Recent results from $\Upsilon(5S)$ data at Belle

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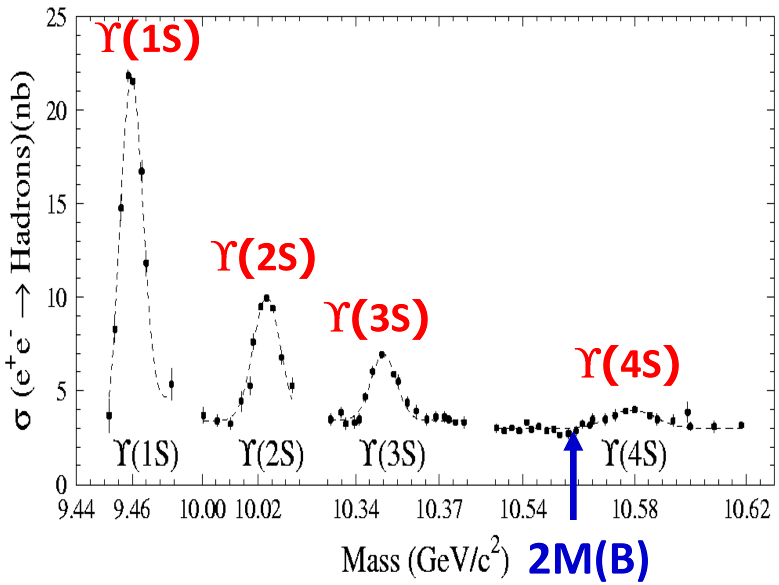
DPF August, 2013

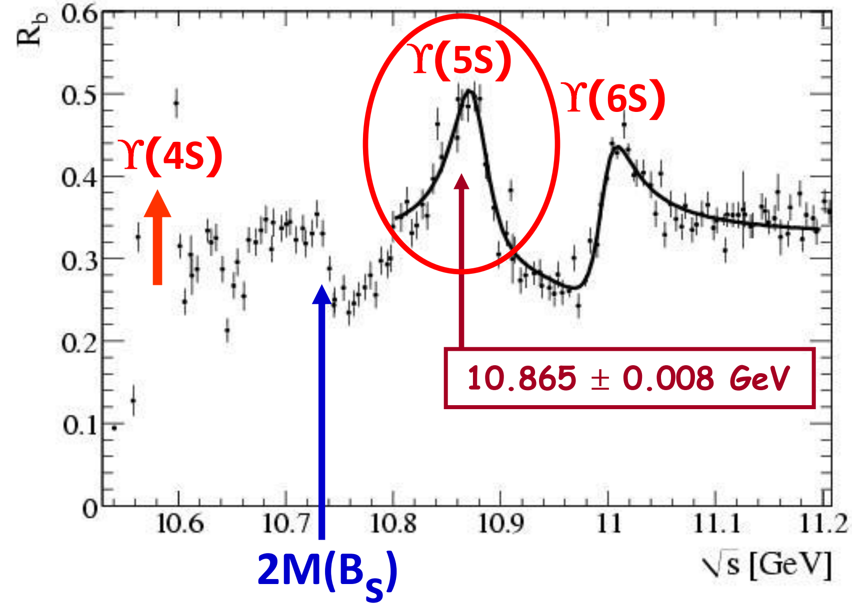
1. Bottomonium at $\Upsilon(5S)$
    1. Search for $Z_b \to B^{(*)}B^{(*)}$
    2. Search for Z_b^0
    3. New $\Upsilon(1D)$ production channel
2. $B_s \to J/\psi\ K^+K^-$, $B_s \to \Lambda_c \Lambda \pi$, semileptonic B_s

Preliminary Results

$e^+e^- \to \Upsilon(5S)$

Bottomonium ($b\bar{b}$) s=1, ℓ=0, $J^{PC}=1^{--}$





Belle: Υ(5S): ~10.865 GeV, 121.4 fb^{-1},

~42×10⁶ $b\bar{b}$ events, ~7×10⁶ B_s pairs

Unique dataset

Υ(5S): just above $B_s^{(*)}\overline{B}_s^{(*)}$ threshold, ~60% $B^{(*)}\overline{B}^{(*)}X$, ~20% $B_s^{(*)}\overline{B}_s^{(*)}$, few bottomonia

$\Rightarrow B_s$ studies

Anomalous production of $\Upsilon(nS)\,\pi^+\pi^-$

PRL100,112001(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

>10^2x

Hypotheses

1. Rescattering $\Upsilon(5S) \to BB\pi\pi \to \Upsilon(nS)\pi\pi$
2. Tetraquark $\Upsilon(5S) \to T_{bb}\pi \to \Upsilon(nS)\pi\pi$
3. Exotic resonance Y_b near $\Upsilon(5S)$
   - analog of Y(4260) resonance with anomalous $\Gamma(J/\psi\, \pi^+\pi^-)$
   - Check shapes of R_b and $\sigma(\Upsilon\pi\pi)$ as function of E_{CM}

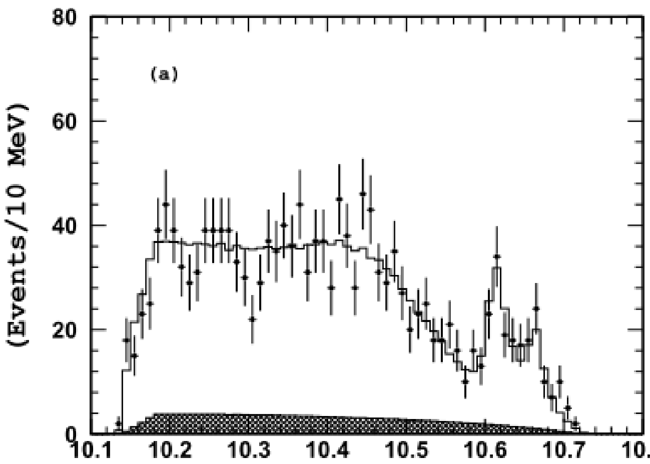
Observations related to the anomalous $\Upsilon(nS)\pi\pi$ rate...

- Observation of the $h_b(1P)$, $h_b(2P)$ PRL 109, 232002 (2012)
- Discovery of the $Z_b^{\pm}(10610)$, $Z_b^{\pm}(10650)$, $Z_b^{0}(10610)$ PRL 108, 122001 (2012)
- Observation of the $\eta_b(1S)$, $\eta_b(2S)$ PRL 109, 232002 (2012)
- Observation of a new decay channel for $\Upsilon(1D)$

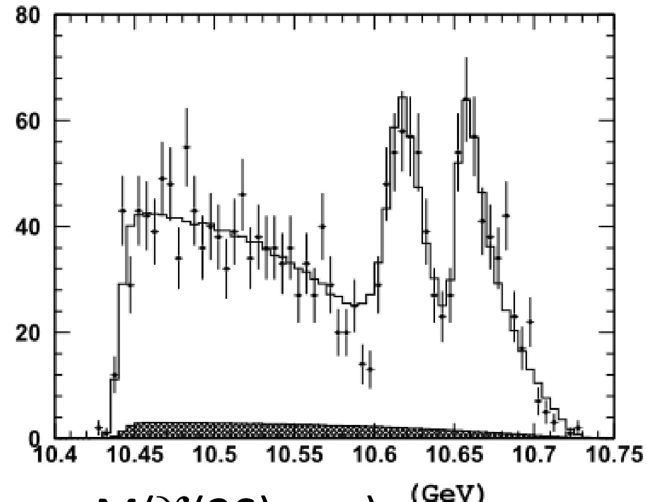
Observation of Charged $Z_b(10610)$, $Z_b(10650)$

PRL 108, 122001 (2012)

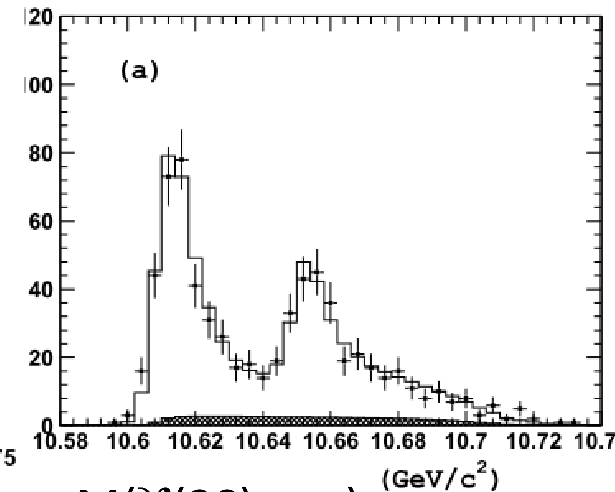
- $\Upsilon(5S) \rightarrow Z_b\pi^{\pm} \rightarrow h_b(nP)\pi^+\pi^-$ (n=1,2)
- $\Upsilon(5S) \rightarrow Z_b\pi^{\pm} \rightarrow \Upsilon(mS)\pi^+\pi^-$ (m=1,2,3)
- Average over 5 channels:
  - $Z_b(10610)$: M = 10607.2±2 MeV Γ=18.4±2.4 MeV
  - $Z_b(10650)$: M = 10652.2±1.5 MeV Γ=11.5±2.2 MeV



$M(\Upsilon(1S)\pi_{max})$

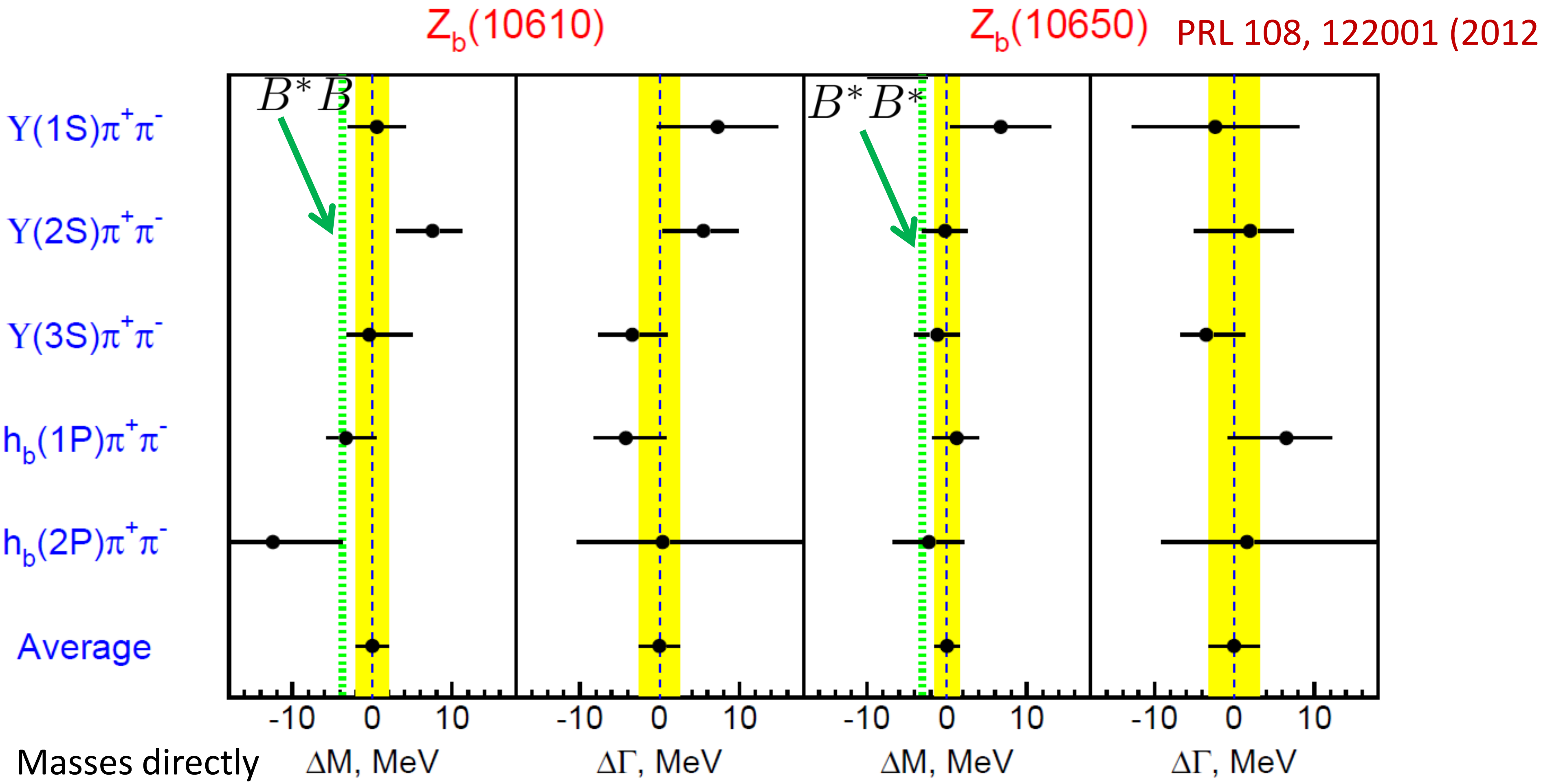


$M(\Upsilon(2S)\pi_{max})$



$M(\Upsilon(3S)\pi_{max})$

Summary of masses and widths of charged Z_b states



Masses directly above $B^*B^{(*)}$ threshold ⇒ molecular interpretation favored

$Z_b(10610)=Z_b$

M=10608.4±2.0 MeV

Γ=15.6±2.5 MeV

$Z_b(10650)=Z_b'$

M=10653.2±1.5 MeV

Γ=14.4±3.2 MeV

Relative phase $Z_b(10610)$ to $Z_b(10650)$
~0° for $\Upsilon\pi\pi$
~180° for $h_b\pi\pi$

