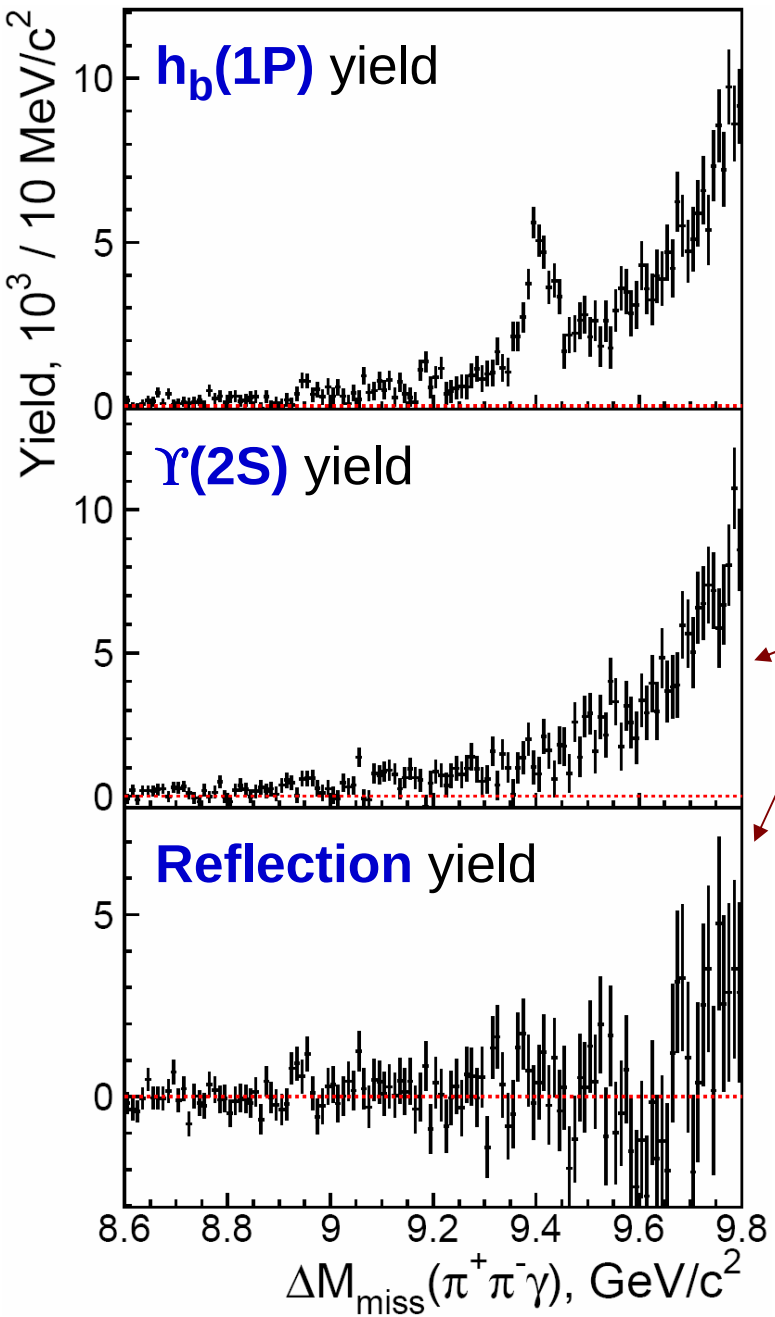
Previous Belle meas.: arXiv:1103.3411

$$(9898.3 \pm 1.1^{+1.0}_{-1.1})\ \mathrm{MeV}/c^2$$

$$\Delta M_{HF}\ [h_b(1P)] = (+1.6 \pm 1.5)\mathrm{MeV}/c^2$$

Combine $\pi^+\pi^-$ with γ,
fit $M_{miss}(\pi^+\pi^-)$ in $\Delta M_{miss}(\pi^+\pi^-\gamma)$ bins $\Rightarrow$

Results of fits to $M_{miss}(\pi^+\pi^-)$ spectra



$\eta_b(1S)$

Peaking background?
MC simulation ⇒ none.

