Semileptonic B_s^0 decays and Spectroscopy from the $\Upsilon(5S)$

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Rheinische Friedrich-Wilhelms-Universität Bonn

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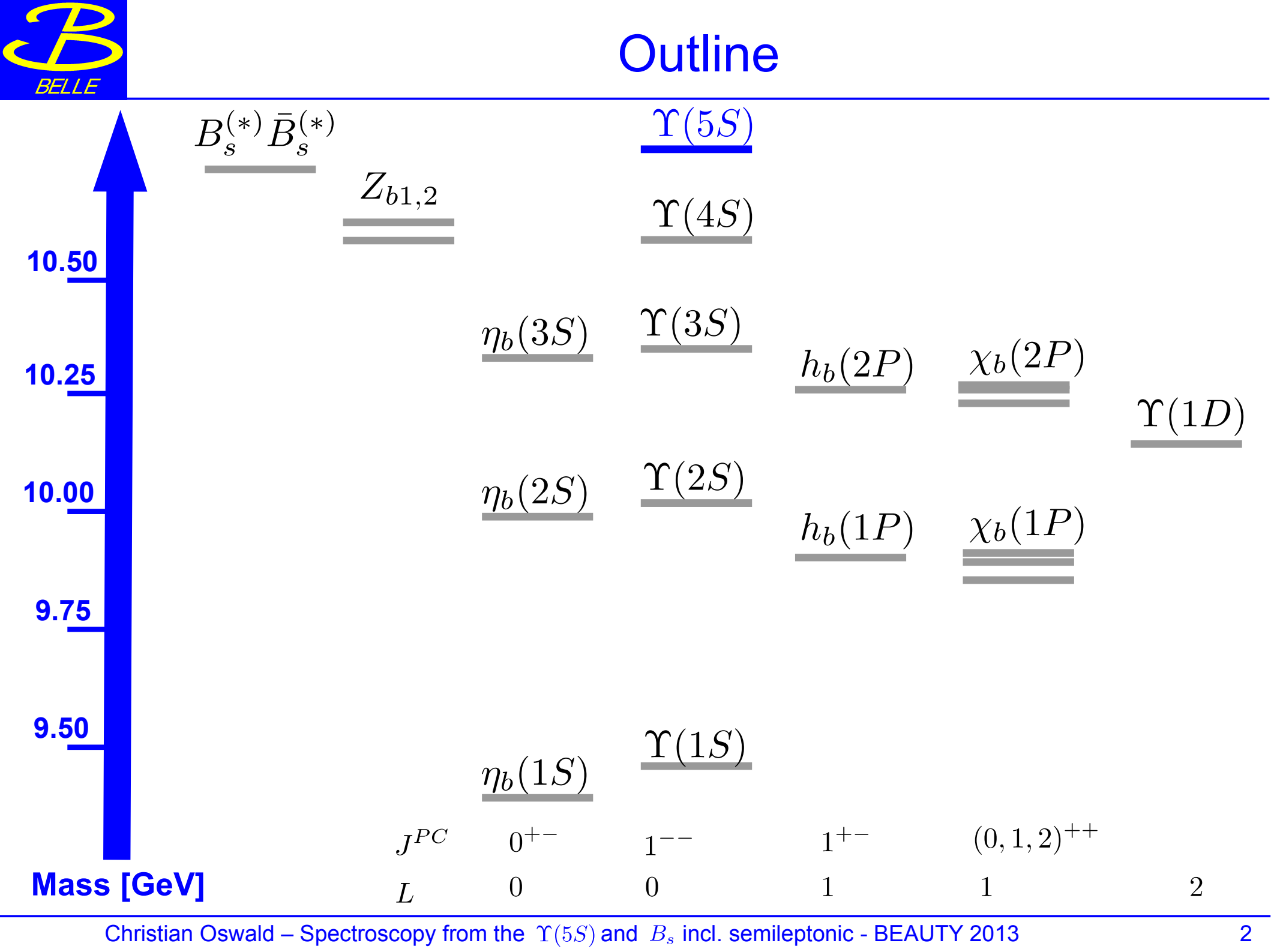
April 11 2013

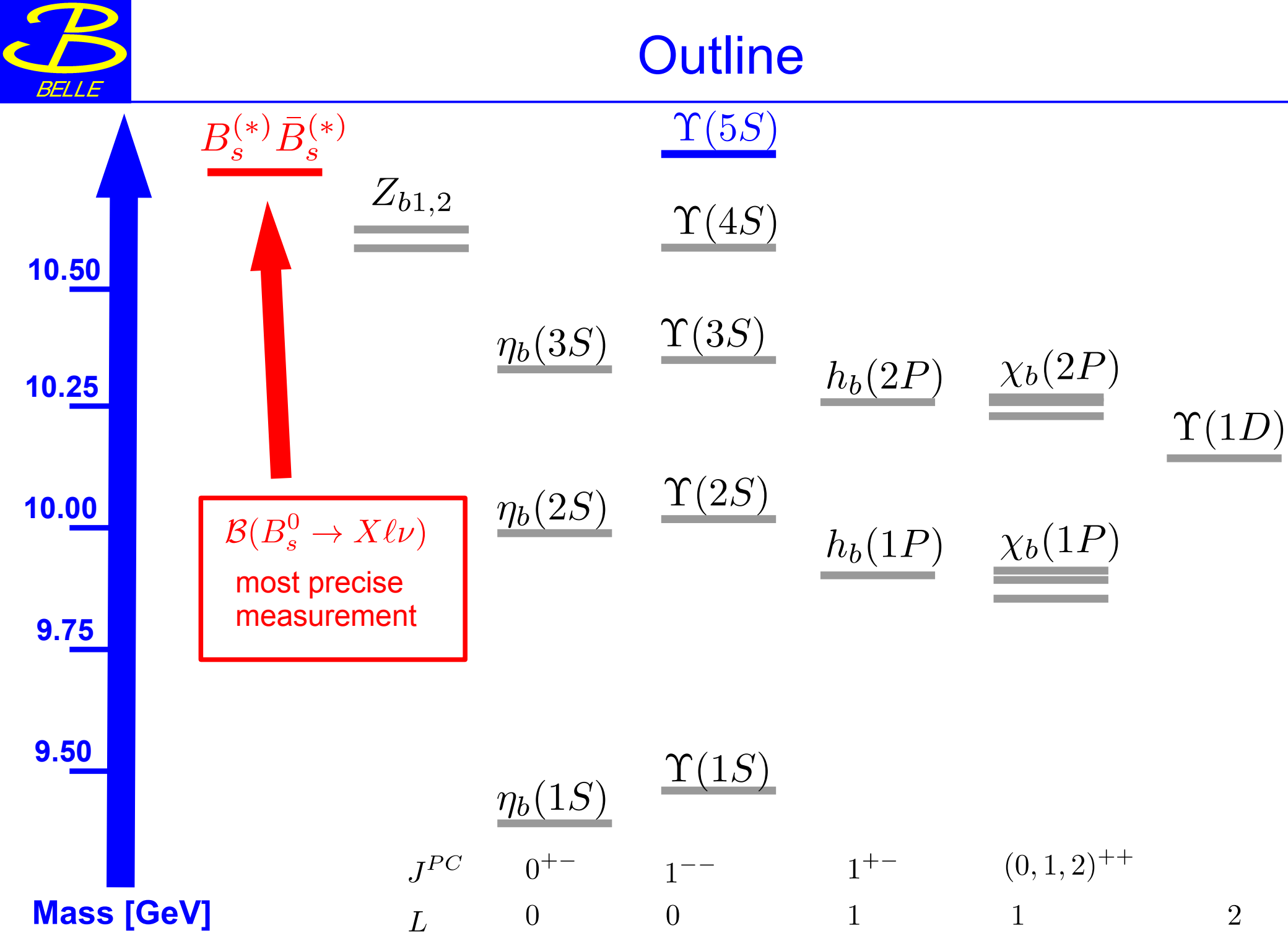
BELLE

universitätbonn

Outline


$B_s^{(*)}\bar{B}_s^{(*)}$
$Z_{b1,2}$
$\Upsilon(5S)$
$\Upsilon(4S)$
$\eta_b(3S)$
$\Upsilon(3S)$
$h_b(2P)$
$\chi_b(2P)$
$\Upsilon(1D)$
$\eta_b(2S)$
$\Upsilon(2S)$
$h_b(1P)$
$\chi_b(1P)$
$\eta_b(1S)$
$\Upsilon(1S)$
10.50
10.25
10.00
9.75
9.50
Mass [GeV]
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2

Outline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$\mathcal{B}(B_s^0 \to X\ell\nu)$
most precise measurement
10.50
10.25
10.00
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Mass [GeV]
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
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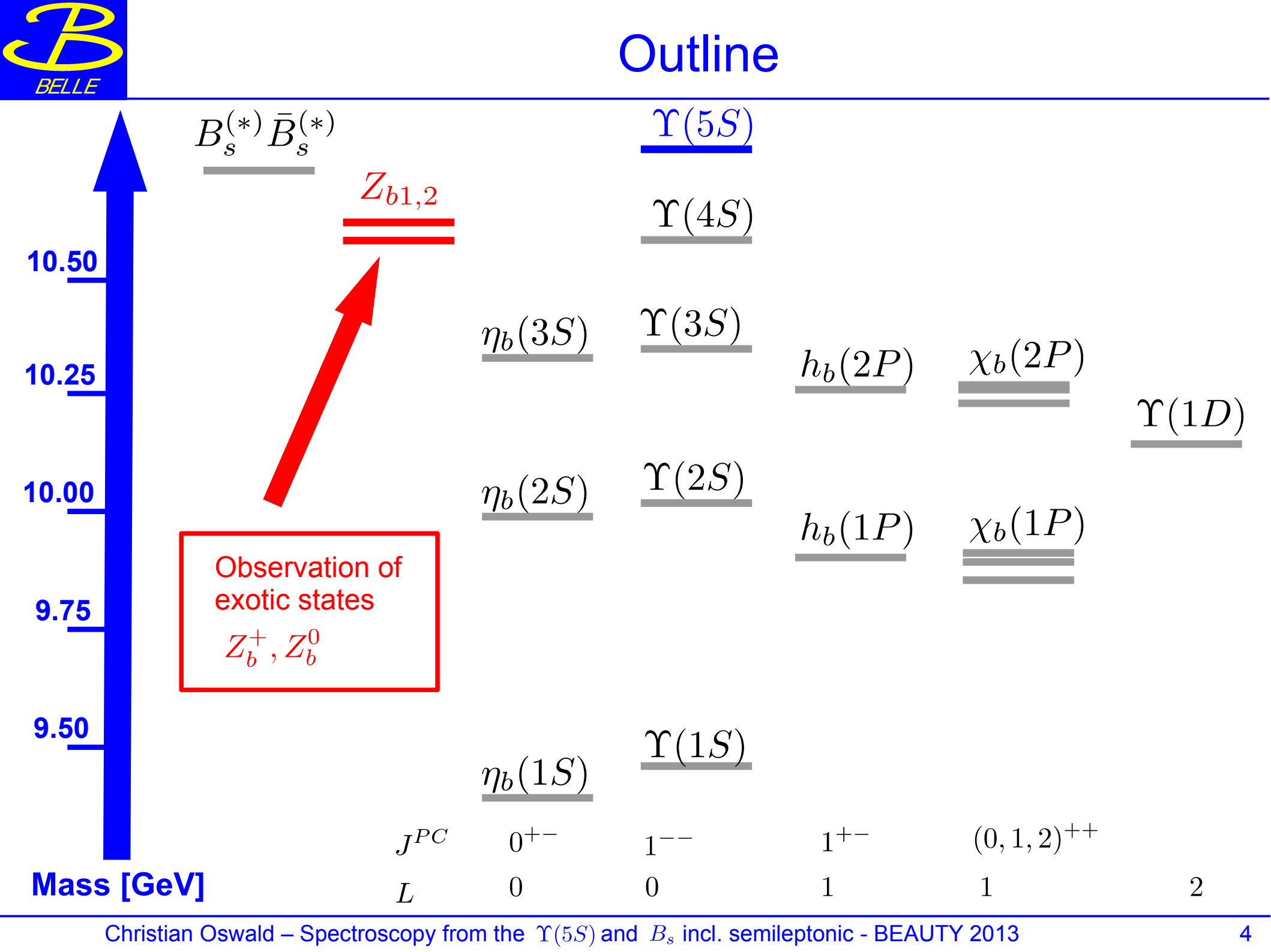
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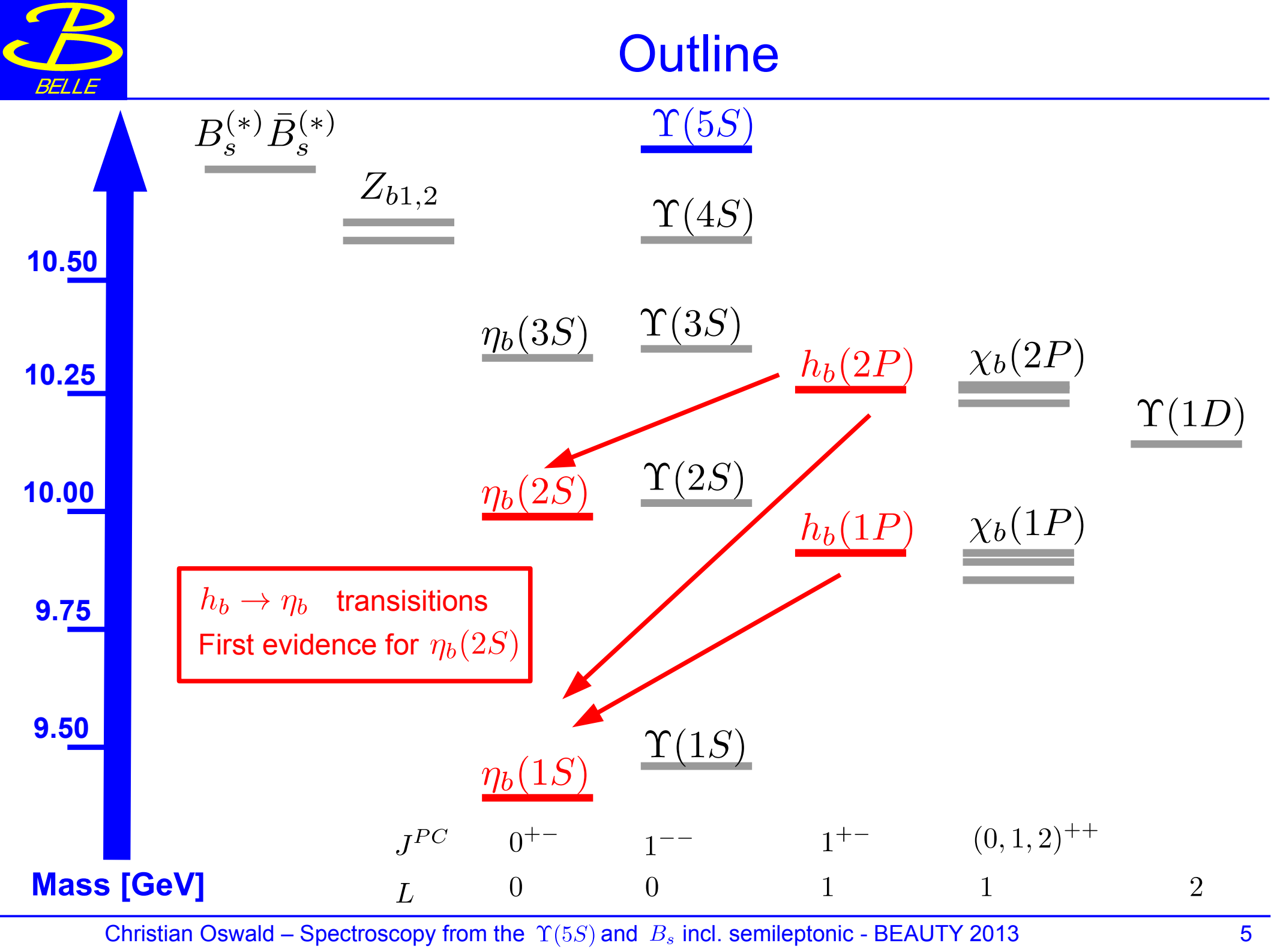
$\Upsilon(1S)$
10.50
10.25
10.00
9.75
9.50
Mass [GeV]
Observation of exotic states
Z_b^+, Z_b^0
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2