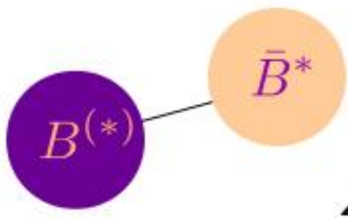
*Also fit for angular dependence. Results favor $J^P=1^+$ over 1^-, 2^+, 2^-

Z_b = Molecule? Look in $\Upsilon(5S) \to B^{(*)}B^{(*)}\pi$

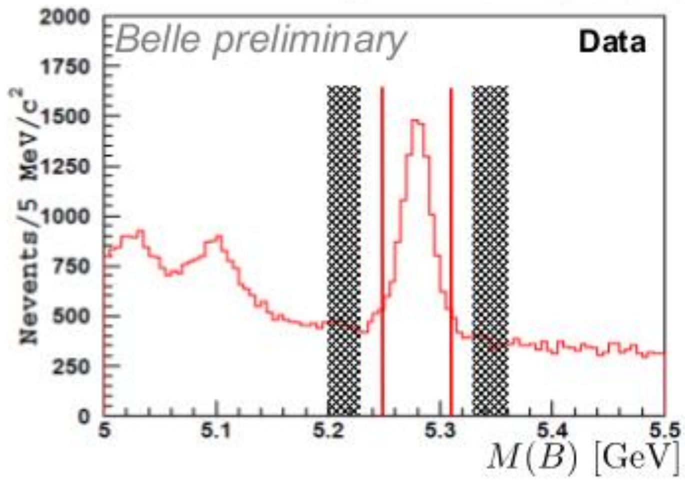
[arXiv:1209:6450]

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

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



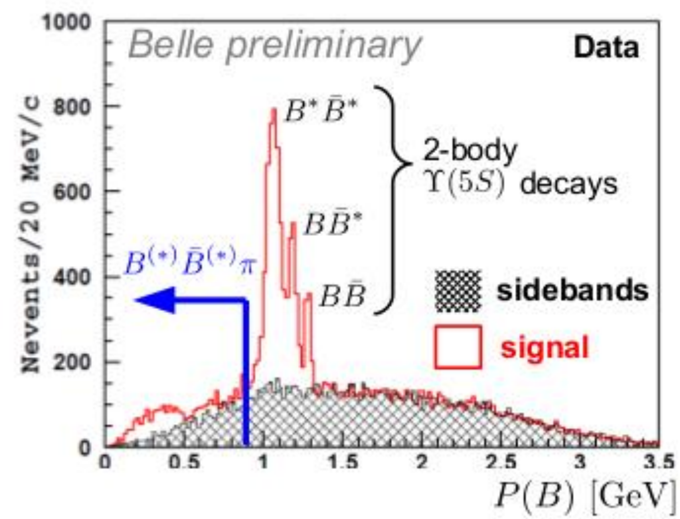
Z_b = **Molecule?**



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

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

Total branching fraction: 1×10^{-4}



Slide from Christian Oswald – Spectroscopy from the Υ(5S) and B_s, incl. semileptonic - BEAUTY 2013

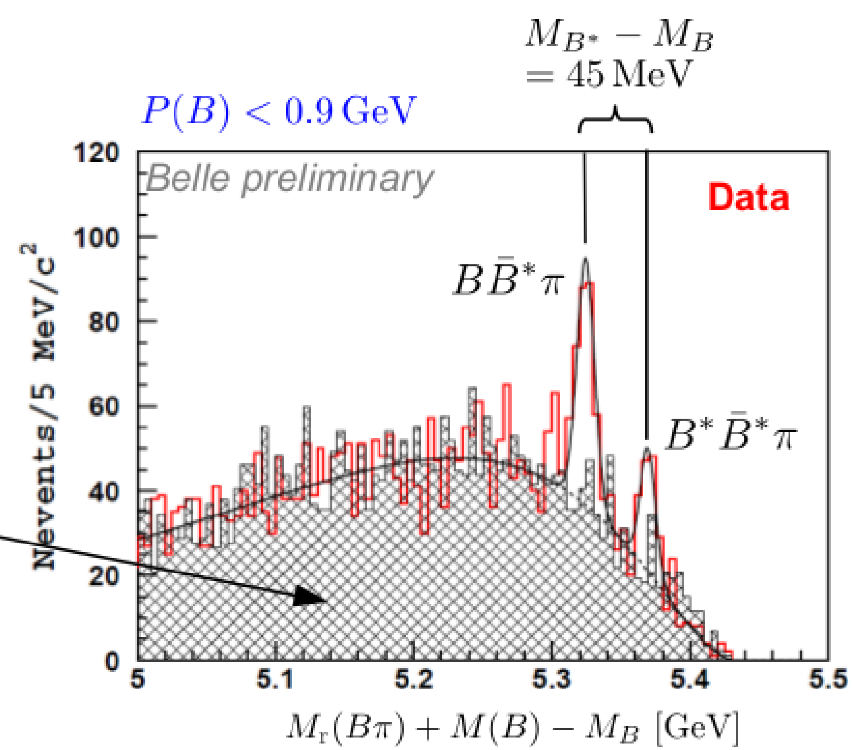
$\Upsilon(5S) \to B^{(*)}B^{(*)}\pi$

[arXiv:1209:6450]

Recoil mass of the $B\pi$ system:

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

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%CL)

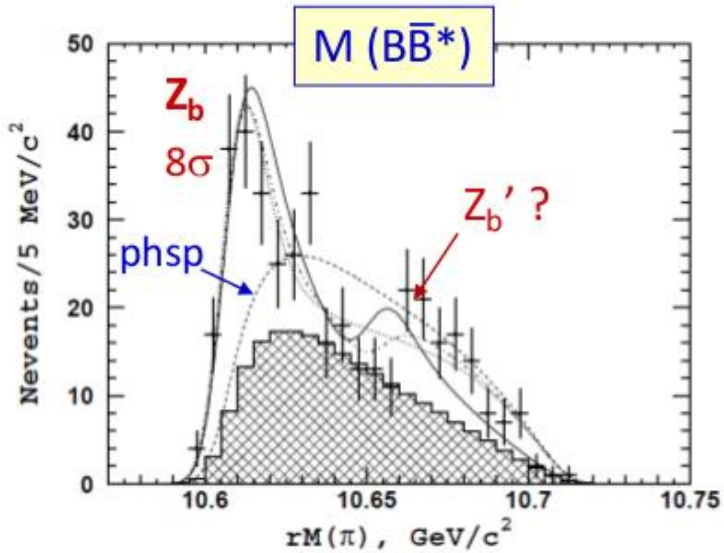
$\mathcal{B}(\Upsilon(5S) \to BB^*\pi) = [2.83 \pm 0.29 \pm 0.46]\%$

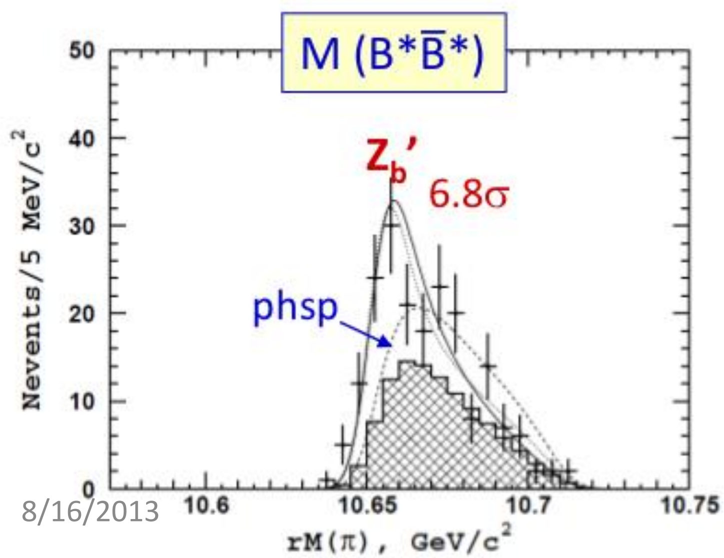
$\mathcal{B}(\Upsilon(5S) \to B^*B^*\pi) = [1.41 \pm 0.19 \pm 0.24]\%$

Slide Adapted from Christian Oswald – Spectroscopy from the Υ(5S) and B_s, incl. semileptonic - BEAUTY 2013

Observation of $Z_b \to BB^*$, $Z_b \to B^*B^*$

arXiv:1209.6450





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

BF[$Z_b' \to B\bar{B}^*$] = $(25 \pm 10)\%$ insignificant

$Z_b' \to BB^*$ suppressed with respect to B^*B^* despite larger PHSP

Molecule ⇒ admixture of BB^* in Z_b' is small.

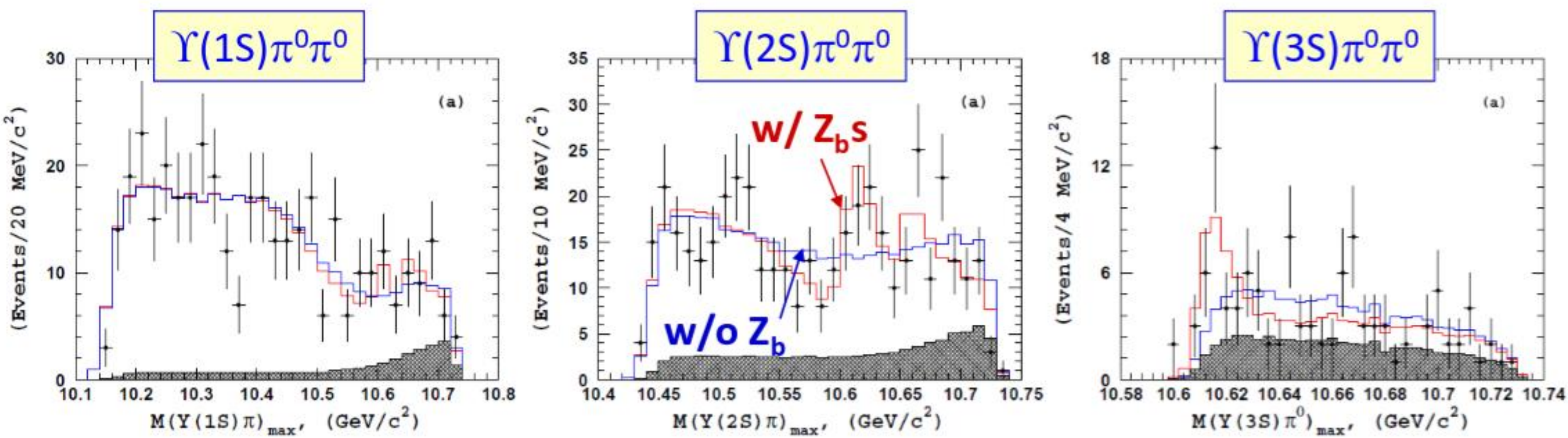
Challenges tetraquark interpretation?

