Quarkonium and quarkonium-like states

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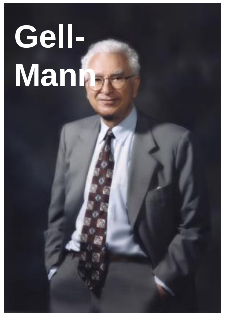
Belle Collaboration

(KEK, December 13, 2013, Tsukuba, Japan)

Constituent Quark Model



The model was proposed independently by Gell-Mann and Zweig in 1964 with three fundamental building blocks:

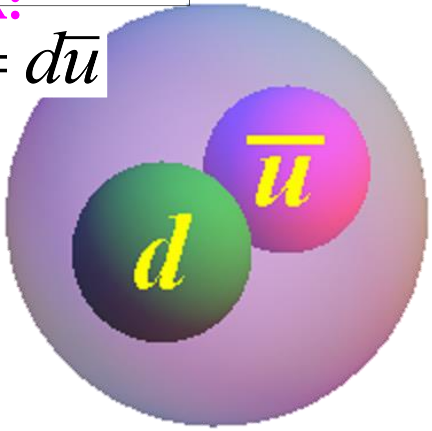
1960's (p,n,λ) $\Rightarrow$ 1970's (u,d,s):

<u>mesons</u> are bound states of a of quark and anti-quark:

$$\pi^+ = u\bar{d} \quad \pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}) \quad \pi^- = d\bar{u}$$

$$K^+ = u\bar{s} \quad K^0 = d\bar{s} \quad \bar{K}^0 = s\bar{d} \quad K^- = s\bar{u}$$

$$\pi^- = d\bar{u}$$

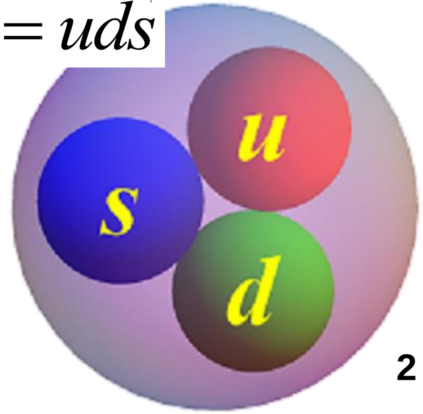


<u>baryons</u> are bound state of 3 quarks:

$$p = uud \quad n = udd \quad \Lambda = uds$$

$$\bar{p} = \bar{u}\bar{u}\bar{d} \quad \bar{n} = \bar{u}\bar{d}\bar{d} \quad \bar{\Lambda} = \bar{u}\bar{d}\bar{s}$$

$$\Lambda = uds$$

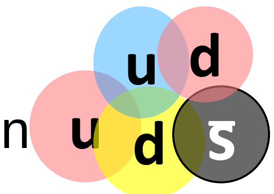


What about other color-singlet combinations?

Other possible "white" combinations of quarks & gluons:

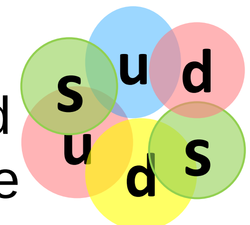
Pentaquark:

S=+1 Baryon



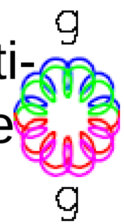
H-diBaryon

tightly bound
6-quark state



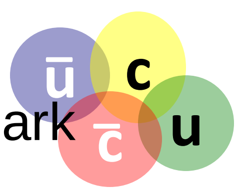
Glueball

Color-singlet multi-
gluon bound state

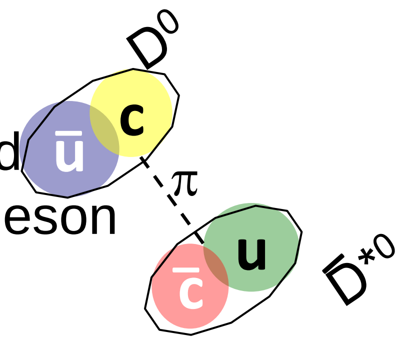


Tetraquark mesons

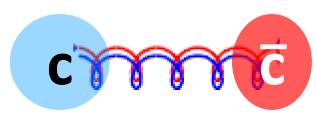
tightly bound
diquark-diantiquark



loosely bound
meson-antimeson
"molecule"



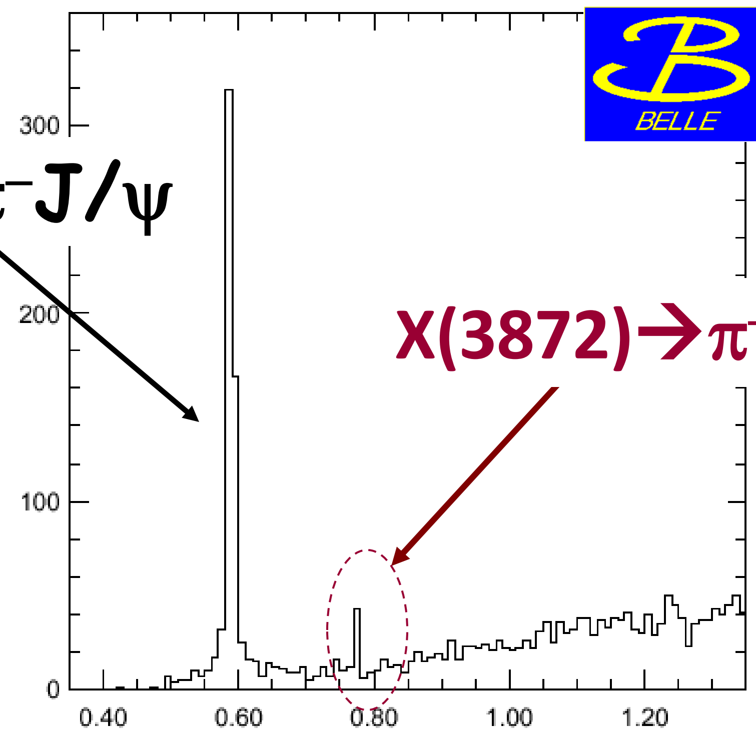
$q\bar{q}$-gluon hybrid mesons



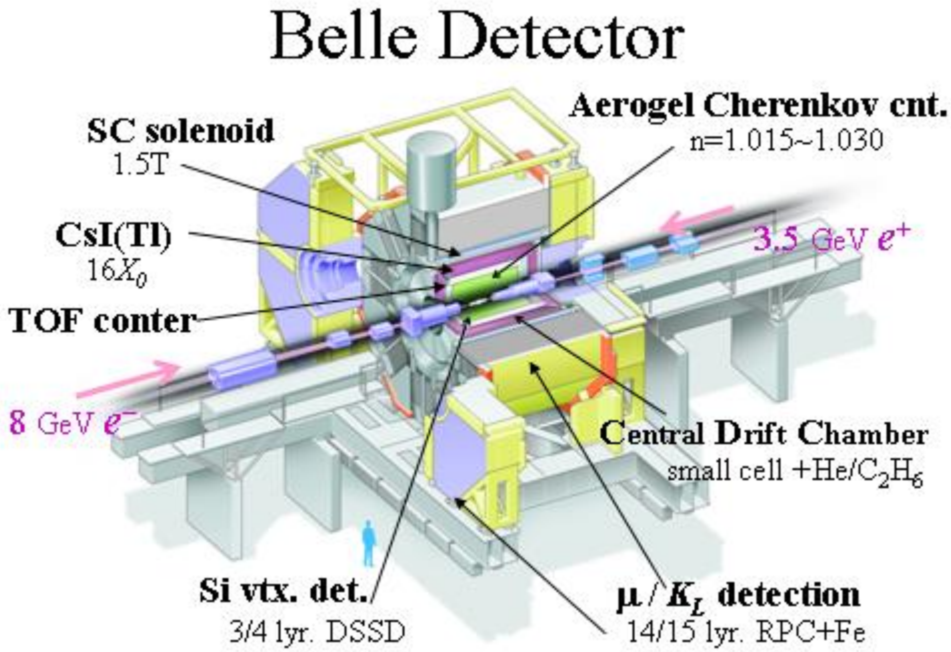
The X(3872) in $B \to K \pi^+\pi^- J/\psi$

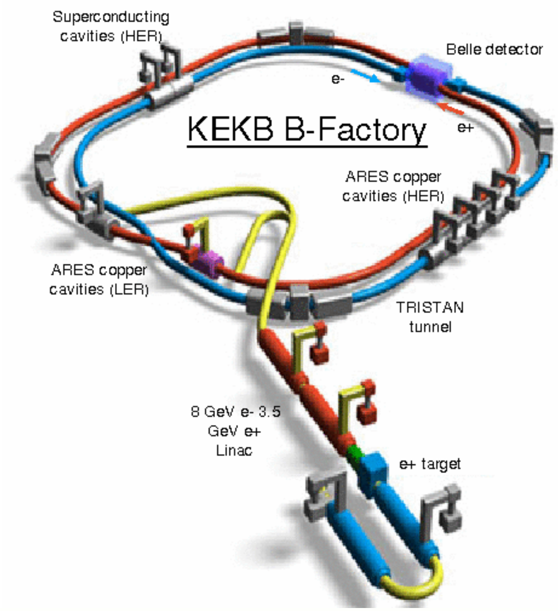
discovered by Belle (140/fb)

PRL 91, 262001 (2003)

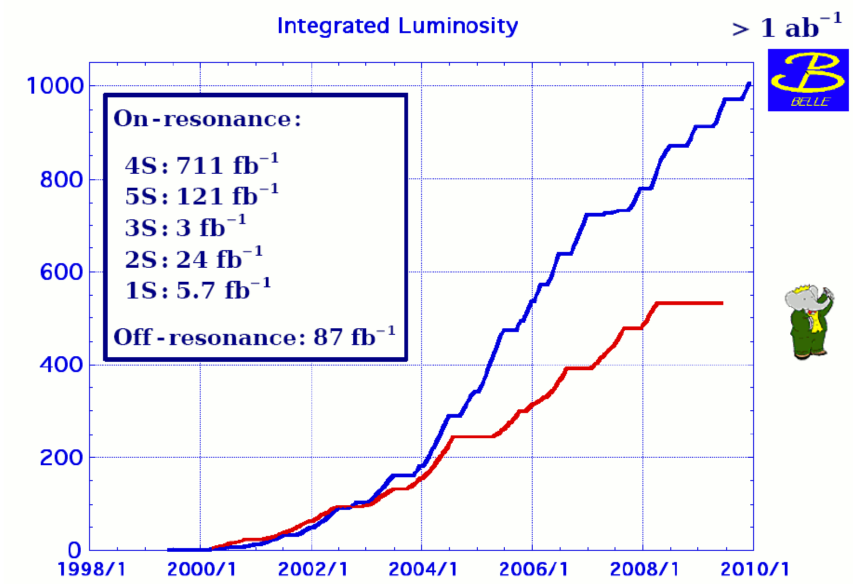


State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6	$1^{++}/2^{-+}$	$B\to K(\pi^+\pi^-J/\psi)$	Belle [85, 86] (12.8), *BABAR* [87] (8.6)	2003
		(<2.2)		$p\bar{p}\to(\pi^+\pi^-J/\psi)+...$	CDF [88–90] (np), DØ [91] (5.2)	
				$B\to K(\omega J/\psi)$	Belle [92] (4.3), *BABAR* [93] (4.0)	
				$B\to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), *BABAR* [96] (4.9)	
				$B\to K(\gamma J/\psi)$	Belle [92] (4.0), *BABAR* [97, 98] (3.6)	
				$B\to K(\gamma\psi(2S))$	*BABAR* [98] (3.5), Belle [99] (0.4)	
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B\to K(\omega J/\psi)$	Belle [100] (8.1), *BABAR* [101] (19)	2004
				$e^+e^-\to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)	
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007
				$e^+e^-\to J/\psi\ (...)$	Belle [54] (5.0)	
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^-\to\gamma(D\bar{D})$	*BABAR* [27] (np), Belle [21] (np)	2007
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-J/\psi)$	Belle [104] (7.4)	2007
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [106, 107] (5.0)	2009
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [103] (5.5)	2007
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-J/\psi)$	*BABAR* [108, 109] (8.0)	2005
					CLEO [110] (5.4)	
					Belle [104] (15)	
				$e^+e^-\to(\pi^+\pi^-J/\psi)$	CLEO [111] (11)	
				$e^+e^-\to(\pi^0\pi^0J/\psi)$	CLEO [111] (5.1)	
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [107] (3.1)	2010
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^-\to e^+e^-(\phi J/\psi)$	Belle [112] (3.2)	2009
$Y(4360)$	4353 ± 11	96 ± 42	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	*BABAR* [113] (np), Belle [114] (8.0)	2007
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B\to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^-\to\gamma(\Lambda_c^+\Lambda_c^-)$	Belle [25] (8.2)	2007
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	Belle [114] (5.8)	2007

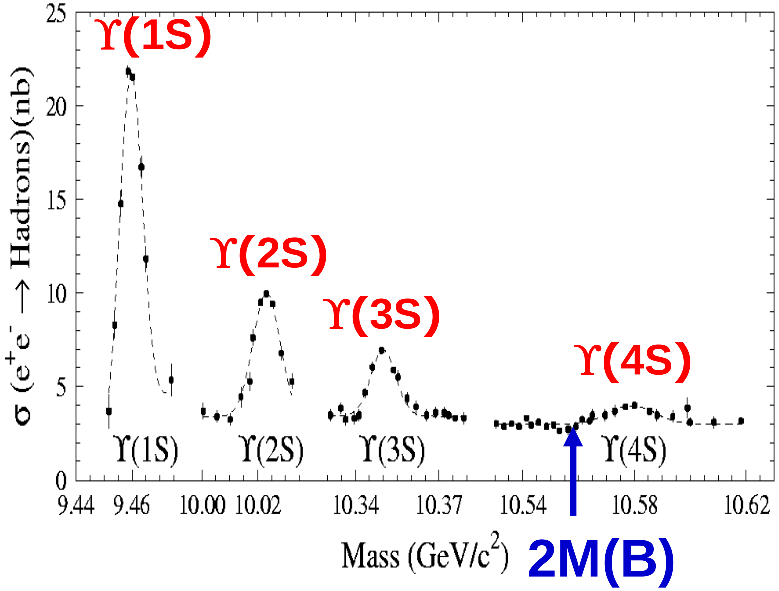


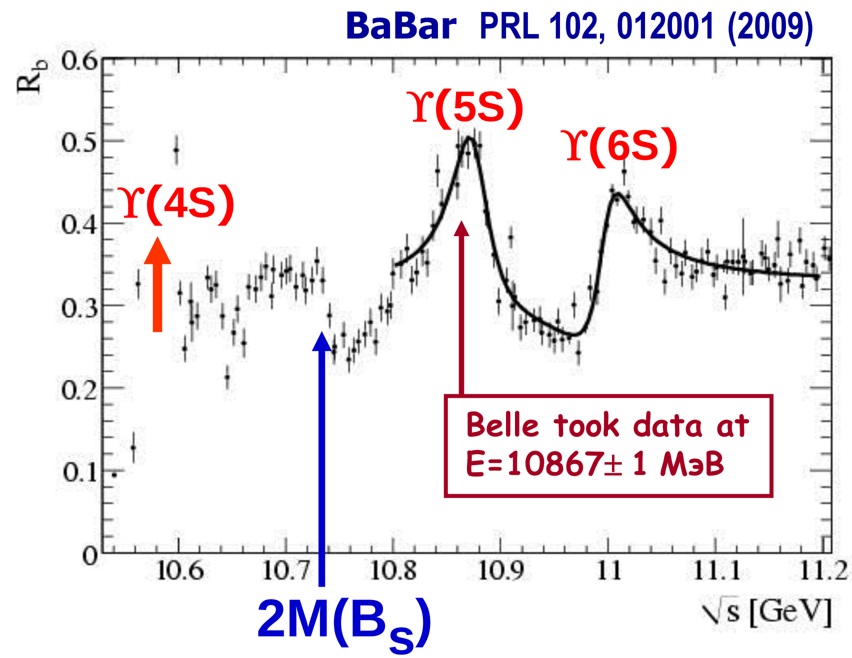


- **3.5 GeV $e^+ \times$ 8.0 GeV e^-.**
- $\mathcal{L}_{\max} = 2.1 \times 10^{34} cm^{-2} s^{-1}$
- **Continuous injection**
  $\rightarrow$ **1.1 fb^{-1}/day.**
- $\int \mathcal{L} dt \approx 1\, ab^{-1}$



e^+e^- hadronic cross-section





$e^+ e^- \to \Upsilon(4S) \to B\bar{B}$, where B is B^+ or B^0

$e^+ e^- \to b\bar{b}\ (\Upsilon(5S)) \to B^{(*)}\bar{B}^{(*)}$, $B^{(*)}\bar{B}^{(*)}\pi$, $B\bar{B}\pi\pi$, $B_s^{(*)}\bar{B}_s^{(*)}$, $\Upsilon(1S)\pi\pi$, ΥX …

main motivation for taking data at $\Upsilon(5S)$

Puzzles of Υ(5S) decays

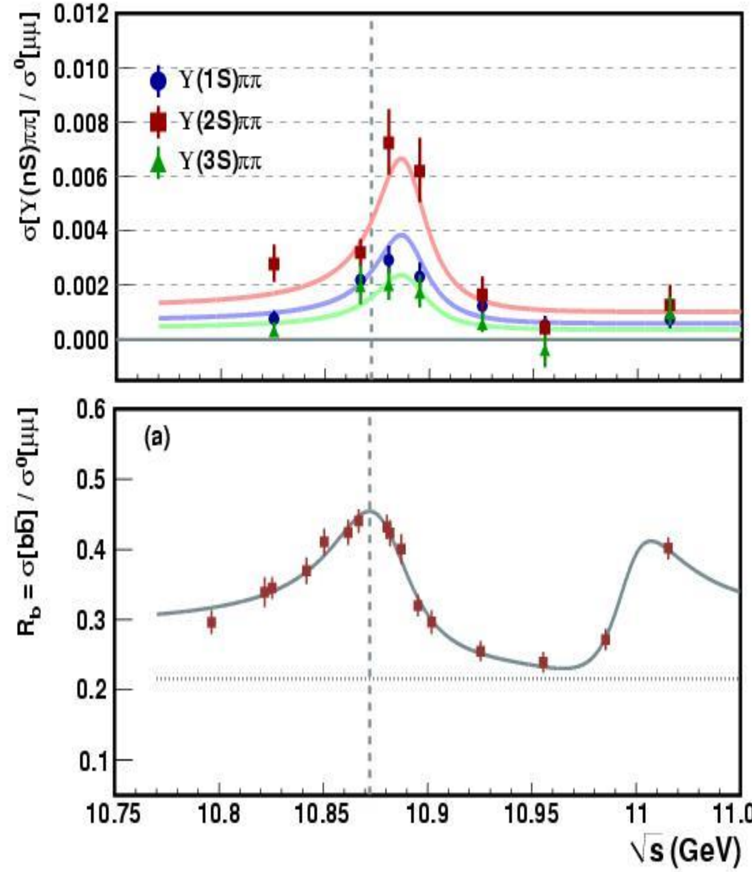
Anomalous production of $\Upsilon(nS)\,\pi^+\pi^-$ with 21.7 fb^{-1}

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

10^2

PRD82,091106R(2010)



(1) Rescattering $\Upsilon(5S) \to BB\pi\pi \to \Upsilon(nS)\pi\pi$

Simonov JETP Lett 87,147(2008)

(2) Exotic resonance Y_b near Υ(5S)
analogue of Y(4260) resonance
with anomalous $\Gamma(J/\psi\,\pi^+\pi^-)$

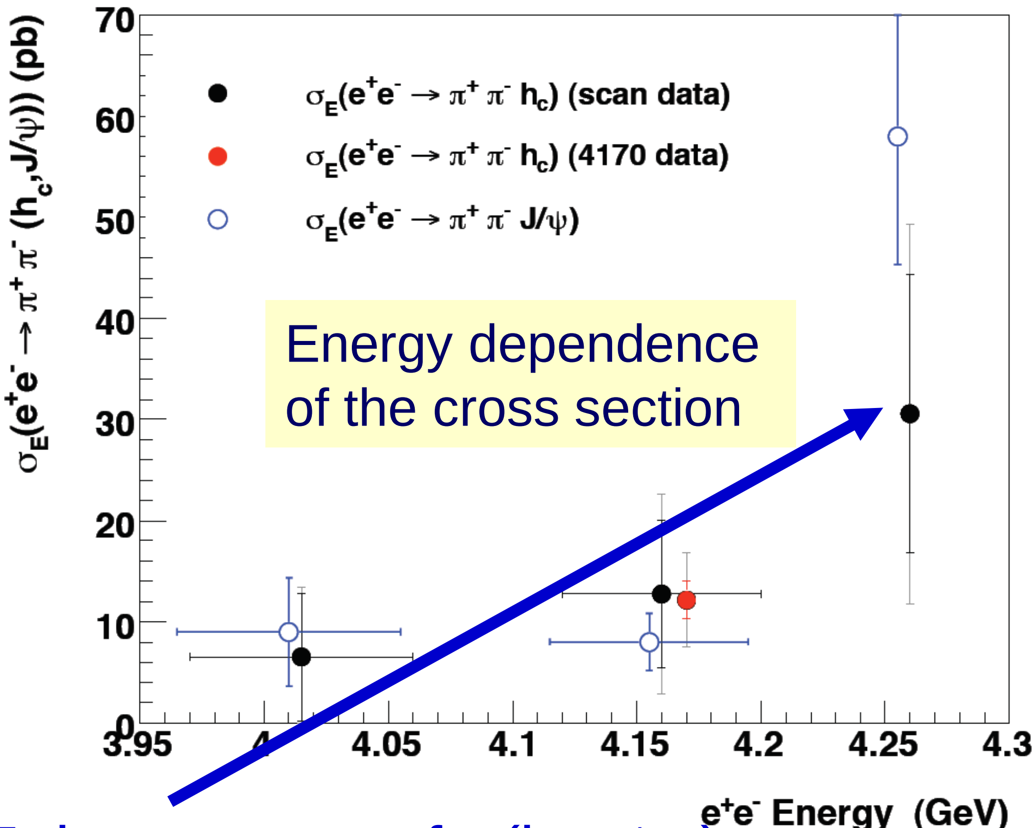
Dedicated energy scan $\Rightarrow$
shapes of R_b and $\sigma(\Upsilon\pi\pi)$ different (2σ)

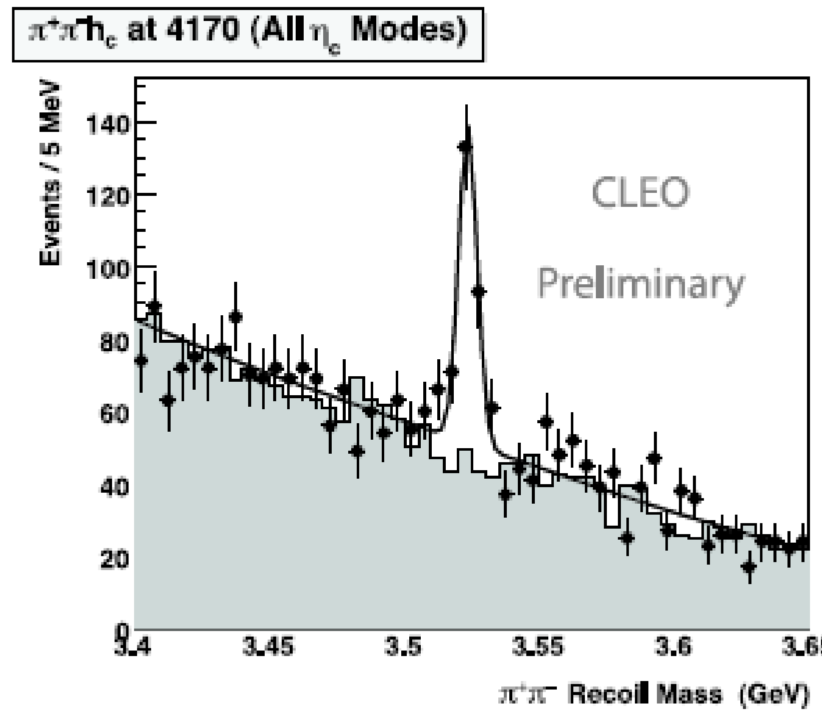
Υ(5S) is very interesting and not yet understood
Finally Belle recorded 121.4fb^{-1} data set at Υ(5S)

Motivation

Observation of $e^+e^- \to \pi^+\pi^- h_c$ by CLEO   arXiv:1104.2025

Ryan Mitchell @ CHARM2010





Enhancement of $\sigma(h_c\, \pi^+\pi^-)$ @ Y(4260) $\Rightarrow$ $\sigma(h_b\, \pi^+\pi^-)$ is enhanced @ Y_b?