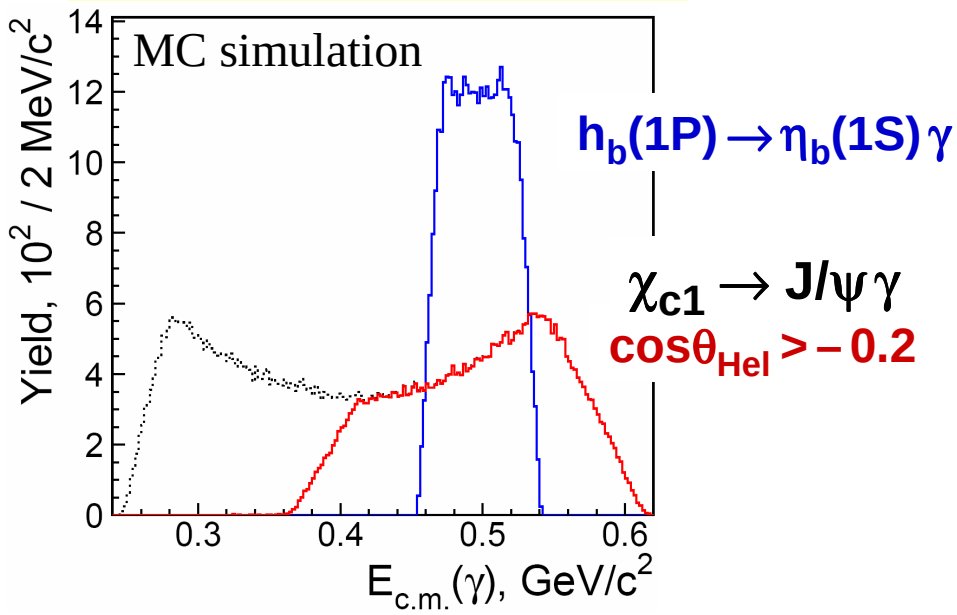
no significant structures

To extract $\eta_b(1S)$ mass, width
⇒ calibration

Calibration

Use decays $B^+ \to \chi_{c1} K^+ \to (J/\psi\, \gamma)\, K^+$

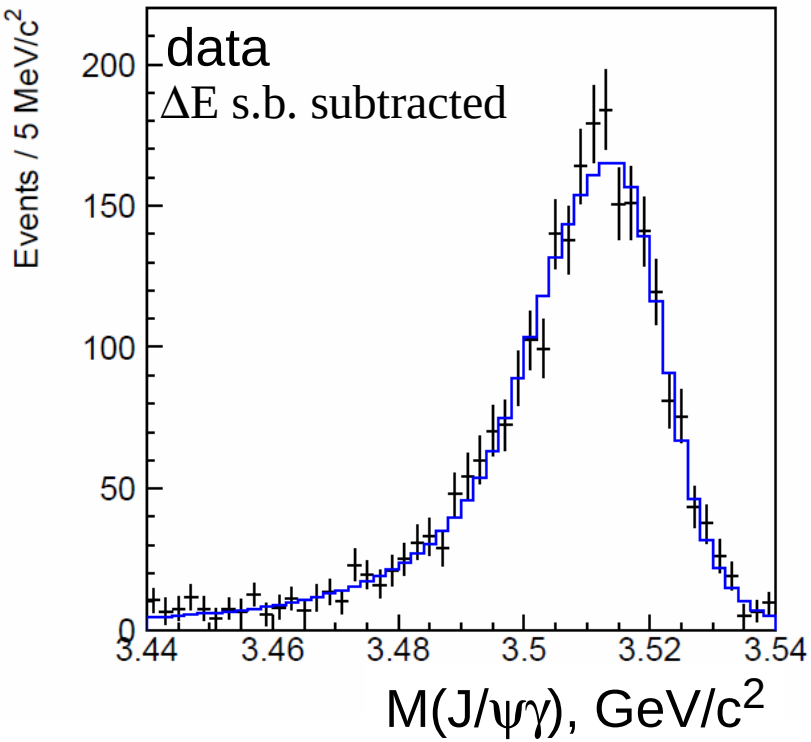
Photon energy spectrum



$\cos\theta_{Hel}(\chi_{c1}) > -0.2 \Rightarrow$ match γ energy of **signal** & **callibration** channels