Search for "$\Upsilon(5S)$"$\to\Upsilon(nS)\pi^0\pi^0$

$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- $Z_b^0(10610)$ signal has 6.5σ significance w/ simultaneous fit in $\Upsilon(2S)$ and $\Upsilon(3S)$ modes, $\Upsilon(1S)$ insignificant. R.Mizuk (QWG 2013)
  - $\Upsilon(2S)$ channel alone: 4.9σ with syst.
- BF[$\Upsilon(5S)\to\Upsilon(1S)\pi^0\pi^0$] = $(2.25\pm0.11\pm0.20)\times10^{-3}$ arXiv:1207.4345
  BF[$\Upsilon(5S)\to\Upsilon(2S)\pi^0\pi^0$] = $(3.66\pm0.22\pm0.48)\times10^{-3}$
  BF[$\Upsilon(5S)\to\Upsilon(3S)\pi^0\pi^0$] = $(2.09\pm0.51\pm0.34)\times10^{-3}$ R.Mizuk (QWG 2013)
  - Consistent with 1/2 of $\Upsilon(5S)\to\Upsilon(nS)\pi^+\pi^-$

PRELIMINARY



Bottomonium Spectroscopy

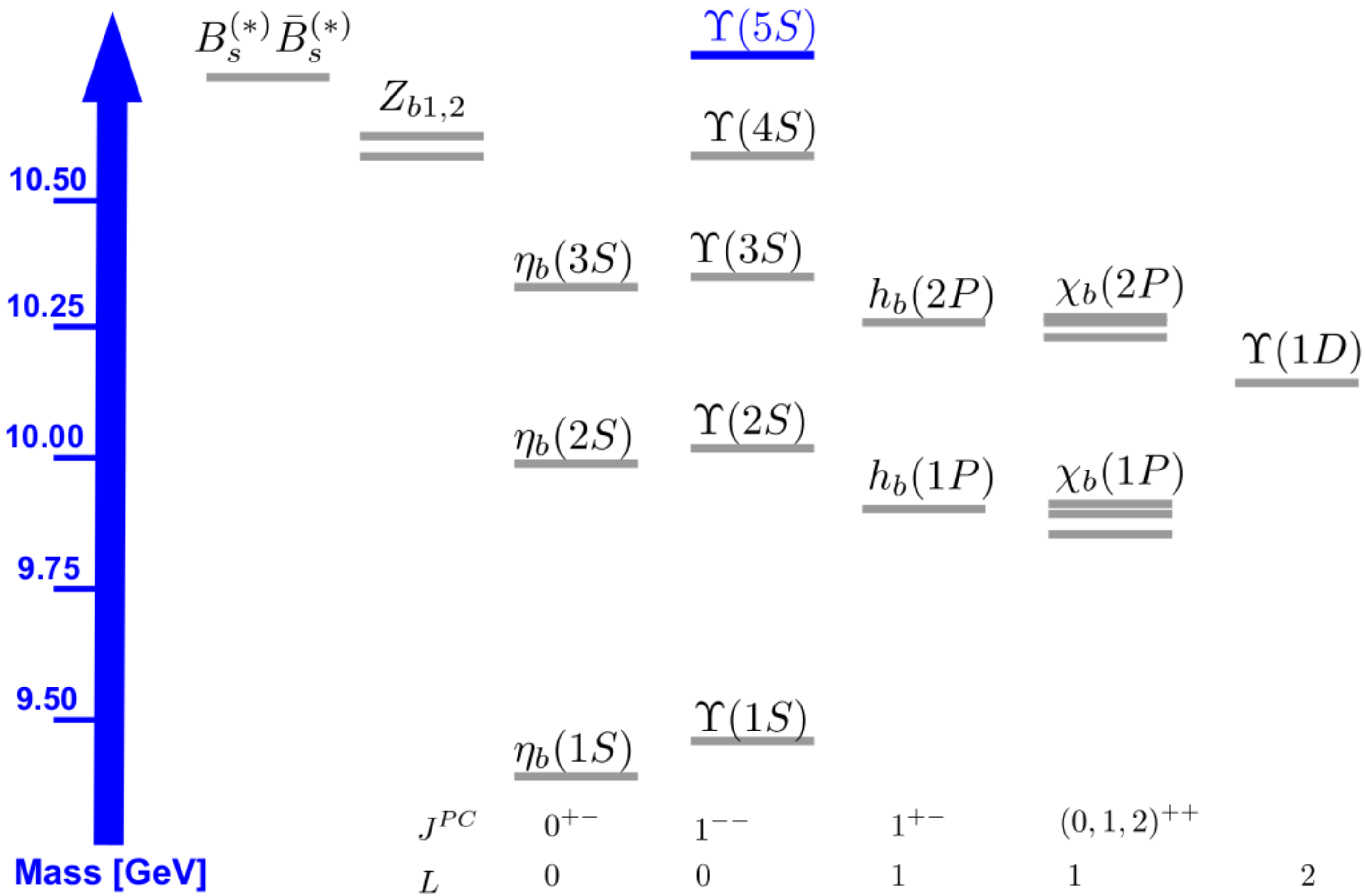
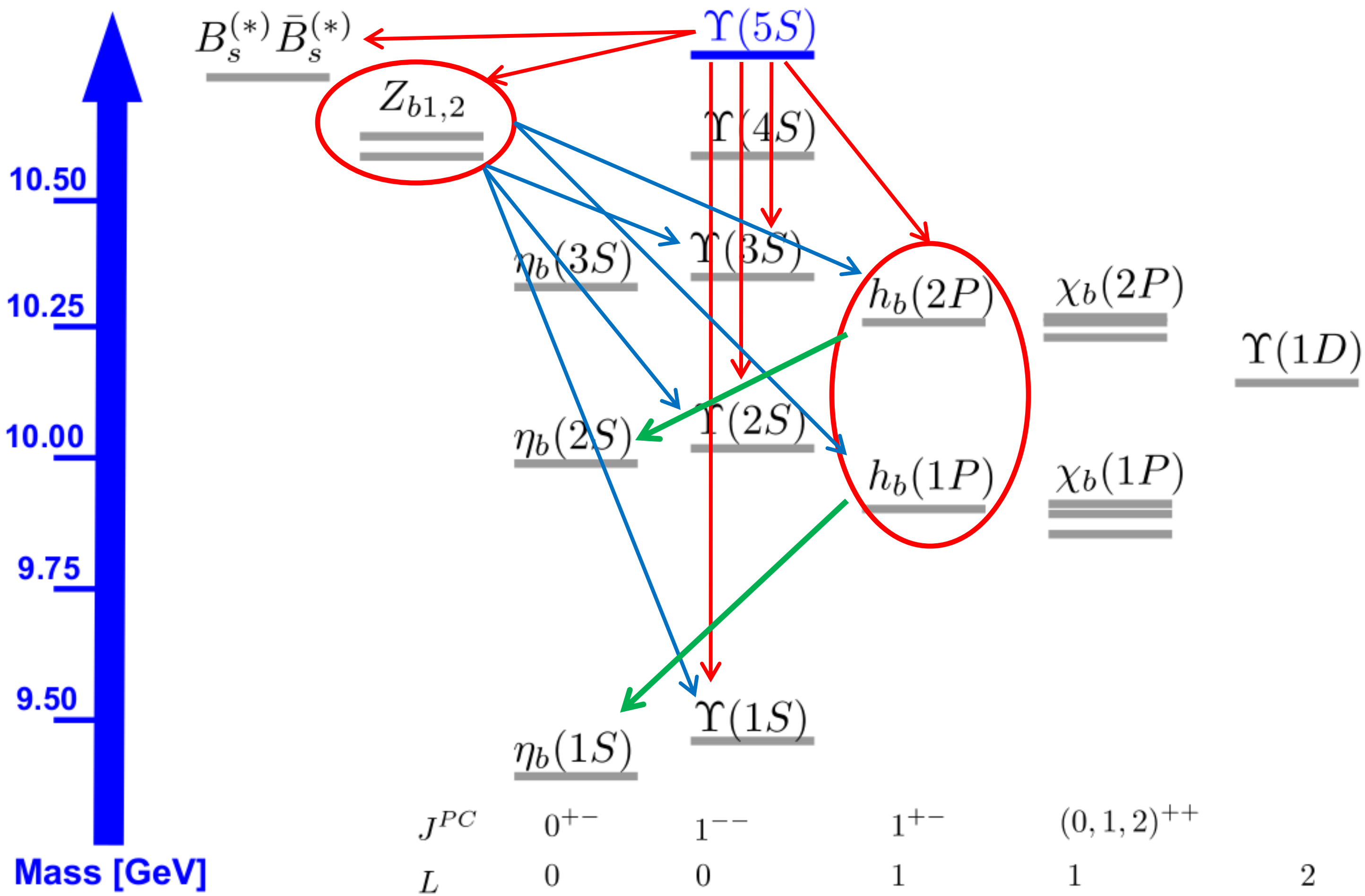


Chart from Christian Oswald – Spectroscopy from the Υ(5S) and B_s incl. semileptonic - BEAUTY 2013

Bottomonium Spectroscopy



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Bottomonium Spectroscopy

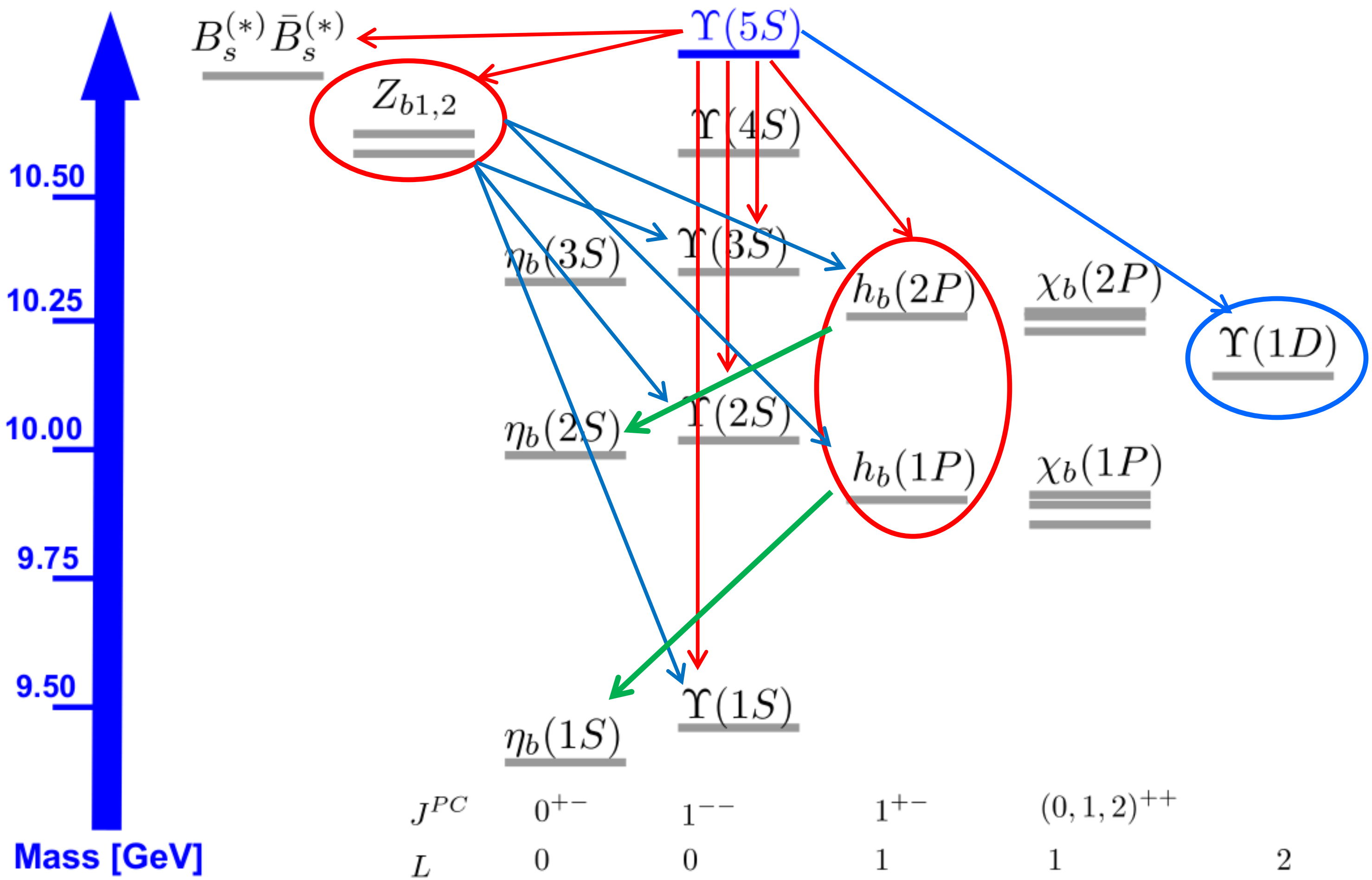
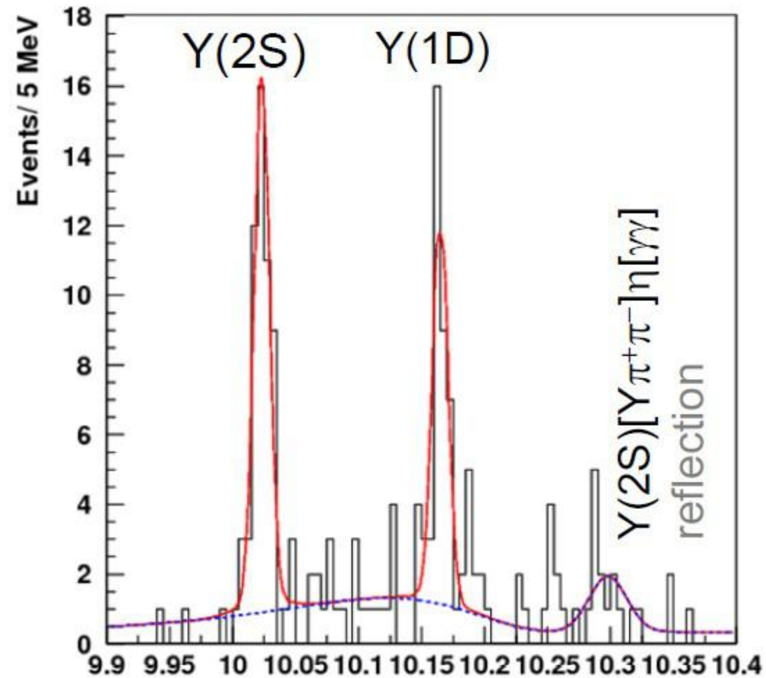