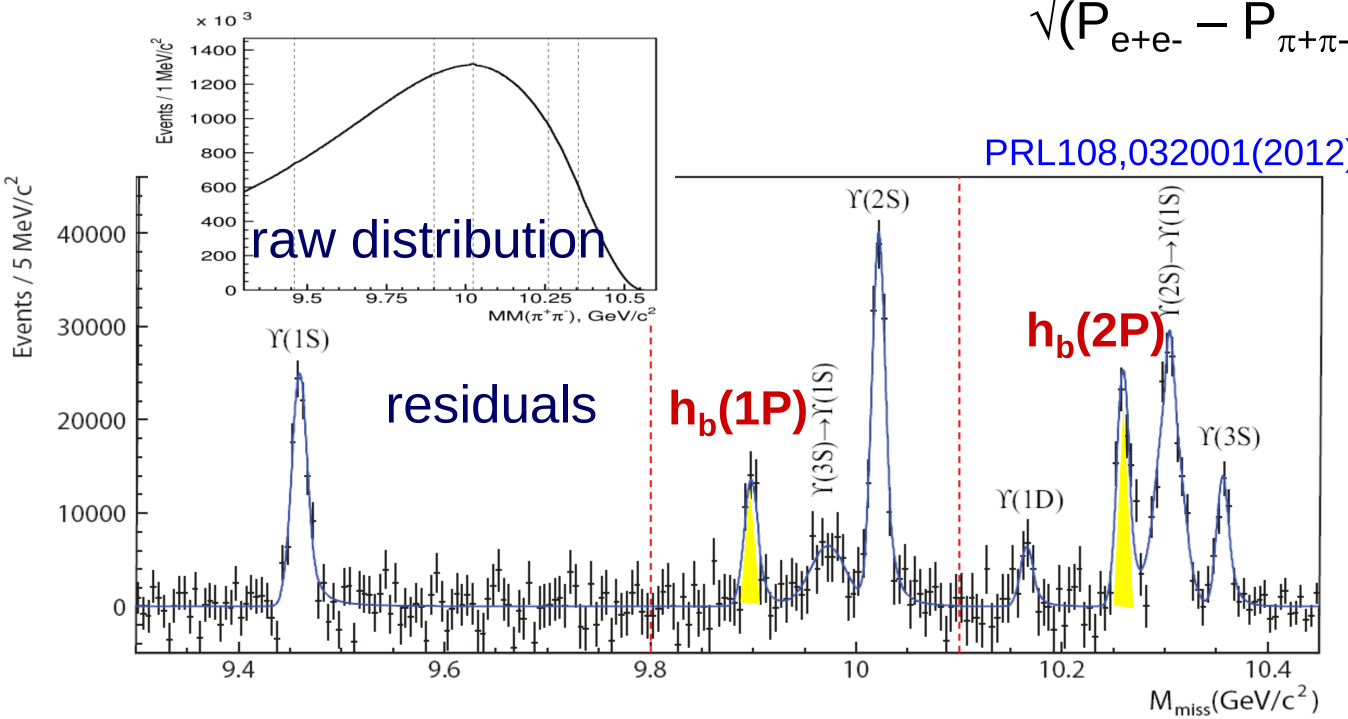
$\Rightarrow$ Belle search for h_b in $\Upsilon(5S)$ data

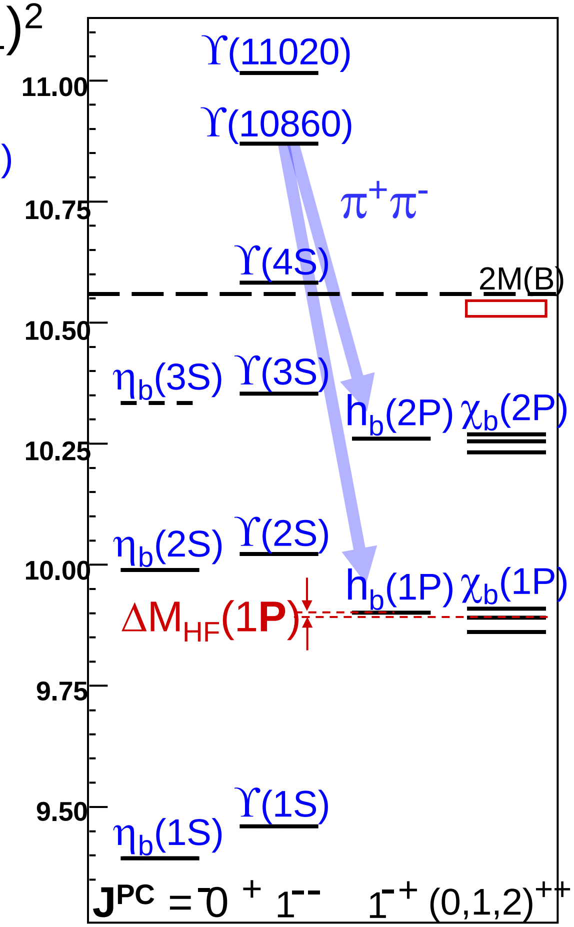
Observation of $h_b(1P,2P)$

$e^+e^- \to \Upsilon(5S) \to h_b(nP)\ \pi^+\pi^-$ ← reconstructed, use $M_{miss}(\pi^+\pi^-)$

$\sqrt{(P_{e+e-} - P_{\pi+\pi-})^2}$

PRL108,032001(2012)





Belle arxiv:1205.6351

$\Delta M_{HF}(\mathbf{1P}) = +0.8 \pm 1.1$ MeV
$\Delta M_{HF}(\mathbf{2P}) = +0.5 \pm 1.2$ MeV

consistent with zero, as expected

Large $h_b(1,2P)$ production rates

c.f. CLEO $e^+e^- \to \psi(4170) \to h_c\ \pi^+\pi^-$

Observation of h_b(1P,2P)

$e^+e^- \to \Upsilon(5S) \to h_b(nP)\ \pi^+\pi^-$ ← reconstructed, use $M_{miss}(\pi^+\pi^-)$

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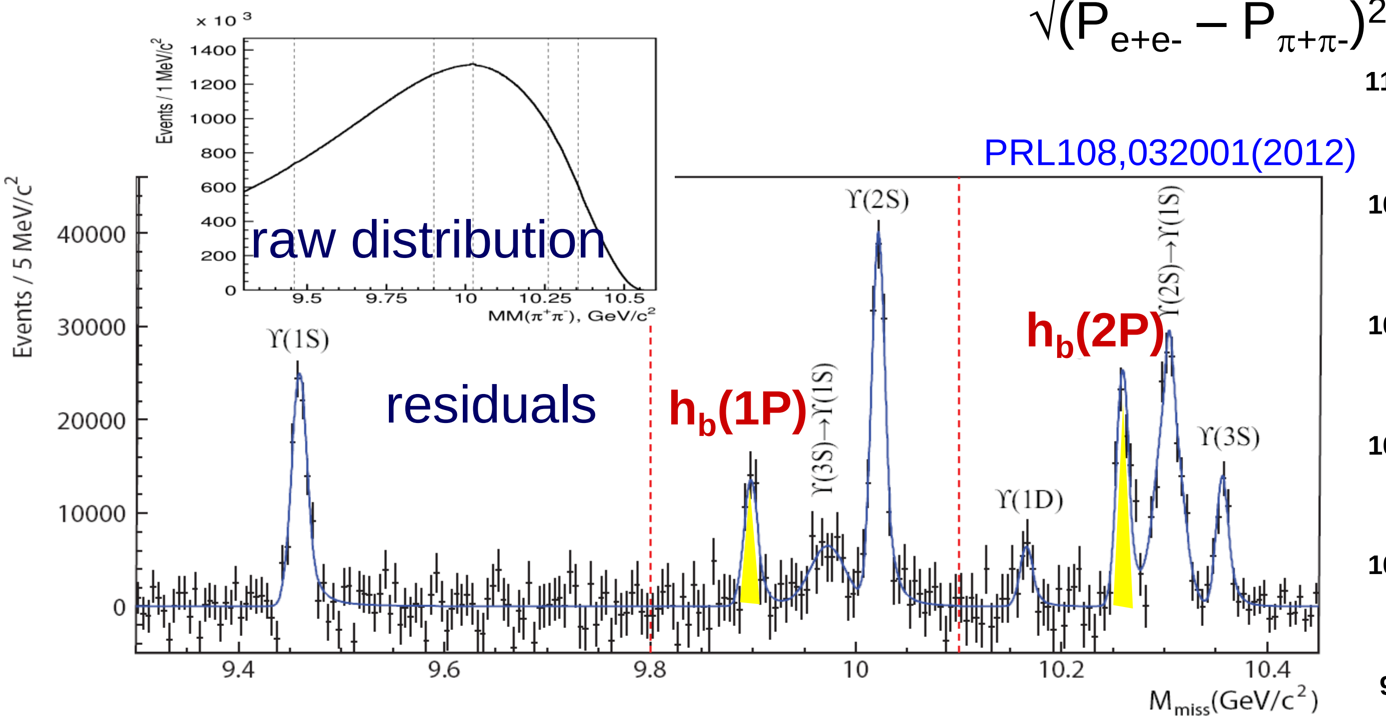
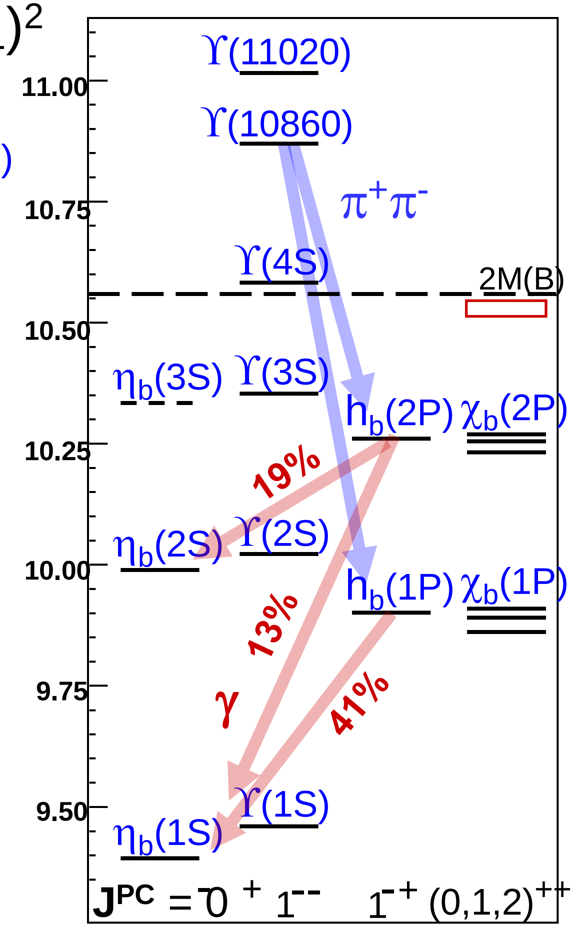
PRL108,032001(2012)





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Large h_b(1,2P) production rates

c.f. CLEO $e^+e^- \to \psi(4170) \to h_c\ \pi^+\pi^-$

h_b(nP) decays are a source of η_b(mS)

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

$e^+e^- \to \Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \to \eta_b(1S)\,\gamma$

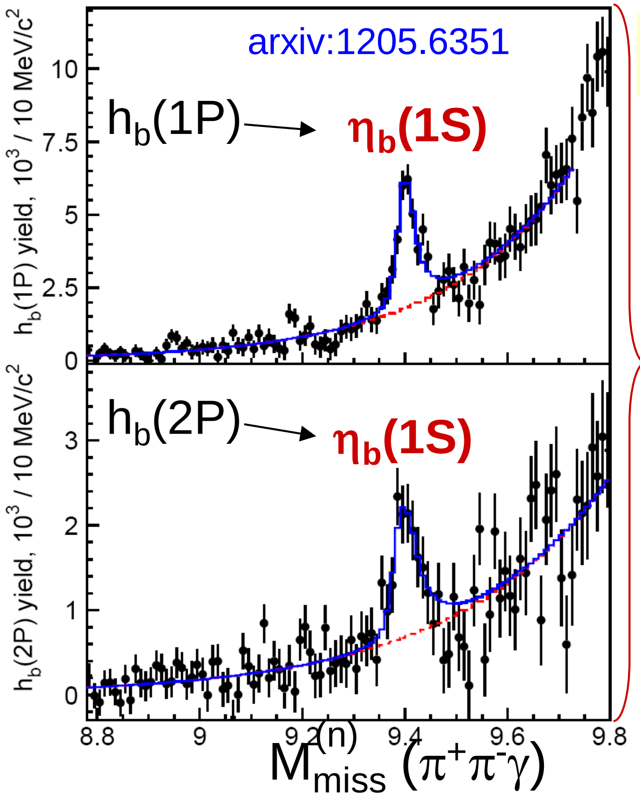
reconstruct $\pi^+\pi^-$ and γ

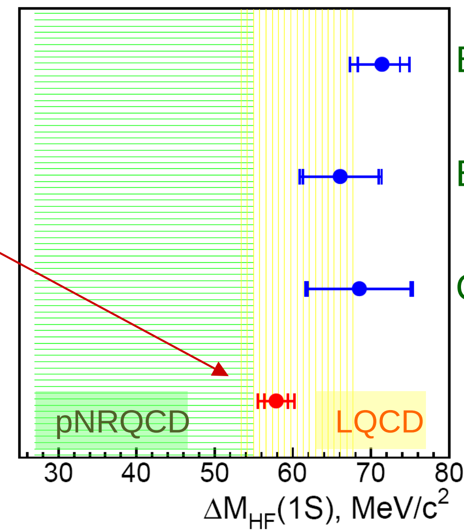
$\Delta M_{HF}(1S)$

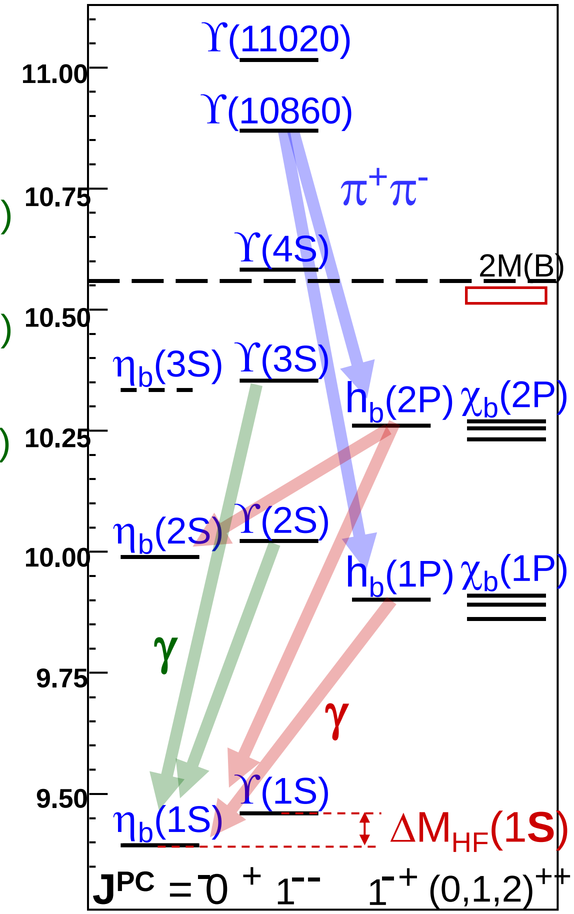
Belle : 57.9 ± 2.3 MeV

PDG'12 : 69.3 ± 2.8 MeV

3σ







Kniehl et al, PRL92,242001(2004)

Meinel, PRD82,114502(2010)

Mizuk et al. Belle PRL 109 (2012) 232002

Belle result decreases tension with theory

First measurement $\Gamma = 10.8\,^{+4.0}_{-3.7}\,^{+4.5}_{-2.0}$ MeV

as expected

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

$e^+e^- \to \Upsilon(5S) \to h_b(nP)\,\pi^+\pi^-$

$\quad\quad\quad\quad\quad\quad\quad\quad\, \to \eta_b(1S)\,\gamma$

reconstruct

$\Delta M_{HF}(1S)$

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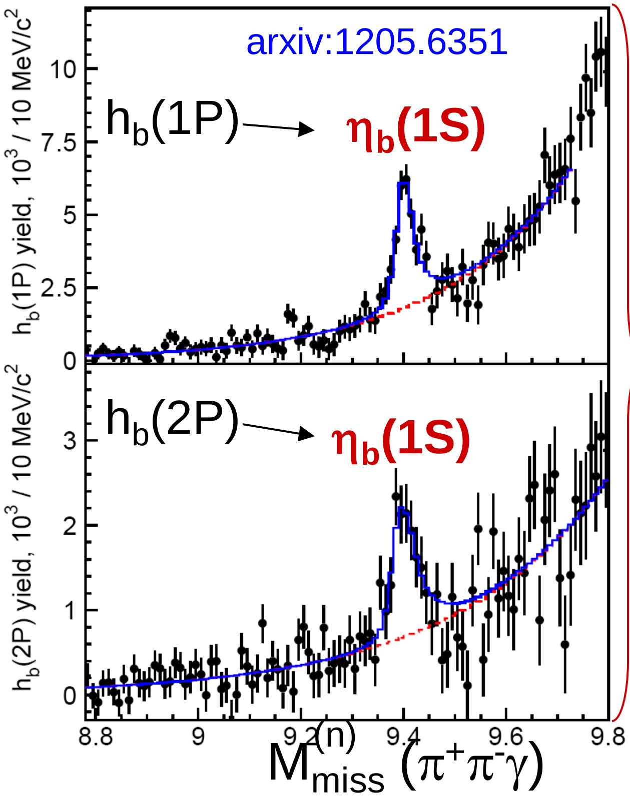
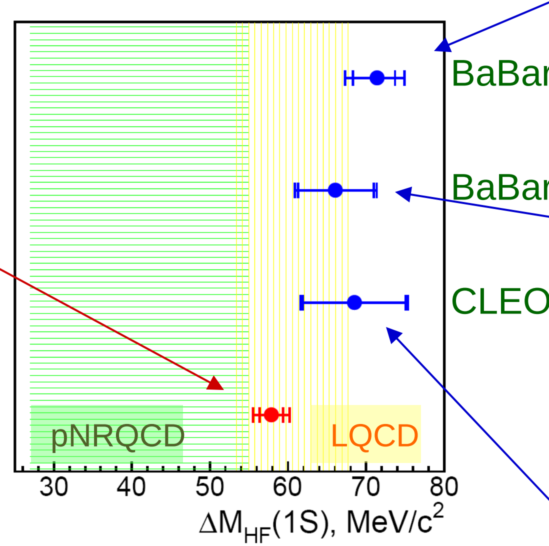
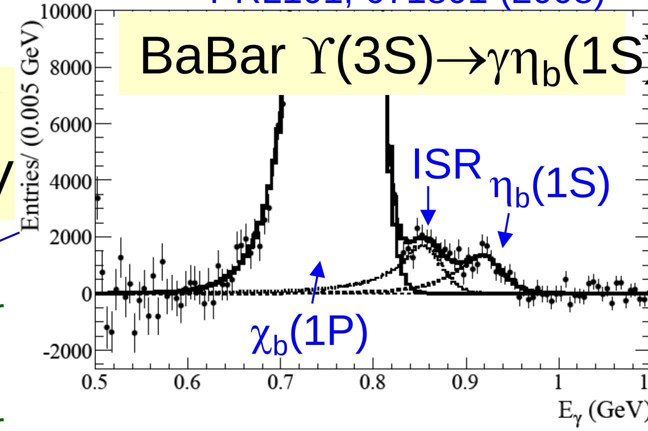


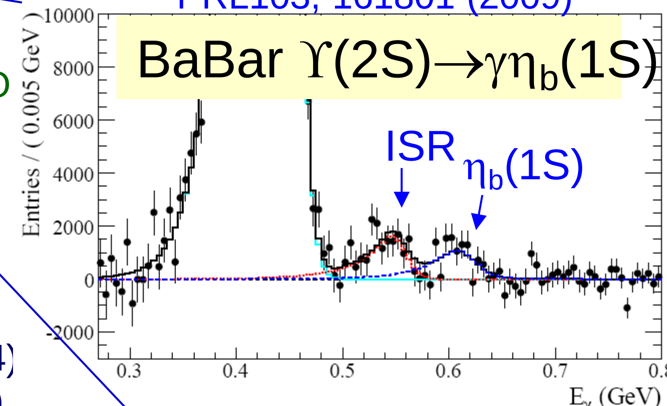


Kniehl et al, PRL92,242001(2004)
Meinel, PRD82,114502(2010)

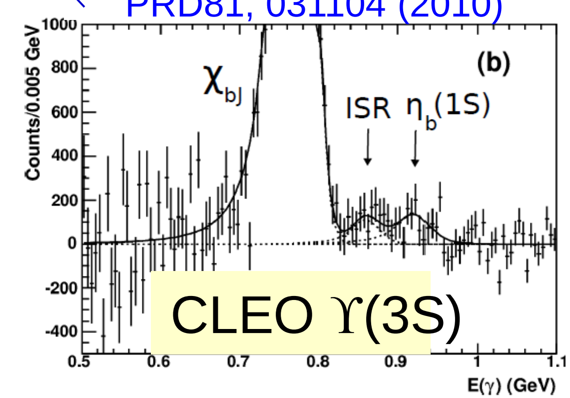
PRL101, 071801 (2008)



PRL103, 161801 (2009)



PRD81, 031104 (2010)



Mizuk et al. Belle PRL 109 (2012) 232002

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First measurement $\Gamma = 10.8\,^{+4.0}_{-3.7}\,^{+4.5}_{-2.0}$ MeV