Calibration (2)

Resolution: double-sided CrystalBall function with asymmetric core

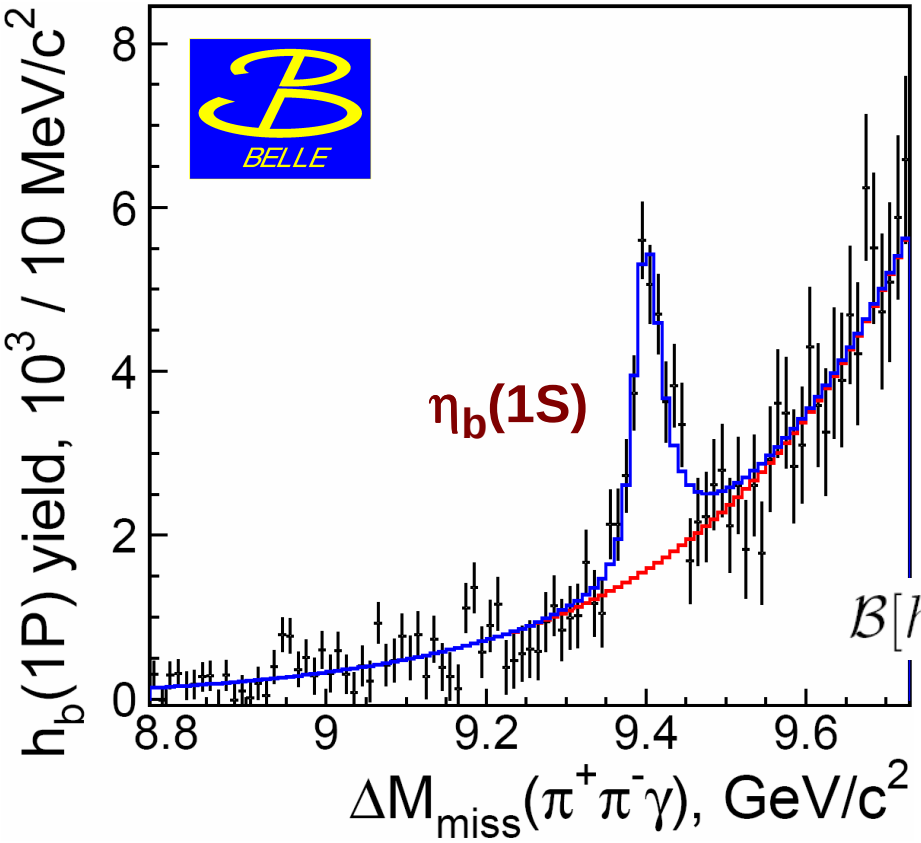


⇒ Correction of MC

mass shift	$-0.7 \pm 0.3\ ^{+0.2}_{-0.4}$ MeV
fudge-factor for resolution	$1.15 \pm 0.06 \pm 0.06$

Fit to $\Delta MM(\pi^+\pi^-\gamma)$ distribution

non-relativistic BW ⊗ resolution + exponential func.