Outline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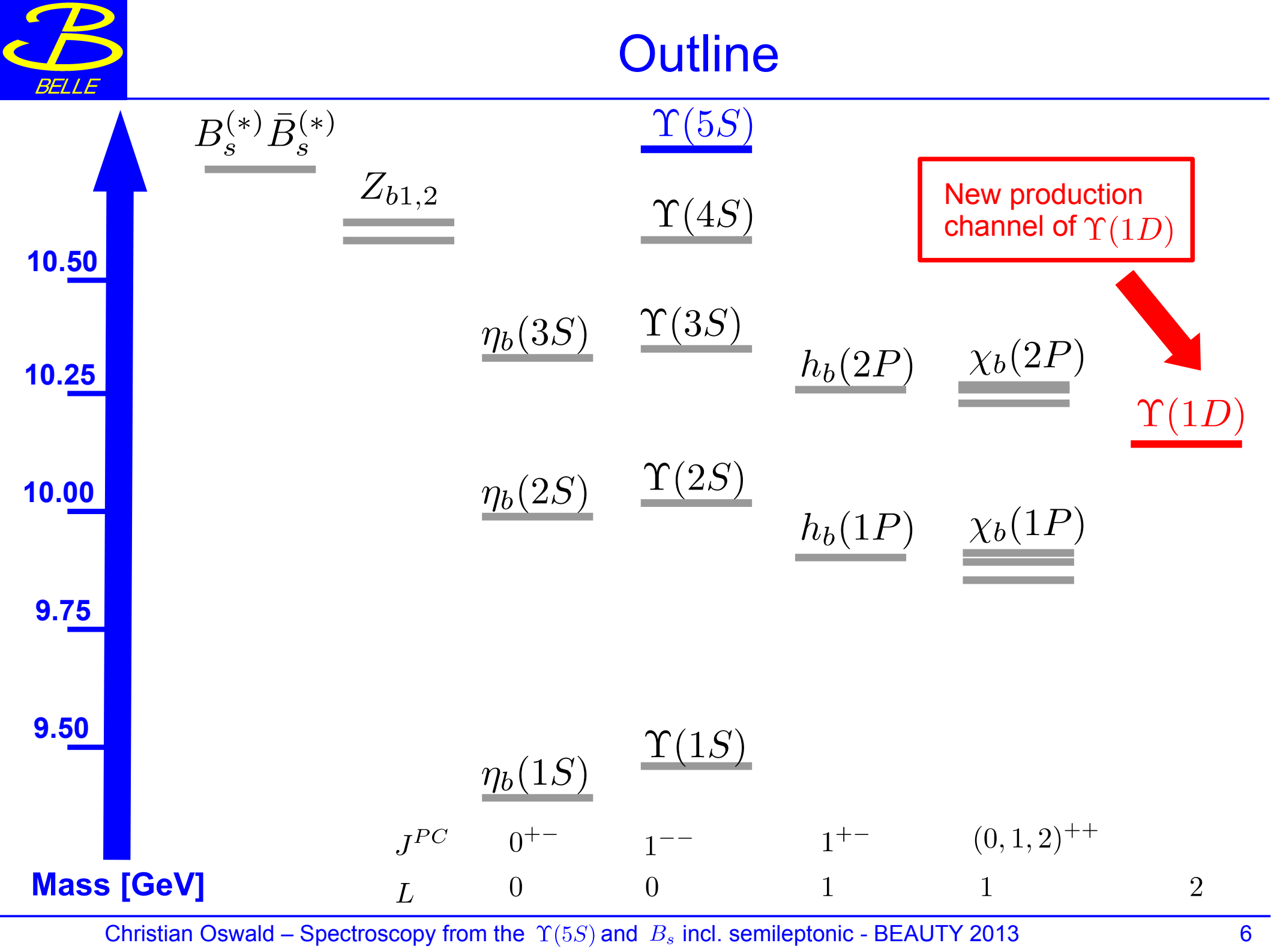
10.00
$h_b(1P)$
$\chi_b(1P)$
$h_b \to \eta_b$ transisitions
First evidence for $\eta_b(2S)$
9.75
9.50
$\Upsilon(1S)$
$\eta_b(1S)$
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2
Mass [GeV]

Outline


$B_s^{(*)}\bar{B}_s^{(*)}$
$\Upsilon(5S)$
$Z_{b1,2}$
$\Upsilon(4S)$
New production channel of $\Upsilon(1D)$
10.50
$\eta_b(3S)$
$\Upsilon(3S)$
$h_b(2P)$
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$\Upsilon(1D)$
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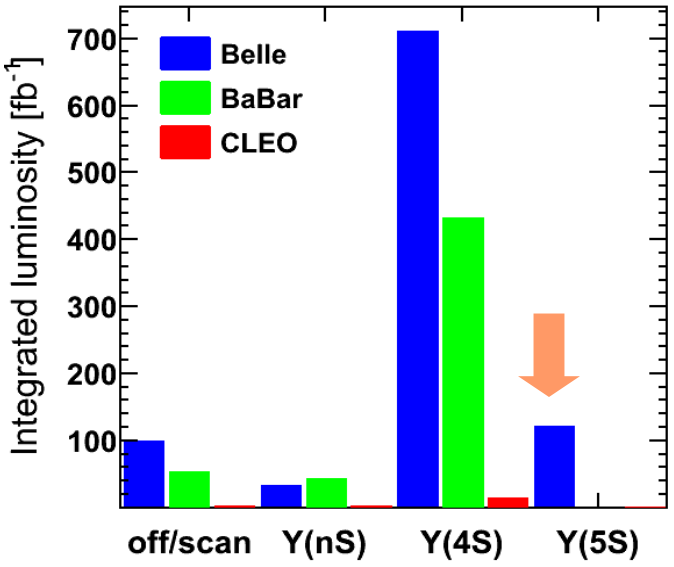
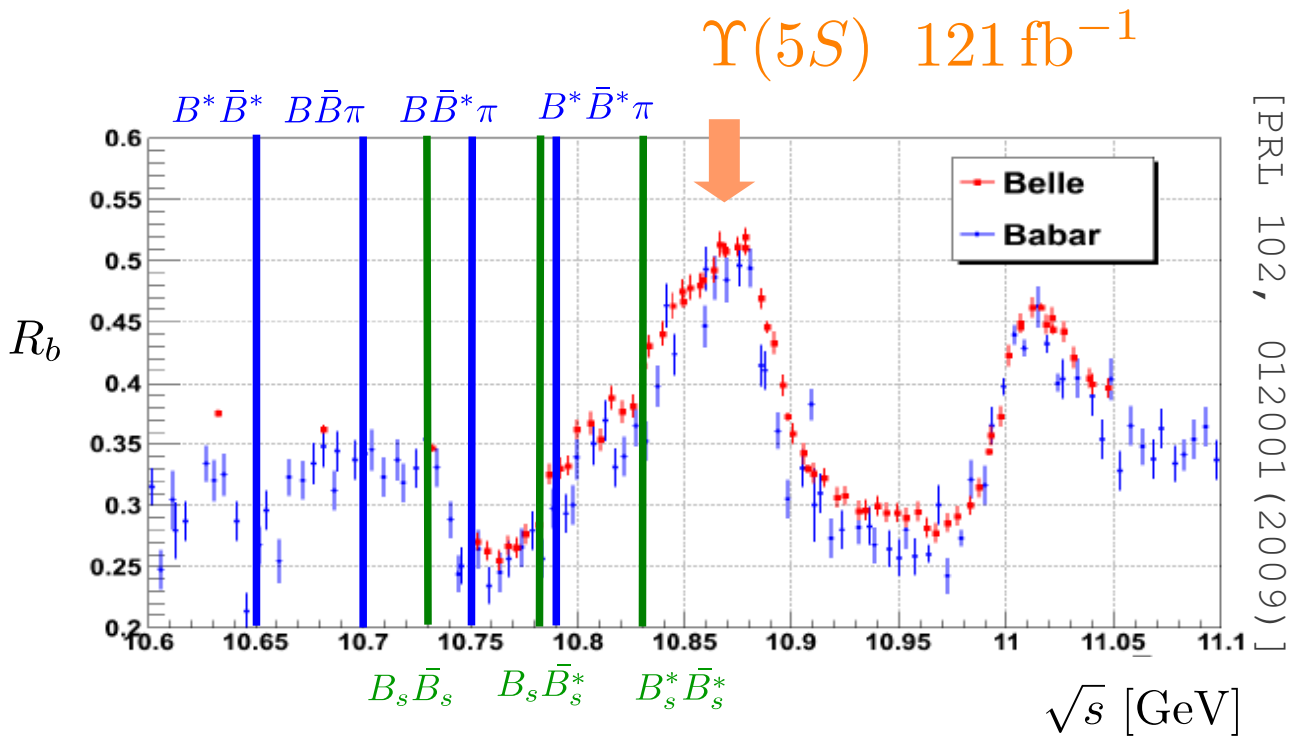
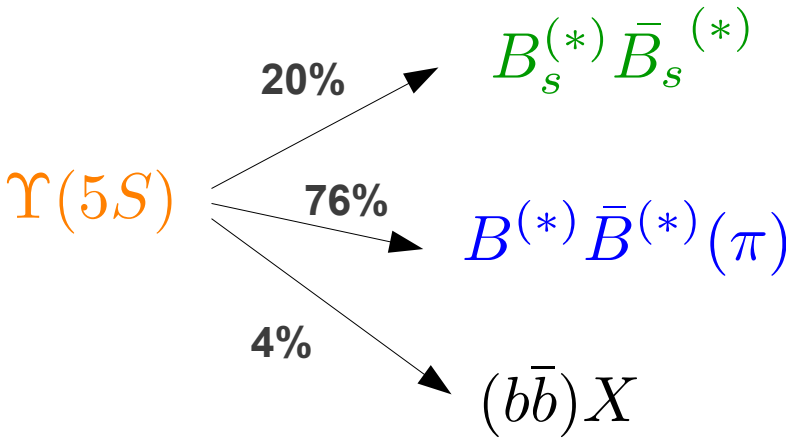
L 0 0 1 1 2
Mass [GeV]

$\Upsilon(5S)$ data sample





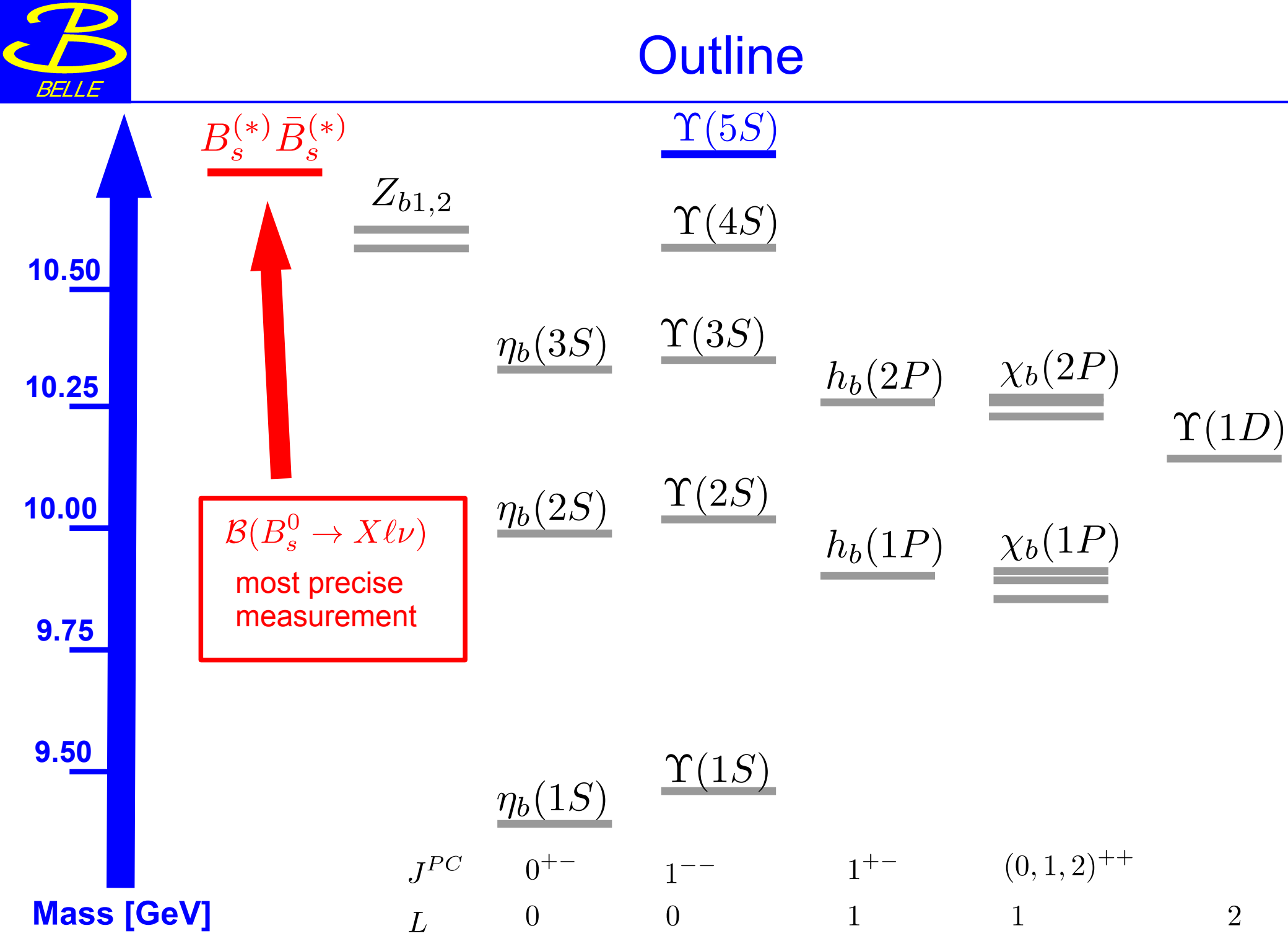


Initial motivation to take data near $\Upsilon(5S)$

Background for B_s^0 studies,
but interesting for spectroscopy

Bottomonium spectroscopy

Outline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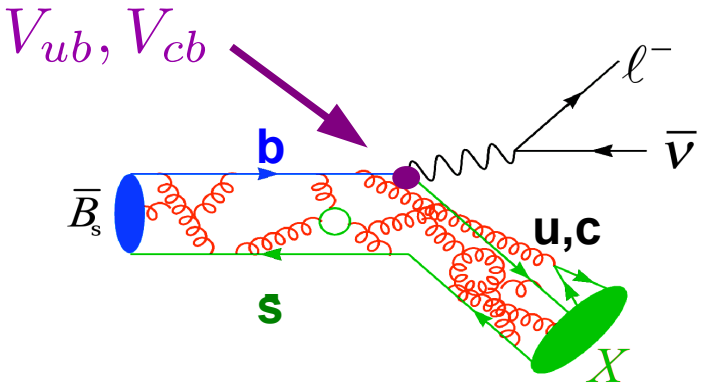
L 0 0 1 1 2
Mass [GeV]

$\mathcal{B}(B_s^0 \to X\ell\nu)$

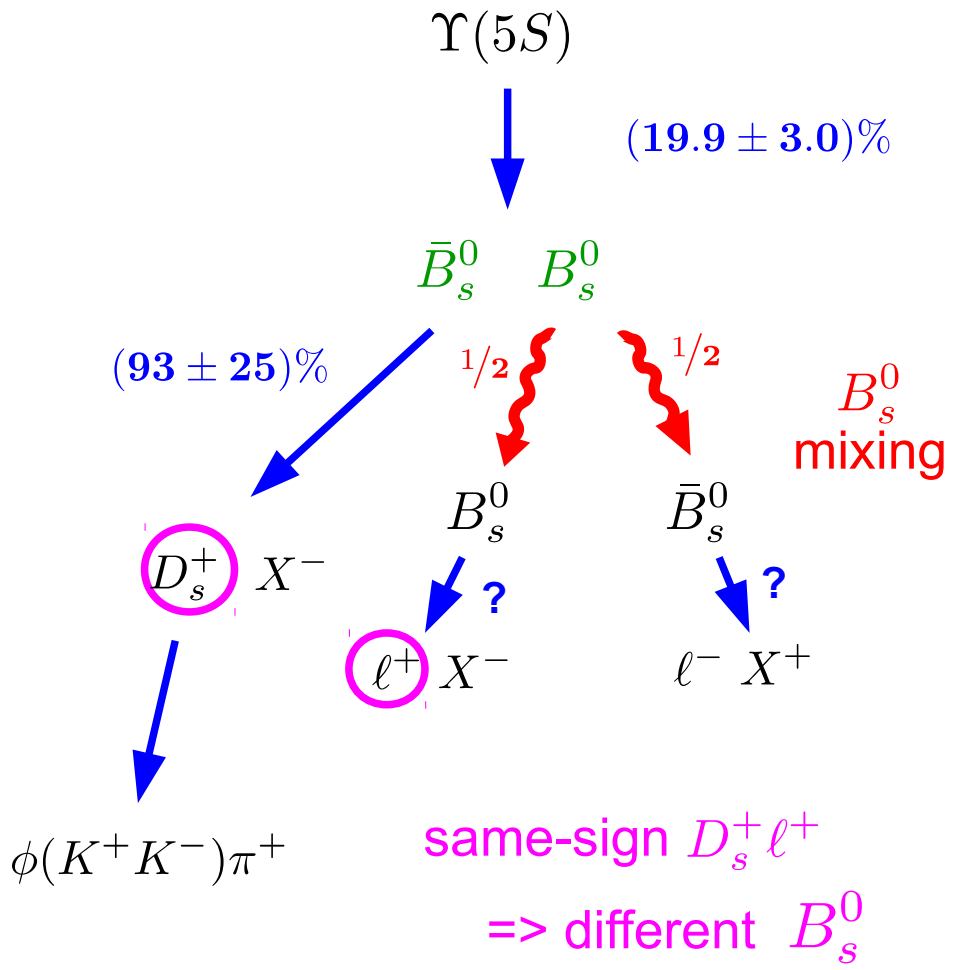


Important parameter for determination of B_s^0 production at LHC and B factories

Theory: ***SU(3) – Flavour Symmetry***:

$$\frac{\Gamma(B_s^0 \to X\ell\nu)}{\Gamma(B^0 \to X\ell\nu)} \approx 0.99 \qquad \ell = e, \mu$$