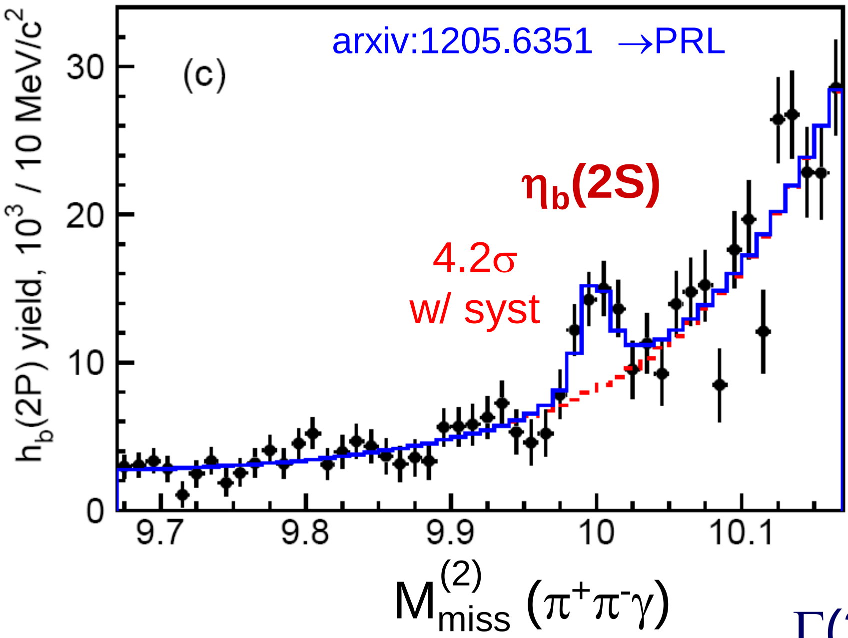
as expected

First evidence for $\eta_b(2S)$

$e^+e^- \to \Upsilon(5S) \to h_b(\mathbf{2P})\ \pi^+\pi^-$

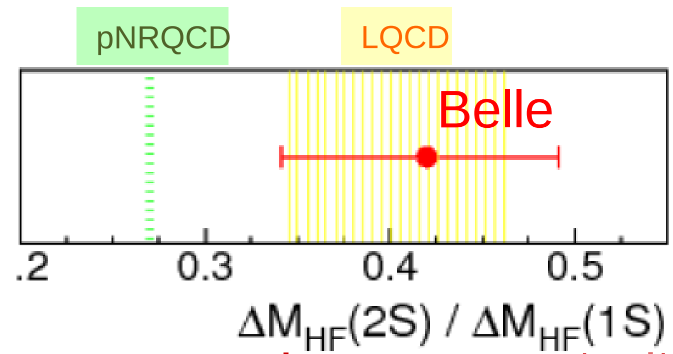
$\to \eta_b(\mathbf{2S})\ \gamma$

Mizuk et al. Belle PRL 109 (2012) 232002



$\Delta M_{HF}(\mathbf{2S}) = 24.3\ ^{+4.0}_{-4.5}$ MeV

First measurement



In agreement with theory

$\Gamma(2S) = 4 \pm 8$ MeV, < 24MeV @ 90% C.L.

expect ~4MeV

Branching fractions		Expectations
$BF[h_b(1P) \to \eta_b(1S)\ \gamma]$ =	$49.2 \pm 5.7^{+5.6}_{-3.3}$ %	41% Godfrey Rosner PRD66,014012(2002)
$BF[h_b(2P) \to \eta_b(1S)\ \gamma]$ =	$22.3 \pm 3.8^{+3.1}_{-3.3}$ %	13%
$BF[h_b(2P) \to \eta_b(2S)\ \gamma]$ =	$47.5 \pm 10.5^{+6.8}_{-7.7}$ %	19%

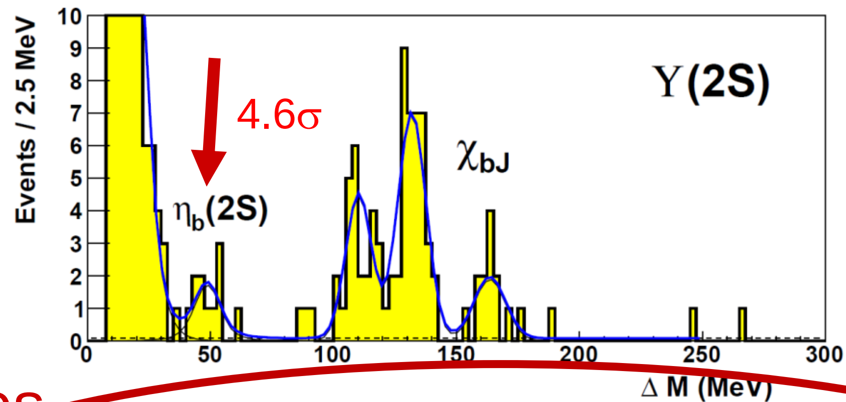
c.f. BESIII $BF[h_c(1P) \to \eta_c(1S)\ \gamma] = 54.3 \pm 8.5$ % 39%

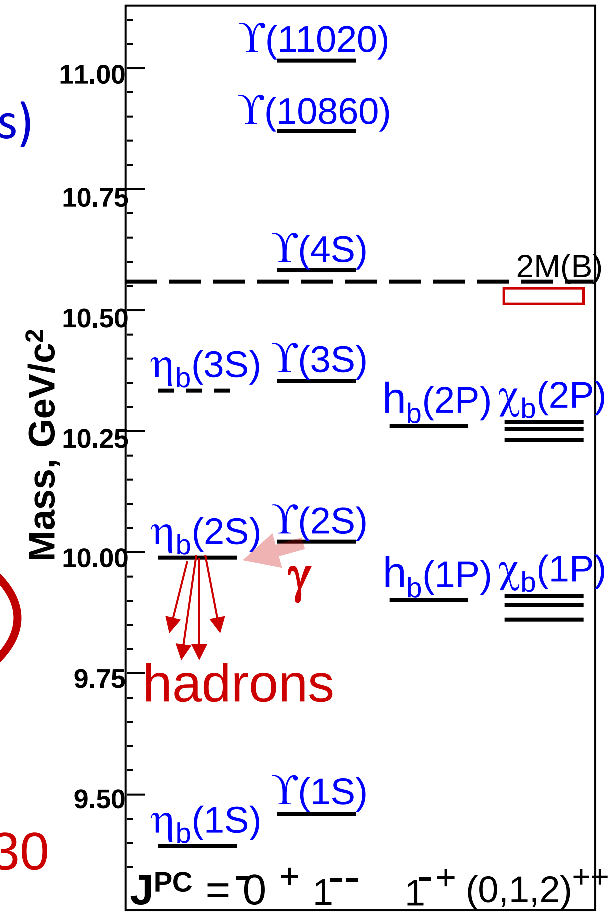
"Signal" of exclusively reconstructed $\eta_b(2S)$

Dobbs, Metreveli, Seth, Tomaradze, Xiao, PRL 109 (2012) 082001 **CLEO data**

$e^+e^- \to \Upsilon(2S) \to \eta_b(2S)\,\gamma$, $\eta_b(2S) \to 4,6,8,10\ \pi^\pm, K^\pm, p/\bar{p}$

(26 channels)





Issues

Bg from final state radiation can mimic signal
e.g. $\Upsilon(2S) \to K^+K^-\ n(\pi^+\pi^-)\ \gamma_{FSR}$
power law tail instead of exponential

not discussed

Large production rate: $N\ \eta_b(2S) \sim 0.2\ N\ \chi_{b1}$

c.f. $\Gamma(\psi' \to \eta_c(2S)\gamma) = 0.007\ \Gamma(\psi' \to \chi_{c1}\gamma)$ factor 30

BESIII arxiv:1205.5103 →PRL

Large $\Delta M_{HF}(2S)$ CLEO 48.7 ± 2.7 MeV ← strong disagreement with theory

Belle $24.3^{+4.0}_{-4.5}$ MeV ← agrees with theory

5σ

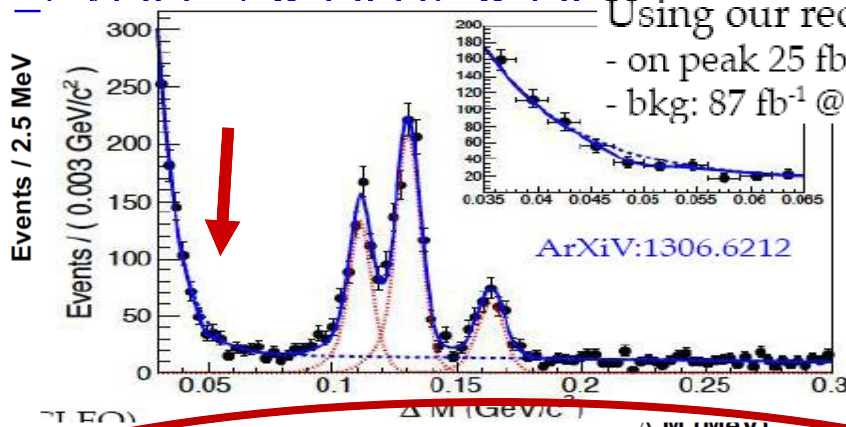
Reported excess is unlikely to be the $\eta_b(2S)$ signal

"Signal" of exclusively reconstructed $\eta_b(2S)$

Dobbs, Metreveli, Seth, Tomaradze, Xiao, PRL 109 (2012) 082001 **CLEO data**

IS DISCONFIRMED BY BELLE:
Using our record data sample:
- on peak 25 fb^{-1} (157.8M $\Upsilon(2S)$ decays, 16x CLEO)
- bkg: 87 fb^{-1} @ 10.52 GeV

$e^+e^- \to$ …



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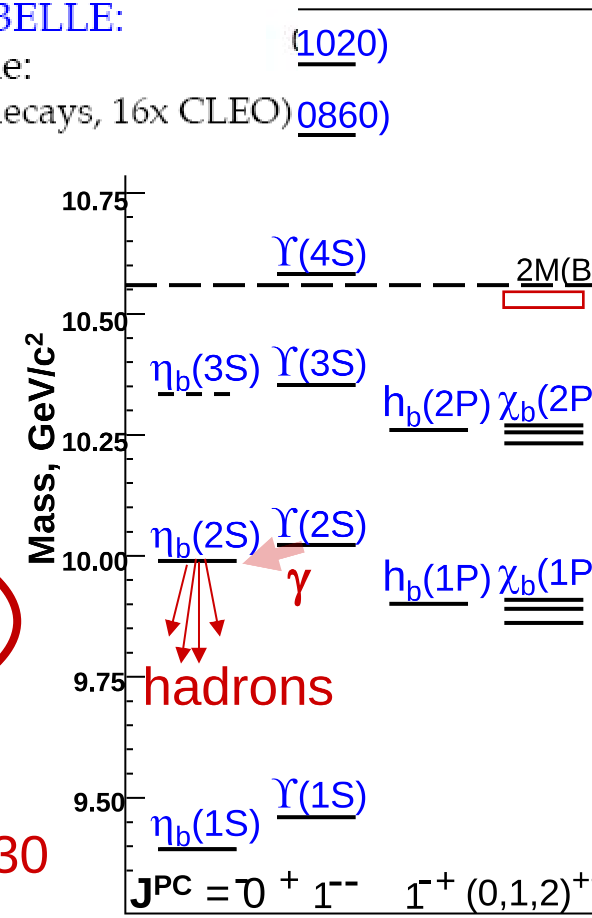
power law tail instead of exponential

not discussed

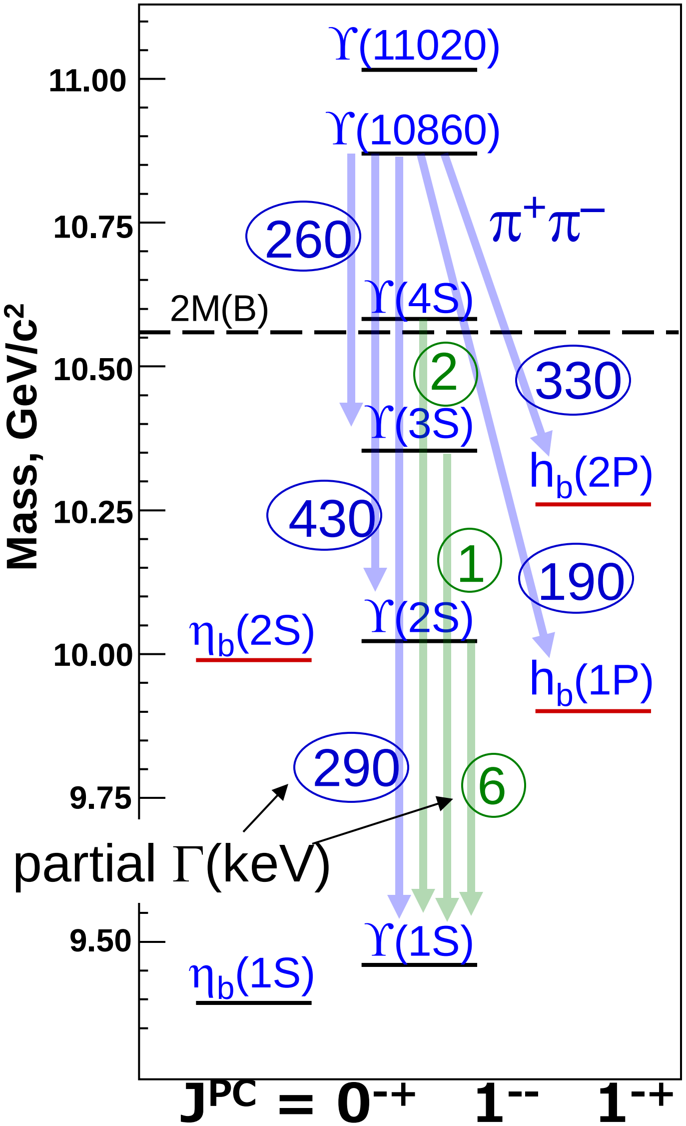


Large production rate: N $\eta_b(2S) \sim 0.2$ N χ_{b1} factor 30
c.f. $\Gamma(\psi' \to \eta_c(2S)\gamma) = 0.007\ \Gamma(\psi' \to \chi_{c1}\gamma)$
BESIII arxiv:1205.5103 $\to$PRL

Large $\Delta M_{HF}(2S)$ CLEO 48.7±2.7 MeV ← strong disagreement with theory
Belle $24.3^{+4.0}_{-4.5}$ MeV ← agrees with theory
5σ

Reported excess is unlikely to be the $\eta_b(2S)$ signal

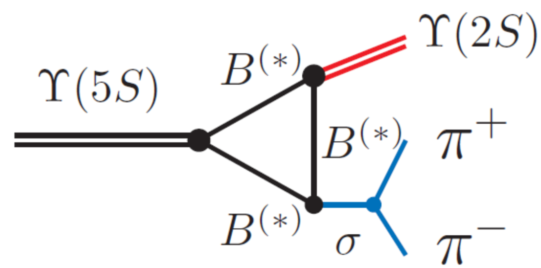
Anomalies in $\Upsilon(5S)\to(b\bar{b})\pi^+\pi^-$ transitions



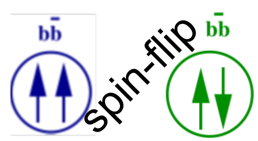
Belle: PRL100, 112001 (2008)

$\Gamma[\Upsilon(\mathbf{5S})\to\Upsilon(1,2,3S)\,\pi^+\pi^-] \overset{\sim 100}{>>} \Gamma[\Upsilon(\mathbf{4,3,2S})\to\Upsilon(1S)\,\pi^+\pi^-]$

$\Leftarrow$ Rescattering of on-shell $B^{(*)}\bar{B}^{(*)}$?



Belle: PRL108, 032001 (2012)



expect suppression $\sim\Lambda_{QCD}/m_b$

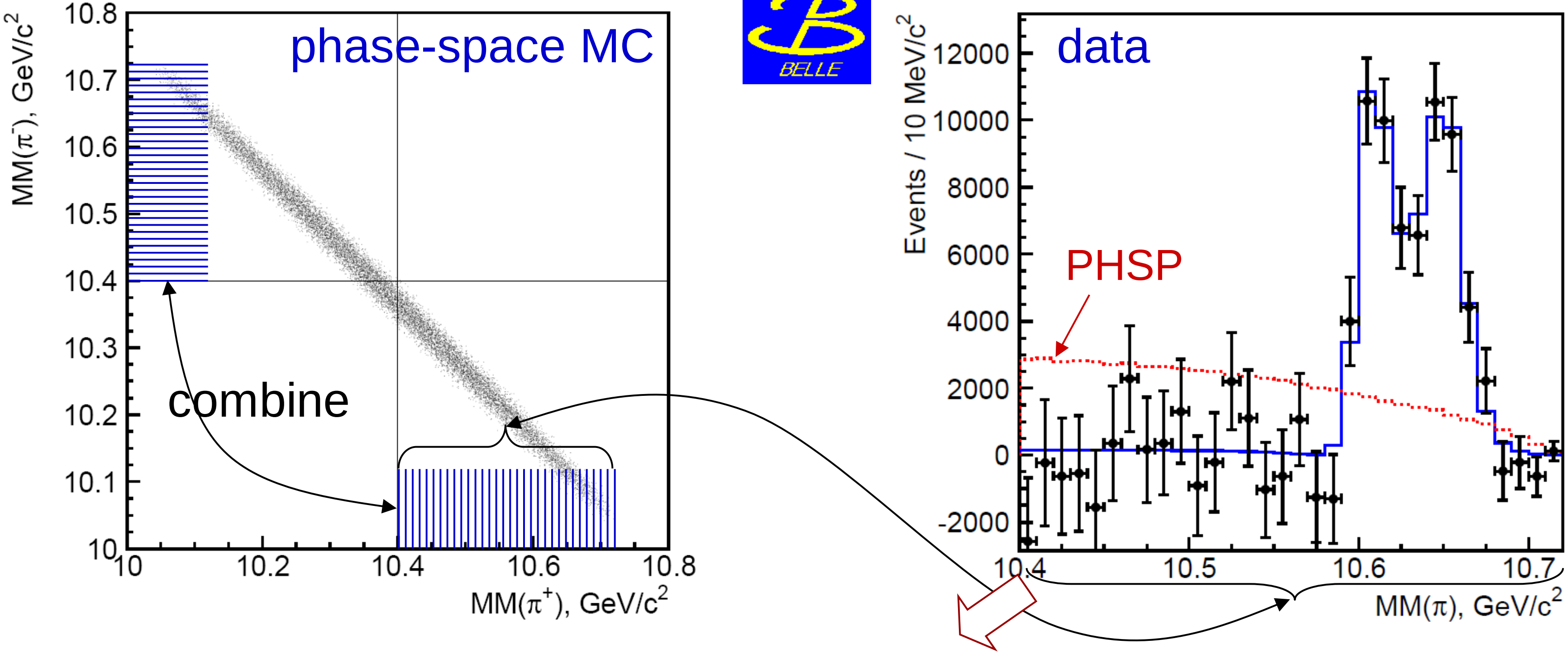
~~Heavy Quark Symmetry~~

Υ(5S) → h_b(1,2P) $\pi^+\pi^-$ are not suppressed

h_b production mechanism? $\Rightarrow$ Study resonant structure in $h_b(mP)\pi^+\pi^-$

Resonant substructure of $\Upsilon(5S) \to h_b(1P)\,\pi^+\pi^-$

$P(h_b) = P_{\Upsilon(5S)} - P(\pi^+\pi^-)$ $\Rightarrow$ **$M(h_b\pi^+) = MM(\pi^-)$** $\Rightarrow$ ***measure $\Upsilon(5S) \to h_b\pi\pi$ yield in bins of $MM(\pi)$***



[preliminary]

Fit function $|BW(s, M_1, \Gamma_1) + ae^{i\phi}BW(s, M_2, \Gamma_2) + be^{i\psi}|^2 \, \frac{qp}{\sqrt{s}}$

Results

$M_1 = 10605.1 \pm 2.2\,^{+3.0}_{-1.0}$ MeV/c² ~$B\bar{B}^*$ threshold

$\Gamma_1 = 11.4\,^{+4.5}_{-3.9}\,^{+2.1}_{-1.2}$ MeV $\quad a = 1.8\,^{+1.0}_{-0.7}\,^{+0.1}_{-0.5}$

$M_2 = 10654.5 \pm 2.5\,^{+1.0}_{-1.9}$ MeV/c² ~$B^*\bar{B}^*$ threshold

$\Gamma_2 = 20.9\,^{+5.4}_{-4.7}\,^{+2.1}_{-5.7}$ MeV $\quad \varphi = 188\,^{+44}_{-58}\,^{+4}_{-9}$ degree

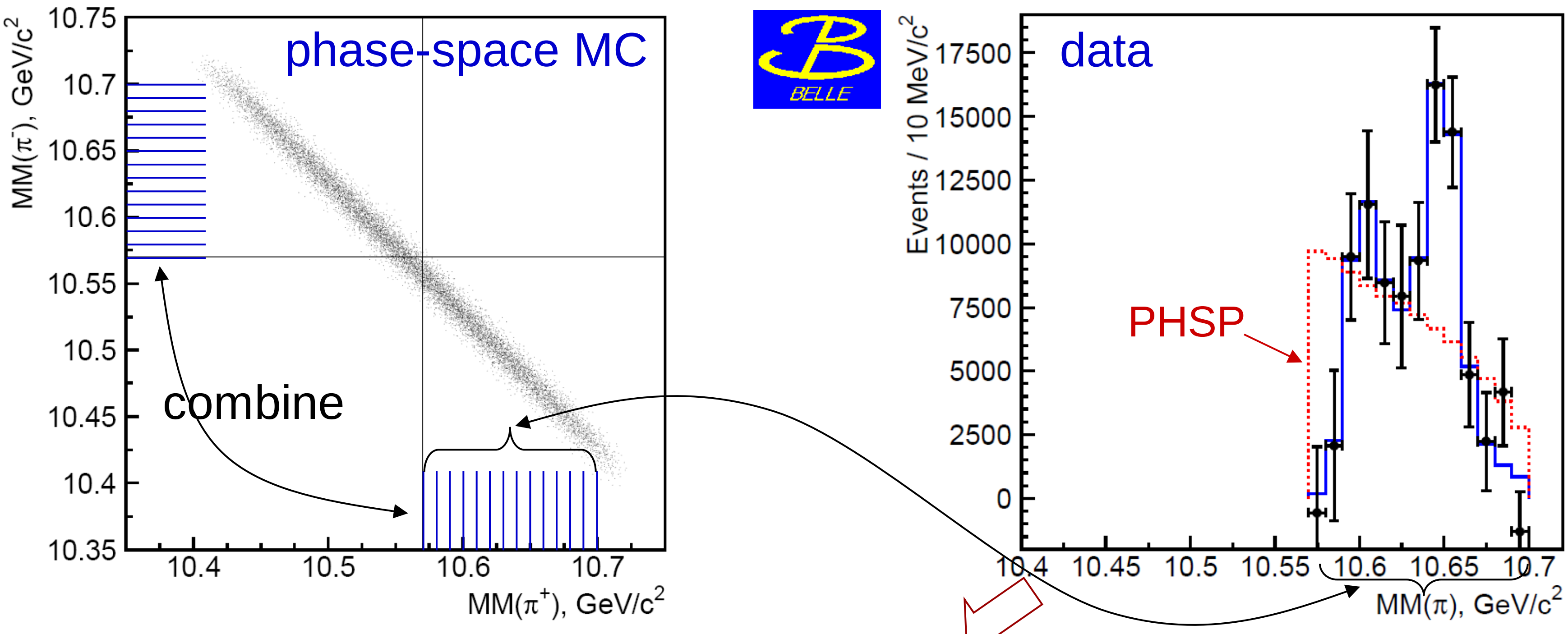
Significances

2 vs.1 : 7.4σ (6.6σ w/ syst)

2 vs.0 : 18σ (16σ w/ syst)

non-res. amplitude ~0

Resonant substructure of $\Upsilon(5S) \to h_b(2P)\,\pi^+\pi^-$



$h_b(1P)\pi^+\pi^-$	$h_b(2P)\pi^+\pi^-$
$M_1 = 10605.1 \pm 2.2\,^{+3.0}_{-1.0}$ MeV/c^2	$10596 \pm 7\,^{+5}_{-2}$ MeV/c^2
$\Gamma_1 = 11.4\,^{+4.5}_{-3.9}\,^{+2.1}_{-1.2}$ MeV	$16\,^{+16}_{-10}\,^{+13}_{-4}$ MeV
$M_2 = 10654.5 \pm 2.5\,^{+1.0}_{-1.9}$ MeV/c^2	$10651 \pm 4 \pm 2$ MeV/c^2
$\Gamma_2 = 20.9\,^{+5.4}_{-4.7}\,^{+2.1}_{-5.7}$ MeV	$12\,^{+11}_{-9}\,^{+8}_{-2}$ MeV
$a = 1.8\,^{+1.0}_{-0.7}\,^{+0.1}_{-0.5}$	$1.3\,^{+3.1}_{-1.1}\,^{+0.4}_{-0.7}$
$\varphi = 188\,^{+44}_{-58}\,^{+4}_{-9}$ degree	$255\,^{+56}_{-72}\,^{+12}_{-183}$ degree

consistent

[preliminary]