PRELIMINARY

$$N[\eta_b(1S)] \quad (21.9 \pm 2.0^{+5.6}_{-1.7}) \cdot 10^3$$

$$M[\eta_b(1S)] \quad (9401.0 \pm 1.9^{+1.4}_{-2.4})\ \mathrm{MeV}/c^2$$

$$\Gamma[\eta_b(1S)] \quad (12.4^{+5.5+11.5}_{-4.6-3.4})\ \mathrm{MeV}$$

$$\mathcal{B}[h_b(1P) \to \eta_b(1S)\gamma] = (49.8 \pm 6.8^{+10.9}_{-5.2})\%$$

C.L.=77%, significance 14σ
(w/ syst. 13σ)

Hyperfine splitting

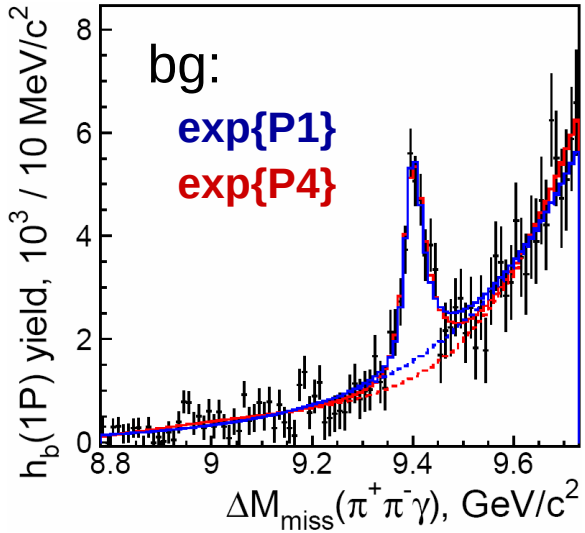
$\Delta M_{HF}\ [\eta_b(1S)] = 59.3 \pm 1.9\ ^{+2.4}_{-1.4}\ \mathrm{MeV}/c^2$

Systematics

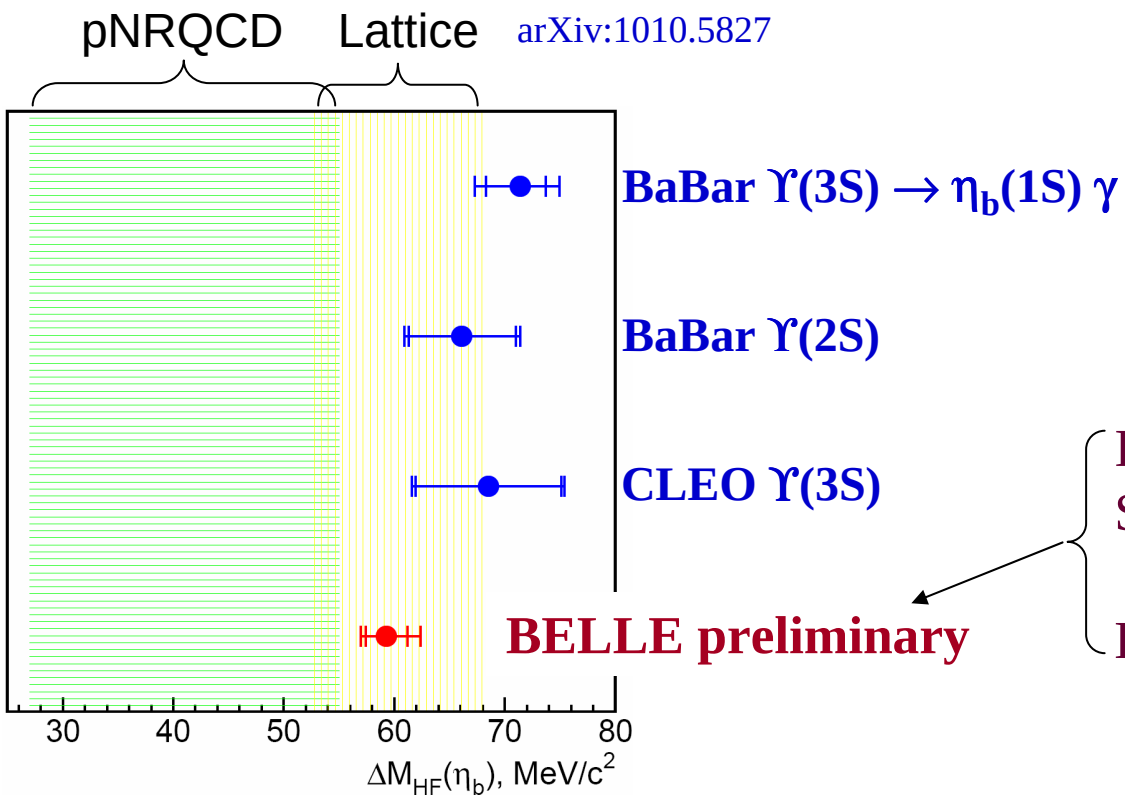
	$N[\eta_b(1S)]$, 10^3	$M[\eta_b(1S)]$, MeV/c^2	$\Gamma[\eta_b(1S)]$, MeV
Range in $MM(\pi^+\pi^-)$ fits	$^{+0.0}_{-0.6}$	$^{+0.0}_{-0.2}$	$^{+0.0}_{-0.1}$
Poly order in $MM(\pi^+\pi^-)$ fits	$^{+0.0}_{-0.6}$	$^{+0.1}_{-0.1}$	$^{+0.0}_{-0.4}$
$\Delta MM(\pi^+\pi^-\gamma)$ binning	$^{+0.2}_{-0.1}$	$^{+0.3}_{-0.8}$	$^{+1.0}_{-0.8}$
Range in $\Delta MM(\pi^+\pi^-\gamma)$ fits	$^{+0.9}_{-0.2}$	$^{+0.1}_{-0.1}$	$^{+1.4}_{-0.3}$
$\Delta MM(\pi^+\pi^-\gamma)$ bg parameterization	$^{+5.5}_{-1.4}$	$^{+0.5}_{-0.2}$	$^{+10.9}_{-2.2}$
Resolution function	$^{+0.2}_{-0.1}$	$^{+0.5}_{-0.5}$	$^{+1.4}_{-1.4}$
Selection requirements	–	$^{+0.4}_{-1.9}$	$^{+3.0}_{-2.0}$
$h_b(1P)$ mass	–	$^{+1.1}_{-1.1}$	–
Total	$^{+5.6}_{-1.7}$	$^{+1.4}_{-2.4}$	$^{+11.5}_{-3.4}$