Chart from Christian Oswald – Spectroscopy from the Υ(5S) and B_s incl. semileptonic - BEAUTY 2013

New Production Channel for $\Upsilon(1D)$

First ℓ=2 found at CLEO
New production channel at Belle

$\Upsilon(5S)$
→ $\Upsilon(1D)\pi^+\pi^-$ → Missing mass MM($\pi^+\pi^-$)
→ $\chi_b 1,2\gamma$
→ $\Upsilon(1S)\gamma$
→ $\mu^+\mu^-$



MM($\pi^+\pi^-$) (GeV)

Significance: 9σ

$$\mathcal{B}(\Upsilon(5S) \to \Upsilon(1D)\pi^+\pi^-)\cdot \sum_{i=1,2} \mathcal{B}(\Upsilon(1D) \to \chi_{bi}\gamma)\cdot\mathcal{B}(\chi_{bi} \to \Upsilon(1S)\gamma) = [2.0\pm0.4]\times10^{-4}$$

$B_s \rightarrow J/\psi\ K^+K^-$, $J/\psi \rightarrow \ell^+\ell^-$

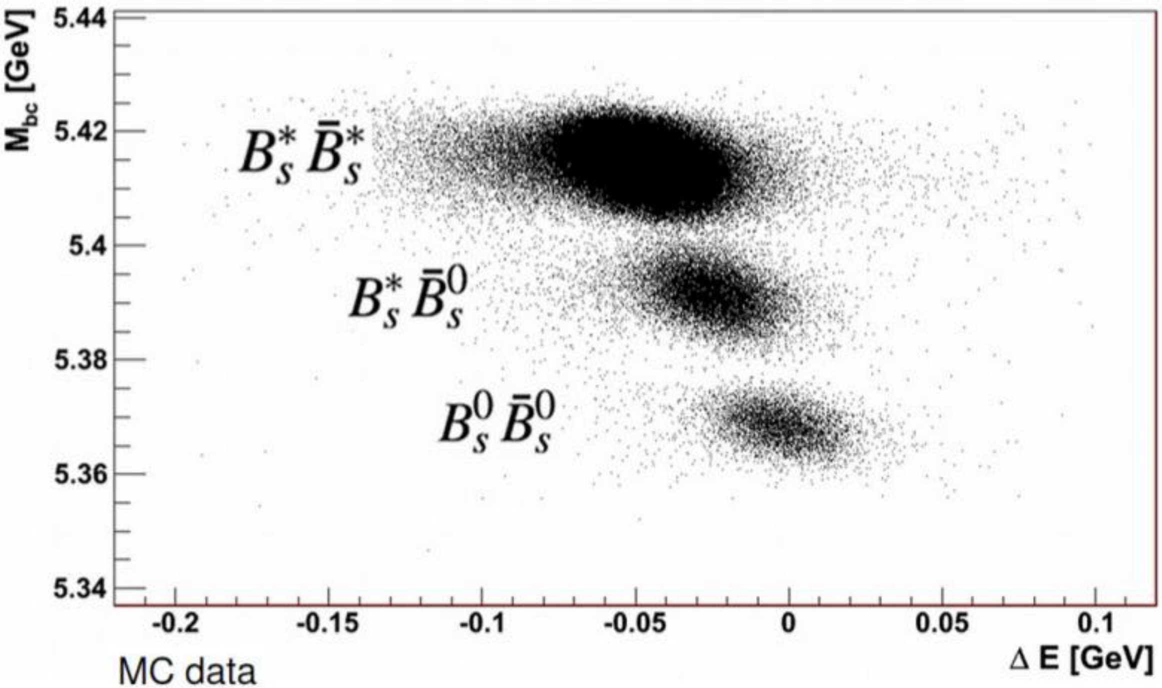
F.Thorne "Bs decays at Belle" EPS-HEP 2013

- $B_s \rightarrow J/\psi\ \phi$
  - important mode for CP violation
  - ϕ_s sensitive to new physics
- $B_s \rightarrow J/\psi$ f2
  - Branching ratio measured by LHCb:

  BF=$(2.61\pm0.20+0.52-0.46\pm0.20)*10^{-4}$
- $B_s \rightarrow J/\psi\ K+K-_{other}$
  - BF only measured by LHCb:

  BF=$(7.70\pm0.08\pm0.39\pm0.60)*10^{-4}$
- Belle advantage:
  - **Absolute** measurement of branching fractions instead of measurement relative to reference decay channel as used by hadron collider experiments.

Signal fitting ($B_s \to J/\psi\ K^+K^-$)



- Full reconstruction of Bs
- No reconstruction of $Bs^* \to Bs\gamma$
- Using two nearly independent kinematic variables for extracting Bs signal

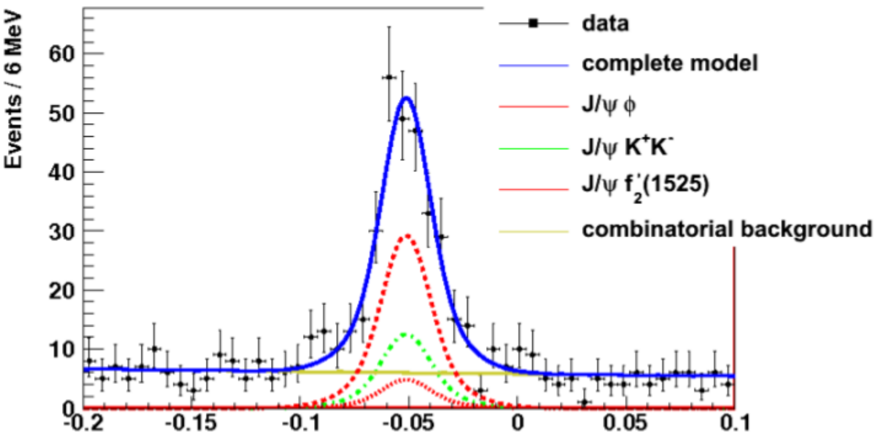
$$M_{bc} = \sqrt{(E_{\rm beam})^2 - (p_B^*)^2}$$

$$\Delta E = E_B^* - E_{\rm beam}$$

Channel	$Bs \to J/\psi\ \phi$	$Bs \to J/\psi\ K^+K^-$	$Bs \to J/\psi\ f_2(1525)$
ΔE	Double Gaussian (μ+μ-) Crystal Ball + Gauss (e+e-)	Double Gaussian (μ+μ-) Crystal Ball + Gauss (e+e-)	Double Gaussian (μ+μ-) Crystal Ball + Gauss (e+e-)
$m(K^+K^-)$	nonrelativistic BW	Argus	nonrelativistic BW

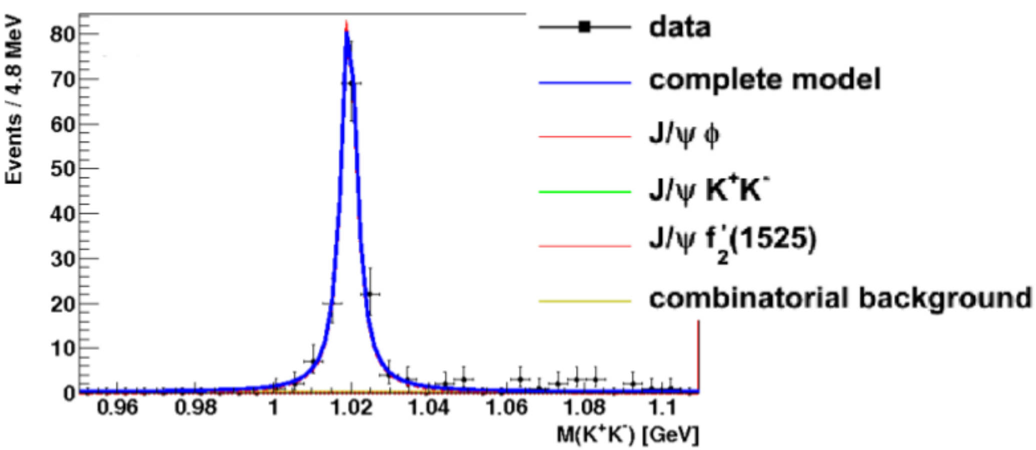
Fit results ($B_s \rightarrow J/\psi\ K^+K^-$)

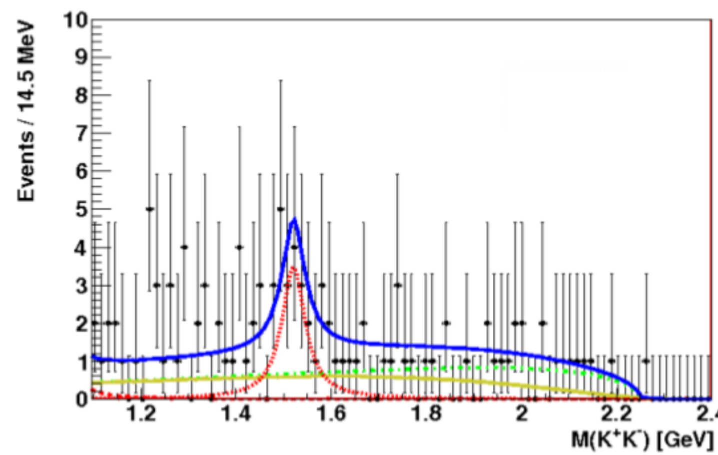
F.Thorne "Bs decays at Belle" EPS-HEP 2013



$J/\psi \rightarrow \mu^+\mu^-$ mode shown

ΔE [GeV]





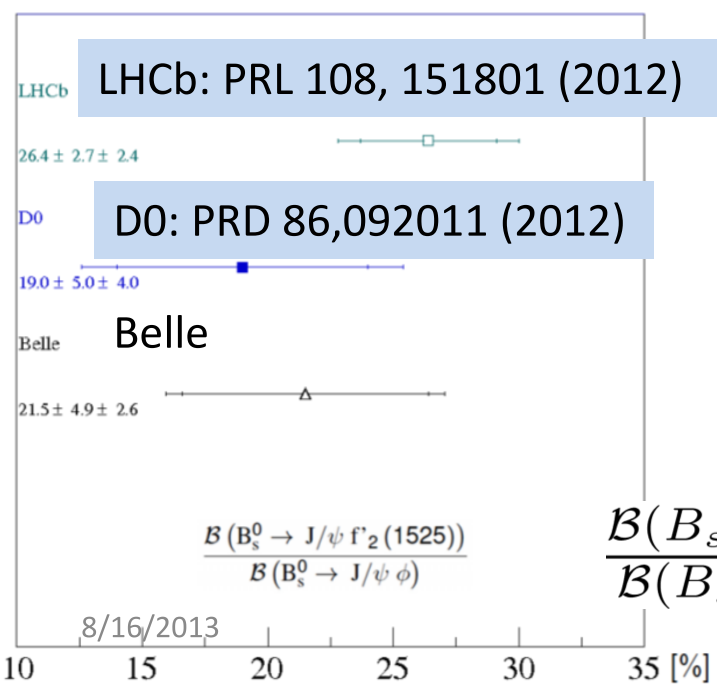
0.95 GeV < $M(K^+K^-)$ < 1.2 GeV

1.1 GeV < $M(K^+K^-)$ < 2.4 GeV

BF($B_s \to J/\psi\, K^+K^-$)

F.Thorne "Bs decays at Belle" EPS-HEP 2013

Channel	Signal Yield (μ+μ-)	Signal Yield (e+e-)
$Bs \to J/\psi\ \phi$	168±13.5	158±13
$Bs \to J/\psi\ K^+K^-_{other}$	83±17	67±14
$Bs \to J/\psi\ f_2(1525)$	34±10	26±8
Background	232±19	300±20



$BF(B_s \to J/\psi\phi) = (1.25) \times 10^{-3}$
$(\pm 0.07(stat) \pm 0.08(syst) \pm 0.22(fs)) \times 10^{-3}$

$BF(B_s \to J/\psi\ f_2'(1525)) = (0.26) \times 10^{-3}$
$(\pm 0.06(stat) \pm 0.02(syst) \pm 0.05(fs)) \times 10^{-3}$