Significances

2 vs.1 : 2.7σ (1.9σ w/ syst)

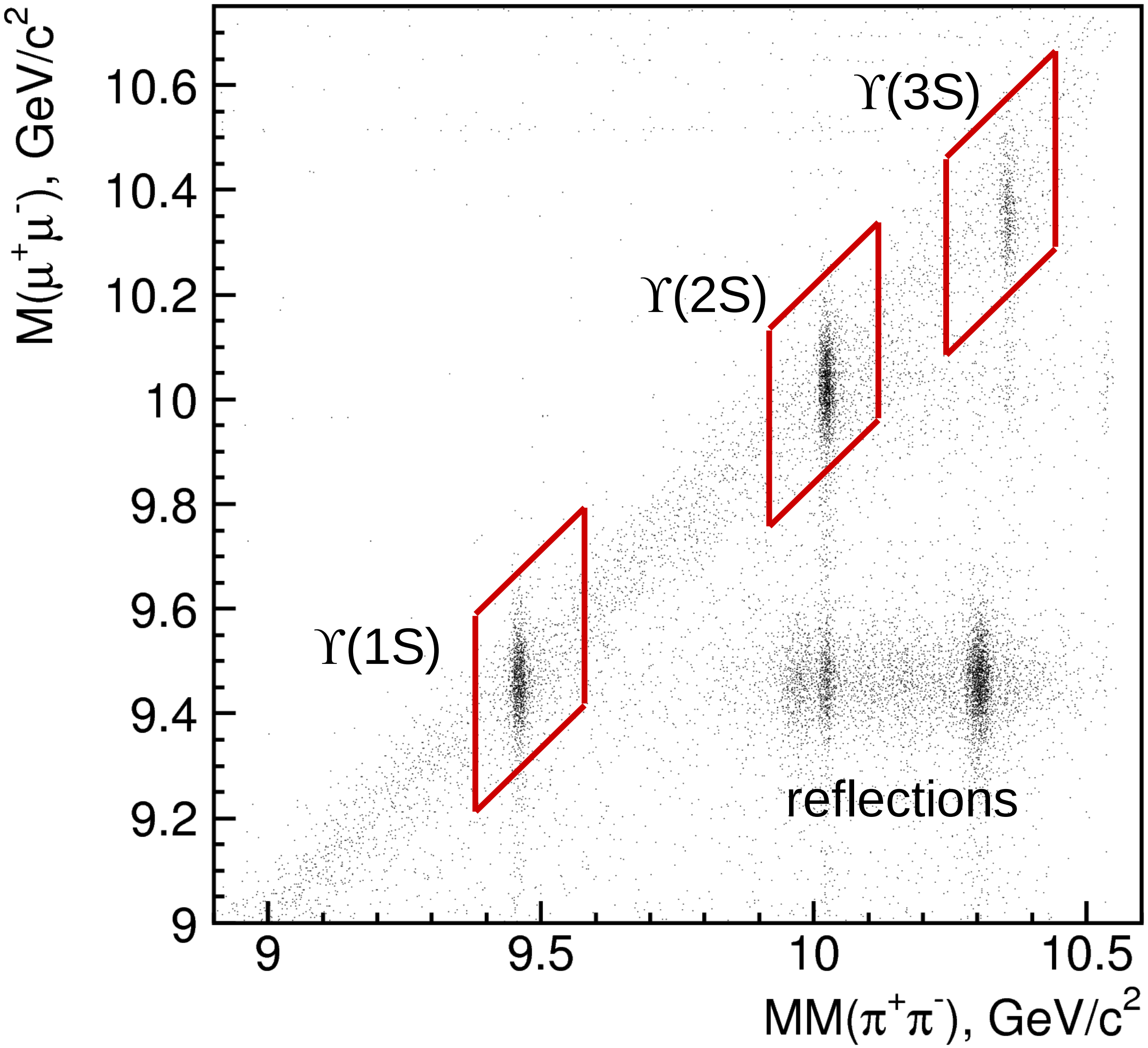
2 vs.0 : 6.3σ (4.7σ w/ syst)

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

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

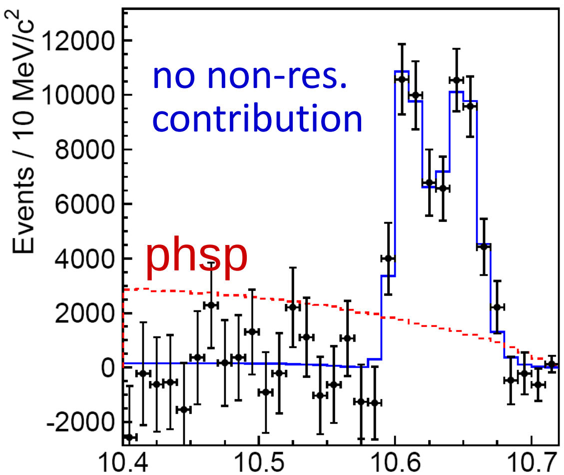
$\Upsilon(nS) \to \mu^+\mu^-$

(n = 1,2,3)



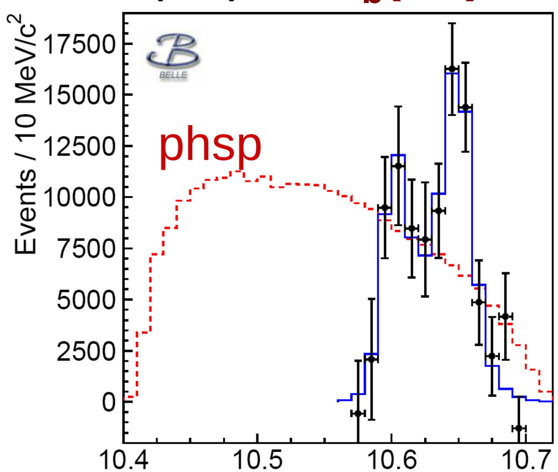
Resonant structure of $\Upsilon(5S) \to (b\bar{b})\pi^+\pi^-$

$\Upsilon(5S) \to h_b(1P)\pi^+\pi^-$



M[$h_b(1P)\ \pi^\pm$]

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



M[$h_b(2P)\ \pi^\pm$]

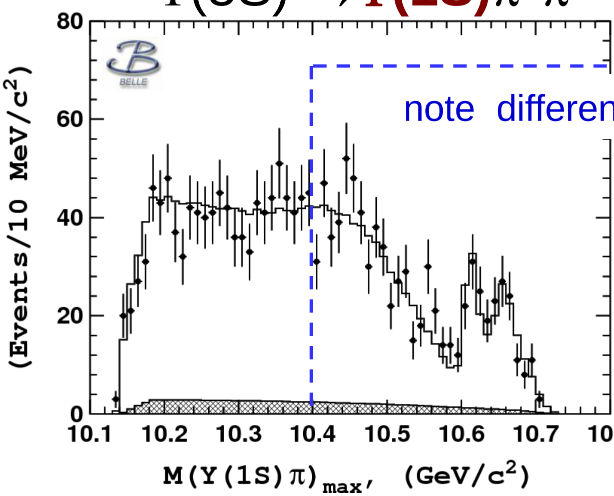
Two peaks are observed in all modes!

Belle: PRL108, 232001 (2012)

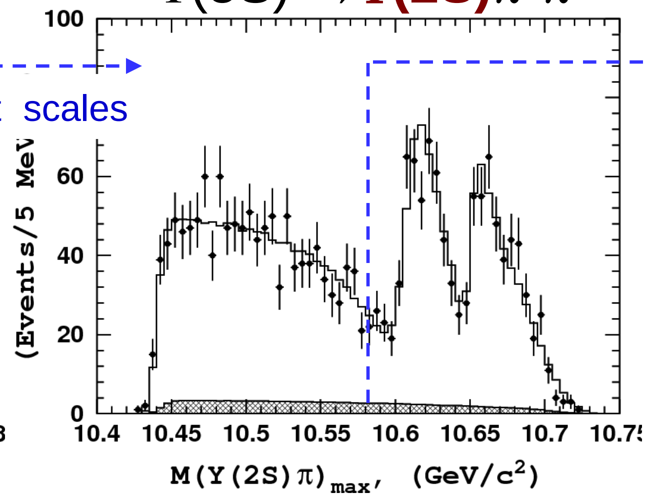
$Z_b(10610)$ and $Z_b(10650)$ should be multiquark states

Dalitz plot analysis

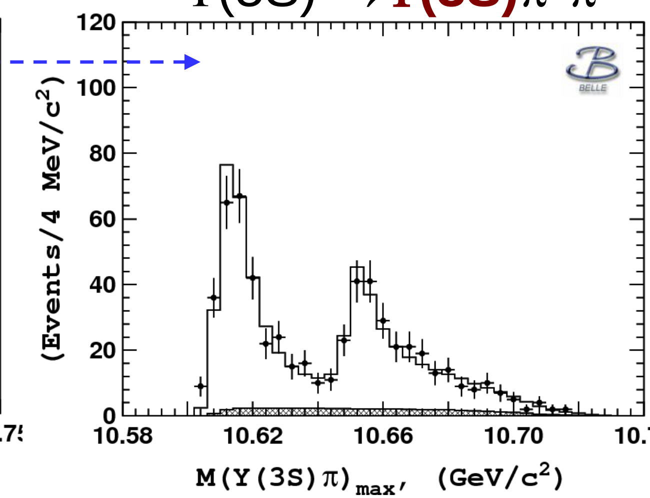
$\Upsilon(5S) \to \Upsilon(1S)\pi^+\pi^-$



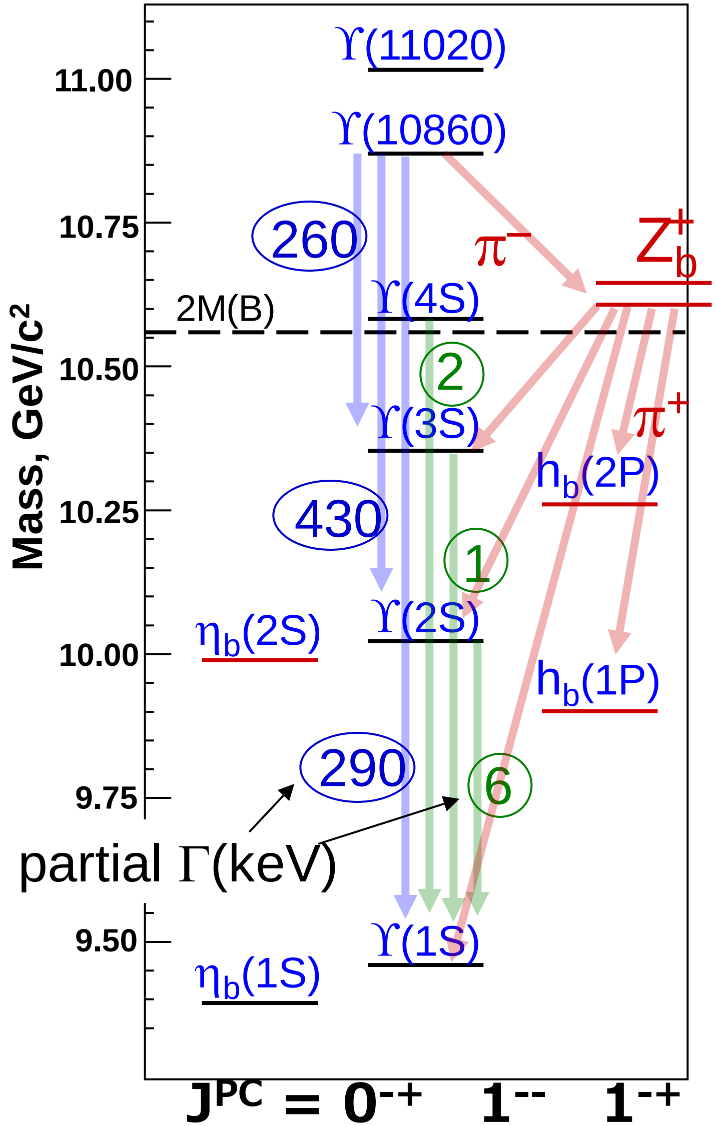
$\Upsilon(5S) \to \Upsilon(2S)\pi^+\pi^-$



$\Upsilon(5S) \to \Upsilon(3S)\pi^+\pi^-$



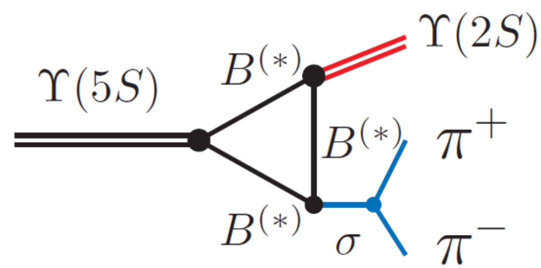
Anomalies in $\Upsilon(5S)\to(b\bar{b})\pi^+\pi^-$ transitions



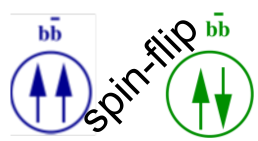
Belle: PRL100, 112001 (2008)

$$\Gamma[\Upsilon(\mathbf{5S})\to\Upsilon(1,2,3S)\,\pi^+\pi^-] \overset{\sim 100}{>>} \Gamma[\Upsilon(\mathbf{4,3,2S})\to\Upsilon(1S)\,\pi^+\pi^-]$$

⇐ Rescattering of on-shell $B^{(*)}\bar{B}^{(*)}$?



Belle: PRL108, 032001 (2012)



expect suppression $\sim\Lambda_{QCD}/m_b$

~~Heavy Quark Symmetry~~

Υ(5S) → h_b(1,2P) $\pi^+\pi^-$ are not suppressed

Branching Fractions

$\Upsilon(nS)\pi^+\pi^-$ production cross section (corrected for the ISR) at sqrt(s) = 10.865 GeV:

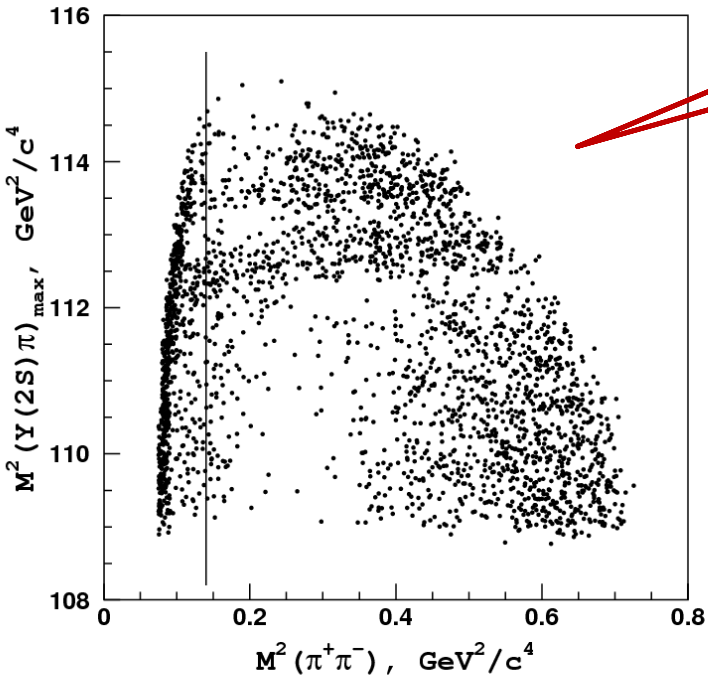
$$\sigma(e^+e^- \to \Upsilon(1S)\pi^+\pi^-) = [2.27 \pm 0.12(stat.) \pm 0.09(syst.)]\ \text{pb}$$
$$\sigma(e^+e^- \to \Upsilon(2S)\pi^+\pi^-) = [4.07 \pm 0.16(stat.) \pm 0.45(syst.)]\ \text{pb}$$
$$\sigma(e^+e^- \to \Upsilon(3S)\pi^+\pi^-) = [1.46 \pm 0.09(stat.) \pm 0.16(syst.)]\ \text{pb}$$

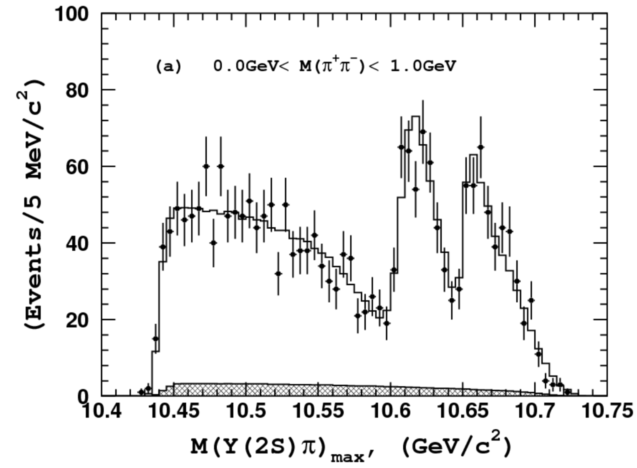
Fractions of individual sub-modes:

Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$
$Z(10610)\pi^\pm$, %	$4.8 \pm 1.2^{+1.5}_{-0.3}$	$18.1 \pm 3.1^{+4.2}_{-0.3}$	$30.0 \pm 6.3^{+5.4}_{-7.1}$
$Z(10650)\pi^\pm$, %	$0.87 \pm 0.32^{+0.16}_{-0.12}$	$4.05 \pm 1.2^{+0.95}_{-0.15}$	$13.3 \pm 3.6^{+2.6}_{-1.4}$
$f_2(1270)$, %	$14.6 \pm 1.5^{+6.3}_{-0.7}$	$4.09 \pm 1.0^{+0.33}_{-1.0}$	–
Total $S-$wave, %	$86.5 \pm 3.2^{+3.3}_{-4.9}$	$101.0 \pm 4.2^{+6.5}_{-3.5}$	$44.0 \pm 6.2^{+1.8}_{-4.3}$
	$h_b(1P)\pi$		$h_b(2P)\pi$
non-resonant, %	3.2 (< 22 at 90% C.L.)		–
$Z_b(10610)$, %	$42.3^{+9.5}_{-12.7}{}^{+6.7}_{-0.8}$		$35.2^{+15.6}_{-9.4}{}^{+0.1}_{-13.4}$
$Z_b(10650)$, %	$60.2^{+10.3}_{-21.1}{}^{+4.1}_{-3.8}$		$64.8^{+15.2}_{-11.4}{}^{+6.7}_{-15.5}$

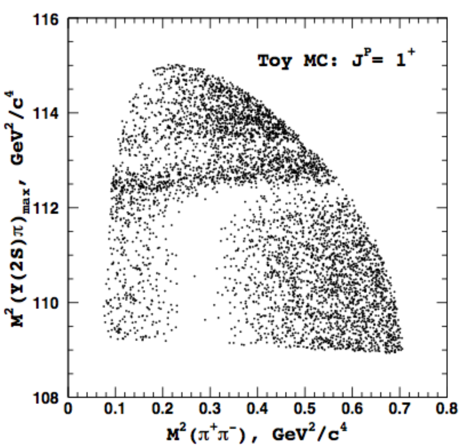
$\Upsilon(5S)\rightarrow\Upsilon(2S)\pi^+\pi^-$: J^P Results

$\Upsilon(2S)\pi^+\pi$ Data

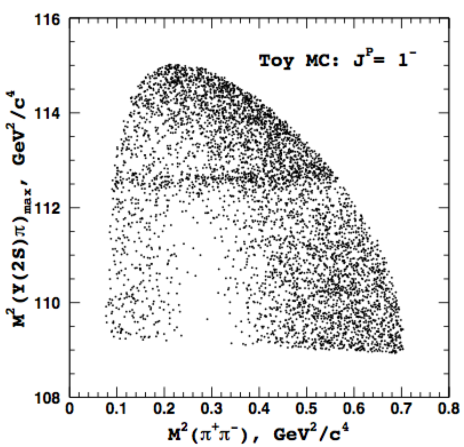




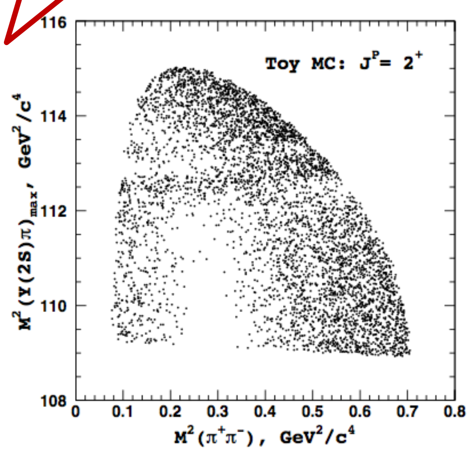
Toy MC with various J^P



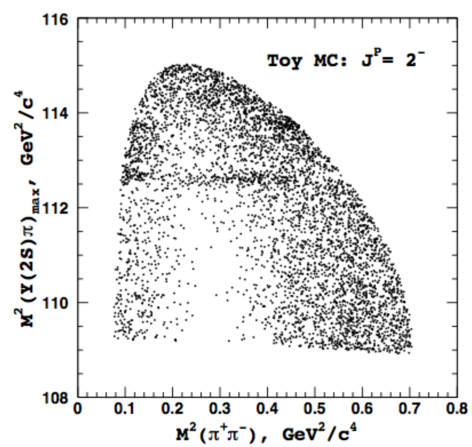
$J^P = 1^+$



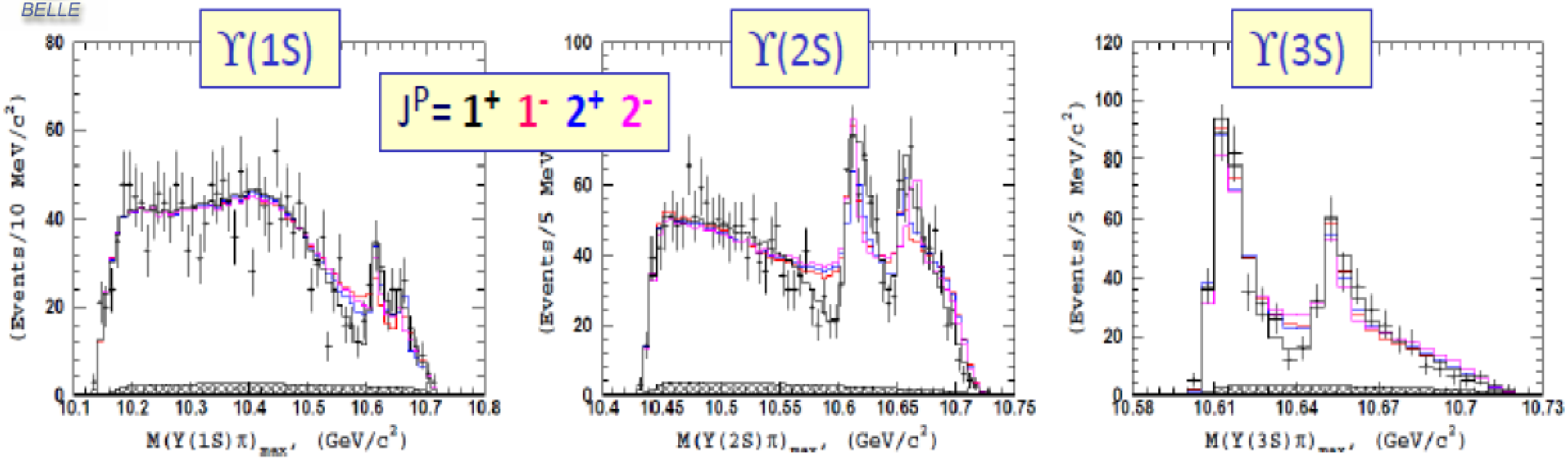
$J^P = 1^-$

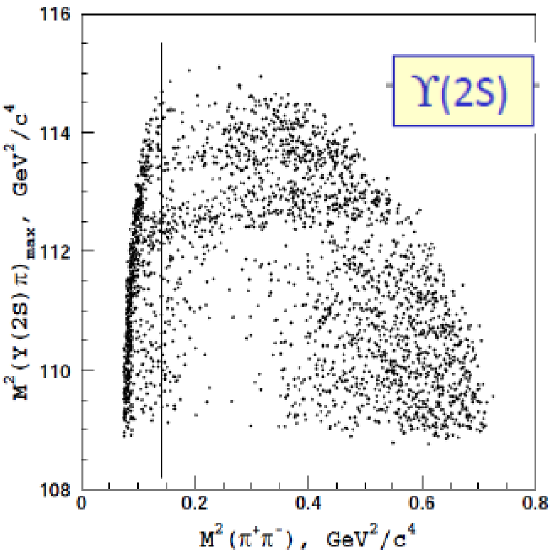


$J^P = 2^+$



$J^P = 2^-$





$Z_b(10610)$ \ $Z_b(10650)$	1^+	1^-	2^+	2^-
1^+	0 (0)	60 (33)	42 (33)	77 (63)
1^-	226 (47)	264 (73)	224 (68)	277 (106)
2^+	205 (33)	235 (104)	207 (87)	223 (128)
2^-	289 (99)	319 (111)	321 (110)	304 (125)

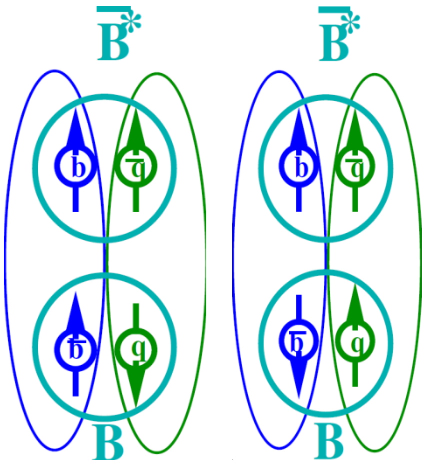
Spin parity of Zb(10610) and Zb(10650) is 1^+.