[JHEP1109,012(2011)]



$$\mathcal{R} = \frac{\mathcal{N}(D_s^+\ell^+)}{\mathcal{N}(D_s^+)} \propto \frac{\mathcal{N}(B_s^0 \to \ell)}{\mathcal{N}(B_s^0)} = \mathcal{B}(B_s^0 \to X\ell\nu) \qquad \frac{\mathcal{N}_s(D_s^+\ell^+) + \mathcal{N}_{u,d}(D_s^+\ell^+)}{\mathcal{N}_s(D_s^+) + \mathcal{N}_{u,d}(D_s^+)}$$

Estimation of the yields from B_s^0 and $B_{u,d}$

$B_s^{0(*)}\bar{B}_s^{0(*)}$

$$N_s(D_s^+)/N_{b\bar{b}} = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to D_s^{\pm} X)$$

$$N(D_s^+\ell^+)/N_{b\bar{b}} = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to X^-\ell^+\nu) \cdot (1-\chi_s) \cdot \mathcal{B}(B_s^0 \to D_s^{\pm} X)$$

$B_{u,d}^{(*)}\bar{B}_{u,d}^{(*)}(\pi)$

$$N_{ud}(D_s^+)/N_{b\bar{b}} = 2 \cdot f_d \cdot \mathcal{B}(B^0 \to D_s^{\pm} X) + 2 \cdot f_u \cdot \mathcal{B}(B^+ \to D_s^{\pm} X)$$

$$N_{ud}(D_s^+\ell^+)/N_{b\bar{b}} =$$

$$2 \cdot \tfrac{f_d}{f_{ud}} \cdot \underbrace{\left[F_{B\bar{B}} + F_{B^*\bar{B}^*} + \tfrac{1}{3}(f_{ud}-F_2)\cdot(F'_{B\bar{B}\pi} + F'_{B^*\bar{B}^*\pi}) + (f_{ud}-F_2)\cdot(1-F'_3)\right] \cdot \left\{\chi_d^{(-)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1-\chi_d^{(-)}\right)\cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X^-\ell^+\nu_\ell)}_{B^{0(*)}\bar{B}^{0(*)} \text{ pairs, } \mathcal{C} \text{ even}}$$

$$+ \; 2 \cdot \tfrac{f_d}{f_{ud}} \cdot \underbrace{\left[F_{B^*\bar{B}} + \tfrac{1}{3}(f_{ud}-F_2)\cdot F'_{B^*\bar{B}\pi}\right] \cdot \left\{\chi_d^{(+)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1-\chi_d^{(+)}\right)\cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X^-\ell^+\nu_\ell)}_{B^0\bar{B}^{0*} \text{ pairs, } \mathcal{C} \text{ odd}}$$

$$+ \; 2 \cdot \tfrac{f_u}{f_{ud}} \cdot \underbrace{\left[F_2 + \frac{1}{3}(f_{ud}-F_2)\cdot F'_3 + (f_{ud}-F_2)\cdot(1-F'_3))\right] \cdot \mathcal{B}(B^+ \to D_s^- X) \cdot \mathcal{B}(B^+ \to X\ell^+\nu_\ell)}_{B^{+(*)}B^{-(*)} \text{ pairs}}$$

$$+ \underbrace{\left[\tfrac{2}{3}\cdot(f_{ud}-F_2)\cdot F'_3\right] \cdot \left(\left\{\chi_d^{(-)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1-\chi_d^{(-)}\right)\cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^+ \to X\ell^+\nu_\ell) + \left\{\chi_d^{(-)} \cdot \mathcal{B}(B^+ \to D_s^+ X) + \left(1-\chi_d^{(-)}\right)\cdot \mathcal{B}(B^+ \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X^-\ell^+\nu_\ell)\right)}_{B^{+(*)}\bar{B}^{0(*)} \text{ and } B^{-(*)}B^{0(*)} \text{ pairs}} .$$

Estimation of the yields from B_s^0 and $B_{u,d}$

$B_s^{0(*)}\bar{B}_s^{0(*)}$

$$N_s(D_s^+)/N_{b\bar{b}} = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to D_s^{\pm} X)$$

$$N(D_s^+\ell^+)/N_{b\bar{b}} = 2 \cdot f_s \cdot \mathcal{B}(B_s^0 \to X^-\ell^+\nu) \cdot (1-\chi_s) \cdot \mathcal{B}(B_s^0 \to D_s^{\pm} X)$$

$B_{u,d}^{(*)}\bar{B}_{u,d}^{(*)}(\pi)$

$$N_{ud}(D_s^+)/N_{b\bar{b}} = 2 \cdot f_d \cdot \mathcal{B}(B^0 \to D_s^{\pm} X) + 2 \cdot f_u \cdot \mathcal{B}(B^+ \to D_s^{\pm} X)$$

$$N_{ud}(D_s^+\ell^+)/N_{b\bar{b}} =$$

$$2 \cdot \tfrac{f_d}{f_{ud}} \cdot \left[F_{B\bar{B}} + F_{B^*\bar{B}^*} + \tfrac{1}{3}(f_{ud}-F_2)\cdot(F'_{B\bar{B}\pi} + F'_{B^*\bar{B}^*\pi}) + (f_{ud}-F_2)\cdot(1-F'_3)\right] \cdot \underbrace{\left\{\chi_d^{(-)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1-\chi_d^{(-)}\right)\cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X^-\ell^+\nu_\ell)}_{B^{0(*)}\bar{B}^{0(*)} \text{ pairs, } \mathcal{C} \text{ even}}$$

$$+ \; 2 \cdot \tfrac{f_d}{f_{ud}} \cdot \left[F_{B^*\bar{B}} + \tfrac{1}{3}(f_{ud}-F_2)\cdot F'_{B^*\bar{B}\pi}\right] \cdot \underbrace{\left\{\chi_d^{(+)} \cdot \mathcal{B}(B^0 \to D_s^+ X) + \left(1-\chi_d^{(+)}\right)\cdot \mathcal{B}(B^0 \to D_s^- X)\right\} \cdot \mathcal{B}(B^0 \to X^-\ell^+\nu_\ell)}_{\text{odd}}$$

$$+ \left[\cdots\right] \cdot \mathcal{B}(B^+ \to D_s^- X) \cdot \mathcal{B}(B^+ \to X \cdots$$

pairs

$$\cdots \mathcal{B}(B^0 \to D_s^- X)\Big\} \cdot \mathcal{B}(B^+ \to \cdots$$

$$\cdots \to D_s^- X)\Big\} \cdot \mathcal{B}(B^0 \to \cdots$$

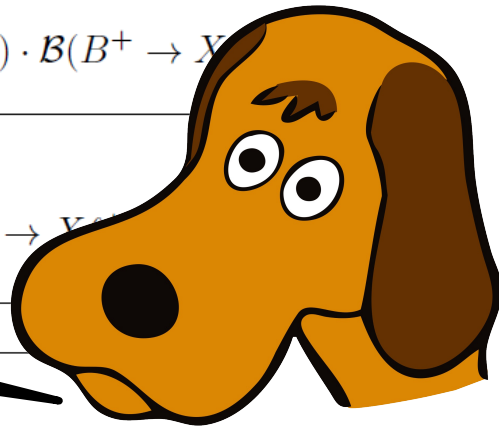
$$\underbrace{\{\chi_d \cdots}_{B^{+(*)}\bar{B}^{0(*)} \text{ and } B^{-(*)}B^{0(*)} \text{ pairs}}$$

I know

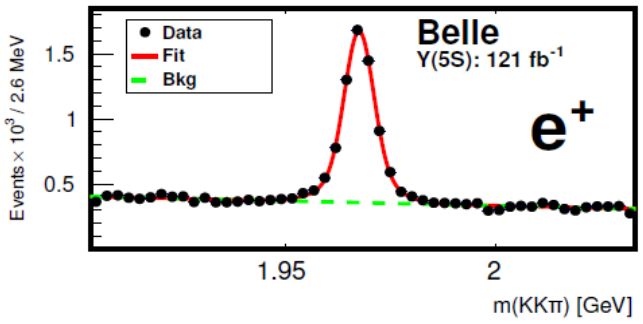
$B_{(s)}\bar{B}_{(s)}(\pi)$ **production at** $\Upsilon(5S)$

$B_{(s)}$ **branching fractions**

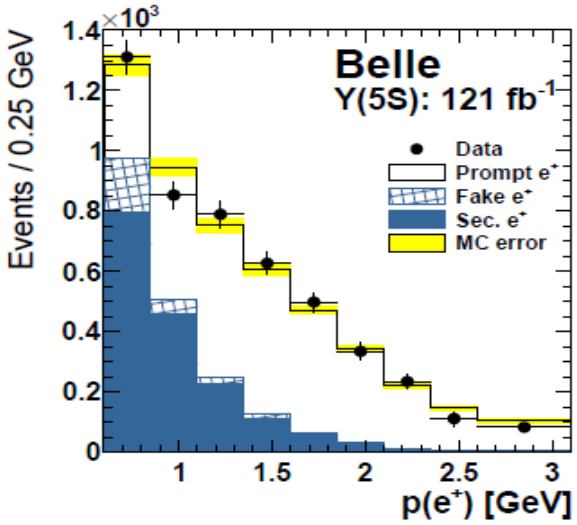
$B^0_{(s)}$ **mixing**



$B_s^0 \to X\ell\nu$: Results



Fits to $M(D_s^+)$ in bins of $p(\ell^+)$



$\chi^2/\mathrm{ndf} = 6.4/7$

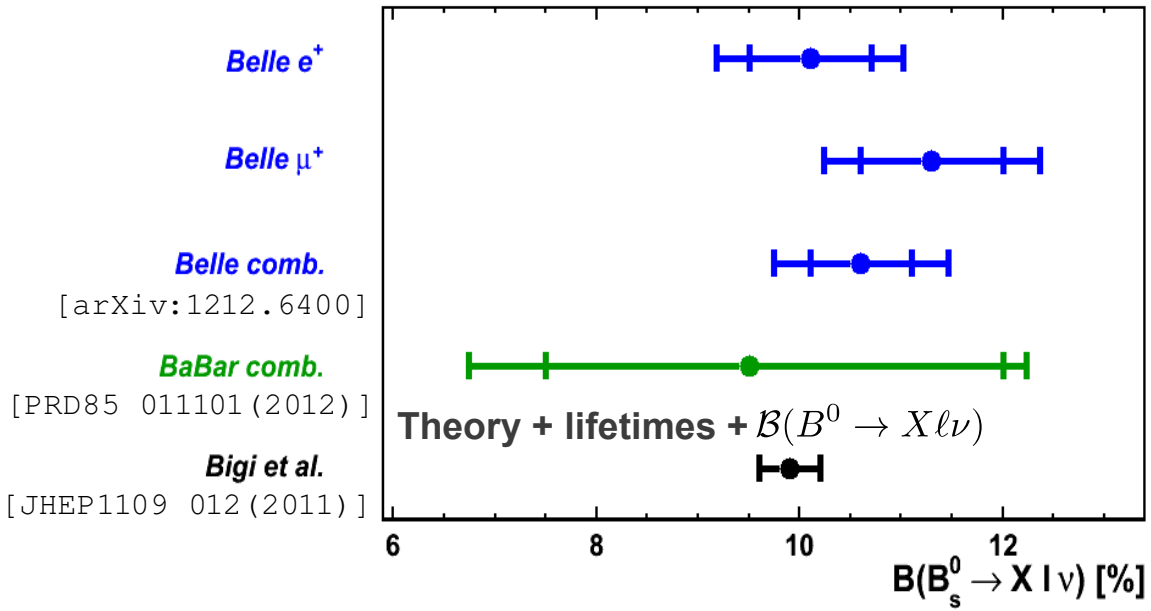
Fit to $p(\ell^+)$

$N(D_s^+\ell^+)$

most precise measurement

$$\mathcal{B}(B_s^0 \to X\ell\nu) = [10.6 \pm 0.5(stat) \pm 0.7(syst)]\%$$

Dominant uncertainty: B_s^0 production at $\Upsilon(5S)$



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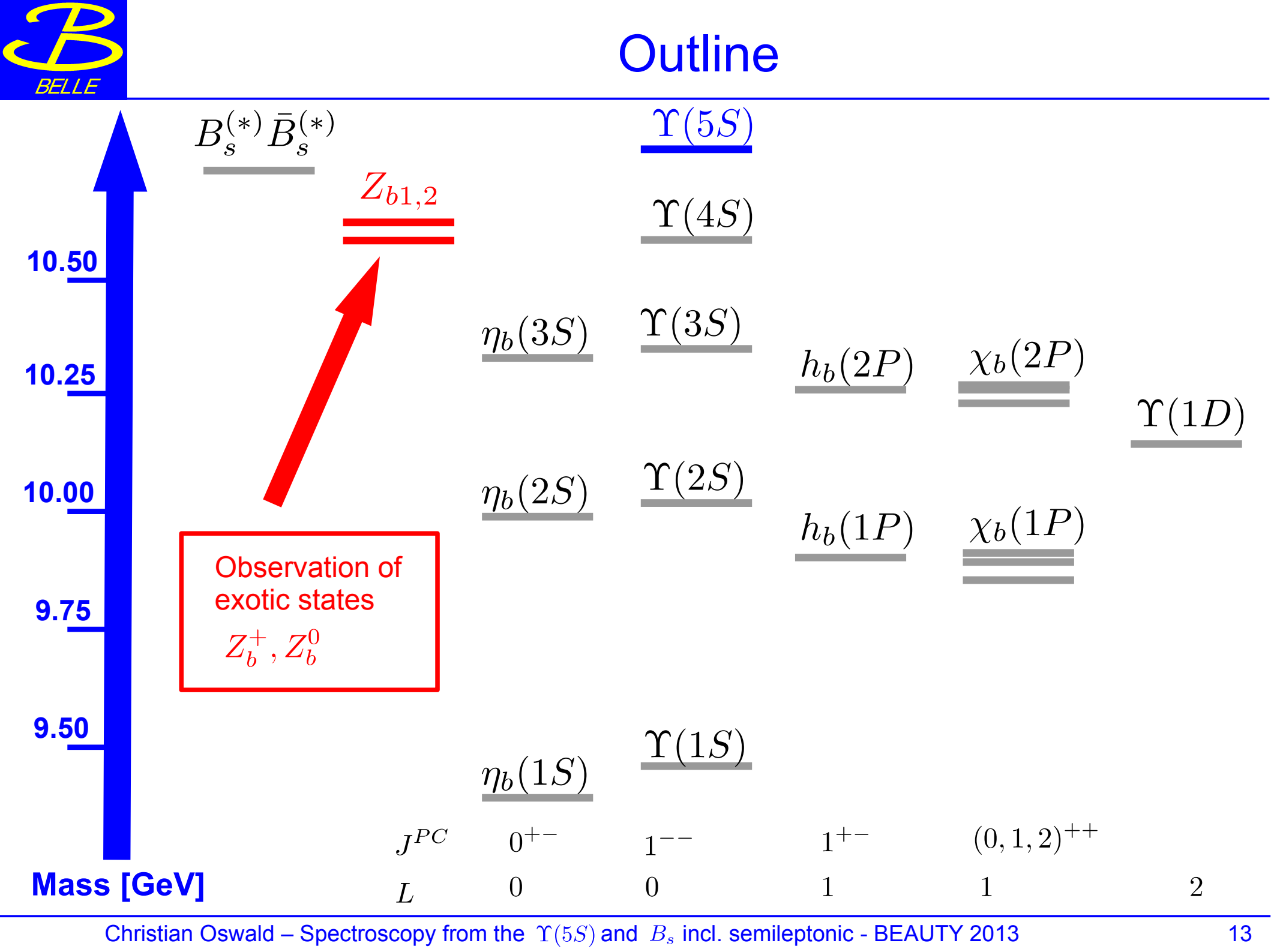
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10.50
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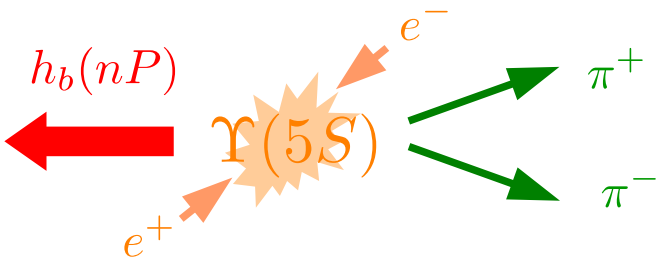
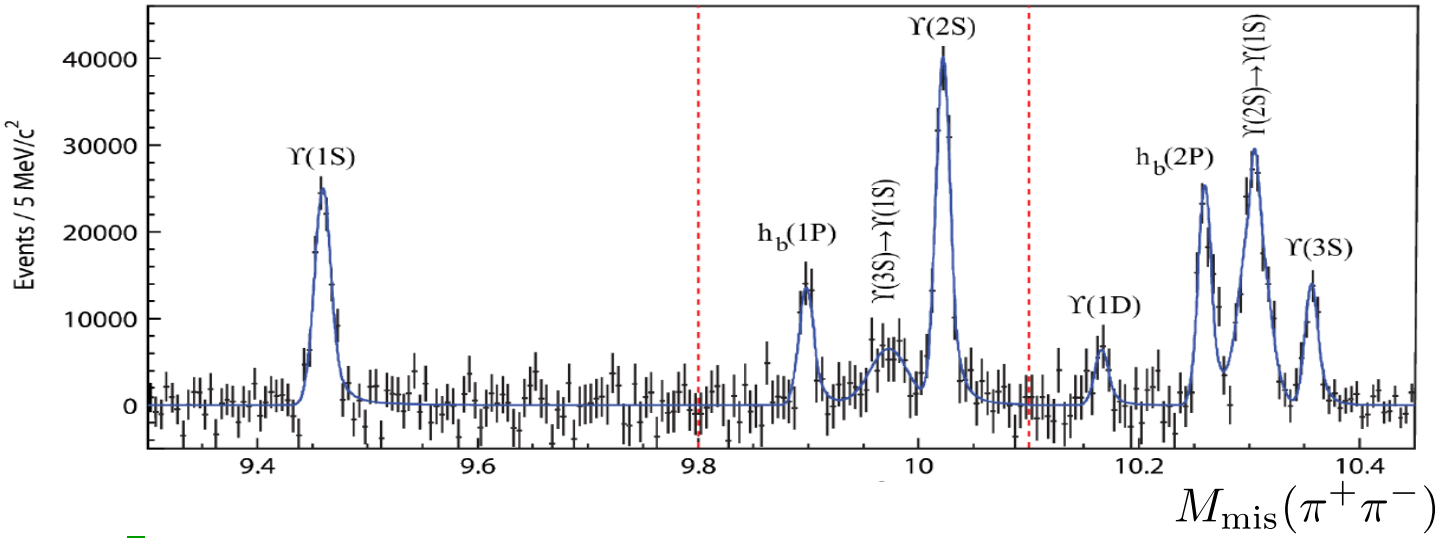
Mass [GeV]
Observation of exotic states
Z_b^+, Z_b^0
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2