$BF(B_s \to J/\psi KK_{other}) = (1.01) \times 10^{-3}$
$(\pm 0.09(stat) \pm 0.10(syst) \pm 0.18(fs)) \times 10^{-3}$

Consistent with results from D0 and LHCb

$$\frac{\mathcal{B}(B_s \to J/\psi f_2')}{\mathcal{B}(B_s \to J/\psi \phi)} = 21.5 \pm 4.9(\mathrm{stat}) \pm 2.6(\mathrm{syst})\%$$

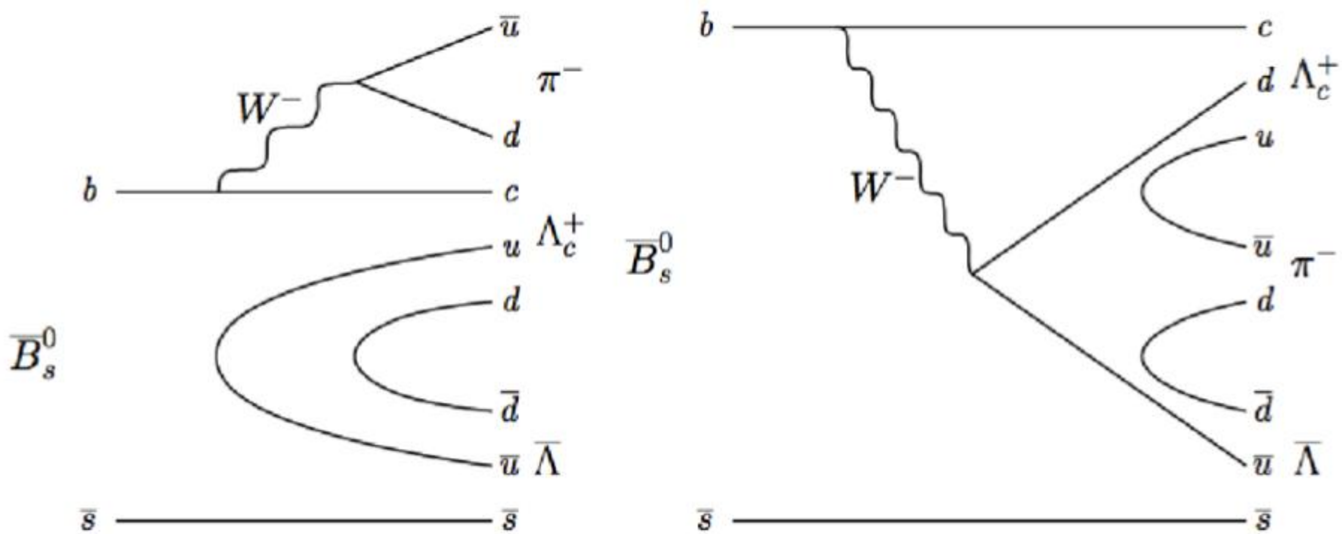
S-wave contribution in ϕ mass region

- Distinguish S- and P-wave with $M(K^+K^-)$
  - (LHCb and CDF use angular analysis)
- Assumptions:
  - S-wave from $J/\psi\ K^+K^-$
  - P-wave from $J/\psi\ \phi$
  - Verified w/ helicity angular distributions of K^+K^-

Experiment	Mass range	S-wave contribution
CDF	1.009 GeV – 1.028 GeV	$(0.8 \pm 0.2)\%$
Belle	1.009 GeV – 1.028 GeV	$(0.47 \pm 0.07(\mathrm{stat}) \pm 0.05(\mathrm{syst})^{+4.5}_{-0}(f_0))\%$
LHCb	1.007 GeV – 1.031 GeV	$(1.1 \pm 0.1^{+0.2}_{-0.1})\%$
Belle	1.007 GeV – 1.031 GeV	$(0.57 \pm 0.09(\mathrm{stat}) \pm 0.06(\mathrm{syst})^{+4.4}_{-0}(f_0))\%$

$\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$

- First evidence of $\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$
- Measure $\mathcal{B}(\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda})$ and compare to $\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-)$



F. Thorne "Bs decays at Belle" EPS-HEP 2013

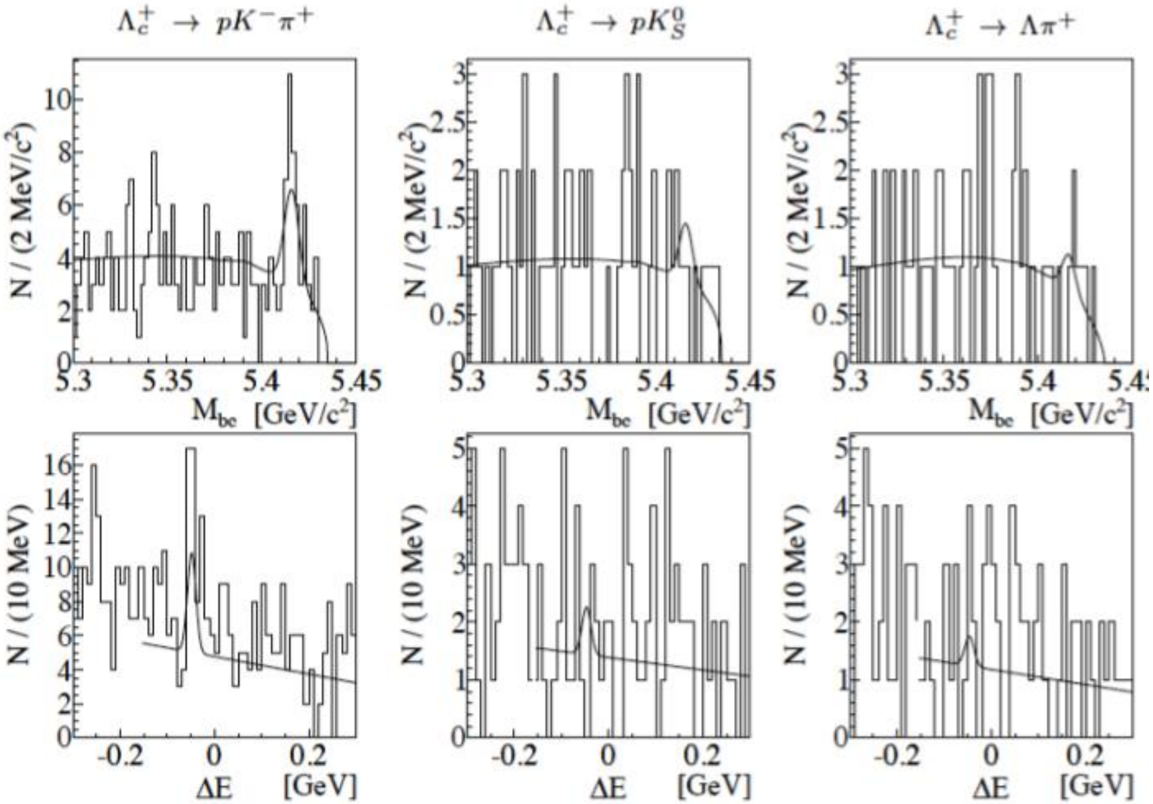
$\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$

- Reconstruction modes and selection criteria for for K_s, Λ, Λ_c

Parameter	Selection criterion
IP (charged tracks)	$\lvert dr \rvert < 0.25\,\mathrm{cm}$ and $\lvert dz \rvert < 1\,\mathrm{cm}$
$\mathrm{K^0_S} \to \pi^+\pi^-$	$\lvert \mathrm{M}(\pi^+\pi^-) - \mathrm{M}(\mathrm{K^0_S}) \rvert < 10\,\mathrm{MeV}/c^2$
$\Lambda \to p\,\pi^-$	$\lvert \mathrm{M}(p\,\pi^-) - \mathrm{M}(\Lambda) \rvert < 4\,\mathrm{MeV}/c^2$
$\Lambda_c^+ \to p\,\mathrm{K}^-\pi^+$ $\Lambda_c^+ \to p\,\mathrm{K^0_S}$ $\Lambda_c^+ \to \Lambda\,\pi^+$	$\lvert \mathrm{M}(rec) - \mathrm{M}(\Lambda_c^+) \rvert < 10\,\mathrm{MeV}/c^2$
$\mathrm{M_{bc}}$	$\mathrm{M_{bc}} > 5.3\,\mathrm{GeV}/c^2$
$\Delta\mathrm{E}$	$\lvert \Delta\mathrm{E} \rvert < 0.3\,\mathrm{GeV}$

$$\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$$

- Fit projections for −71 MeV < ΔE < −23 MeV and 5.405 GeV < M_{bc} < 5.427 GeV



$$\bar{B}_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$$

Obtained signal yields:

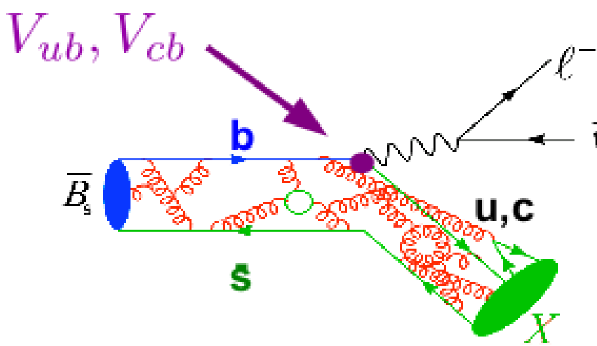
Channel	$\Lambda_c^+ \to p K^- \pi^+$	$\Lambda_c^+ \to p K^0_S$	$\Lambda_c^+ \to \Lambda \pi^+$
rec. efficiency [%]	12.5	5.9	8.7
Yield [events]	20.3	3.0	1.9

Obtained branching ratio

$$\mathcal{B}(\bar{B}_s^0 \to \Lambda_c^+ \pi^- \bar{\Lambda}) = (3.6 \pm 1.1(\text{stat})^{+0.3}_{-0.5}(\text{sys}) \pm 0.9(\Lambda_c^+) \pm 0.7(N_{\bar{B}_s^0})) \times 10^{-4}$$

measured at 4.4 σ significance (systematic included)
similar to $\mathcal{B}(B^- \to \Lambda_c^+ \bar{p} \pi^-) = (2.8 \pm 0.8) \times 10^{-4}$

BF($B_s \to X \ell \nu$)

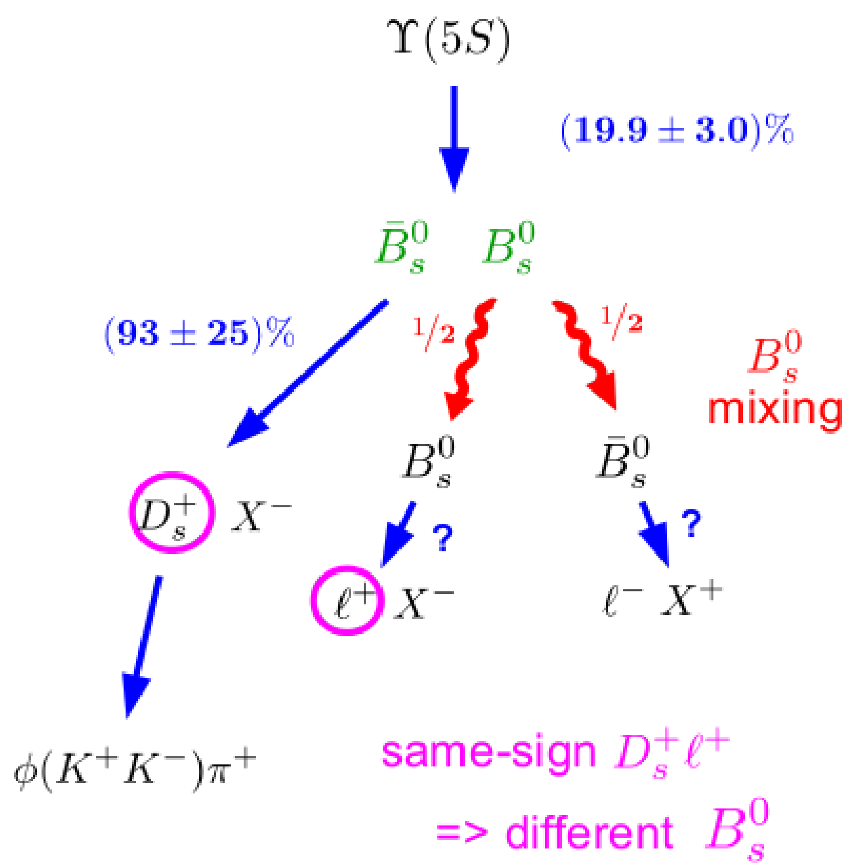


Important parameter for determination of B_s^0 production at LHC and B factories

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

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

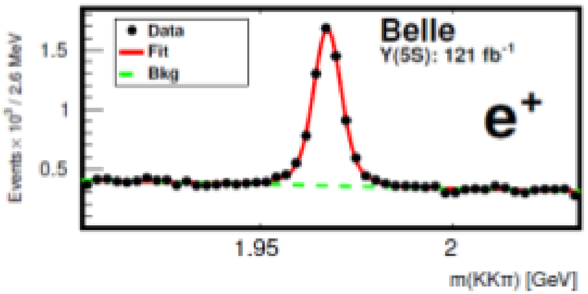
[JHEP1109,012(2011)]