All other $J^P<3$ are excluded.

Heavy quark structure in Z_b

A.B.,A.Garmash,A.Milstein,R.Mizuk,M.Voloshin PRD84 054010 (arXiv:1105.4473)

Wave func. at large distance – B(*)B*



$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} - \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} + \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

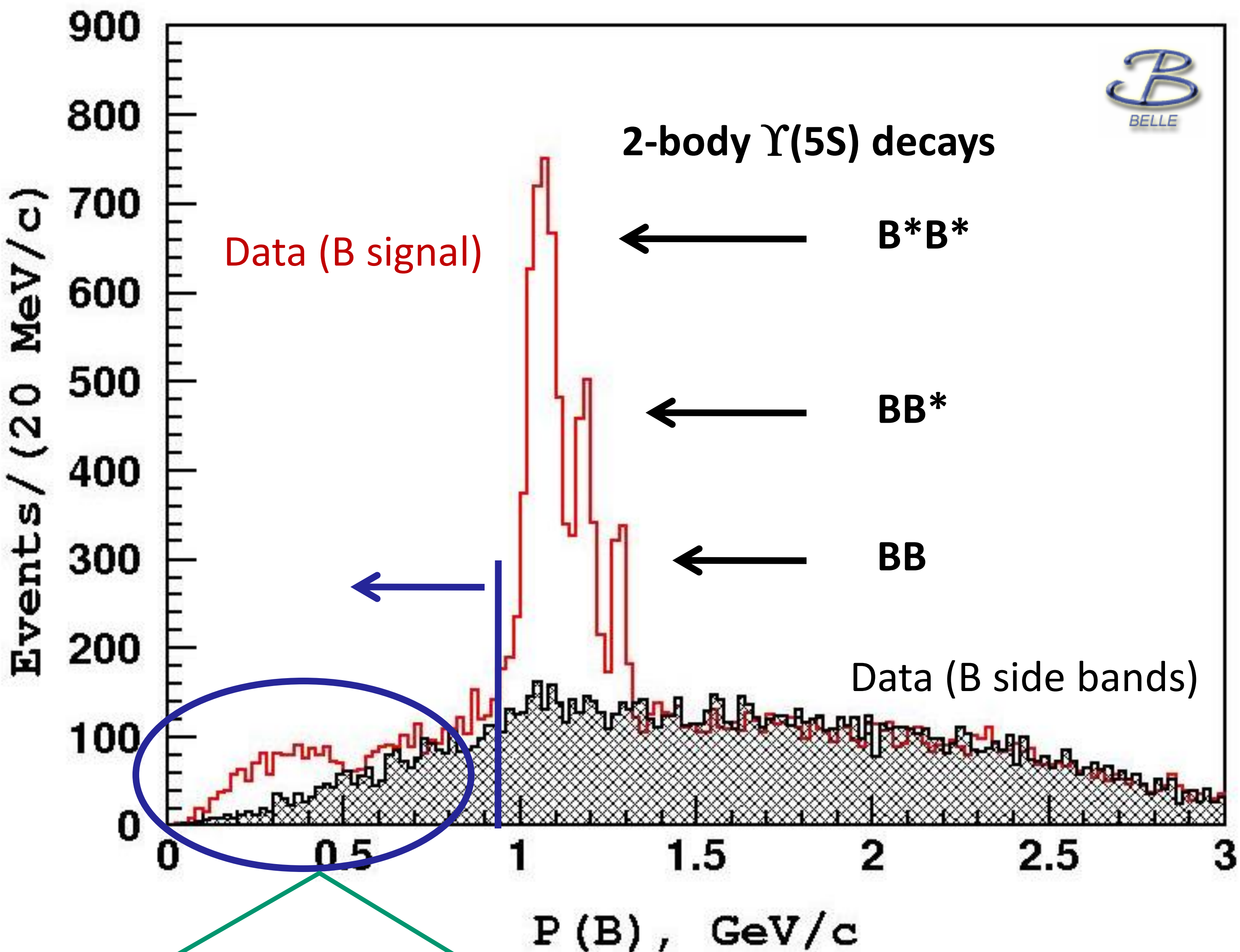
Explains

- Why $h_b\pi\pi$ is unsuppressed relative to $\Upsilon\pi\pi$
- Relative phase ~0 for Υ and ~180^0 for h_b
- Production rates of Z_b(10610) and Z_b(10650) are similar
- Widths –”–
- Dominant decays to B(*)B*

Other Possible Explanations

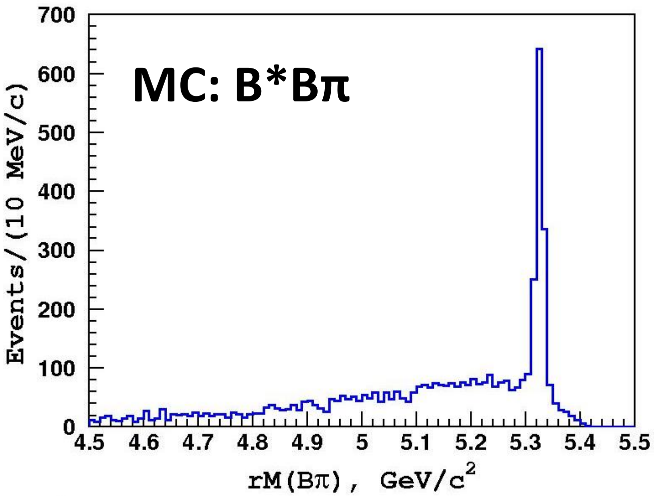
- Coupled channel resonances (I.V.Danilkin et al, arXiv:1106.1552)
- Cusp (D.Bugg Europhys.Lett.96 (2011),arXiv:1105.5492)
- Tetraquark (M.Karliner, H.Lipkin, arXiv:0802.0649)

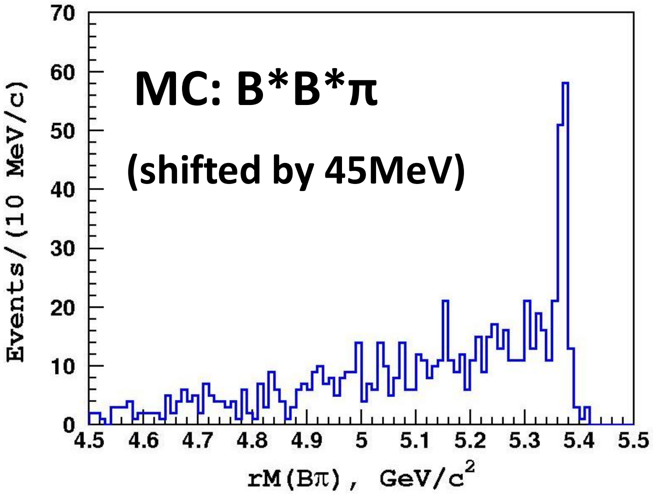
$\Upsilon(5S)\to B^*B^{(*)}\pi$: B Selection

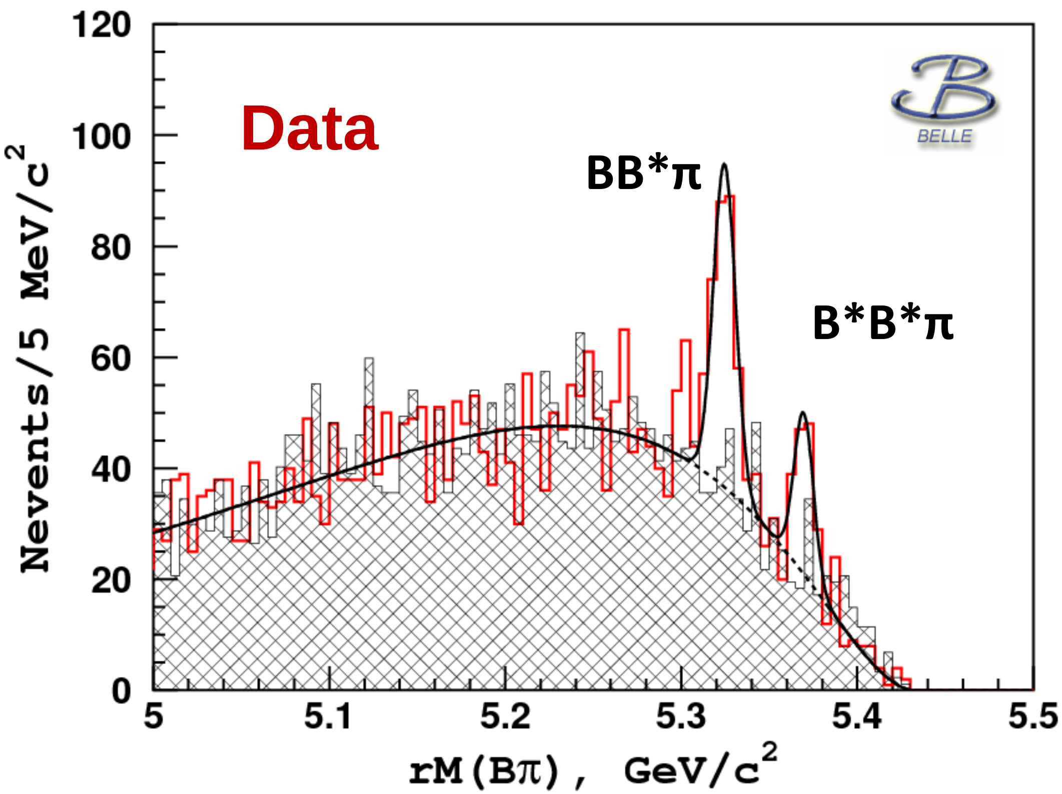


3-body ϒ(5S) -> B(*)B(*)π decays & rad. return to ϒ(4S): P(B)<0.9 GeV/c

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







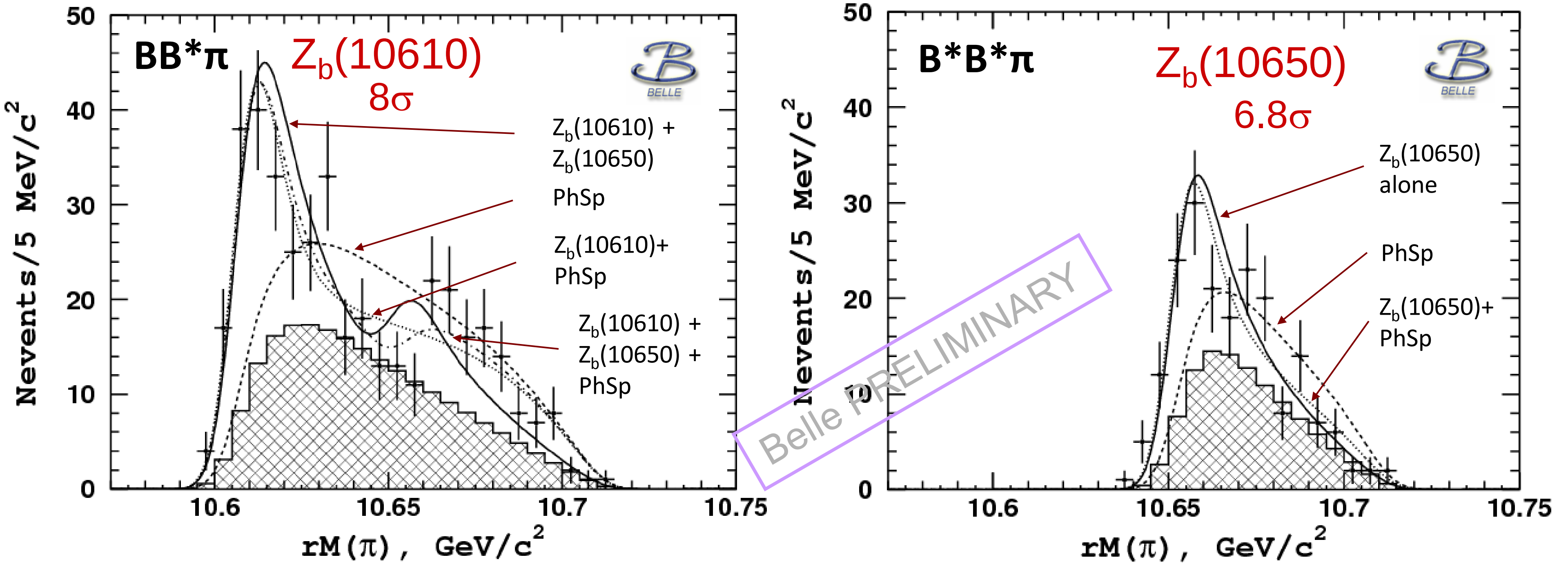
Red histogram – right sign Bπ combinations;
Hatched histogram – wrong sign Bπ combinations;
Solid line – fit to right sign data.

Belle PRELIMINARY

Fit yields: $N(BB\pi) = 0.3 \pm 14$

$N(BB^*\pi) = 184 \pm 19$ (9.3σ) $N(B^*B^*\pi) = 82 \pm 11$ (5.7σ)

$\Upsilon(5S) \rightarrow B^*B^{(*)}\pi$: Signal Region



points – right sign Bπ combinations (data);
lines – fit to data with various models (times PHSP, convolved with resolution function = Gaussian with σ=6MeV).
hatched histogram – background component

B*B*π signal is well fit to just $Z_b(10650)$ signal alone

BB*π data fits (almost) equally well to a sum of $Z_b(10610)$ and $Z_b(10650)$ or to a sum of $Z_b(10610)$ and non-resonant.

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

Branching fractions of $\Upsilon(10680)$ decays (including neutral modes):

$BB\pi$ < 0.60% (90%CL)

$BB^*\pi$ = 4.25 ± 0.44 ± 0.69%

$B^*B^*\pi$ = 2.12 ± 0.29 ± 0.36%

To be compared with PRD 81 (2010)
f($BB^*\pi$) = (7.3±2.2±0.8)%
f($B^*B^*\pi$) = (1.0±1.4±0.4)%

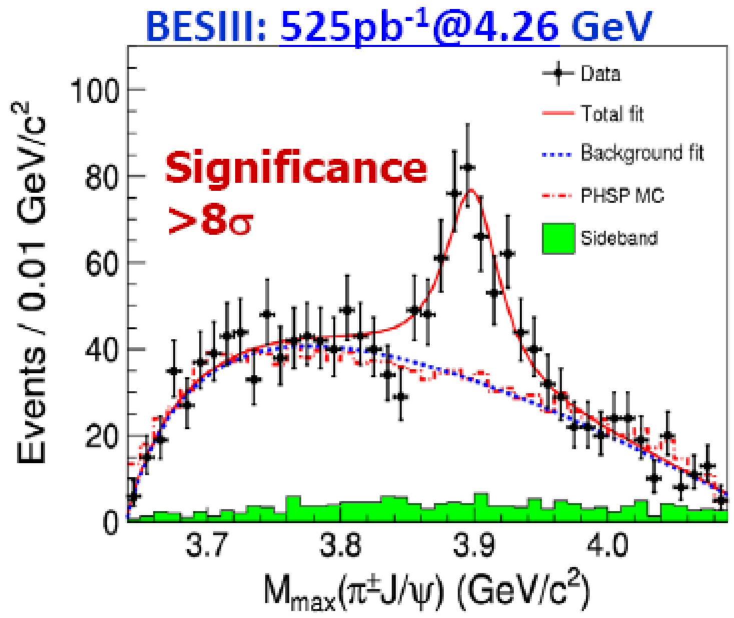
Assuming Z_b decays are saturated by the already observed $\Upsilon(nS)\pi$, $h_b(mP)\pi$ and B(*)B* channels, one can calculate complete table of relative branching fractions:

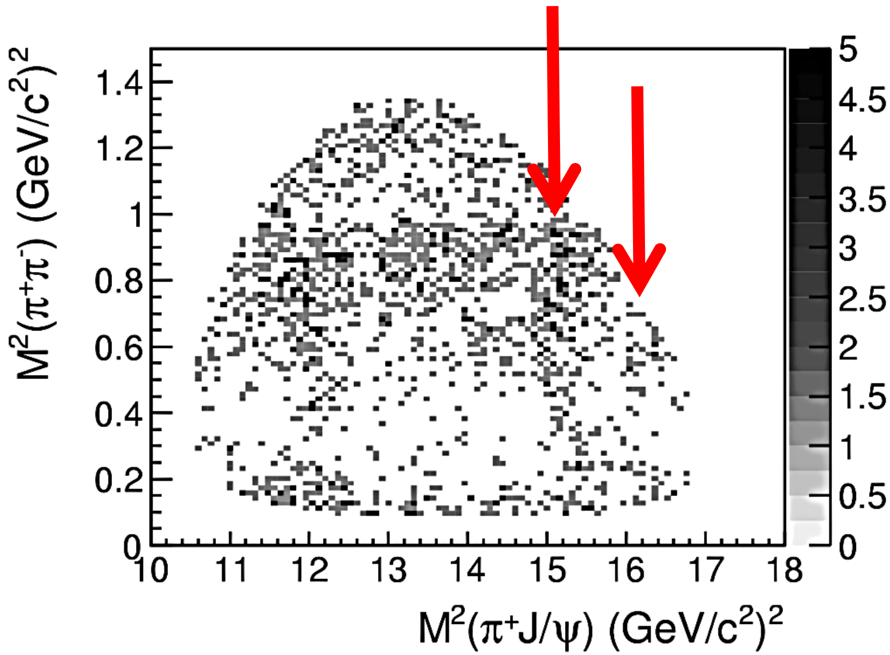
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	0.32 ± 0.09	0.24 ± 0.07
$\Upsilon(2S)\pi^+$	4.38 ± 1.21	2.40 ± 0.63
$\Upsilon(3S)\pi^+$	2.15 ± 0.56	1.64 ± 0.40
$h_b(1P)\pi^+$	2.81 ± 1.10	7.43 ± 2.70
$h_b(2P)\pi^+$	4.34 ± 2.07	14.8 ± 6.22
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	86.0 ±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

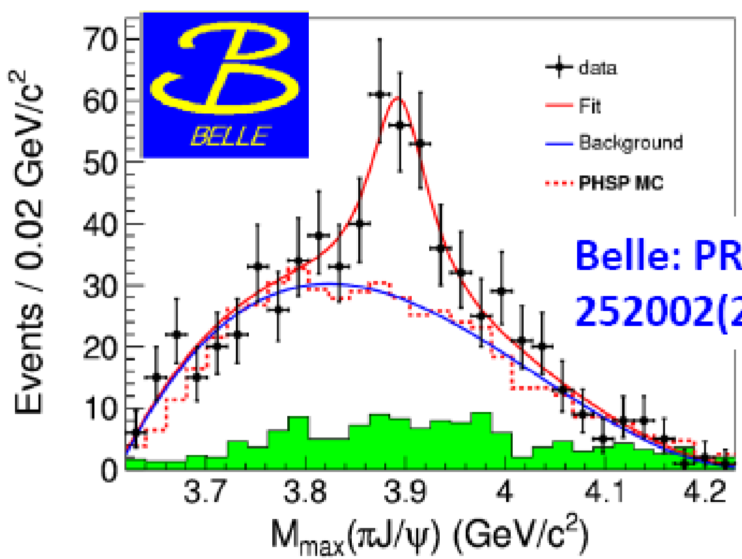
Belle PRELIMINARY

B(*)B* channels dominate Z_b decays !

Observation of $Z_c(3900)$ at BESIII







Belle: PRL 110, 252002(2013)

BESIII: PRL110, 252001 (2013)

- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events

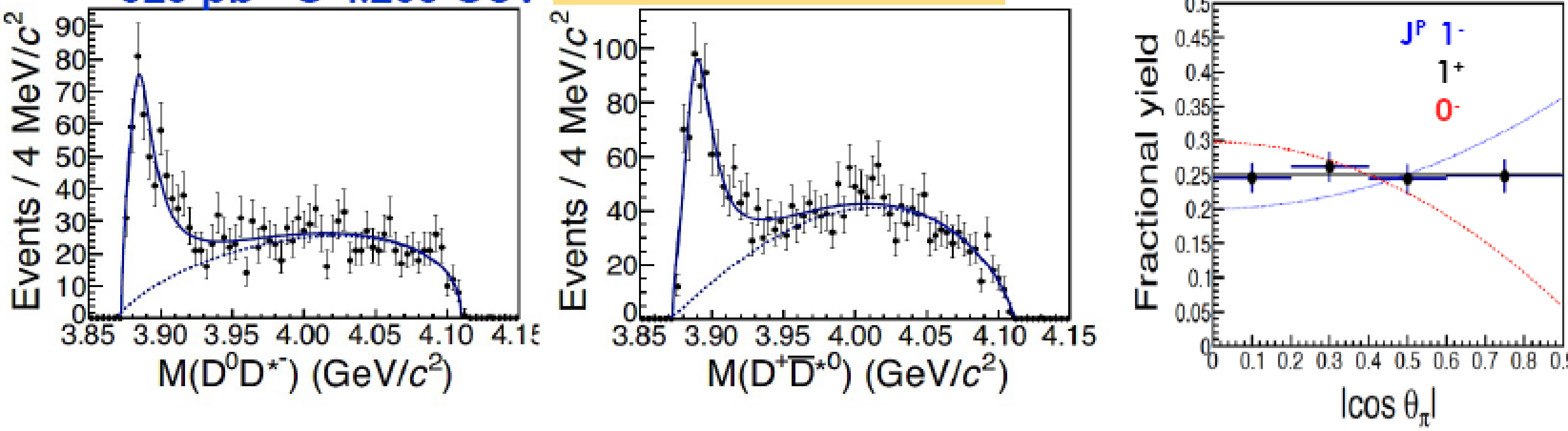
The mass position is 24 MeV away from DD* threshold!

A Partial wave analysis is on going!