Observation of $\Upsilon(5S) \to h_b(nP)\pi^+\pi^-$



$$M_{\rm mis}(\pi^+\pi^-)^2 = (E_{\Upsilon(5S)} - E_{\pi\pi})^2 - p_{\pi\pi}{}^2$$



$$\frac{\Gamma(\Upsilon(5S) \to h_b(nP)\pi^+\pi^-)}{\Gamma(\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-)} = \begin{cases} 0.45 \pm 0.08\ ^{+0.07}_{-0.12} & [h_b(1P)] \\ 0.77 \pm 0.08\ ^{+0.22}_{-0.17} & [h_b(2P)] \end{cases}$$

Spin flip not suppressed

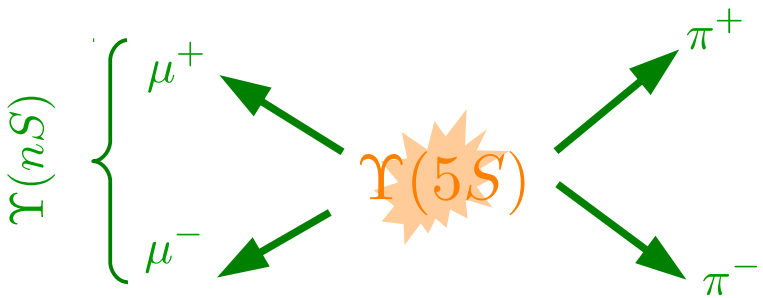
Violation of heavy quark spin symmetry

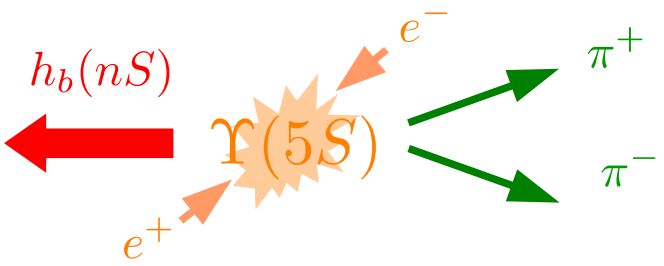
Exotic decay mechanism

[PRL 108, 032001 (2012)]

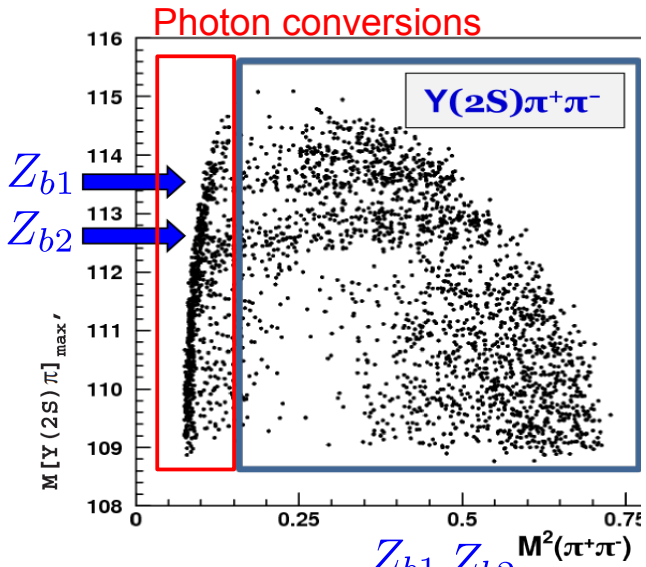
Discovery of Z_{b1}^+, Z_{b2}^+

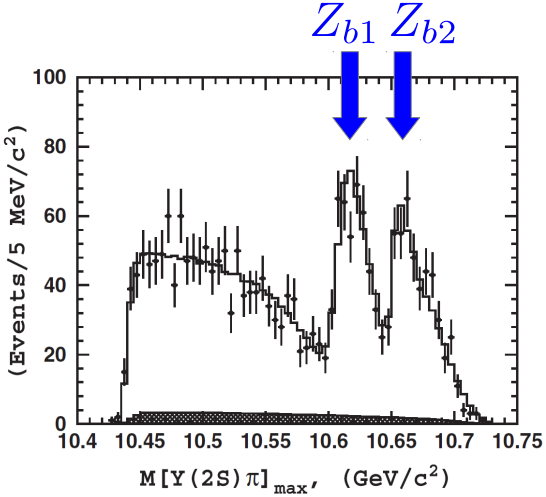
[PRL 108, 122001 (2012)]

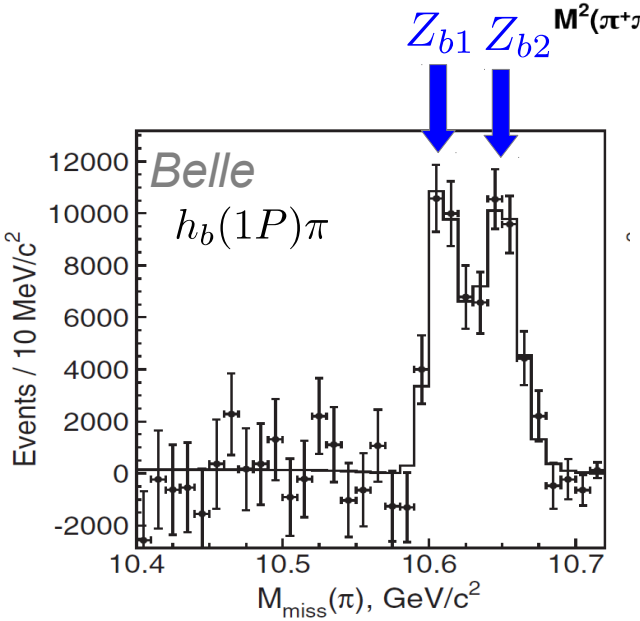


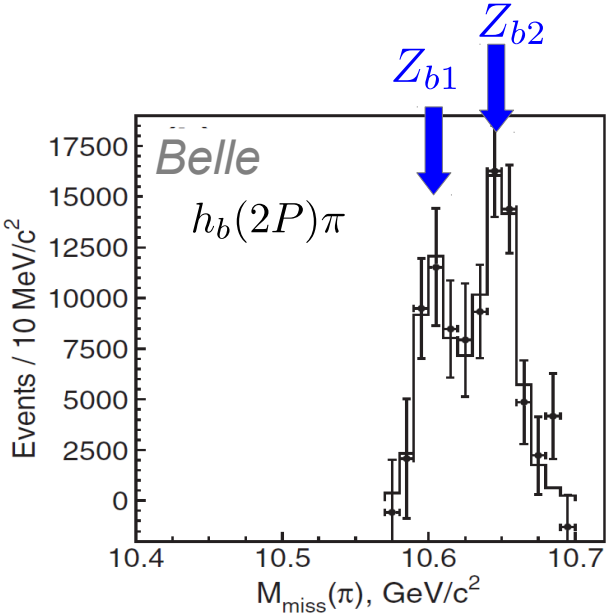


$M_{\rm mis}(\pi^+\pi^-) = M(h_b)$ fits
in bins of $M_{\rm mis}(\pi) = M(h_b\pi)$









Saturated with Z_{b1} and Z_{b2}
Non-resonant amplitude consistent with zero

Very limited phase space,
Consistent with Z_{b1} and Z_{b2}

Summary of Z_b masses and widths

$Z_b(10610)$

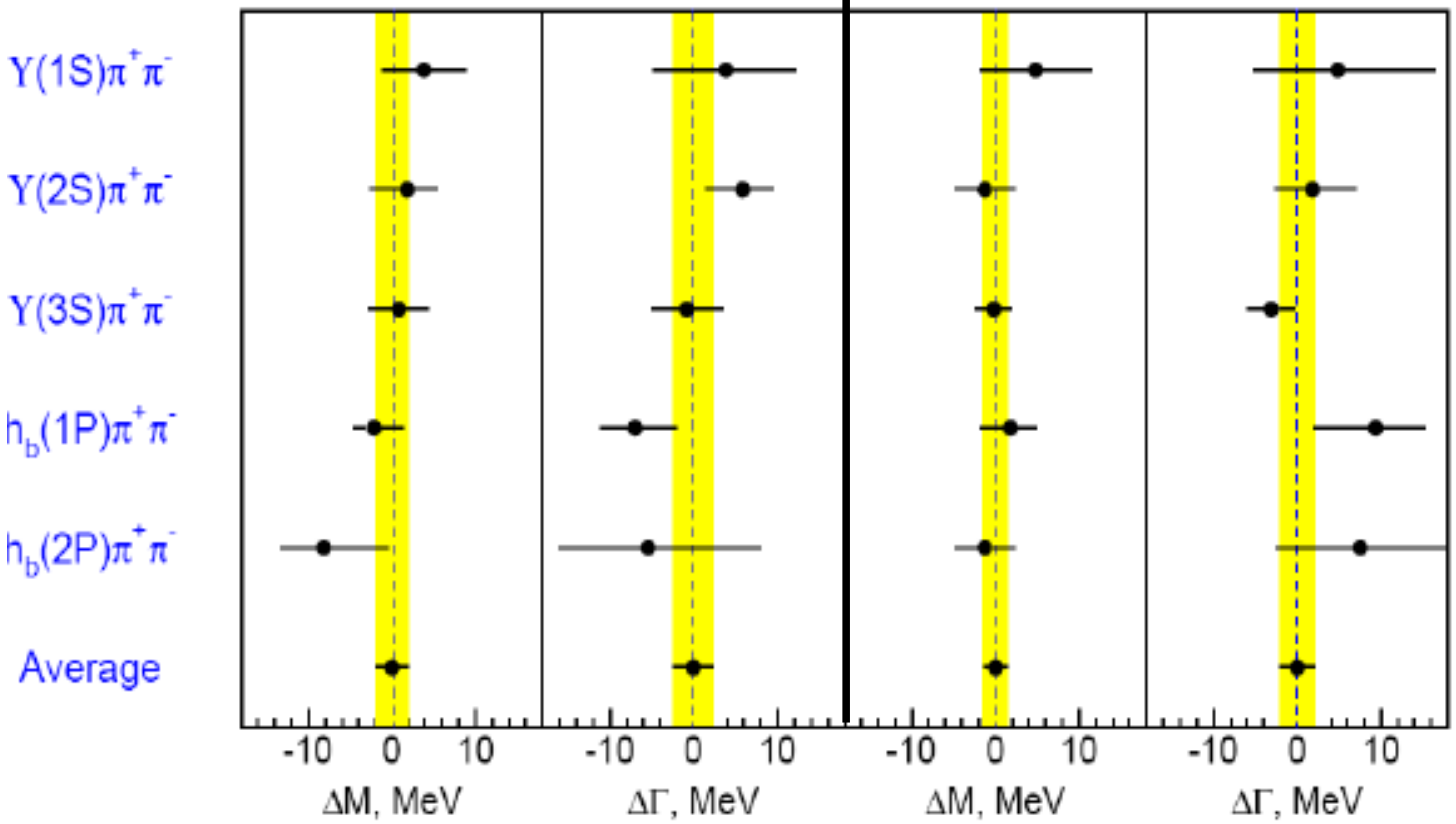
$M = [10607.2 \pm 2.0]$ MeV

$\Gamma = [18.4 \pm 2.5]$ MeV

$Z_b(10650)$

$M = [10652.2 \pm 1.5]$ MeV

$\Gamma = [11.5 \pm 2.2]$ MeV

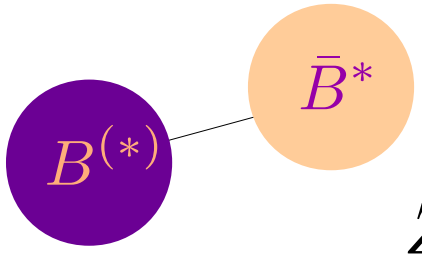


$\Upsilon(5S) \to B^{(*)}\bar{B}^*\pi$

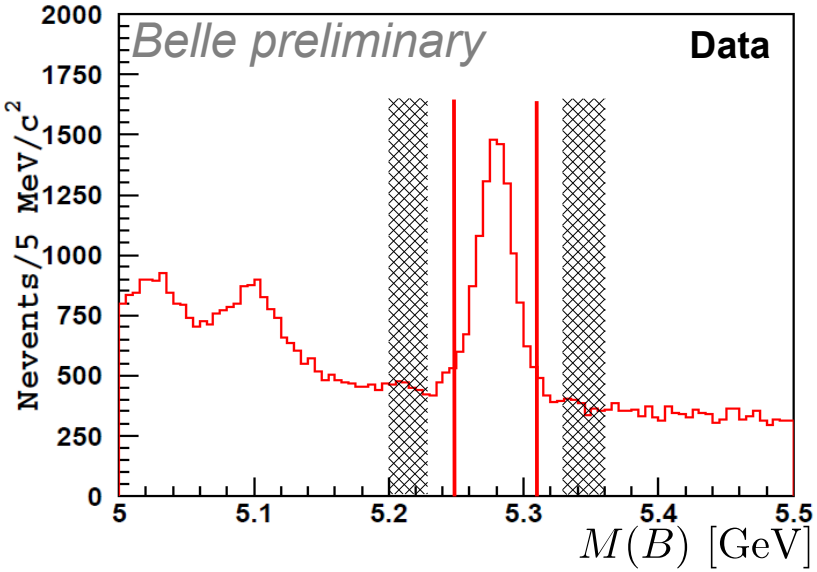
[arXiv:1209:6450]

$M(Z_b(10610)) \approx M(B\bar{B}^*)$

$M(Z_b(10650)) \approx M(B^*\bar{B}^*)$



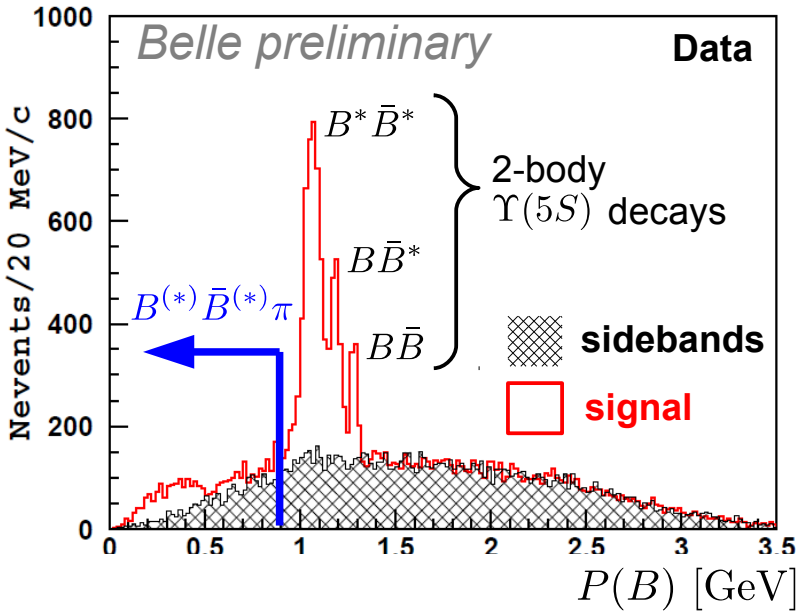
Z_b = Molecule?