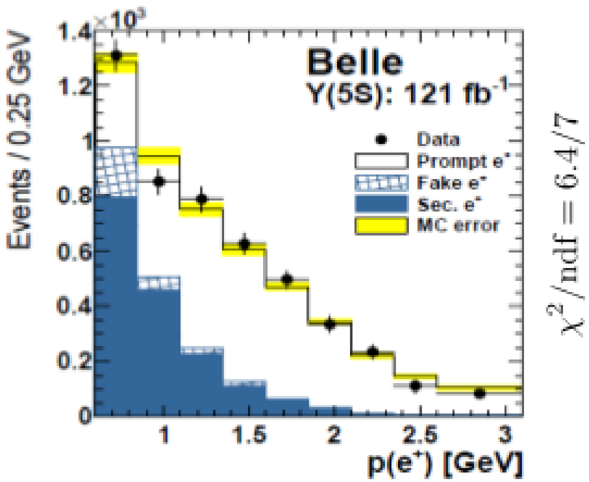
$$\mathcal{R} = \frac{\mathcal{N}(D_s^+\ell^+)}{\mathcal{N}(D_s^+)} \propto \frac{\mathcal{N}(B_s^0 \to \ell)}{\mathcal{N}(B_s^0)} = \mathcal{B}(B_s^0 \to X\ell\nu) \qquad \frac{\mathcal{N}_s(D_s^+\ell^+) + \mathcal{N}_{u,d}(D_s^+\ell^+)}{\mathcal{N}_s(D_s^+) + \mathcal{N}_{u,d}(D_s^+)}$$

Slide Adopted from Christian Oswald – Spectroscopy from the Υ(5S) and B_s, incl. semileptonic - BEAUTY 2013

BF($B_s \to X \ell \nu$)



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



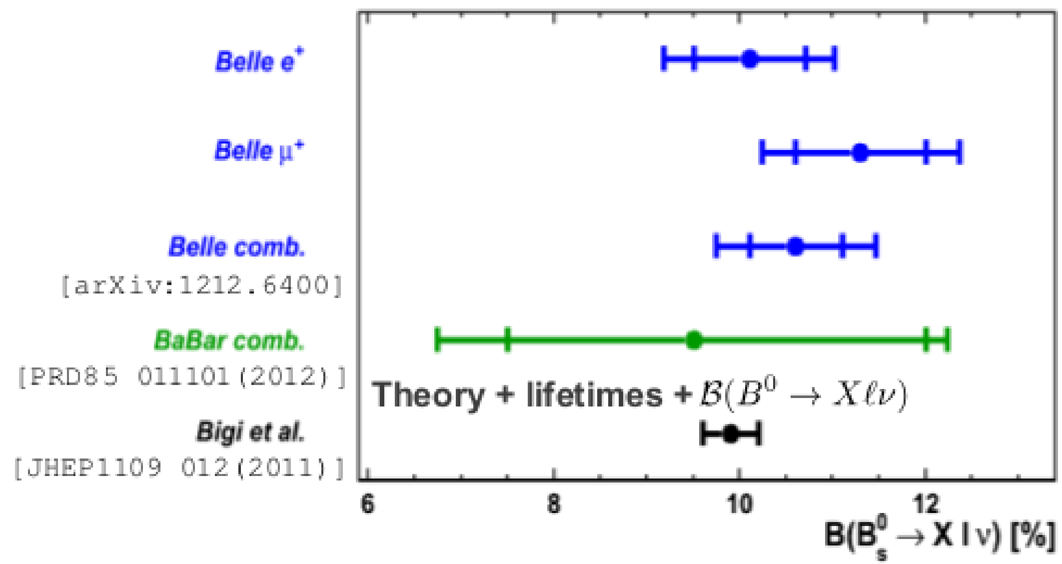
Fit to $p(\ell^+)$

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

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 $\Upsilon(5S)$



Slide Adapted from Christian Oswald – Spectroscopy from the Υ(5S) and B_s, incl. semileptonic - BEAUTY 2013

Summary

- New Υ(1D) production channel

$$\mathcal{B}(\Upsilon(5S)\to\Upsilon(1D)\pi^+\pi^-)\cdot\sum_{i=1,2}\mathcal{B}(\Upsilon(1D)\to\chi_{bi}\gamma)\cdot\mathcal{B}(\chi_{bi}\to\Upsilon(1S)\gamma)=[2.0\pm0.4]\times10^{-4}$$

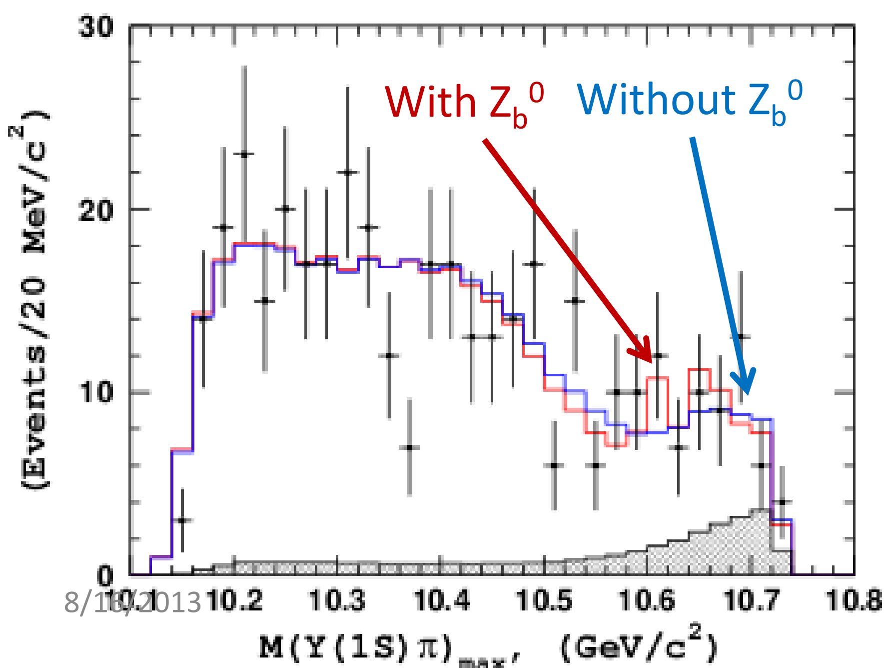
- Observation of Z_b(10610)$\to$BB*(8σ), Z_b(10650)$\to B^*B^*$(6.8σ)
  - Rates suggestive of molecular interpretation
- Observation of Z_b^0 with 6.5σ significance
- Measurements of BF($B_s \to J/\psi$ KK), BF($B_s \to J/\psi\ \phi$), BF($B_s \to J/\psi\ f_2'(1525)$)
  - S-wave contribution smaller than LHCb values, but in agreement with CDF
- Evidence for $\bar{B}_s \to \Lambda_c^+\pi^-\bar{\Lambda}$ with a 4.4σ BF measurement
- Most precise measurement of BF($B_s \to X\,\ell\,\nu$) = (10.6$\pm$0.5$\pm$0.7)%

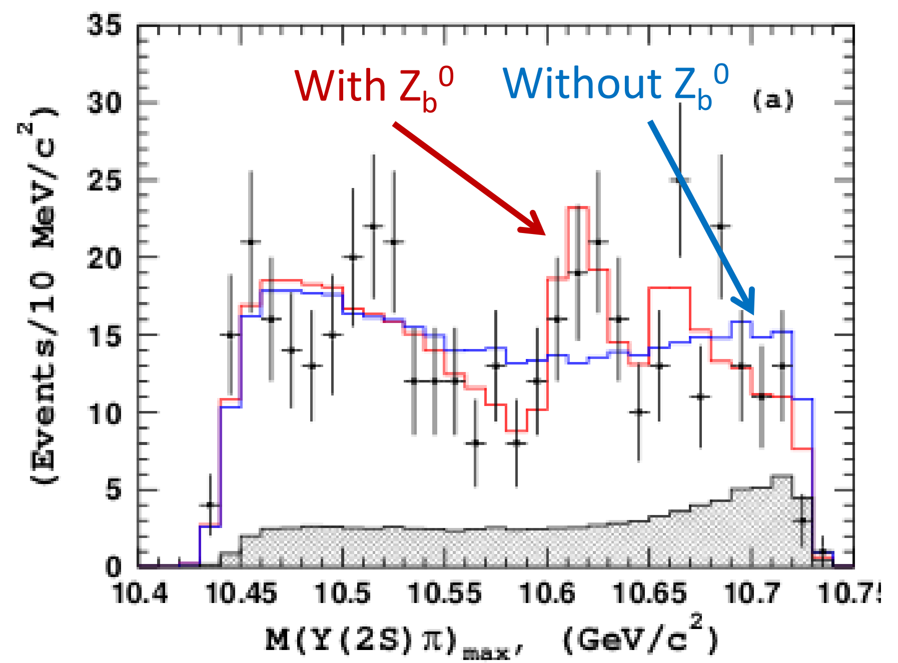
Backups

Search for "$\Upsilon(5S)$"$\rightarrow\Upsilon(nS)\pi^0\pi^0$

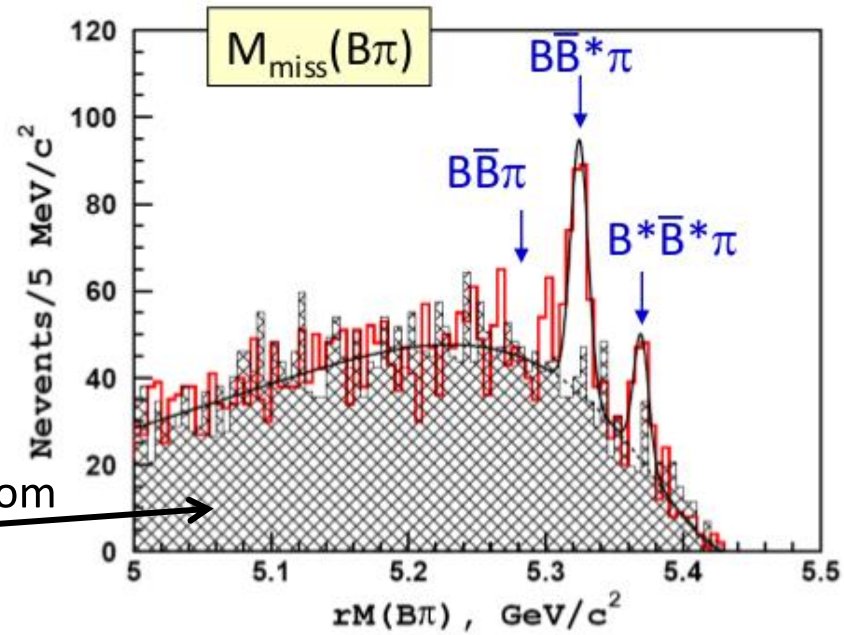
$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- Z_b^0(10610) signal has 6.5σ significance simultaneous fit in Υ(2S) and Υ(3S) modes, Υ(1S) insignificant. arXiv:1207.4345 PRELIMINARY
  - Υ(2S) channel alone stat. sig.: 5.3σ, 4.9σ with syst.
  - M=10609±8.6±6 MeV (Z_b^+ M = 10607.2±2 MeV)
- BF[$\Upsilon(5S)\rightarrow\Upsilon(1S)\pi^0\pi^0$] = $(2.25\pm0.11\pm0.20)\times10^{-3}$
  BF[$\Upsilon(5S)\rightarrow\Upsilon(2S)\pi^0\pi^0$] = $(3.66\pm0.22\pm0.48)\times10^{-3}$
  - Consistent with 1/2 of $\Upsilon(5S)\rightarrow\Upsilon(nS)\pi^+\pi^-$





$\Upsilon(5S) \to BB\pi, BB^*\pi, B^*B^*\pi$



Background determined from wrong-sign π

$\mathcal{B}[\Upsilon(5S) \to B^{(*)}\bar{B}^{(*)}\pi]$	arXiv:1209.6450		PRD81, 112003(2010)
	Belle 121.4 fb^{-1}	significance	Belle 23.6 fb^{-1}
$B\overline{B}$	$< 0.60\%$ at 90% C.L.		$(0 \pm 1.2)\%$
$B^*\overline{B} + B\overline{B}^*$	$(4.25 \pm 0.44 \pm 0.69)\%$	9.3σ	$(7.3 \pm 2.3)\%$
$B^*\overline{B}^*$	$(2.12 \pm 0.29 \pm 0.36)\%$	5.7σ	$(1.0 \pm 1.4)\%$