Observation of $Z_c(3885)$ in $e^+e^- \to \pi^-(D^*D)^+$

525 pb^{-1} @ 4.260 GeV

BESIII: 1310.1163



- M = 3883.9±1.5±4.2 MeV; Γ = 24.8±3.3±11.0 MeV
- σ×B = 85.3±6.6±22.0 pb [pole position]
- **fits favor 1$^+$ distribution assumption**

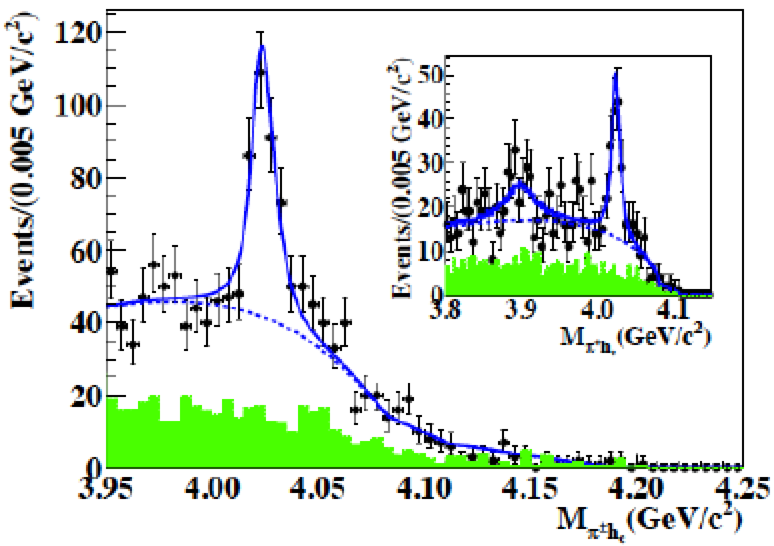
fit with mass-dependent-width BW with phase space and efficiency correction

$$\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

Assuming $Z_c(3885)$ due to $Z_c(3900)$

Observation of $Z_c(4020)$ in $e^+e^- \to h_c\pi^+\pi^-$

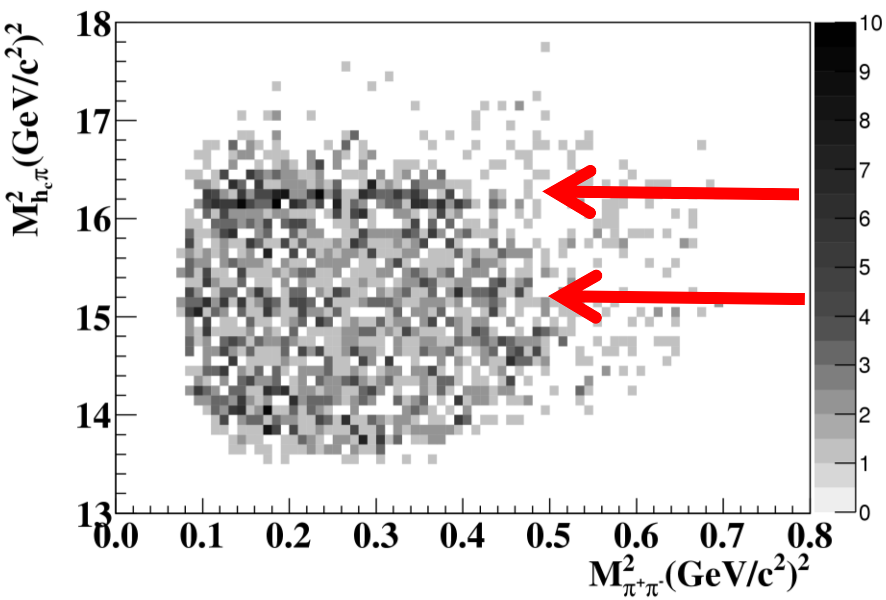
BESIII: 1309.1896



Simultaneous fit to 4.23/4.26/4.36 GeV data, 16 η_c decay modes.

$M = 4022.9 \pm 0.8 \pm 2.7\ \mathrm{MeV}/c^2$

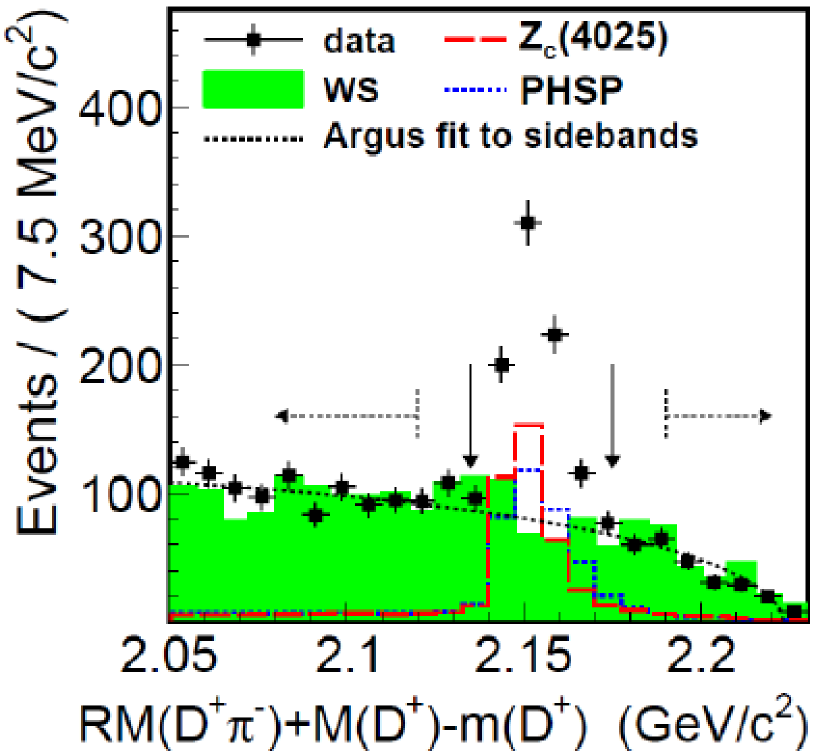
$\Gamma = 7.9 \pm 2.7 \pm 2.6\ \mathrm{MeV}$

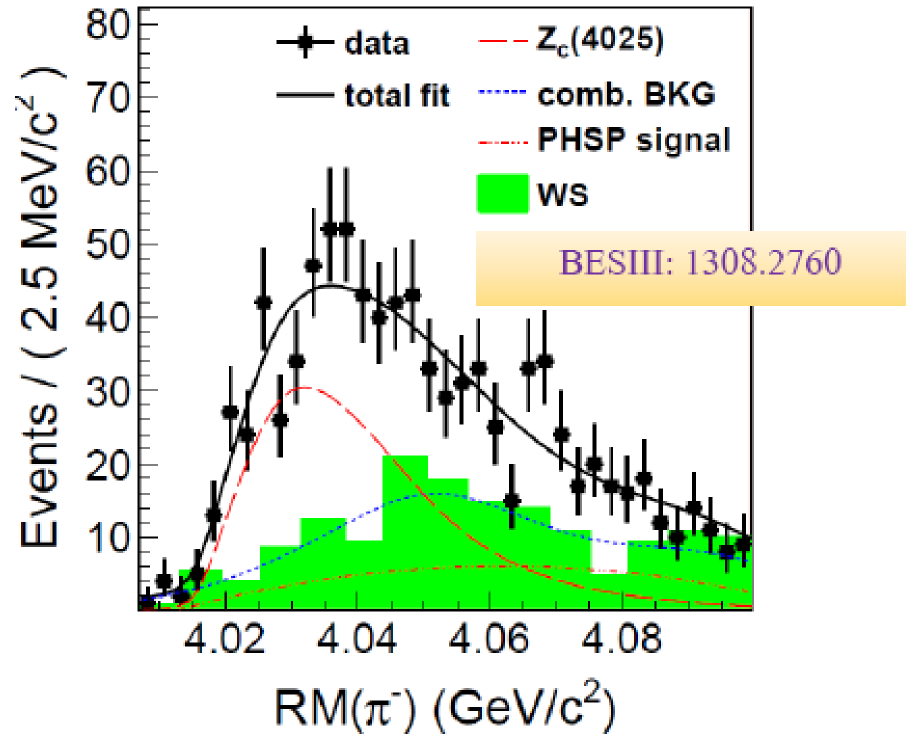


Significance: 8.9σ ($Z_c(4020)$)

No significant $Z_c(3900)$ (2.1σ)

Observation of $Z_c(4025)$ in $e^+e^- \to \pi^-(D^*D^*)^+$





Fit to $\pi^\pm$ recoil mass yields 401±47 $Z_c(4025)$ events. **>10σ**

$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV; $\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7$ MeV

$$\sigma(e^+e^- \to \pi^\pm(D^*\bar{D}^*)^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

$$R = \frac{\sigma(e^+e^- \to \pi^\pm Z_c^\mp(4025) \to \pi^\pm(D^*\bar{D}^*)^\mp)}{\sigma(e^+e^- \to \pi^\pm(D^*\bar{D}^*)^\mp)} = (65 \pm 9 \pm 6)\%$$

Summary of the Z_c states

Channel	Mass (MeV/c^2)	Width (MeV)
$\pi^{\pm} J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$(D\bar{D}^*)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
	2σ difference	1σ difference
$\pi^{\pm} h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
	1σ difference	2σ difference

Close to $D\bar{D}^*$ threshold (3875 MeV)

Close to $D^*\bar{D}^*$ threshold (4017 MeV)

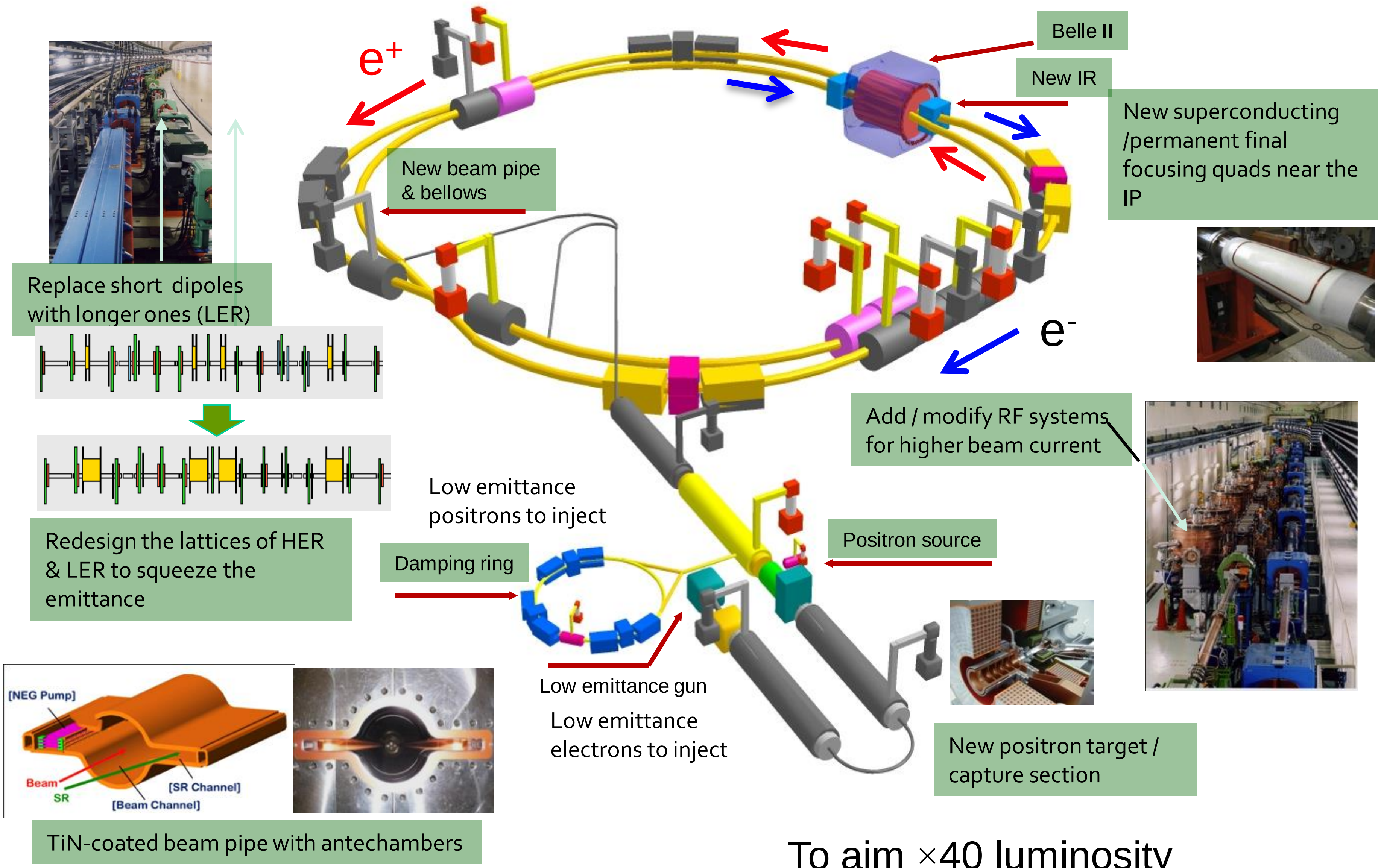
- At least 4-quarks; Charged; Near threshold;
- Couples to DD final states larger than charmonium final states;

Bottomonium-like vs Charmonium-like states

- Charged Upsilon-like structure
- Z_b are very close to $\bar{B}B^*$, $B^*\bar{B}^*$ threshold
- $I^G J^{P(C)} = 1^+ \, 1^{+\,(-)}$
- Observed both in the hidden-bottom modes: $\pi\Upsilon(1S,2S,3S)$, $\pi\, h_b(1P,2P)$ and open-bottom modes: $\bar{B}B^*$, $B^*\bar{B}^*$
- $B(^*)\bar{B}^*$ domonate Z_b decays with the branching ratio 86% and 73%

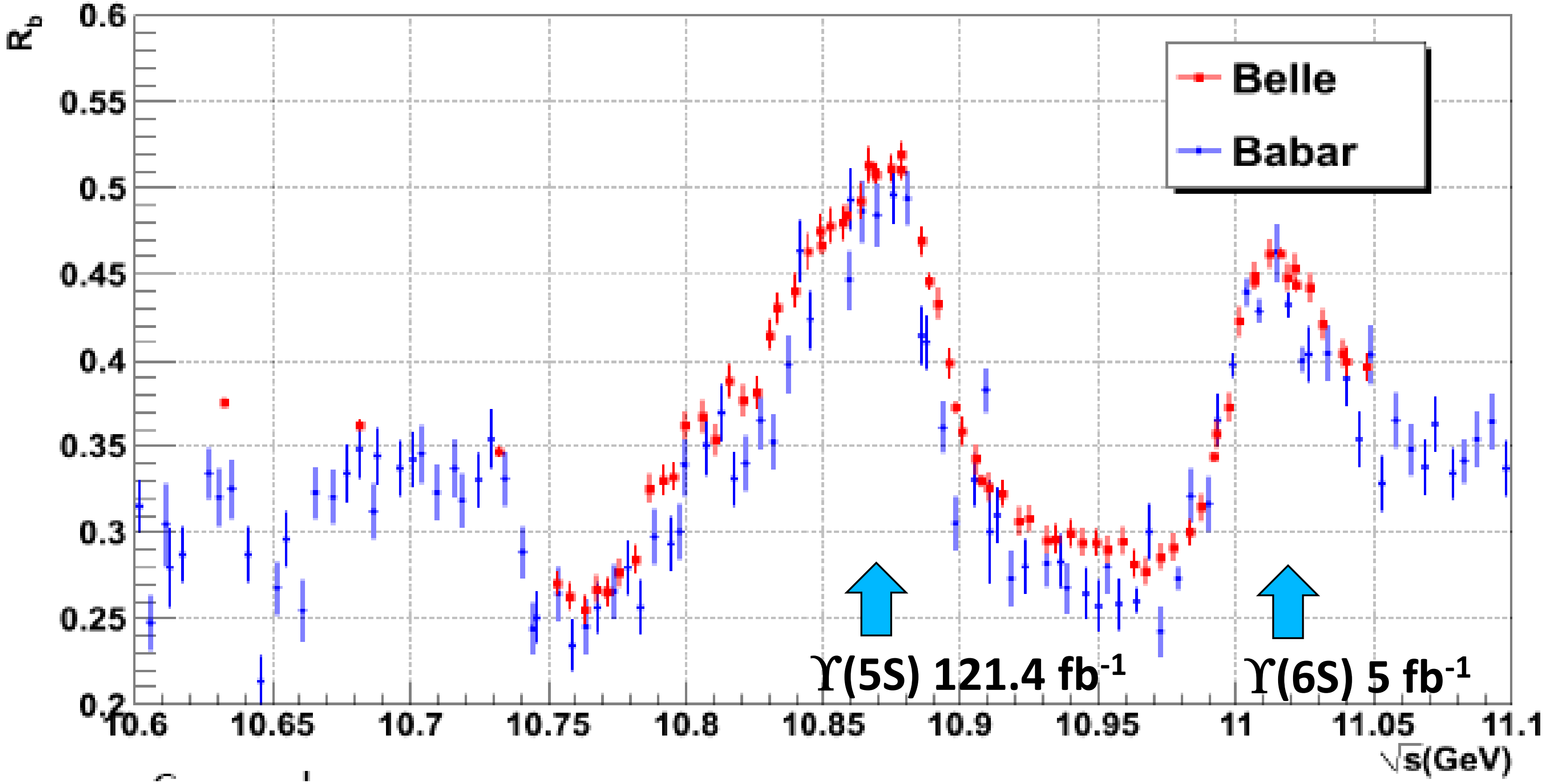
- Charged charmonium-like structure
- Z_c are very close to $\bar{D}D^*$, $D^*\bar{D}^*$ threshold
- $I^G J^{P(C)} = 1^+ \, 1^{+\,(-)}$
- Observed both in the hidden-charm modes: $\pi\, J/\psi$, $\pi\, h_c$ and open-charm modes: $\bar{D}D^*$, $D^*\bar{D}^*$
- $\bar{D}D^*$ dominates $Z_c(3900)$ decay

SuperKEKB



To aim ×40 luminosity

First measurements



- Measurements of the $\Upsilon(nS)\pi^+\pi^-$, $h_b\pi^+\pi^-$ cross-section vs energy
- Z_b's cross-section
- Radiative and hadronic transitions

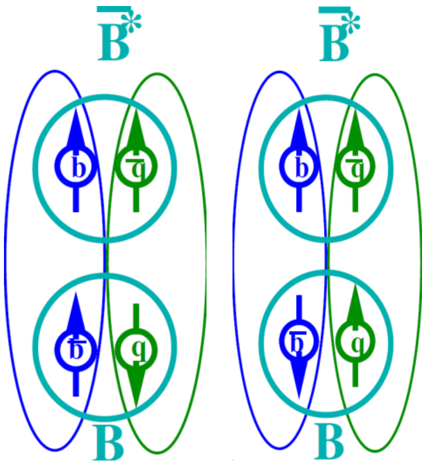
Heavy quark structure in Z_b

A.B.,A.Garmash,A.Milstein,R.Mizuk,M.Voloshin PRD84 054010 (arXiv:1105.4473)

Wave func. at large distance – B(*)B*

$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} - \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$

$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} + \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$



Explains

- Why $h_b\pi\pi$ is unsuppressed relative to $\Upsilon\pi\pi$
- Relative phase ~0 for Υ and ~180^0 for h_b
- Production rates of Z_b(10610) and Z_b(10650) are similar
- Widths   –"–

Predicts

- Existence of other similar states

arXiv:1105.5829

$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} - \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

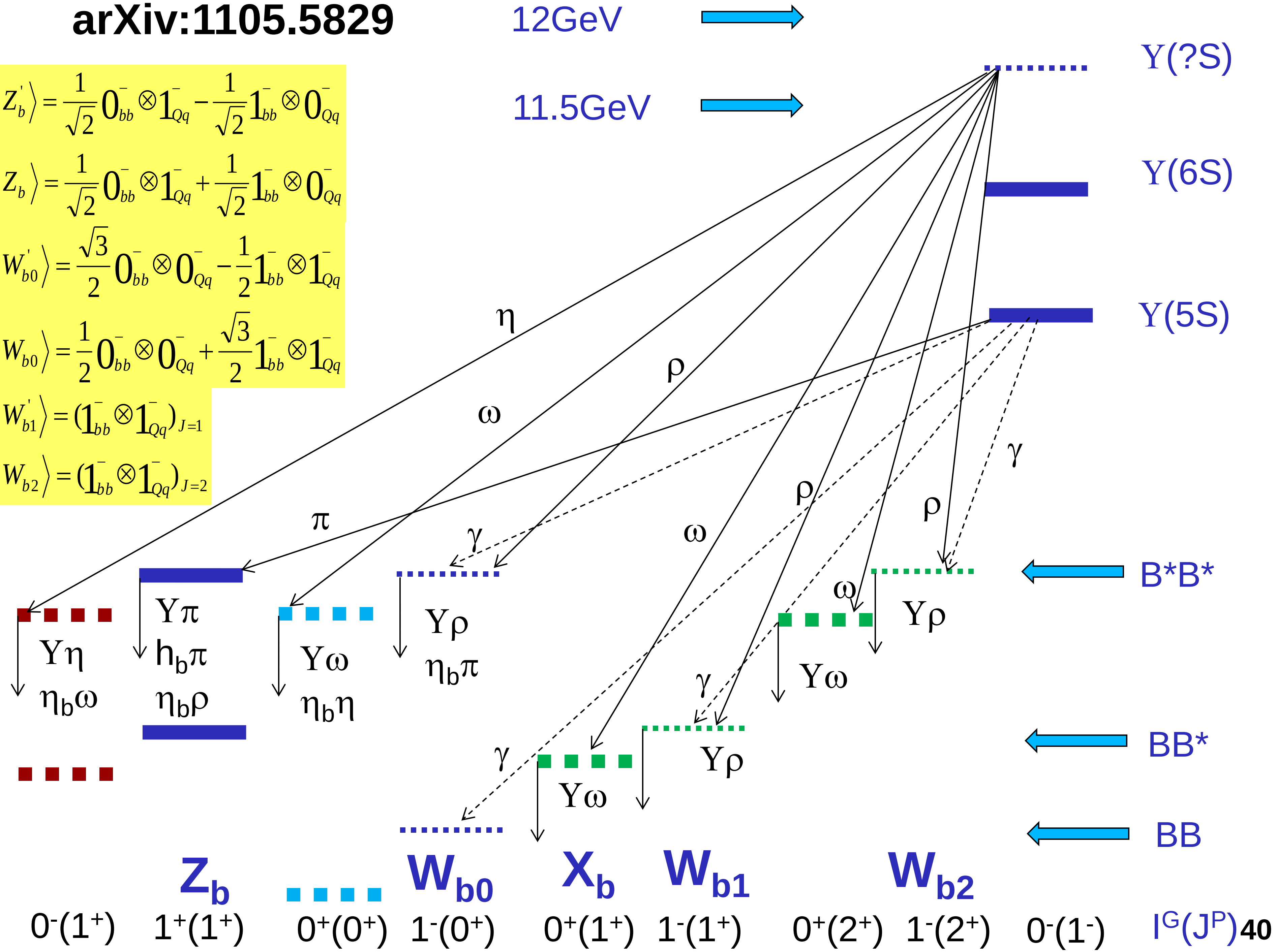
$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}} + \frac{1}{\sqrt{2}} 1^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}}$$

$$|W_{b0}'\rangle = \frac{\sqrt{3}}{2} 0^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}} - \frac{1}{2} 1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}}$$

$$|W_{b0}\rangle = \frac{1}{2} 0^-_{b\bar{b}} \otimes 0^-_{Q\bar{q}} + \frac{\sqrt{3}}{2} 1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}}$$

$$|W_{b1}'\rangle = (1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}})_{J=1}$$

$$|W_{b2}\rangle = (1^-_{b\bar{b}} \otimes 1^-_{Q\bar{q}})_{J=2}$$



Summary

- The first exotic bottomonium-like Z_b^+ states were discovered in decays to $\Upsilon(1S)\pi^+$, $\Upsilon(2S)\pi^+$, $\Upsilon(3S)\pi^+$, $h_b(1P)\pi^+$, $h_b(2P)\pi^+$
- Spin parity of Zbs is 1^+
- Zbs mainly decay to BB* and B*B*final states

  $Z_b(10610)$ dominantly decays to BB*, but $Z_b(10650)$ to B*B*
  Decay fraction of $Z_b(10650)$ to BB* is currently not statistically significant, but at least less than to B*B*
- Phase space of Y(5S)->B(*)B*π is tiny, relative motion B(*)B*is small, which is favorable to the formation of the molecular type states
- Y(5S) [and possible Y(6S)] is ideal factory of molecular states
- In heavy quark limit we can expect more molecular states in vicinity of the BB, BB* and B*B*. To study the new states we need the energy up to 12GeV

Studies of Z_b's properties may help us to understand exotic states in charm sector

We enter the new region – Physics of Highly Excited Quarkonium

or/and

Chemistry of Heavy Flavor

We can expect much more from Super B factory

Back up slides

Tetraquark?