One *charged* pion and
full reconstruction of one B meson:

$$
\begin{aligned}
B^+ &\to J/\psi[\mu^+\mu^-]K^+ \\
&\to \bar{D}^0[K^+\pi^-,\ K^+\pi^-\pi^+\pi^-]\pi^+ \\
B^0 &\to J/\psi[\mu^+\mu^-]K^{0*}[K^+\pi^-], \\
&\to D^-[K^+\pi^-\pi^-]\pi^+, \\
&\to D^{*-}[K^+2\pi^-,\ K^+\pi^+3\pi^-,\ K^+\pi^02\pi^-]\pi^+
\end{aligned}
$$

Total branching fraction: 1×10^{-4}



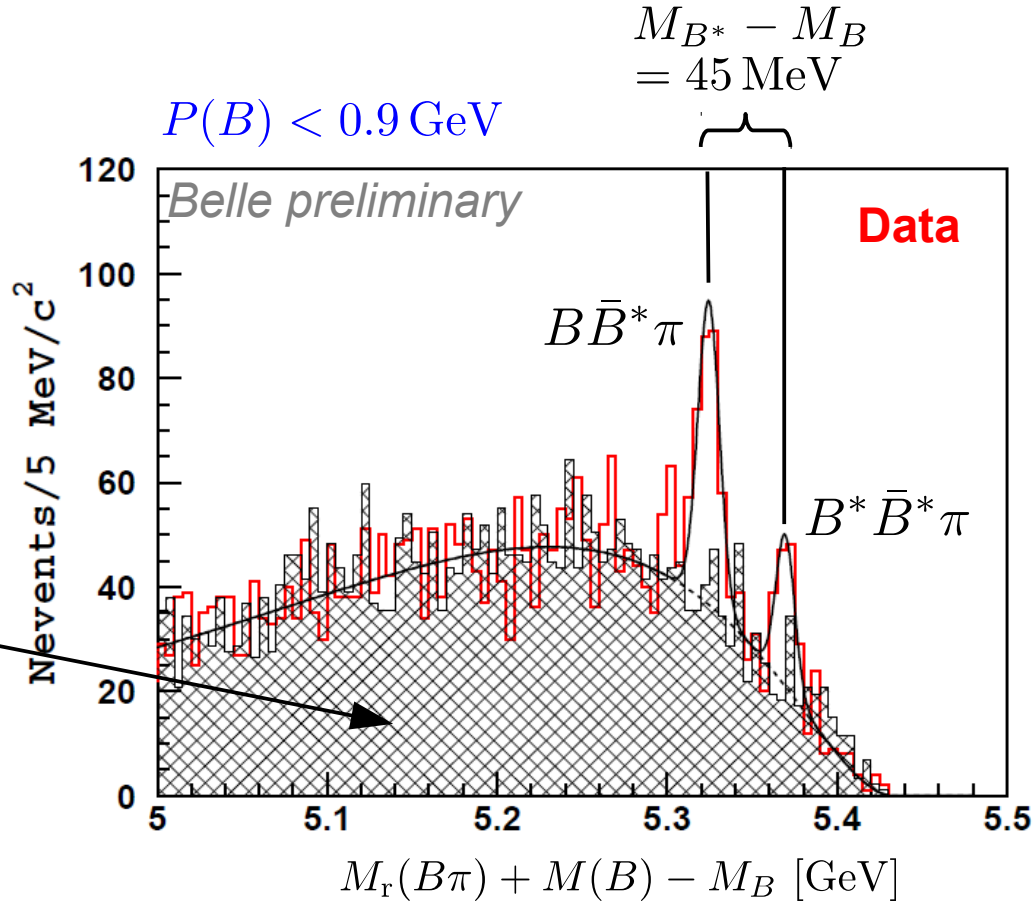
$\Upsilon(5S) \to B^{(*)}\bar{B}^*\pi$: Results

[arXiv:1209:6450]

Recoil mass of the $B\pi$ system:

$$M_{\rm r}(B\pi) = \sqrt{E^2_{\Upsilon(5S)} - P(B\pi)^2}$$

Shape of combinatorial background estimated from wrong-sign $B\pi$ combinations in data



Belle preliminary

$N_{BB\pi} = 1 \pm 14$

$N_{BB^*\pi} = 184 \pm 19 \quad (9.3\sigma)$

$N_{B^*B^*\pi} = 82 \pm 11 \quad (5.7\sigma)$

$\mathcal{B}(\Upsilon(5S) \to BB\pi) < 0.4\%\ (90\%\text{CL})$

$\mathcal{B}(\Upsilon(5S) \to BB^*\pi) = [2.83 \pm 0.29 \pm 0.46]\%$

$\mathcal{B}(\Upsilon(5S) \to B^*B^*\pi) = [1.41 \pm 0.19 \pm 0.24]\%$

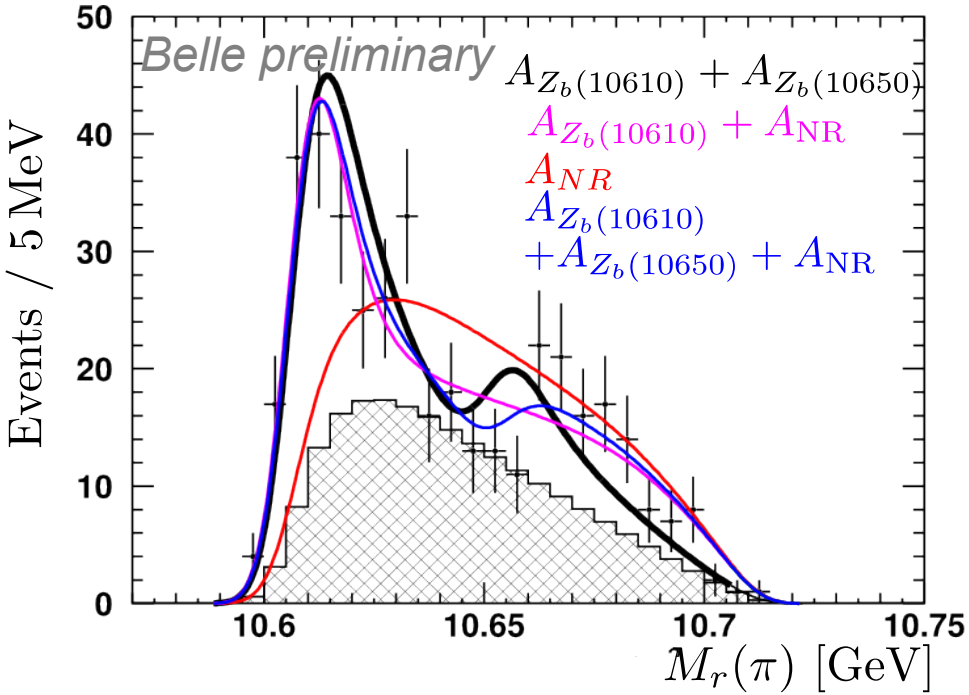
Interpretations as $Z_b \to B^{(*)}\bar{B}^*$?

[arXiv:1209:6450]

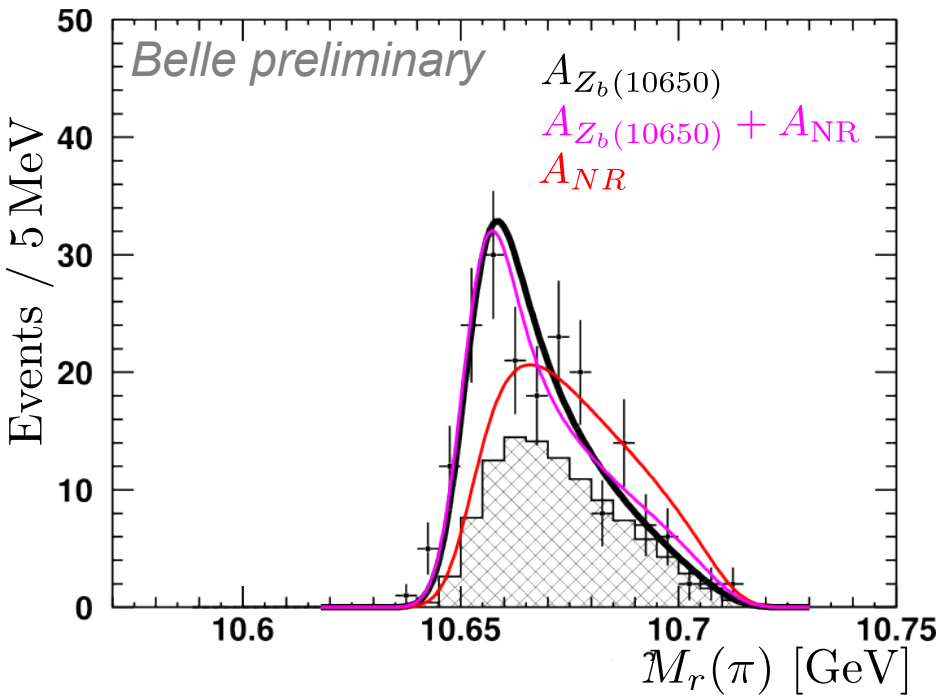
Fit function:

$$f = \epsilon(M_r(\pi)) \cdot \left[\text{Bkg} + A_{Z_b(10610)} + A_{Z_b(10650)} + A_{\text{NR}}\right]$$

$BB^*\pi$



$B^*B^*\pi$



Can be described by two models:

$A_{Z_b(10610)} + A_{Z_b(10650)}$ or $A_{Z_b(10610)} + A_{\text{NR}}$

Significance of $Z_b \to B\bar{B}^*$ signal: $> 8\sigma$

Well described by

$Z_b(10650)$ or $A_{Z_b(10650)} + A_{\text{NR}}$

Significance of $Z_b \to B^*\bar{B}^*$ signal: 6.8σ

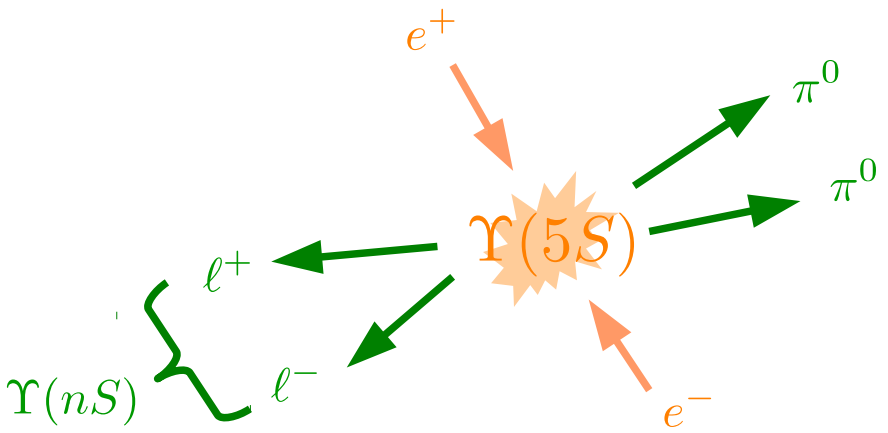
Z_{b1}, Z_{b2} branching fractions

Assuming that Z_{b1}, Z_{b2} decay only via the observed modes....

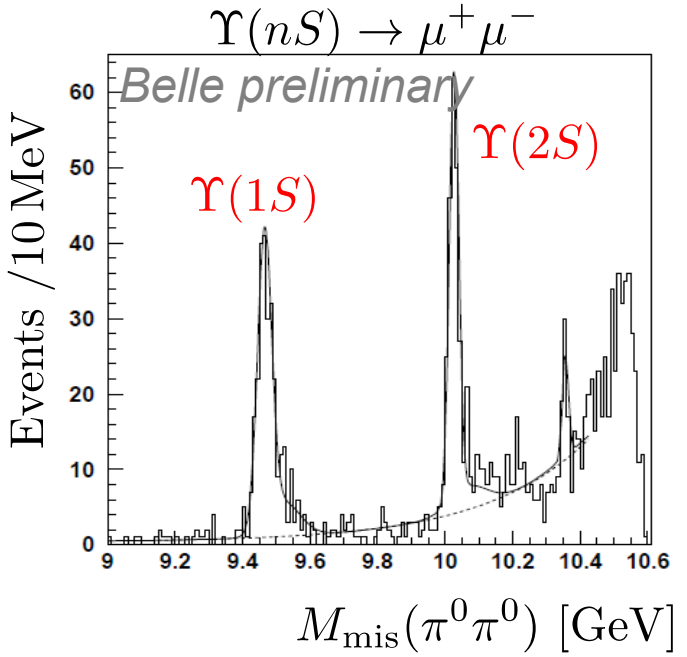
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ± 3.6	–
$B^{*+}\bar{B}^{*0}$	–	73.4 ± 7.0

Dominant decays via $B\bar{B}^*$ and $B^*\bar{B}^*$

First observation of $\Upsilon(5S) \to \Upsilon(1S, 2S)\pi^0\pi^0$



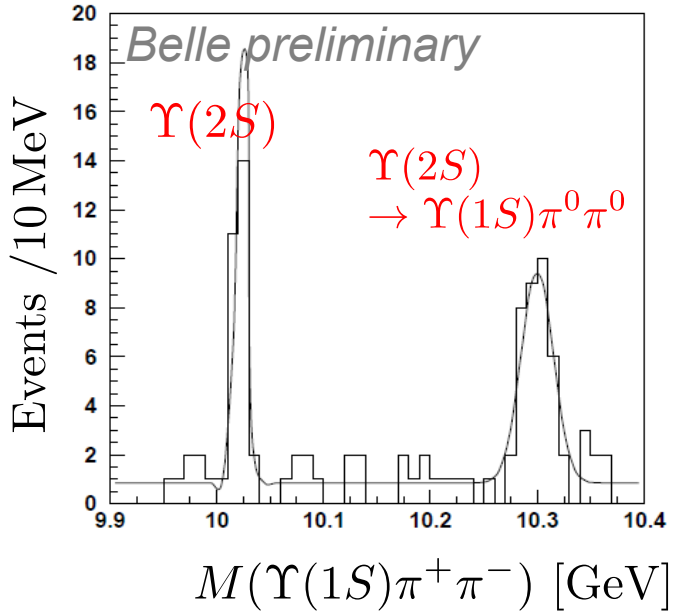
$$M_{\rm mis}(\pi^0\pi^0)^2 = (E_{\Upsilon(5S)} - E_{\pi 0\pi 0})^2 - p_{\pi 0\pi 0}{}^2$$



Belle preliminary

	$\mathcal{B}(\Upsilon(5S) \to \Upsilon(nS)\pi^0\pi^0)$
$n = 1$	$[2.25 \pm 0.11 \pm 0.20] \times 10^{-3}$
$n = 2$	$[3.79 \pm 0.24 \pm 0.49] \times 10^{-3}$

~½ of corresponding $\pi^+\pi^-$ mode

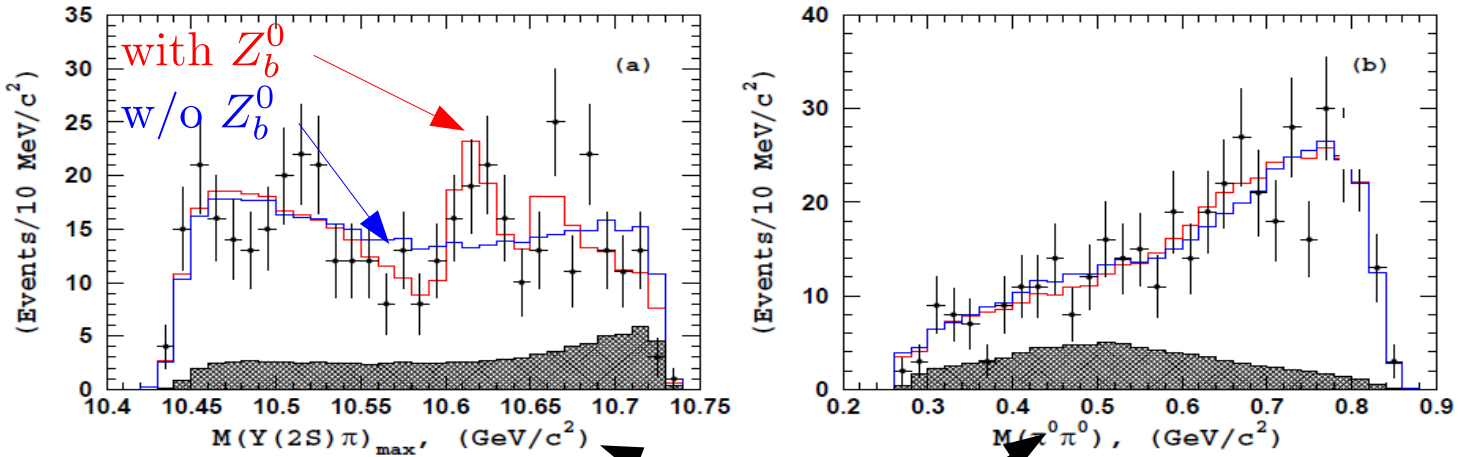


[arXiv:1207:4345]