BF($B_s \to X \ell \nu$)

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

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

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

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

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

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

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

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

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

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

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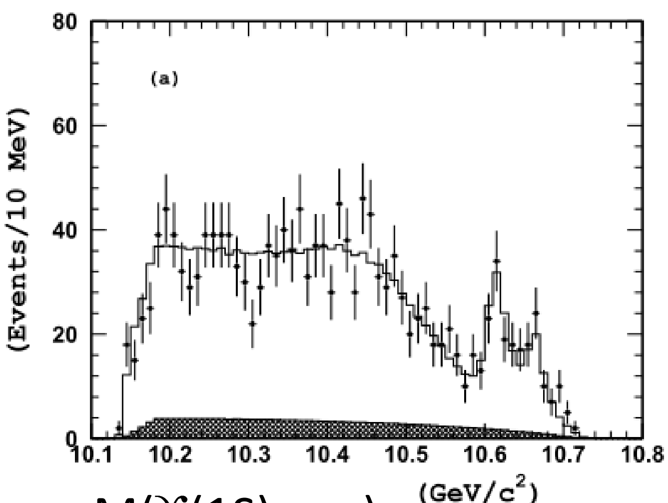
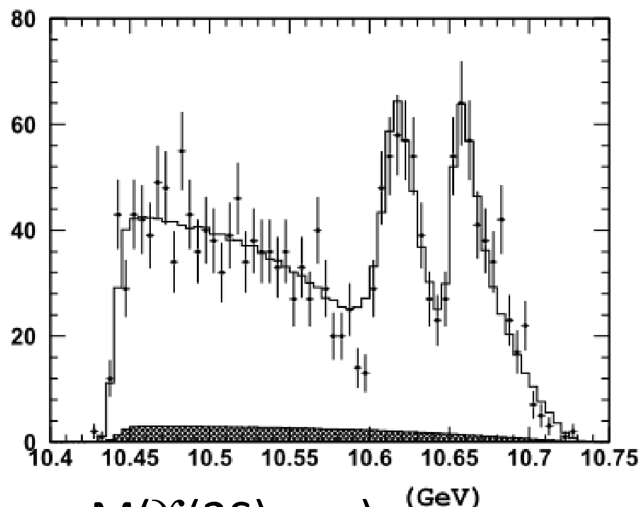
Observation of Charged $Z_b(10610)$, $Z_b(10650)$

PRL 108, 122001 (2012)

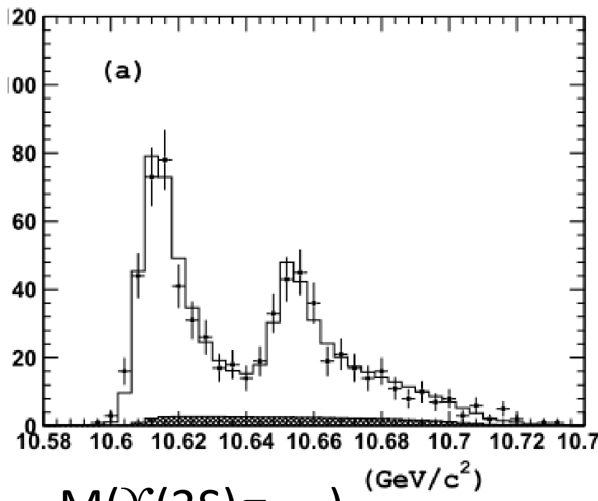
- $\Upsilon(5S) \to Z_b\pi^{\pm} \to h_b(nP)\pi^+\pi^-$ (n=1,2)
- $\Upsilon(5S) \to Z_b\pi^{\pm} \to \Upsilon(mS)\pi^+\pi^-$ (m=1,2,3)
- Average over 5 channels:
  - $Z_b(10610)$: M = 10607.2±2 MeV Γ=18.4±2.4 MeV
  - $Z_b(10650)$: M = 10652.2±1.5 MeV Γ=11.5±2.2 MeV



$M(\Upsilon(1S)\pi_{max})$



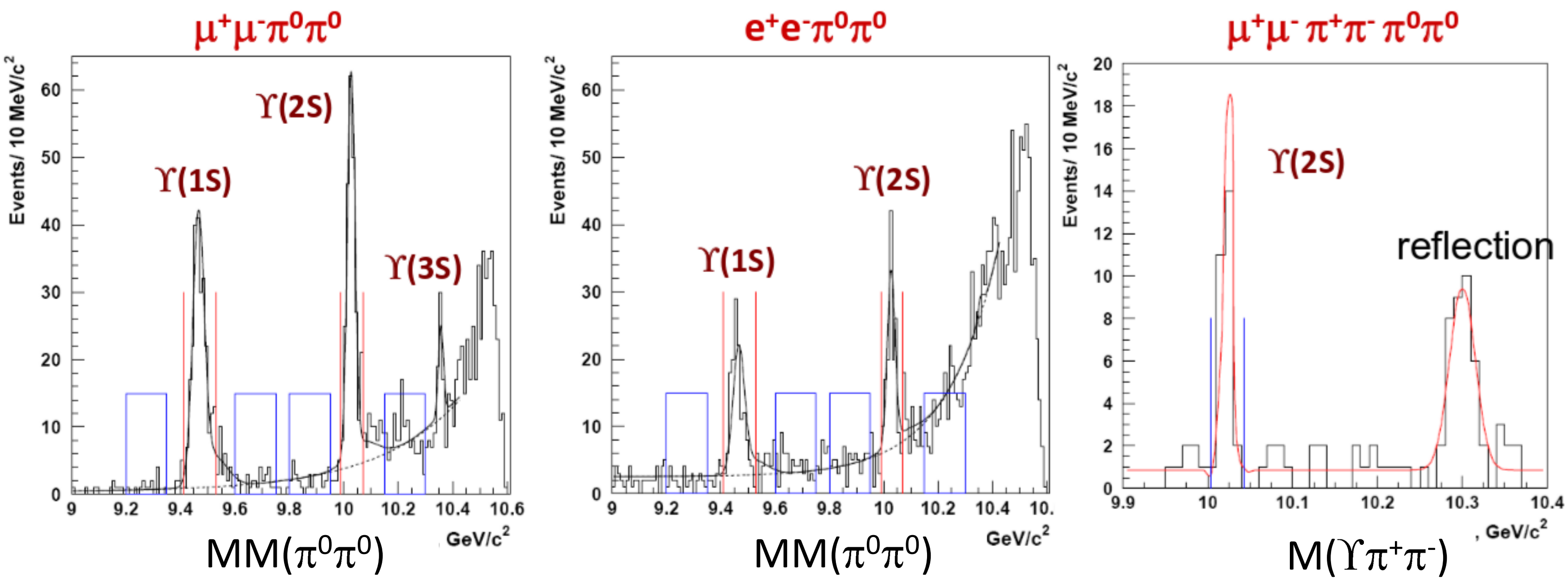
$M(\Upsilon(2S)\pi_{max})$



$M(\Upsilon(3S)\pi_{max})$

Search for Z_b^0: "$\Upsilon(5S)$"$\to\Upsilon(nS)\pi^0\pi^0$

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



$$MM(\pi^0\pi^0) = \sqrt{(E_{\Upsilon(5S)} - E^*_{\pi^0\pi^0})^2 - p^{*2}_{\pi^0\pi^0}}$$

PRELIMINARY

arXiv:1207.4345

BF[$\Upsilon(5S)\to\Upsilon(1S)\pi^0\pi^0$] = $(2.25\pm0.11\pm0.20)\ 10^{-3}$

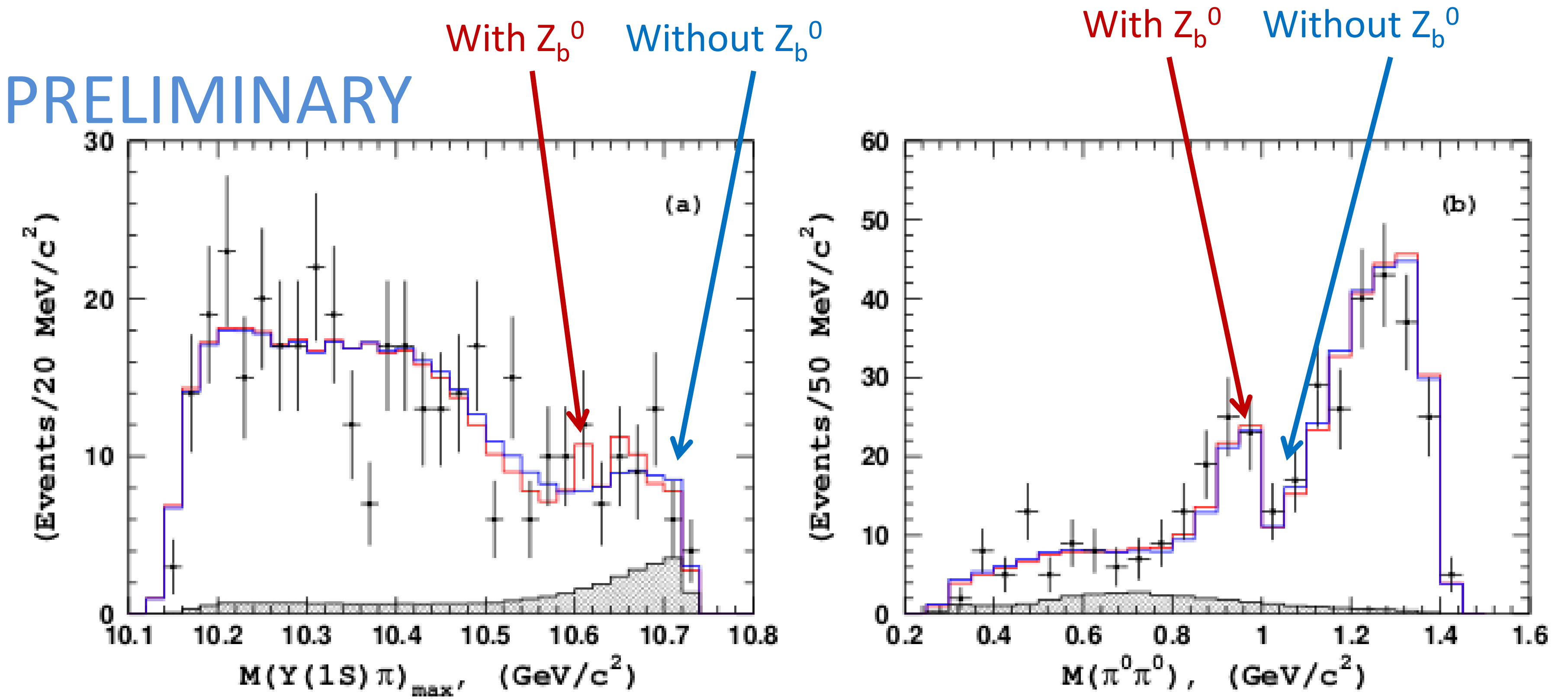
BF[$\Upsilon(5S)\to\Upsilon(2S)\pi^0\pi^0$] = $(3.79\pm0.24\pm0.49)\ 10^{-3}$

Consistent with 1/2 of $\Upsilon(5S)\to\Upsilon(nS)\pi^+\pi^-$

Dalitz Analysis of "$\Upsilon(5S)$"$\rightarrow\Upsilon(1S)\pi^0\pi^0$

$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- Z_b^0 signal is not statistically significant
  - Not excluded