M ~ 10.2 – 10.3 GeV

Ying Cui, Xiao-lin Chen, Wei-Zhen Deng,
Shi-Lin Zhu, High Energy Phys.Nucl.Phys.31:7-13, 2007
(hep-ph/0607226)

M ~ 10.5 – 10.8 GeV

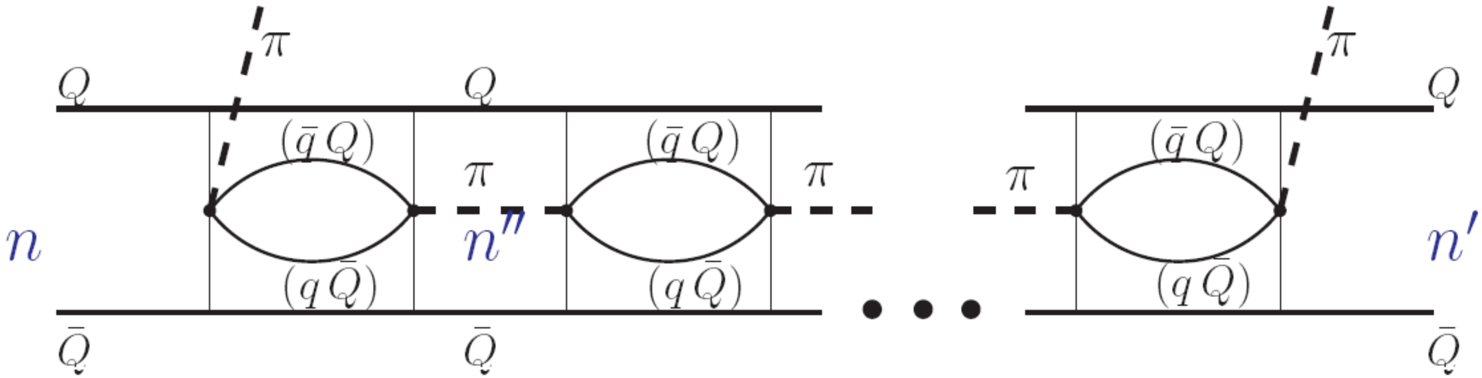
Tao Guo, Lu Cao, Ming-Zhen Zhou, Hong Chen, (1106.2284)

M ~ 9.4, 11 GeV

M.Karliner, H.Lipkin, (0802.0649)

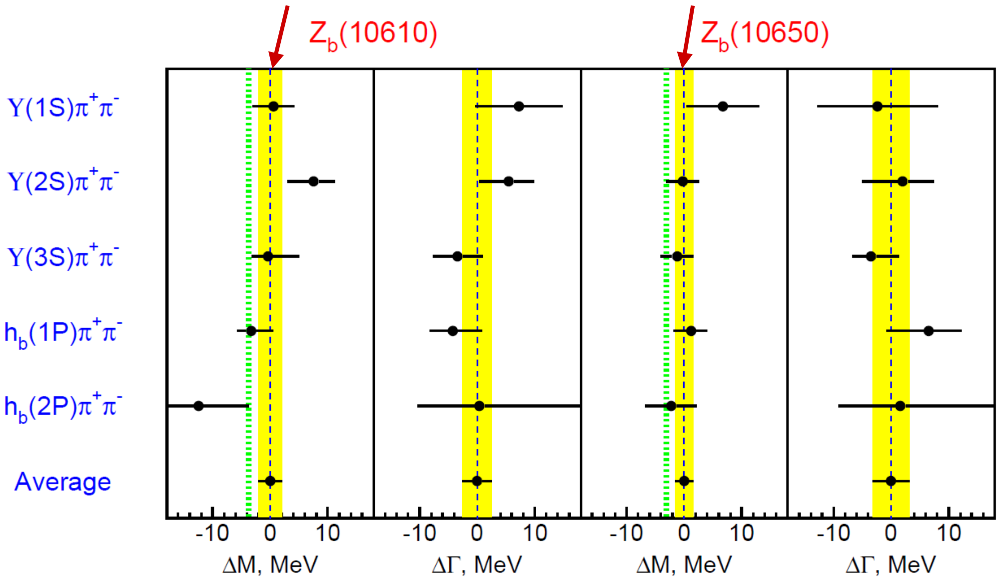
Coupled channel resonance?

I.V.Danilkin, V.D.Orlovsky, Yu.Simonov arXiv:1106.1552



No interaction between B(*)B* or ϒπ is needed to form resonance

No other resonances predicted

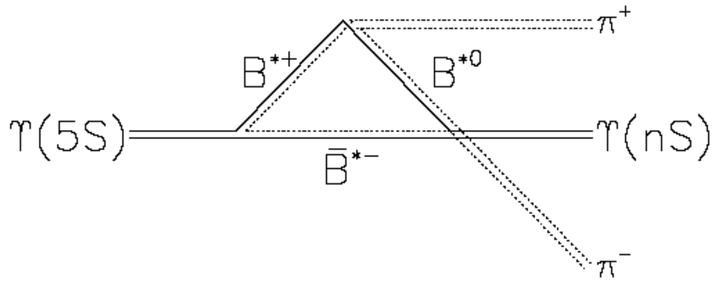


B(*)B* interaction switched on ⇒ individual mass in every channel?

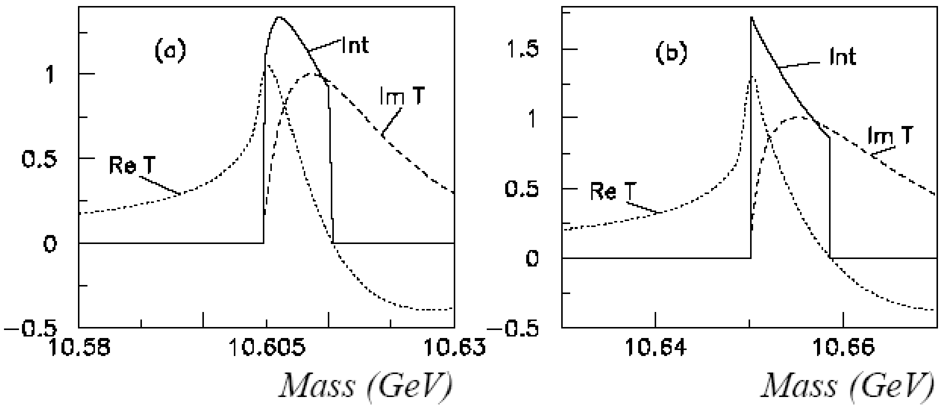
Cusp?

D.Bugg Europhys.Lett.96 (2011) (arXiv:1105.5492)

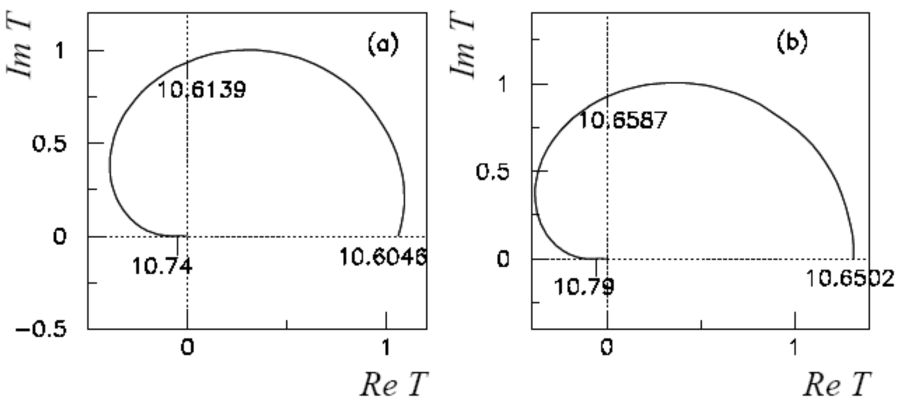
Amplitude

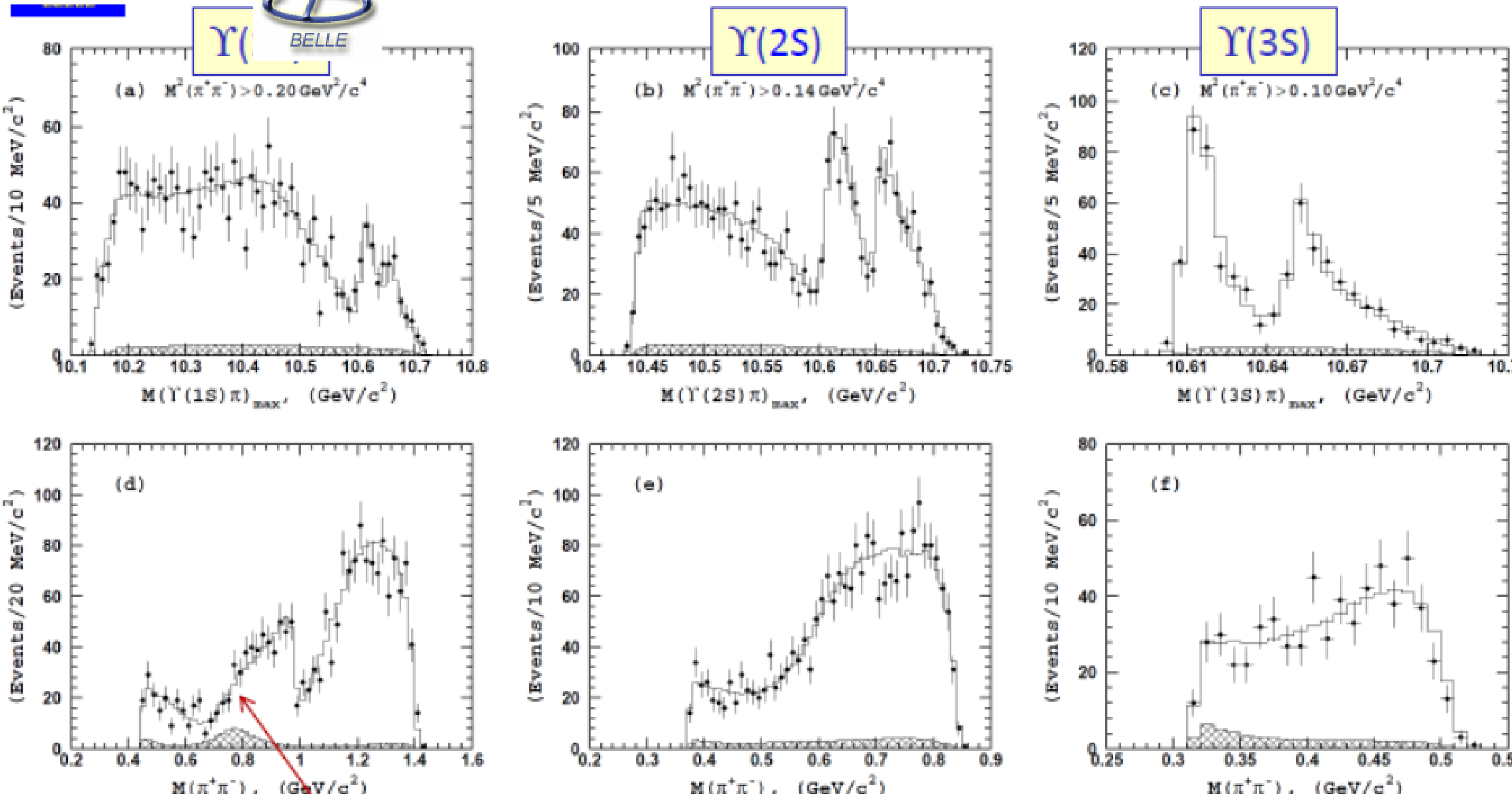


Line-shape



Not a resonance





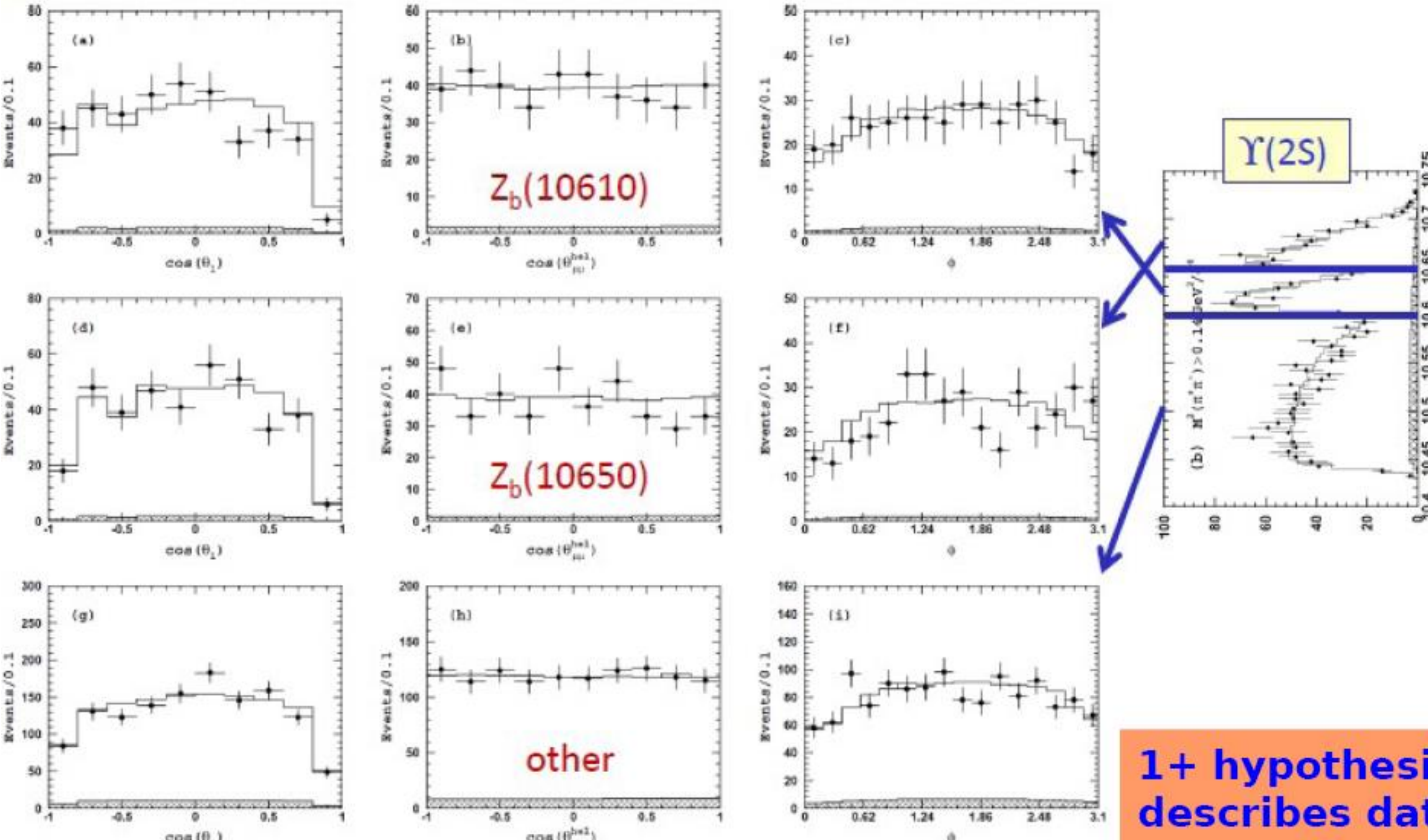
PRL108,122001

Improvement due to inclusion of σ state

BW amplitudes describe Z_b states very well.

Resonant behavior of Z_b amplitudes (intensity & phase).

21

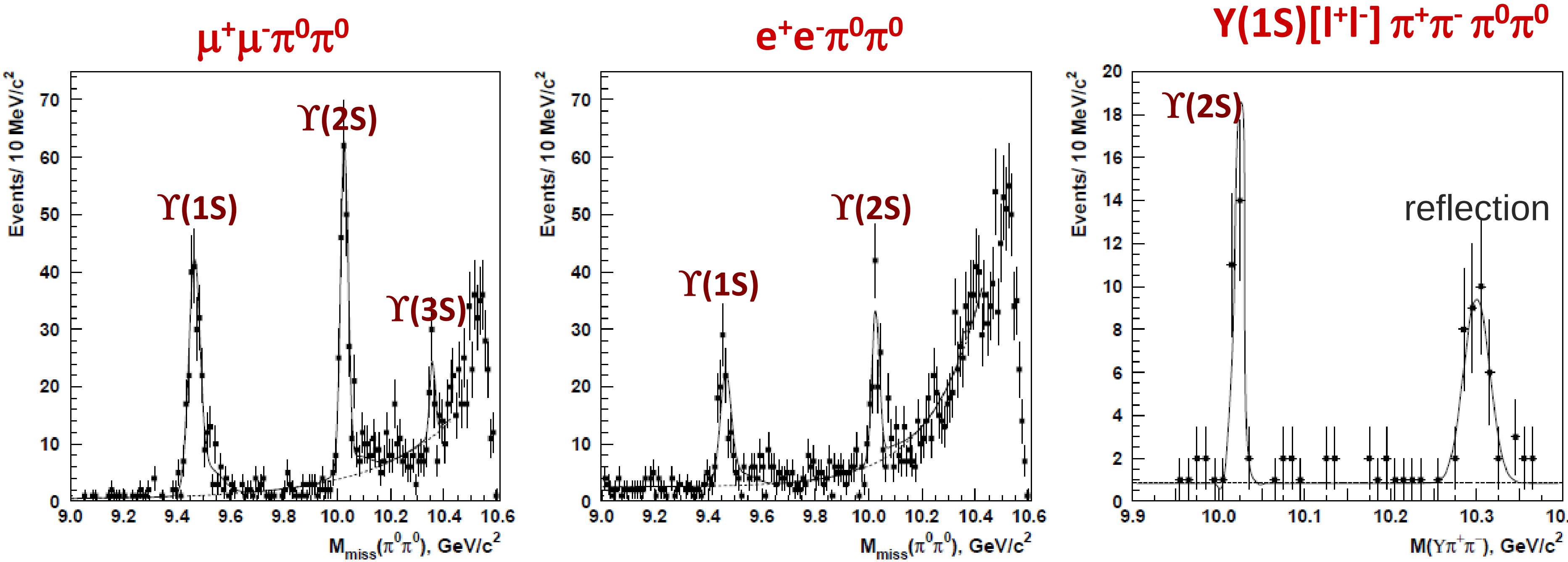


$\angle(\pi_1, \text{Z-axis})$ $\Upsilon(2S)$ helicity angle $\angle[\text{plane}(\pi_1, \text{Z-axis}), \text{plane}(\pi^+\pi^-)]$

1+ hypothesis describes data very well

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

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



$\sigma[e^+e^-\rightarrow\Upsilon(5S)\rightarrow\Upsilon(1S)\pi^0\pi^0] = (1.16\pm0.06\pm0.10)$ pb

$\sigma[e^+e^-\rightarrow\Upsilon(5S)\rightarrow\Upsilon(2S)\pi^0\pi^0] = (1.87\pm0.11\pm0.23)$ pb

$\sigma[e^+e^-\rightarrow\Upsilon(5S)\rightarrow\Upsilon(3S)\pi^0\pi^0] = (0.98\pm0.24\pm0.19)$ pb

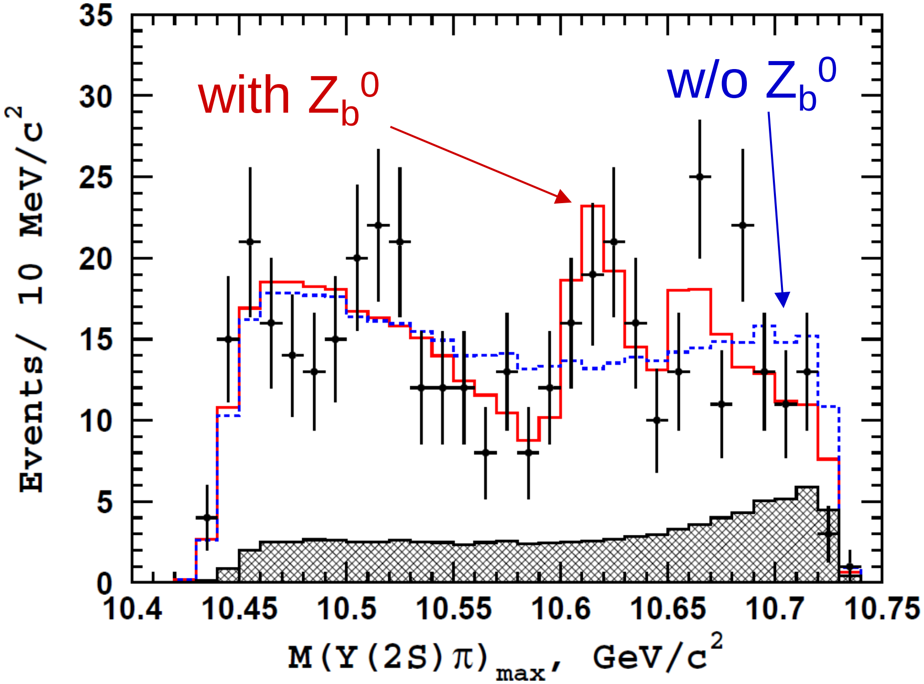
Consistent with ½ of $Y(nS)\pi^+\pi^-$

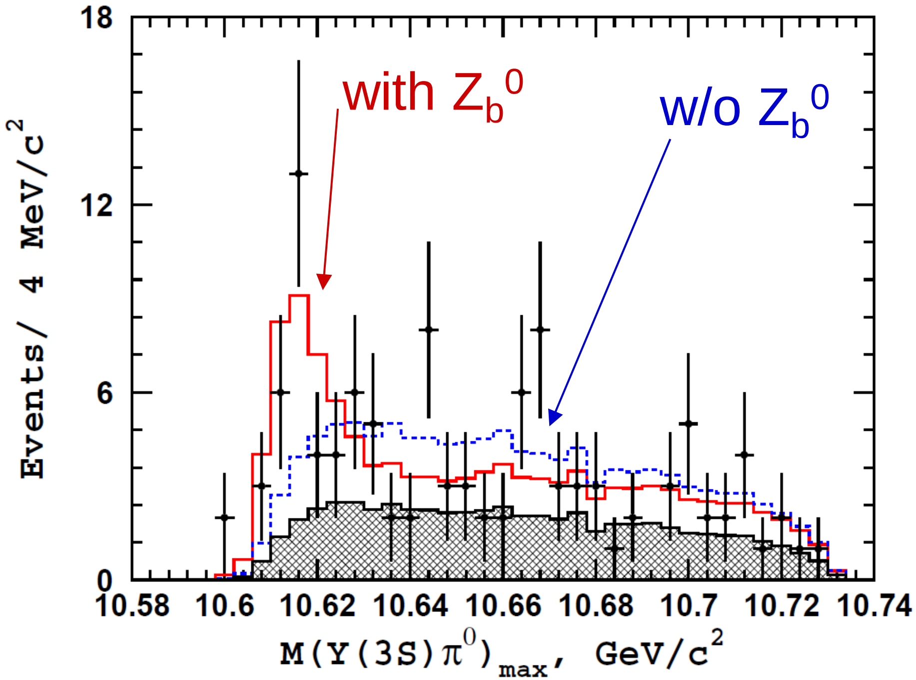
arXiv:1308.2646, accepted for publication in Phys. Rev. D