Search for Z_b^0 in $\Upsilon(5S) \to \Upsilon(1S, 2S)\pi^0\pi^0$

Dalitz analysis:
Non-resonant component, Z_{b1}^0, Z_{b2}^0 and also contributions from $f_0(980)$ and $f_2(1270)$

$Y(2S)\pi^0\pi^0$



$\chi^2/\mathrm{ndf} = 27.0/28$

$\chi^2/\mathrm{ndf} = 39.7/28$

Background estimated from $M(\Upsilon(2S))$ sidebands

$Z_b^0(10610)$ signal found with significance 4.9σ

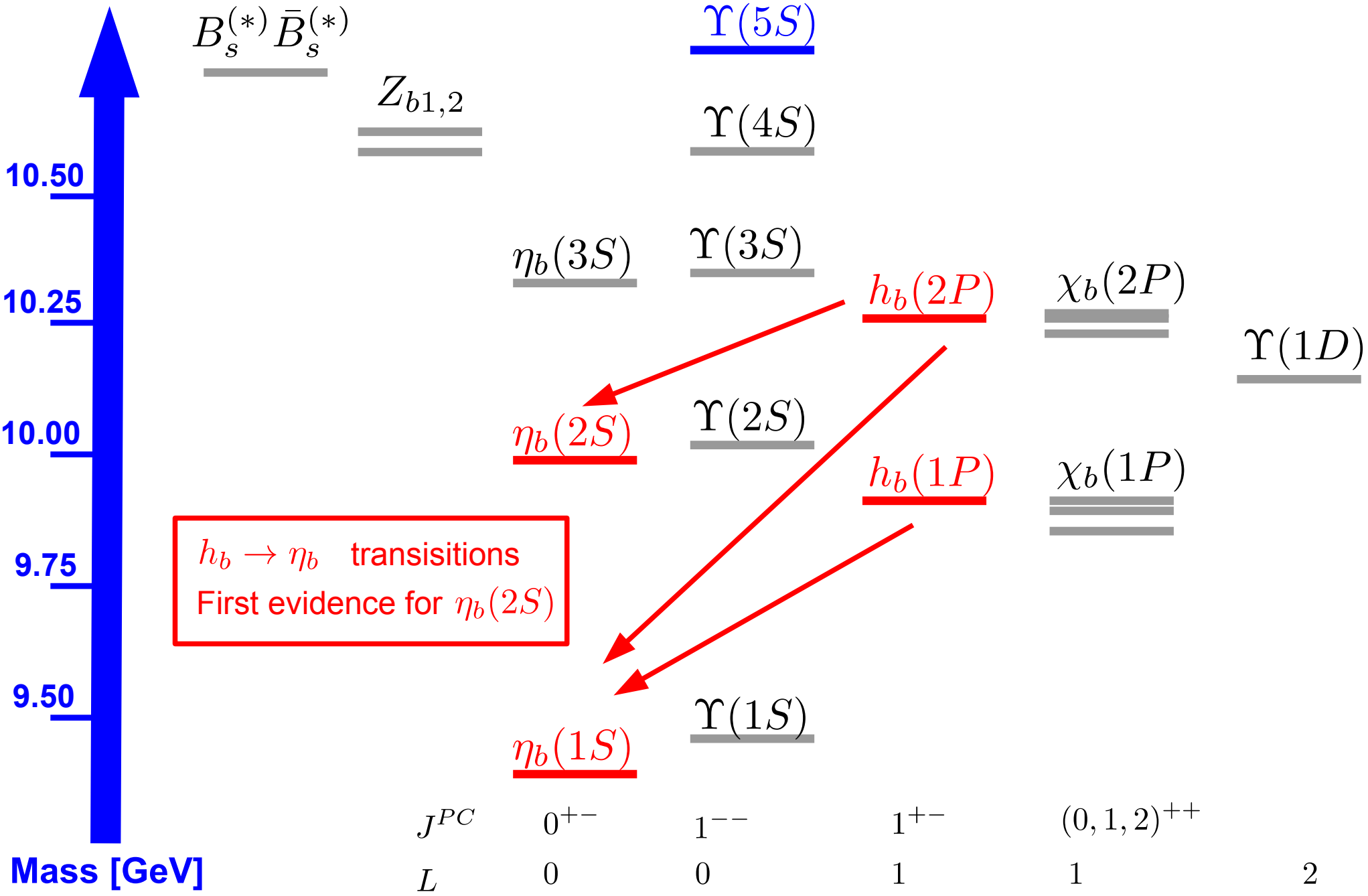
$M(Z_{b1}^0) = [10609 \pm 8 \pm 6]$ MeV compared to $M(Z_{b1}^+) = 10607.2 \pm 2.0$MeV

$Z_b^0(10650)$ signal with significance $\approx 2\sigma$

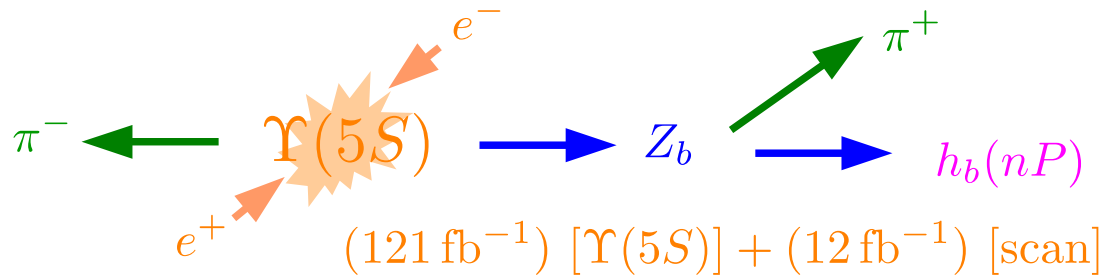
$Y(1S)\pi^0\pi^0$ No significant Z_b^0 signal, but existence not excluded

[arXiv:1207:4345]

Outline

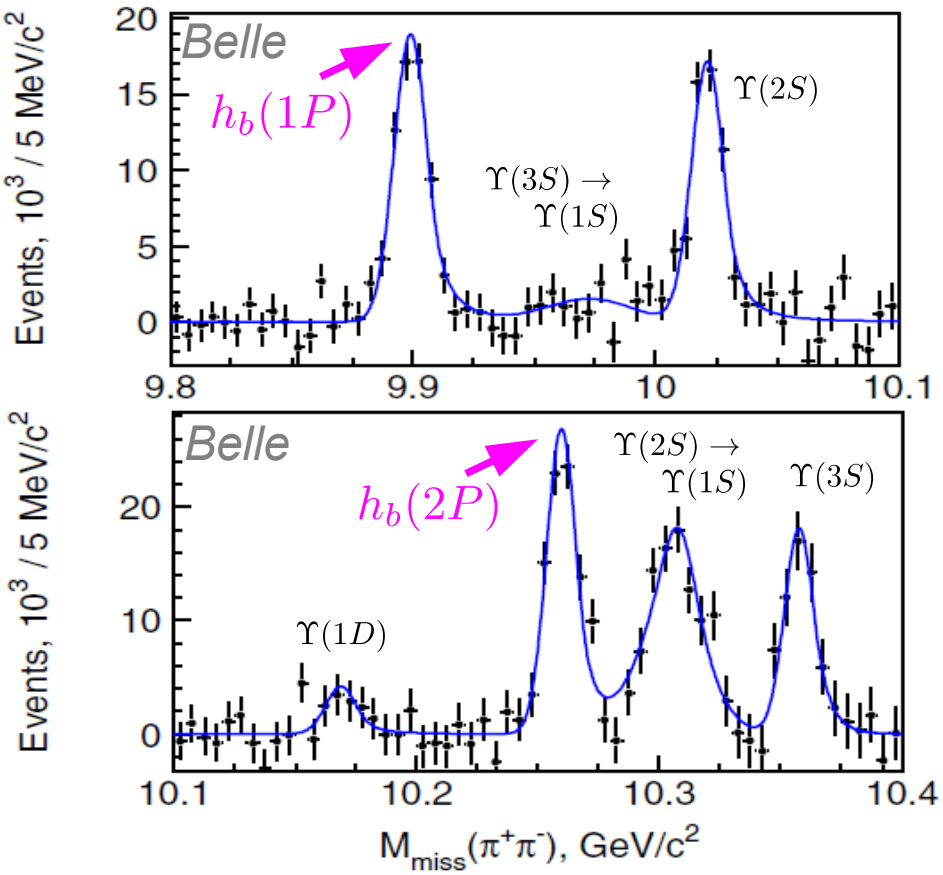

$B_s^{(*)}\bar{B}_s^{(*)}$
$\Upsilon(5S)$
$Z_{b1,2}$
$\Upsilon(4S)$
10.50
$\eta_b(3S)$
$\Upsilon(3S)$
10.25
$h_b(2P)$
$\chi_b(2P)$
$\Upsilon(1D)$
$\eta_b(2S)$
$\Upsilon(2S)$
10.00
$h_b(1P)$
$\chi_b(1P)$
$h_b \to \eta_b$ transisitions
First evidence for $\eta_b(2S)$
9.75
9.50
$\Upsilon(1S)$
$\eta_b(1S)$
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2
Mass [GeV]

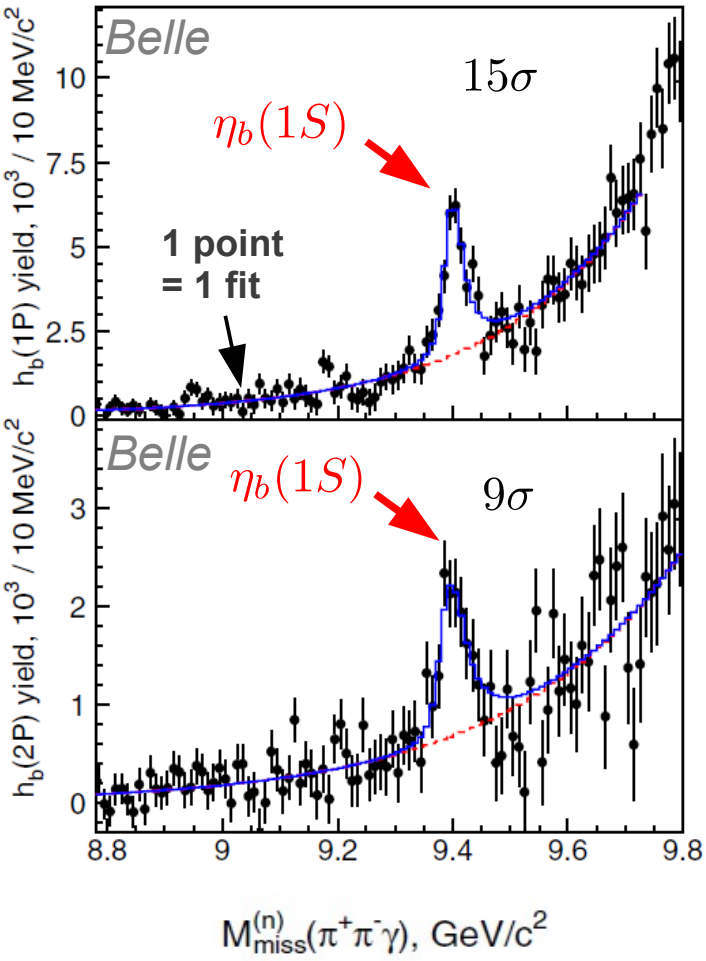
Observation of $h_b(1,2P) \to \eta_b(1S)$



reconstructed particles

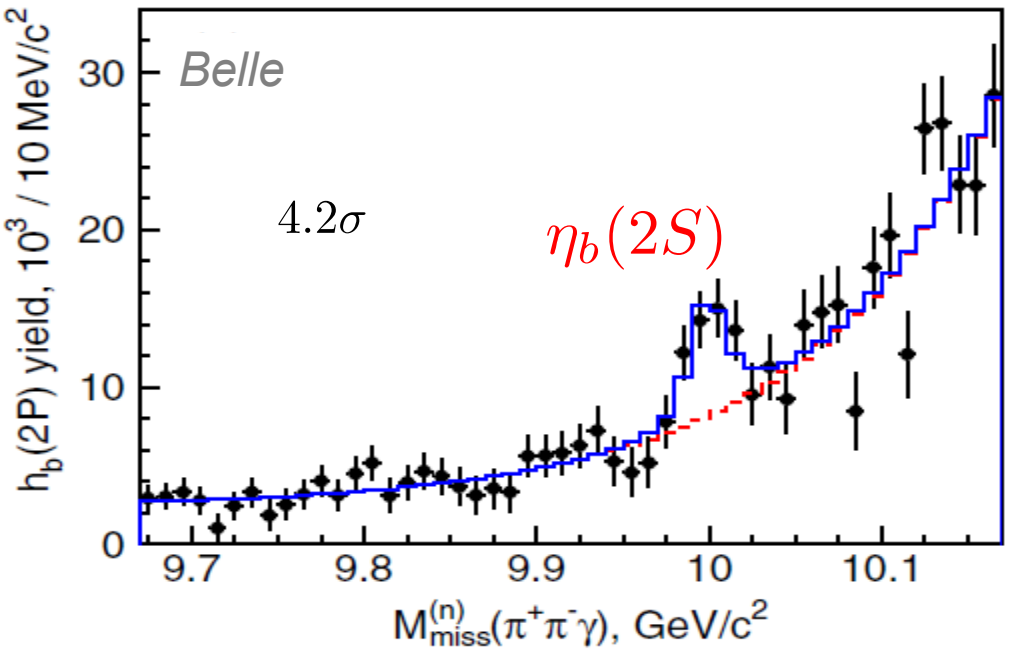
[PRL 109, 232002 (2012)]





$M(\eta_b(1S)) = [9402.4 \pm 1.5 \pm 1.8]$ MeV $\qquad \Gamma(\eta_b(1S)) = [10.8\ ^{+4.0}_{-3.7}\ ^{+4.5}_{-2.0}]$ MeV

Evidence for $\eta_b(2S)$



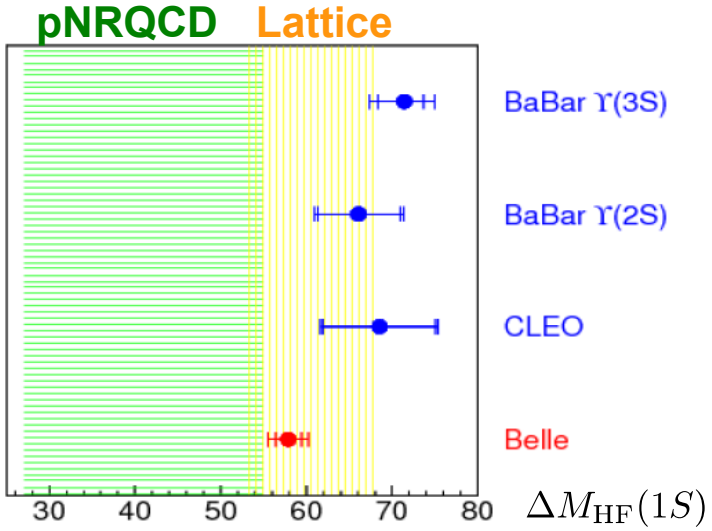
$M(\eta_b(2S)) = [9999.0 \pm 3.5\ ^{+2.8}_{-1.9}]$ MeV $\Gamma(\eta_b(2S)) < 24$ MeV (90% C.L.)