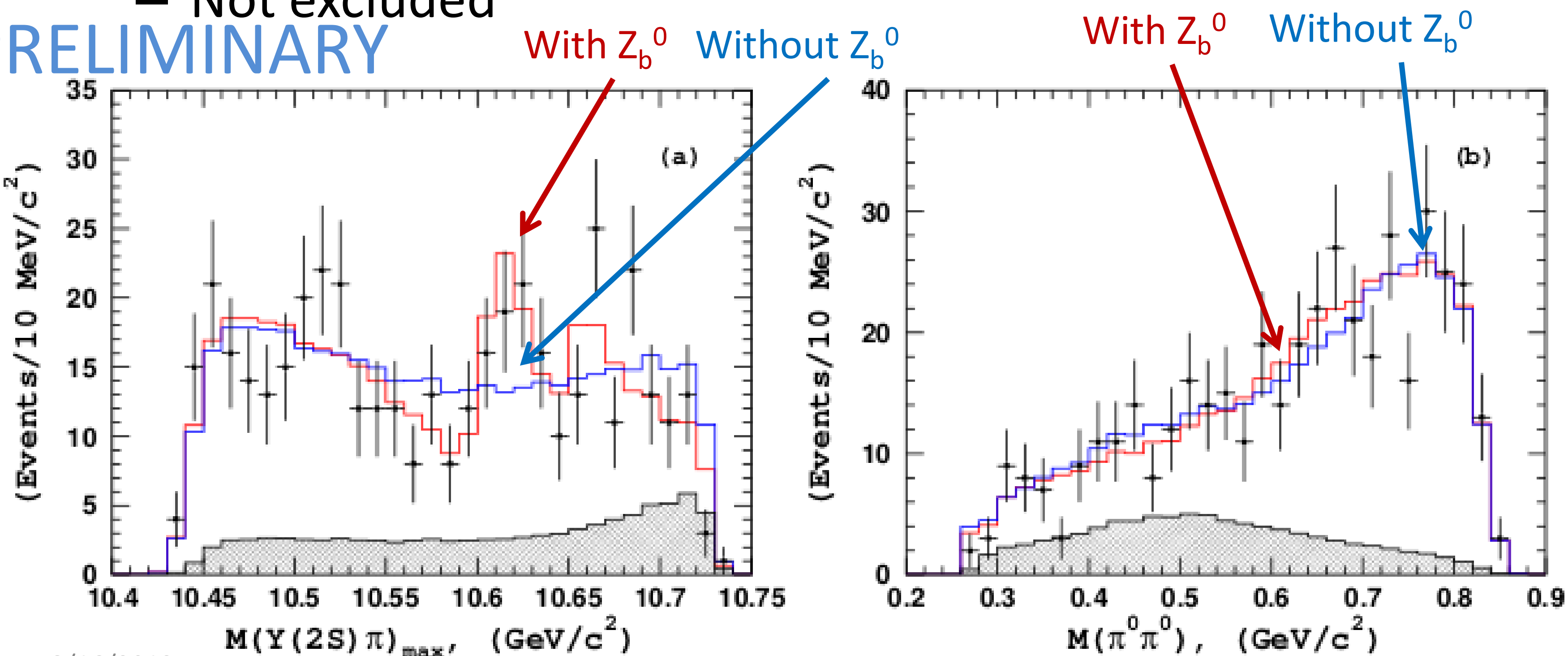
arXiv:1207.4345

Dalitz Analysis of "Υ(5S)"→Υ(2S)$\pi^0\pi^0$

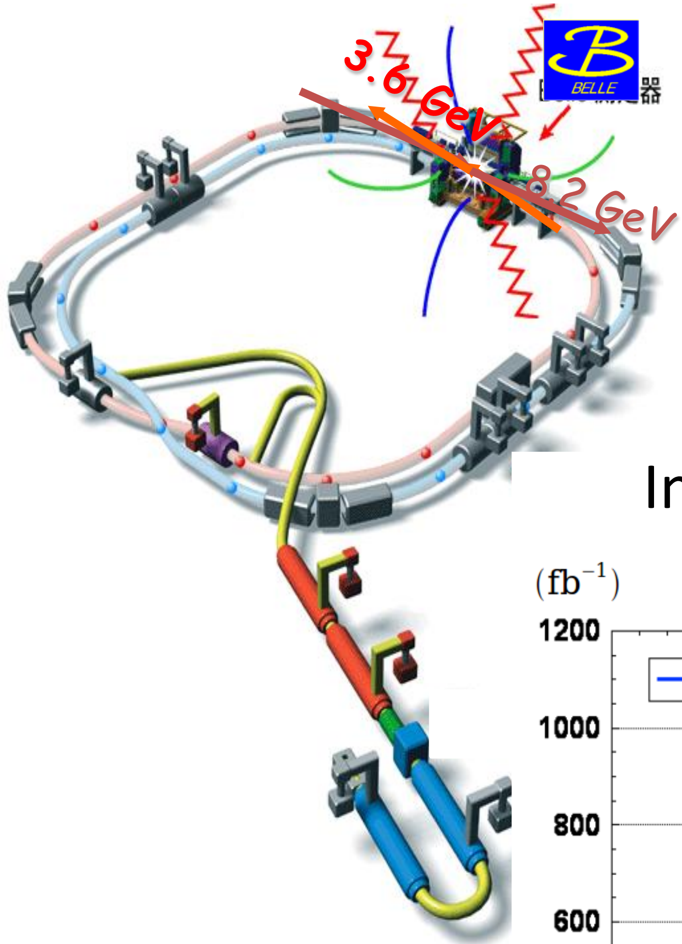
$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$

- Z_b^0(10610) signal has statistical significance 5.3σ, 4.9σ with systematics
  - M=10609±8.6±6 MeV (Z_b^+ M = 10607.2±2 MeV)
- Z_b^0(10650) not statistically significant (~2σ)
  - Not excluded

PRELIMINARY



arXiv:1207.4345

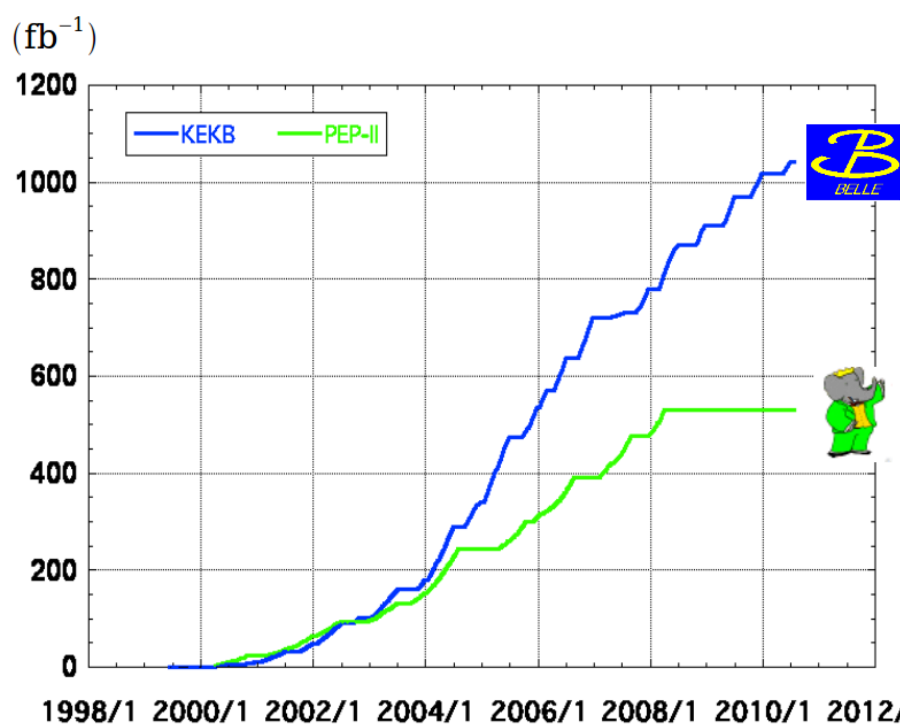


KEKb

Tsukuba, Japan

- Asymmetric e^+e^- storage rings

Integrated Luminosity



Res/E_{CM}(GeV)/lum

ϒ(1S): 9.46, 5.75 fb^{-1}
ϒ(2S): 10.02, 25 fb^{-1}
ϒ(3S): 10.36, 2.95 fb^{-1}
ϒ(4S): 10.58, 710.5 fb^{-1}
ϒ(5S): 10.87, 121.4 fb^{-1}

Off resonance/scan:
~100 fb^{-1}

ϒ(2S): 10.02, 14 fb^{-1}
ϒ(3S): 10.36, 30 fb^{-1}
ϒ(4S): 10.58, 433 fb^{-1}

Off resonance:
~54 fb^{-1}

Puzzles of Υ(5S) decays

1. Anomalous production of $\Upsilon(nS)\,\pi^+\pi^-$

PRL100,112001(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

>10^2x

Hypotheses

1. Rescattering $\Upsilon(5S)\to BB\pi\pi\to\Upsilon(nS)\pi\pi$
   Meng et al. Phys.Rev.D78:034022,2008

2. Tetraquark $\Upsilon(5S)\to T_{bb}\pi\to\Upsilon(nS)\pi\pi$
   Karliner et al. arXiv:0802.0649v2; Xiang Liu et al. Eur. Phys. J. C (2009) 61: 411–428; Yan-Rui Liu et al. Eur.Phys.J.C56:63-73,2008; N. Brambilla et al, Eur.Phys.J. C71 (2011) 1534; N. Brambilla et al. CERN Yellow Report, CERN-2005-005, Geneva: CERN, 2005.- 487 p.

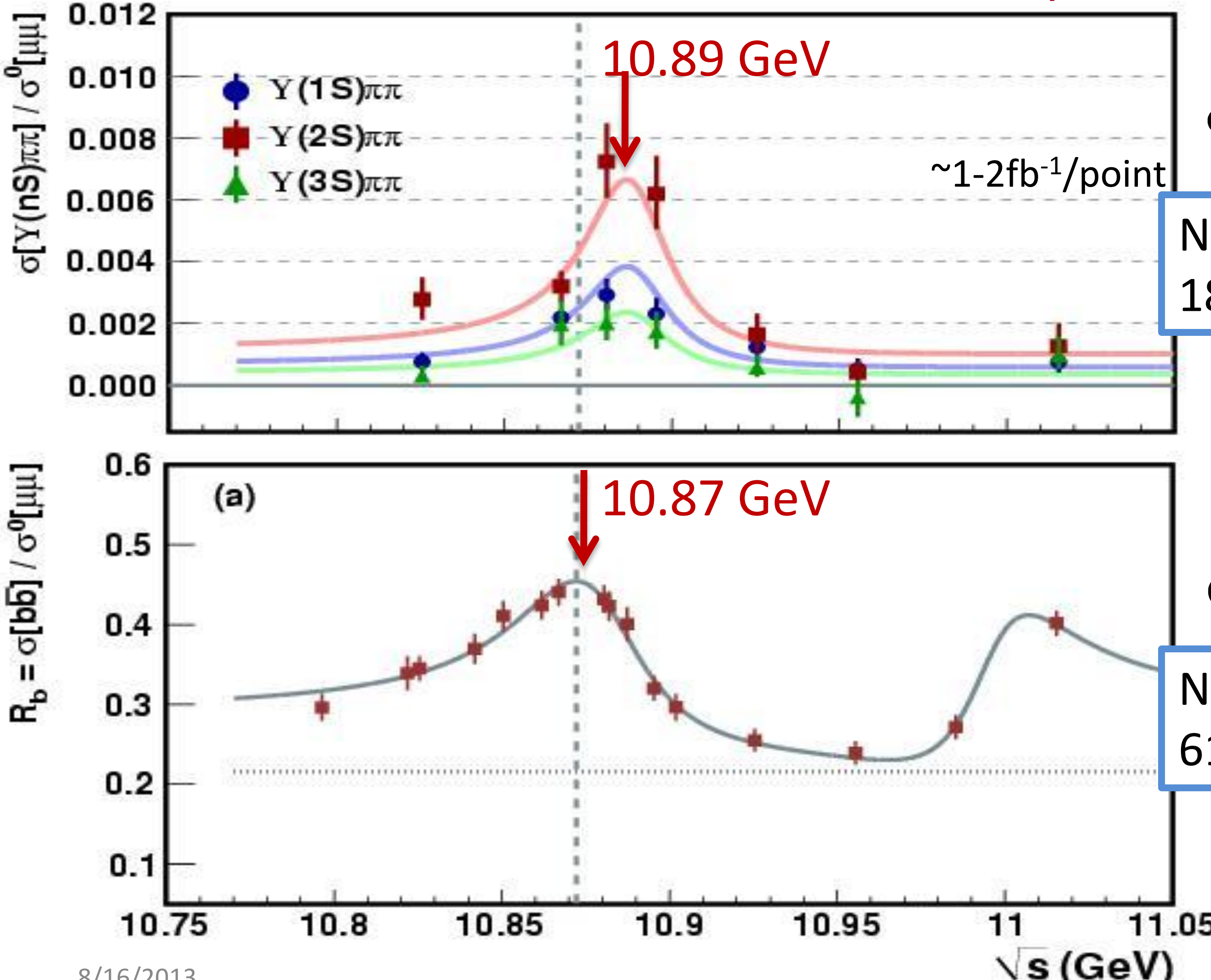
3. Exotic resonance Y_b near $\Upsilon(5S)$
   - analog of Y(4260) resonance with anomalous $\Gamma(J/\psi\,\pi^+\pi^-)$
   - Check shapes of R_b and $\sigma(\Upsilon\pi\pi)$ as function of E_{CM}

   Hou et al., Phys.Rev.D74:017504,2006
   Ali et al. Phys.Rev.Lett.104:162001,2010

Search for Anomalous Structure: Energy Scan

- R_b peaks at 10.87, $\sigma(\Upsilon\pi\pi)$ peaks at 10.89

PRD82,091106R(2010)



$\sigma[\Upsilon(nS)\pi\pi]/\sigma[\mu\mu]$

New scan:
18 additional points

Define R_b:
$\sigma[bb]/\sigma[\mu\mu]$

New scan:
61 additional points

$\sqrt{s}(GeV)$