Variations of background parameterization:
P2, P3, exp{P1}, exp{P2}, exp{P3}, exp{P4},
sum of two exponential func.

→ dominant syst. error on yield and width,
mass is stable



Discussion



Improvement in accuracy
Significant difference
w.r.t. BaBar ϒ(3S)
Decrease of tension with theory

$\Gamma[\eta_b(1S)]$ $(12.4^{+5.5+11.5}_{-4.6-3.4})$ MeV

potential models : Γ = 5 – 20 MeV

$\mathcal{B}[h_b(1P) \to \eta_b(1S)\gamma] = (49.8 \pm 6.8^{+10.9}_{-5.2})\%$

Godfrey & Rosner : BF = 41%

Conclusions

PRELIMINARY

Update of M [h_b(1P)] :

$(9899.0 \pm 0.4 \pm 1.0)\,\mathrm{MeV}/c^2$

ΔM_{HF} [h_b(1P)] = (0.8 ± 1.1)MeV/c^2

First observation of $h_b(1P) \to \eta_b(1S)\gamma$

$M[\eta_b(1S)]$ $(9401.0 \pm 1.9^{+1.4}_{-2.4})\,\mathrm{MeV}/c^2$

ΔM_{HF} [η_b(1S)] = $59.3 \pm 1.9\,^{+2.4}_{-1.4}$ MeV/c^2

$\Gamma[\eta_b(1S)]$ $(12.4^{+5.5+11.5}_{-4.6-3.4})$ MeV

$\mathcal{B}[h_b(1P) \to \eta_b(1S)\gamma] = (49.8 \pm 6.8^{+10.9}_{-5.2})\%$

single most precise measurement of η_b(1S) mass

significantly different from current world average

first measurement of η_b(1S) width

BF, mass, width in agreement with theoretical expectations

Radiative decays of h_b(2P) are coming