[PRL 109, 232002 (2012)]

Branching fractions [%]	Belle	Godfrey & Rosner
$h_b(1P) \to \gamma\eta_b(1S)$	$49.2 \pm 5.7\ ^{+5.6}_{-3.3}$	41
$h_b(2P) \to \gamma\eta_b(1S)$	$22.3 \pm 3.8\ ^{+3.1}_{-3.3}$	13
$h_b(2P) \to \gamma\eta_b(2S)$	$47.5 \pm 10.5\ ^{+6.8}_{-7.7}$	19

Hyperfine splitting $\Delta M_{\rm HF}$

$$\Delta M_{\rm HF}(nS) = M(\Upsilon(nS) - M(\eta_b(nS))$$



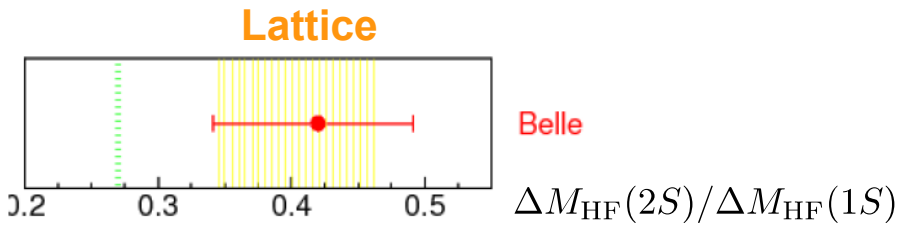
[Eur.Phys.J. C71, 1534(2011)]

Probes the spin dependence of bound-state energy levels

Puts constraints on theoretical descriptions of spin-spin interaction.

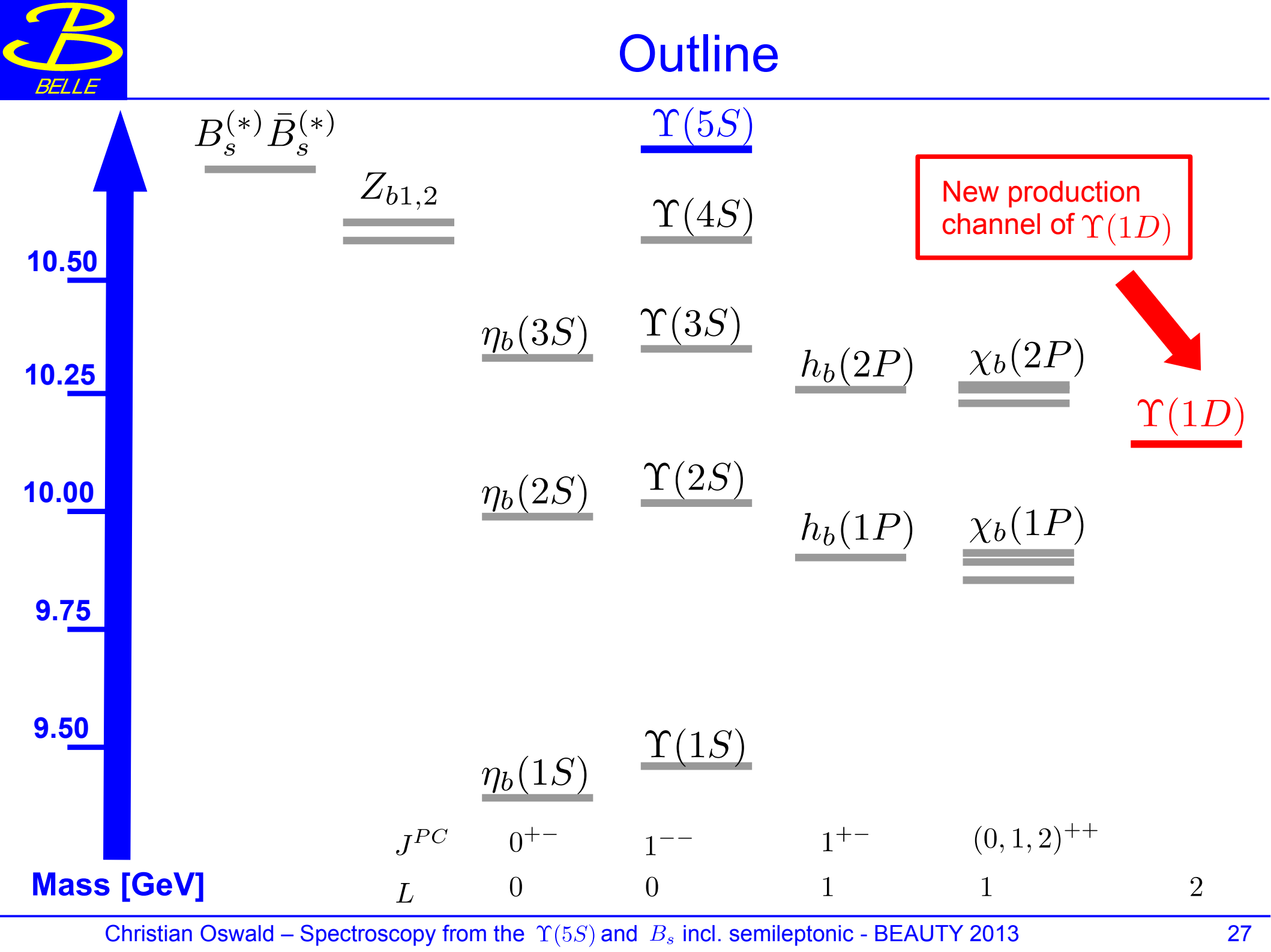
Serves also to extract α_s.

$$\Delta M_{\rm HF}(1S) = [57.9 \pm 2.3]\ \text{MeV}$$
$$\Delta M_{\rm HF}(2S) = [24.3\ ^{+4.0}_{-4.5}]\ \text{MeV}$$



[PRD 82, 114502(2010)]

Outline

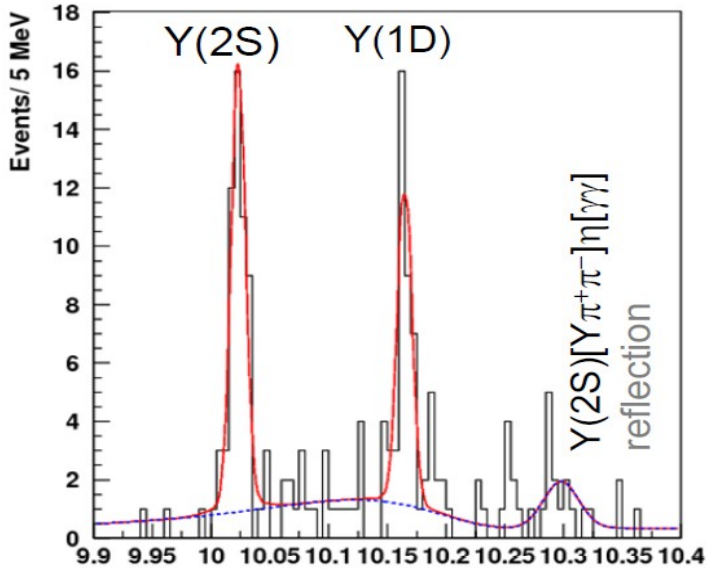

$B_s^{(*)}\bar{B}_s^{(*)}$
$Z_{b1,2}$
$\Upsilon(5S)$
$\Upsilon(4S)$
New production channel of $\Upsilon(1D)$
$\eta_b(3S)$
$\Upsilon(3S)$
$h_b(2P)$
$\chi_b(2P)$
$\Upsilon(1D)$
$\eta_b(2S)$
$\Upsilon(2S)$
$h_b(1P)$
$\chi_b(1P)$
$\eta_b(1S)$
$\Upsilon(1S)$
10.50
10.25
10.00
9.75
9.50
Mass [GeV]
J^{PC} 0^{+-} 1^{--} 1^{+-} $(0,1,2)^{++}$
L 0 0 1 1 2

$\Upsilon(5S) \to \Upsilon(1D)\pi^+\pi^-,\ \Upsilon(1,2S)\eta^{(\prime)}$

$\Upsilon(1D)$, first L=2 state found at CLEO

New production channel found at Belle:

$e^+e^- \to \Upsilon(5S)$
↳ $\Upsilon(1D)\ \pi^+\pi^-$ — Missing mass →
↳ $\chi_{b1,2}\ \gamma$
↳ $\Upsilon(1S)\ \gamma$
↳ $\mu^+\mu^-$



$M_{\rm mis}(\pi^+\pi^-)$ [GeV]

Significance: 9σ

$$\mathcal{B}(\Upsilon(5S) \to \Upsilon(1D)\pi^+\pi^-) \cdot \sum_{i=1,2} \mathcal{B}(\Upsilon(1D) \to \chi_{bi}\gamma) \cdot \mathcal{B}(\chi_{bi} \to \Upsilon(1S)\gamma) = [2.0 \pm 0.4] \times 10^{-4}$$

Using the same sample and reconstructing $\eta \to \pi^+\pi^-\pi^0[\gamma\gamma],\ \eta \to \gamma\gamma,\ \eta' \to \eta[\gamma\gamma]\pi^+\pi^-$

	$\Upsilon(1S)\eta$	$\Upsilon(2S)\eta$	$\Upsilon(1S)\eta'$
$\mathcal{B}(\Upsilon(5S) \to X)$	$[7.3 \pm 1.6] \times 10^{-4}$	$[38.1 \pm 4.2] \times 10^{-4}$	$< 1.1 \times 10^{-4}$ (90% CL)

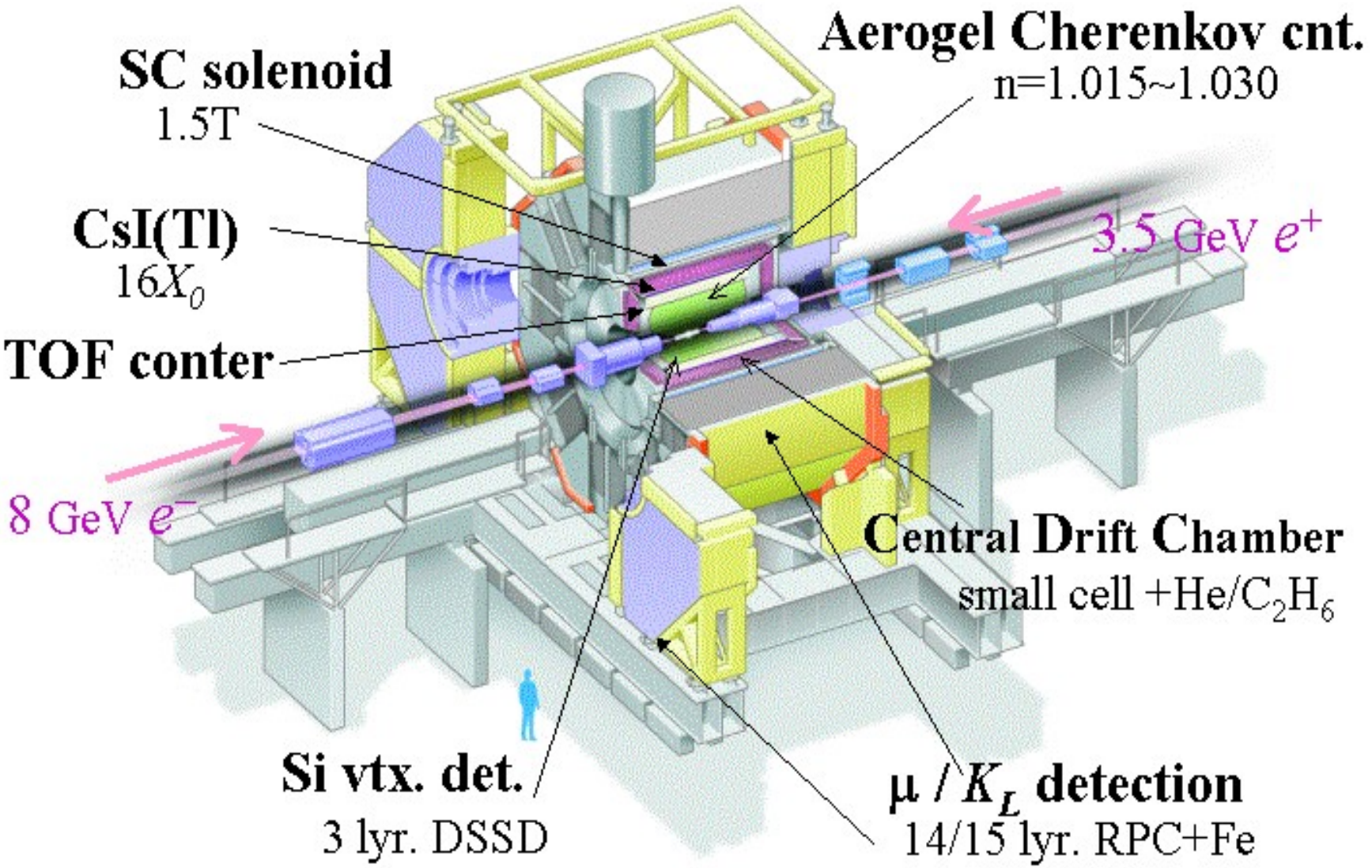
Summary

- Most precise measurement of $\mathcal{B}(B_s^0 \to X\ell\nu_\ell)$ [arXiv:1212.6400]
- Discovery of new exotic Z_b states, $B^{(*)}B^*$ molecules? [PRL 108, 032001(2012)] [PRL 108, 122001(2012)] [arXiv:1207:4345] [arXiv:1209:6450]
- Observation of $h_b(1,2P) \to \eta_b(1,2S)$ and evidence for $\eta_b(2S)$ [PRL 109, 232002 (2012)]
- New production channel of $\Upsilon(1D)$ found

Stay tuned, more interesting physics from the $\Upsilon(5S)$ is in the queue for summer!

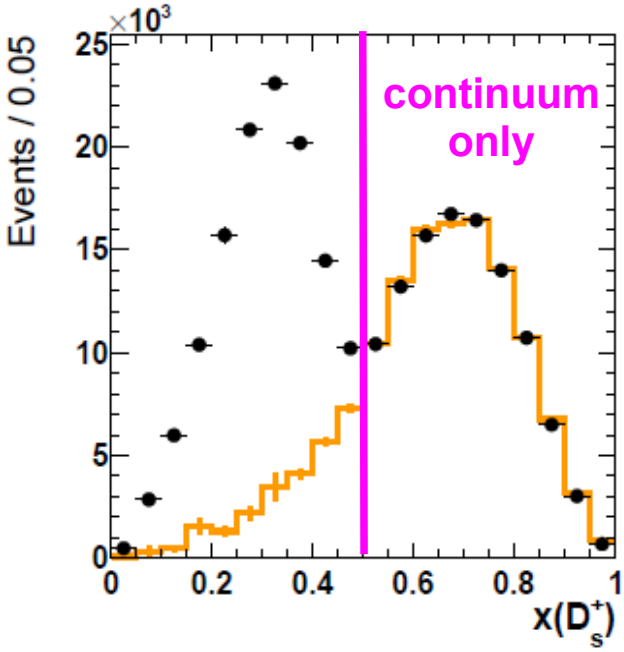
BACKUP

The Belle detector

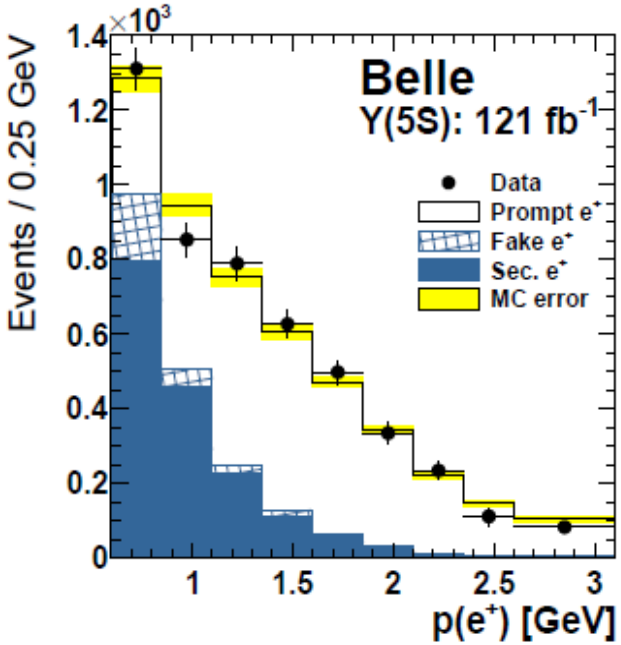


Momentum spectra obtained from $M(KK\pi)$ fits

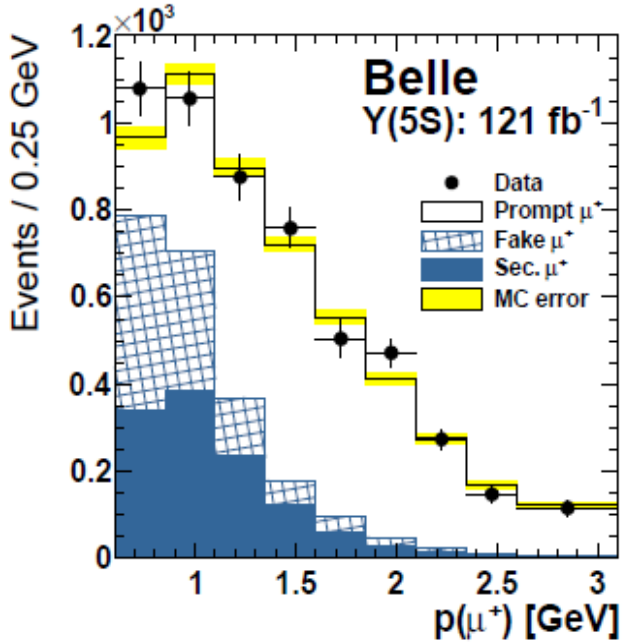
$N(D_s^+)$



$N(D_s^+ e^+)$



$N(D_s^+ \mu^+)$



$e^+e^- \to c\bar{c} \to D_s^+ X$ **contribution estimated from** $M(KK\pi)$ **fits to „off resonance data“ collected below BB production threshold**

$$x(D_s^+) = \frac{P^*(D_s^+)}{P^*_{\max}(D_s^+)} < 0.5$$

$$= \frac{P^*(D_s^+)}{\sqrt{s/4 - m(D_s^+)^2}}$$

Signal extraction by two-component χ^2 ***fit:***

Prompt leptons (signal)

Secondary and fake leptons $B_s^0 \to X \hookrightarrow \ell$

$B_s^0 \to X\ell\nu$: Results

Relative uncertainty in % on Br

Detector effects	1.2
Fitting procedure	2.4
Background modelling	1.8
Signal modelling	1.4
External parameters	6.0
Total systematic	7.0
Statistical	4.2

Largest systematic uncertainty:
Estimation of the B_s^0 production at $\Upsilon(5S)$

$$\mathcal{R} = \frac{\mathcal{N}_s(D_s^+\ell^+) + \mathcal{N}_{u,d}(D_s^+\ell^+)}{\mathcal{N}_s(D_s^+) + \mathcal{N}_{u,d}(D_s^+)}$$

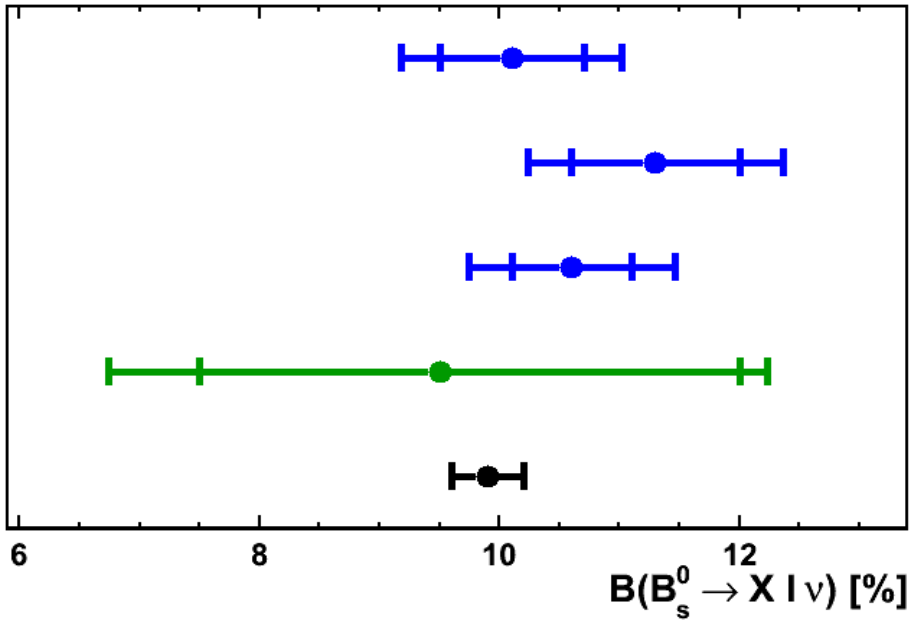
Uncertainties appear in the numerator and denominator => partial cancellation

$$\mathcal{B}(B_s^0 \to X\ell\nu) = [10.6 \pm 0.5(stat) \pm 0.7(syst)]\%$$

[hep-ex:1212.6400]

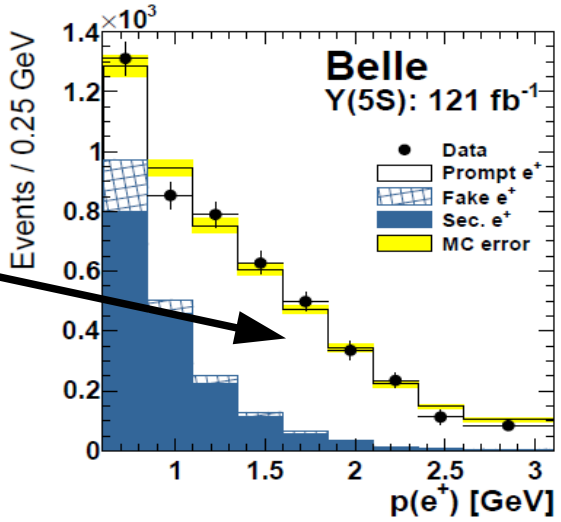
[PRD85,011101(2012)]

[JHEP1109,012(2011)]

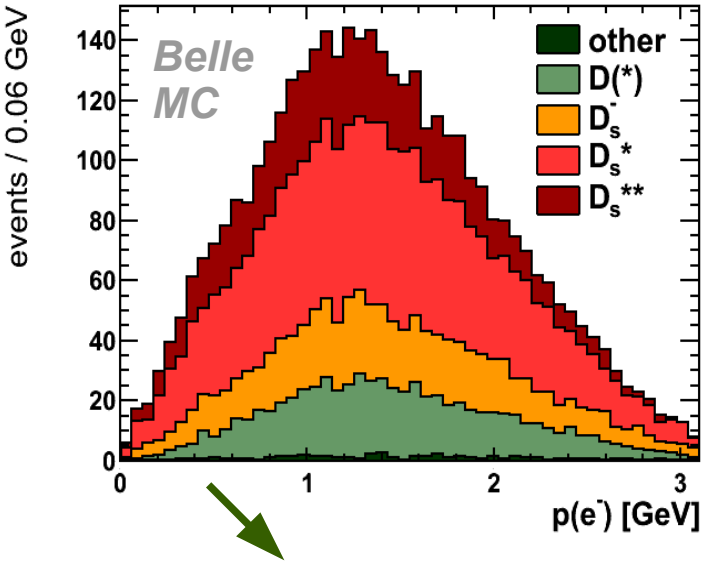


Exklusive analysis: $B_s^0 \to D_s^{(*)} \ell \nu$

Composition of the signal?

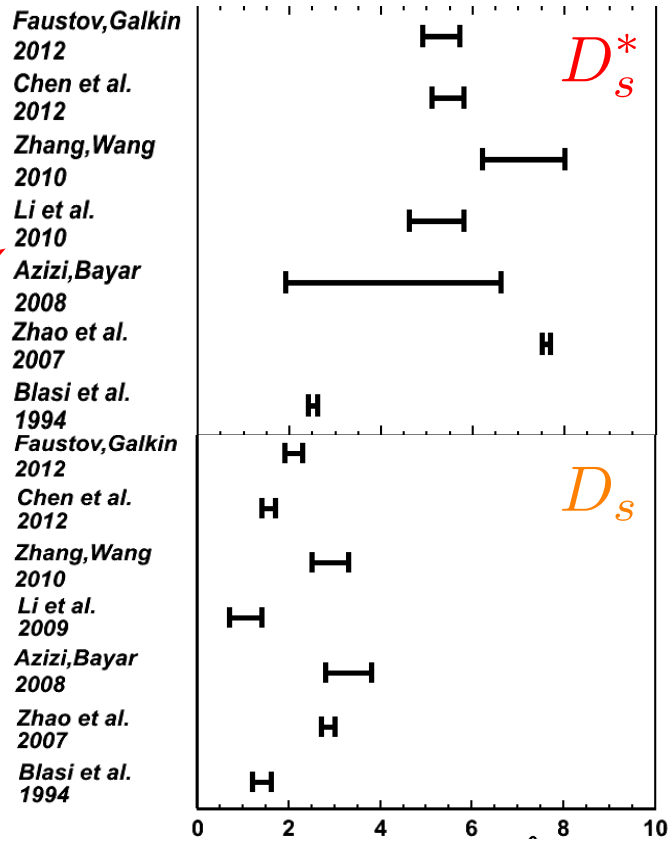


Similar momentum distributions



Estimated from other measurements

THEORY

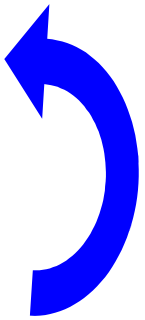


Branching fraction in %

Anonamously large rate to $\Upsilon(nS)\pi\pi$

[PRL 100, 112001 (2008)]

	Γ [MeV]
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$	$0.52\ ^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.0060
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.0009
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	0.0019



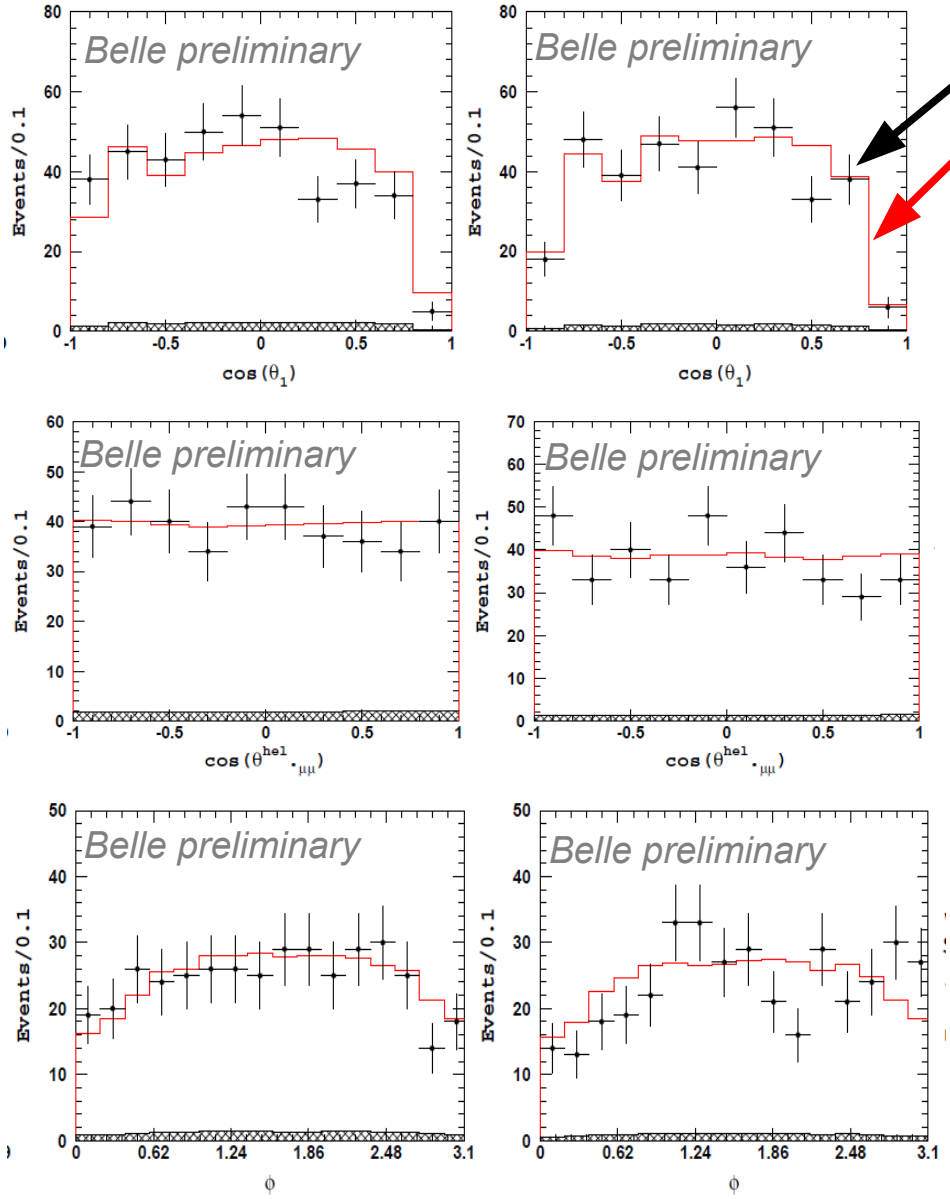
2 orders of magnitude!

Admixture of Y_b (counterpart of $\Upsilon(4260)$ in charmonium)?
Tetraquarks?

Amplitude analysis of $\Upsilon(5S) \to \Upsilon(nS)\pi^+\pi^-$

Fit projections

$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^- \to \mu^+\mu^-\pi^+\pi^-$



Data

$J^P = 1^+$

Model

Likelihood values for fits to the various models

J^P	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
1^+	0	0	0
1^-	64	264	73
2^+	41	207	87
2^-	59	304	125

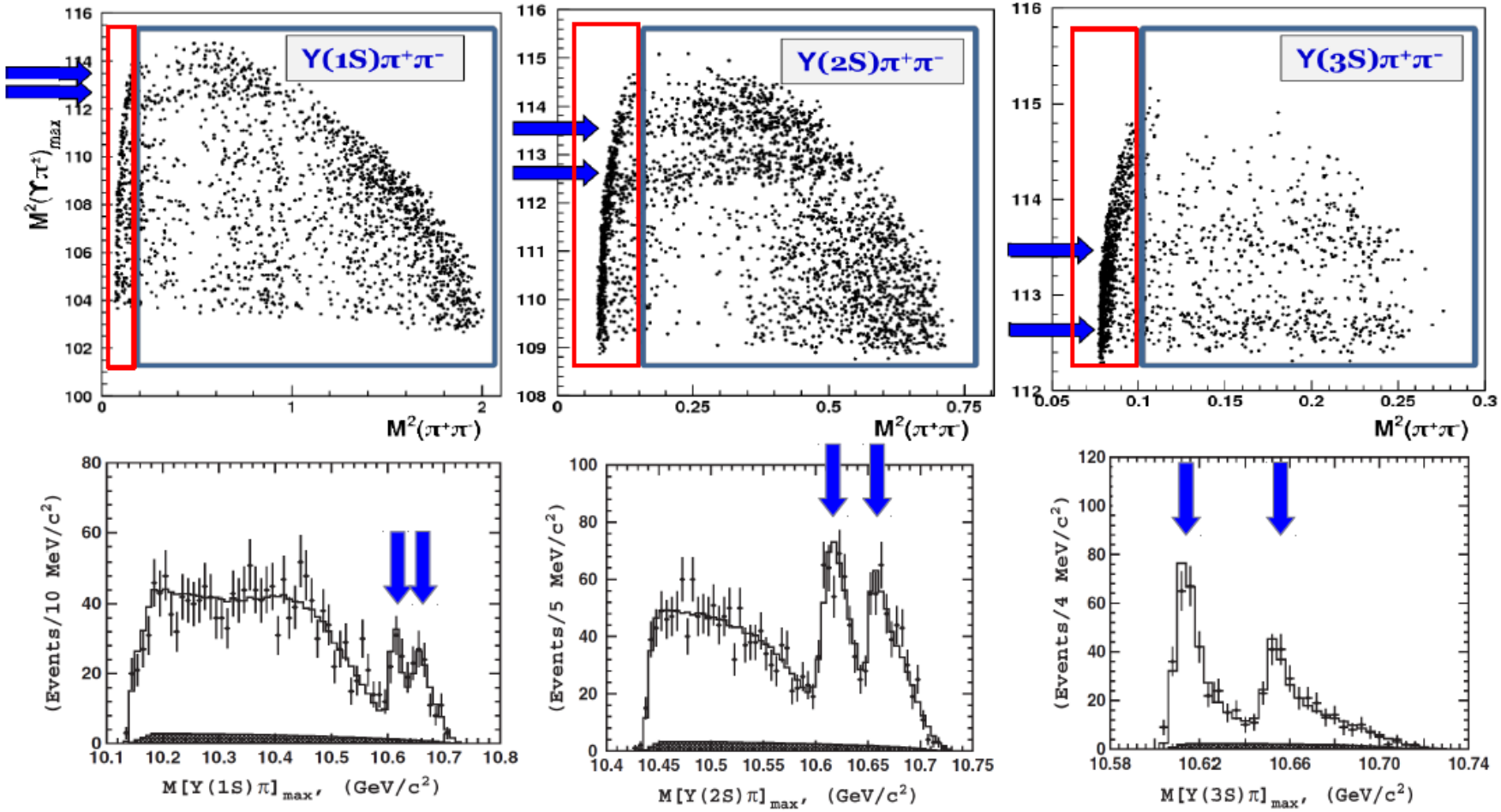
Belle preliminary

Confirms $J^P = 1^+$ hypothesis

Discovery of Z_b

$$S(s_1, s_2) = \underbrace{A(Z_{b1}) + A(Z_{b2})}_{\text{Breit-Wigner, symmetrised for pion exchange}} + \underbrace{A(f_o(980))}_{\text{Flatte}} + \underbrace{A(f_2(1275))}_{\text{Breit-Wigner}} + \underbrace{A_{\mathrm{NR}}}_{C_1 + C_2 \cdot M^2(\pi\pi)}$$

Background from photon conversions => excluded



PRL 108, 122001 (2012)

$h_b \to \eta_b$ method