$\Upsilon(2S)\pi^0\pi^0$ Dalitz analysis

arXiv:1308.2646

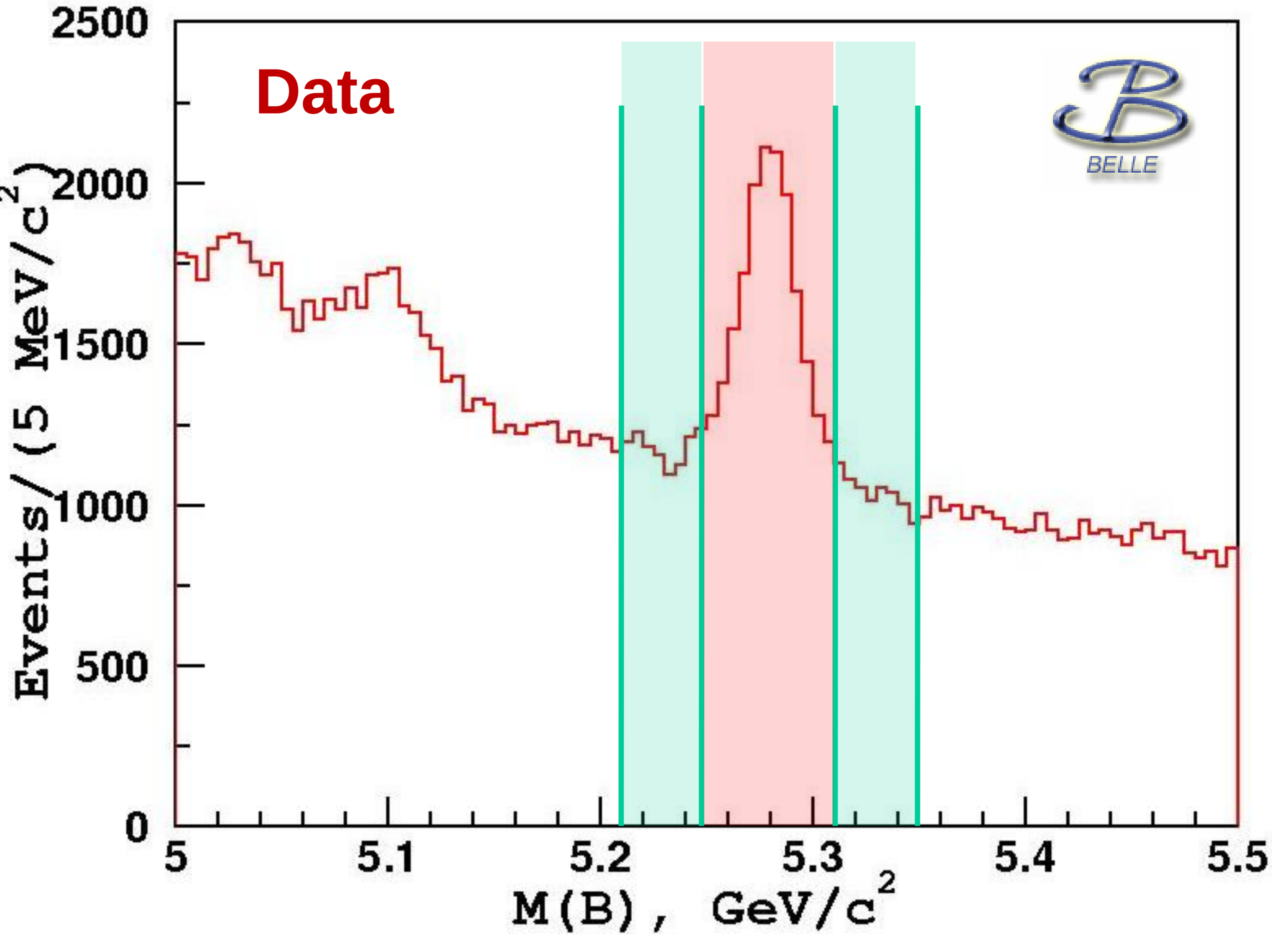
$$M(s_1, s_2) = A_{Z1} + A_{Z2} + A_{f_0} + A_{f_2} + A_{NR}$$





- Z_b^0 resonant structure has been observed in $\Upsilon(2S)\pi^0\pi^0$ and $\Upsilon(3S)\pi^0\pi^0$
- Statistical significance of $Z_b^0(10610)$ signal is 6.5σ including systematics
- $Z_b^0(10650)$ signal is not significant (~2σ), not contradicting with its existence
- $Z_b^0(10610)$ mass from the fit $M=10609 \pm 4 \pm 4$ MeV/c² $M(Z_b^+)=10607\pm2$ MeV/c²

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



Charged B:

- $D^0[K\pi, K\pi\pi\pi]\pi^-$
- $J/\psi[\mu\mu]\ K^-$

Neutral B:

- $D^+[K\pi\pi]\pi^-$
- $J/\psi[\mu\mu]\ \bar{K}^{*0}$
- $D^{*+}[K\pi, K\pi\pi, K\pi\pi\pi]\pi^-$

Effective B fraction:
$Br[B \to f] = (143 \pm 15) \times 10^{-5}$

B candidate invariant mass distribution. All modes combined. Select B signal within 30-40 MeV (depending on B decay mode) around B nominal mass.

Selection

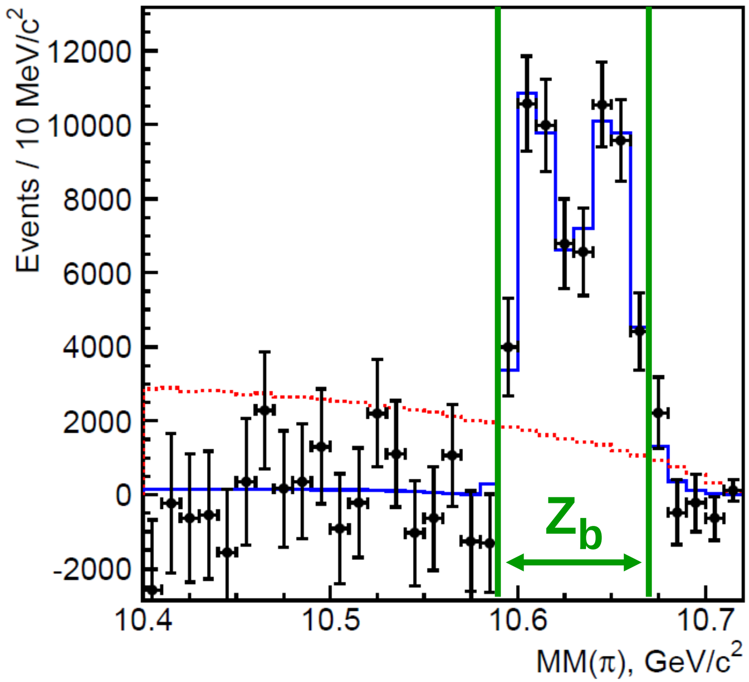
Decay chain $\Upsilon(5S) \to Z_b^+ \pi^-$
$\hookrightarrow h_b(nP)\, \pi^+$
$\hookrightarrow \eta_b(mS)\, \gamma$

reconstruct

R_2<0.3

Hadronic event selection; continuum suppression using event shape; π^0 veto.

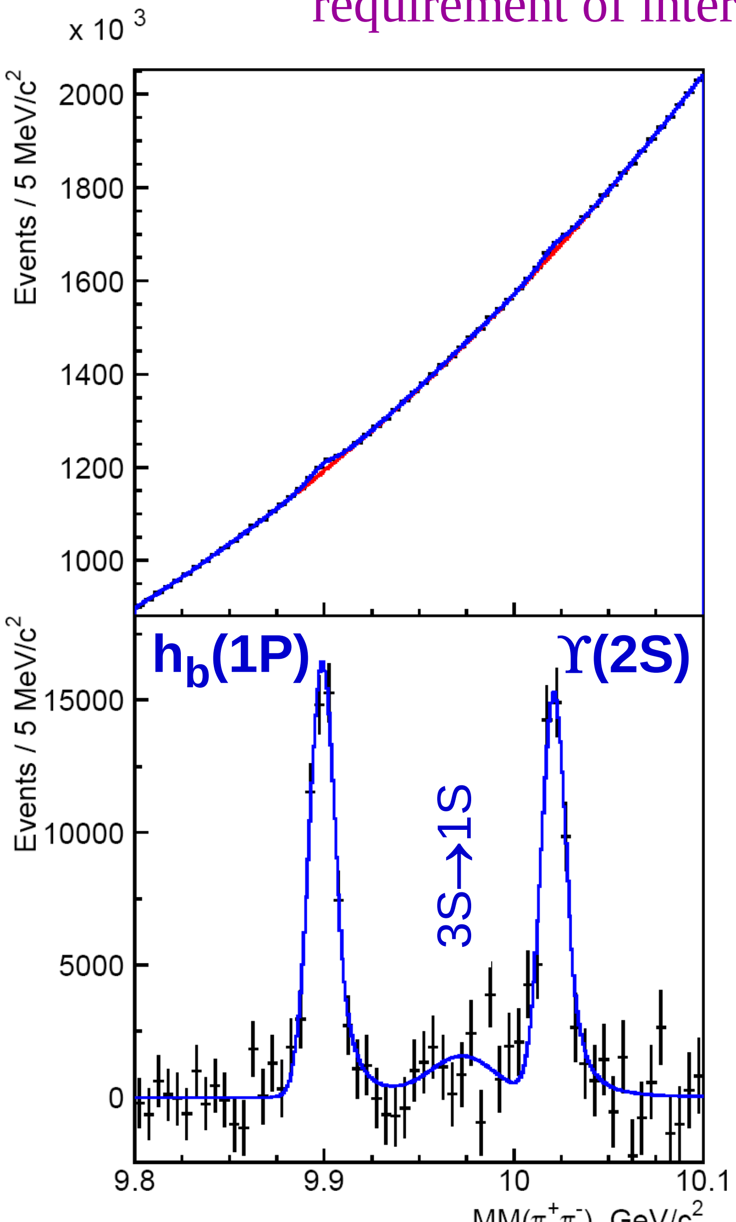
Require intermediate Z_b : **10.59 < MM(π) < 10.67 GeV**



bg. suppression ×5.2

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

requirement of intermediate Z_b



Update of M [h_b(1P)] :

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

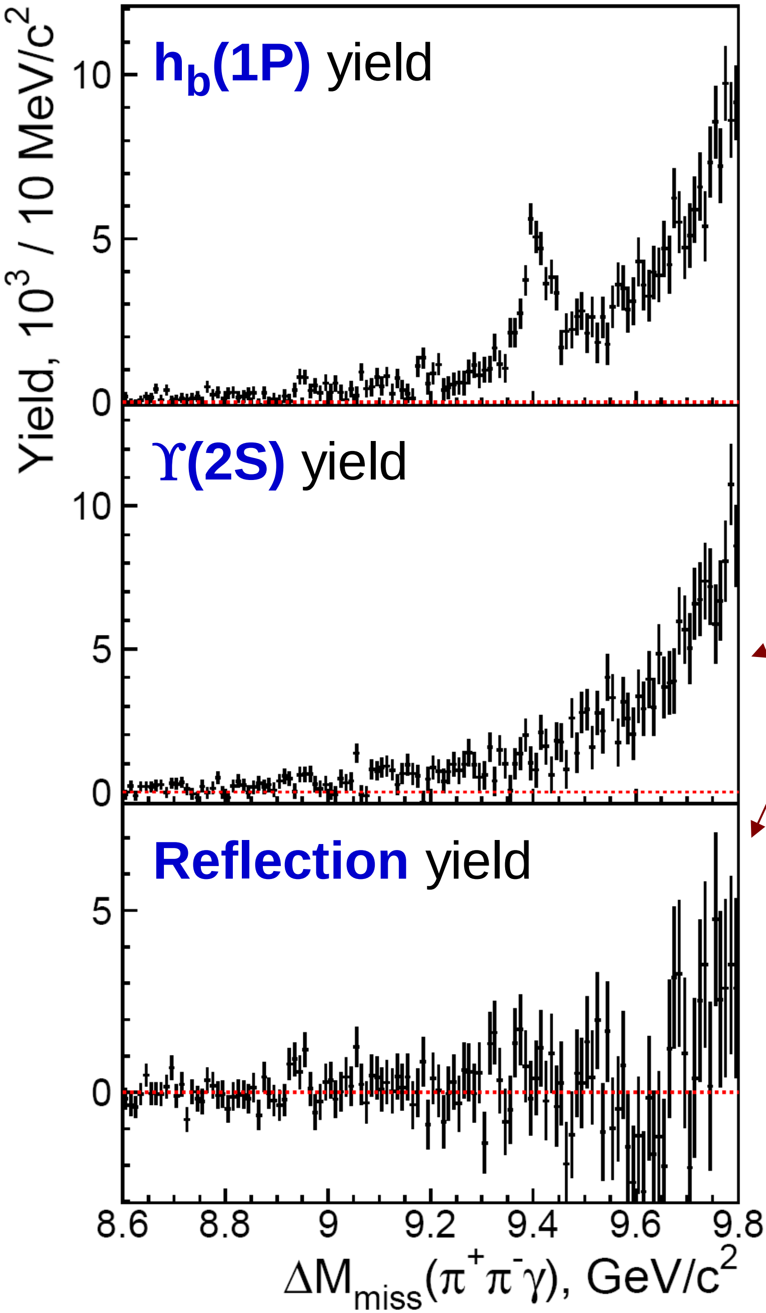
ΔM_{HF} [h_b(1P)] = $(+0.8 \pm 1.1)\mathrm{MeV}/c^2$

Previous Belle meas.: arXiv:1103.3411

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

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

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



$\eta_b(1S)$

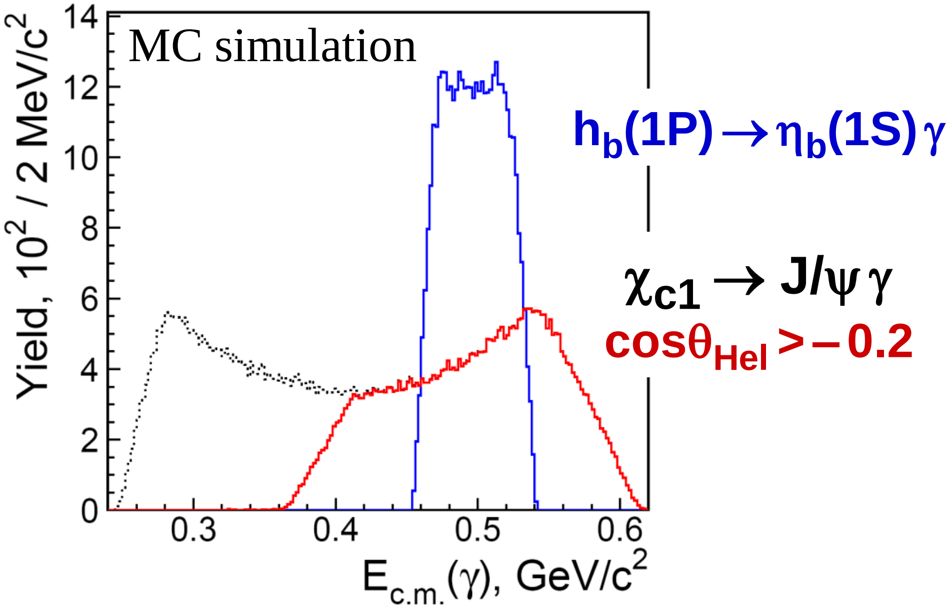
Peaking background?
MC simulation ⇒ none.

no significant structures

Calibration

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

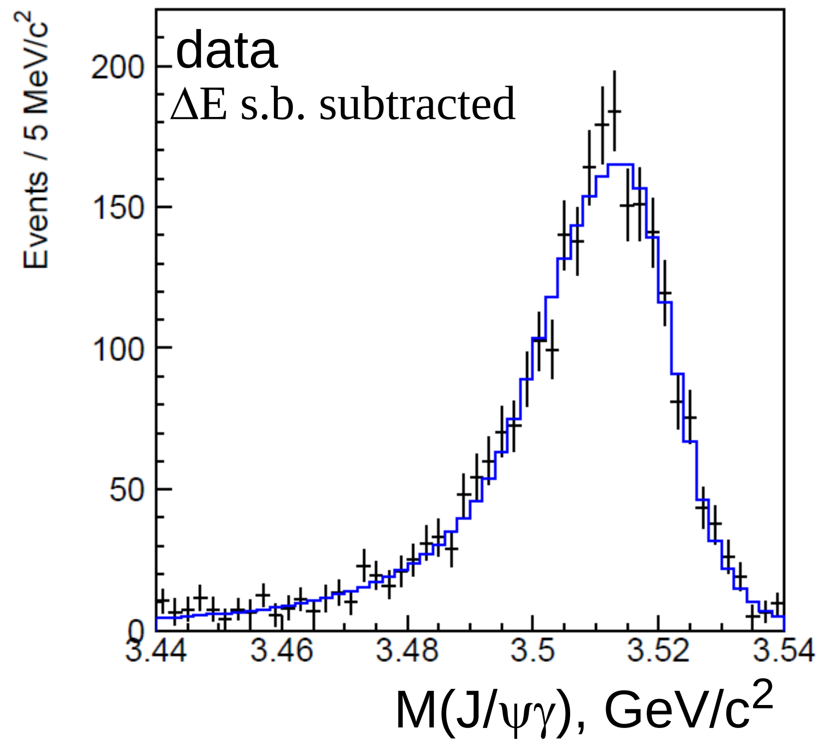
Photon energy spectrum



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

Calibration (2)

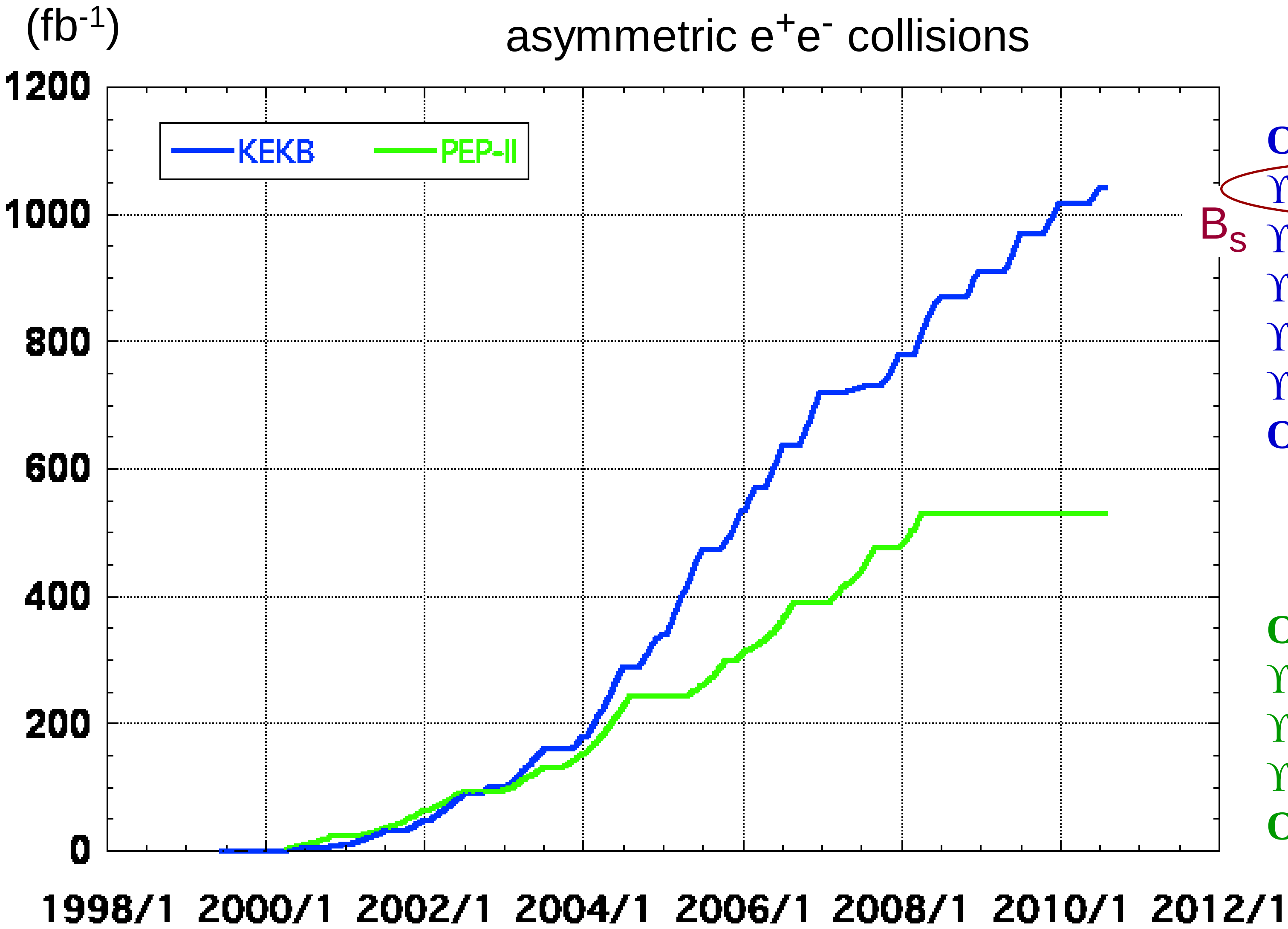
Resolution: double-sided CrystalBall function with asymmetric core



⇒ Correction of MC

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

Integrated Luminosity at B-factories



> 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan :

~100 fb-1

530 fb^{-1}

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

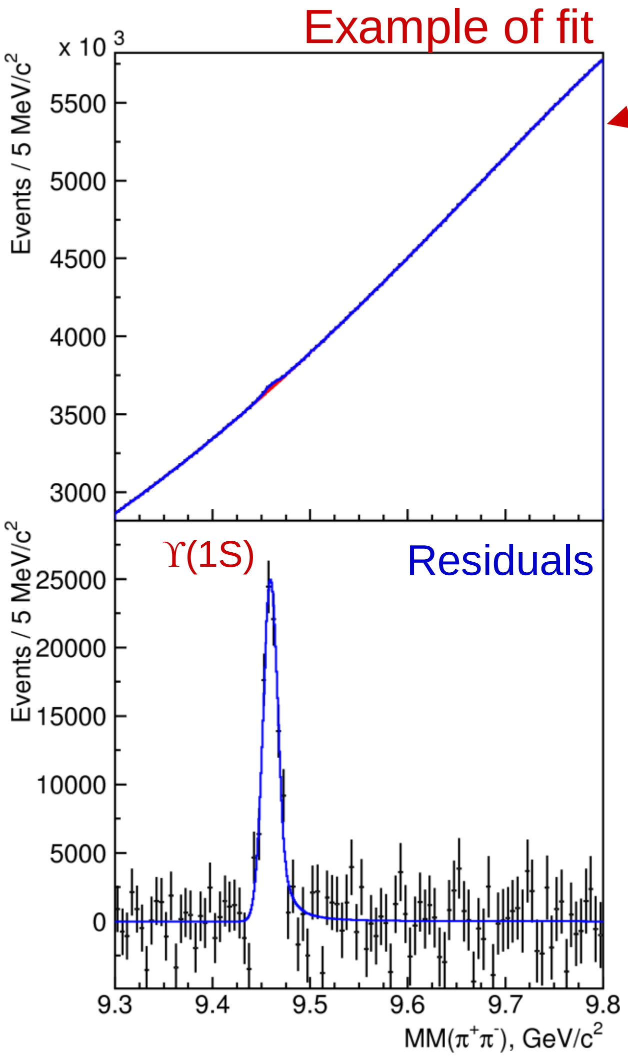
$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

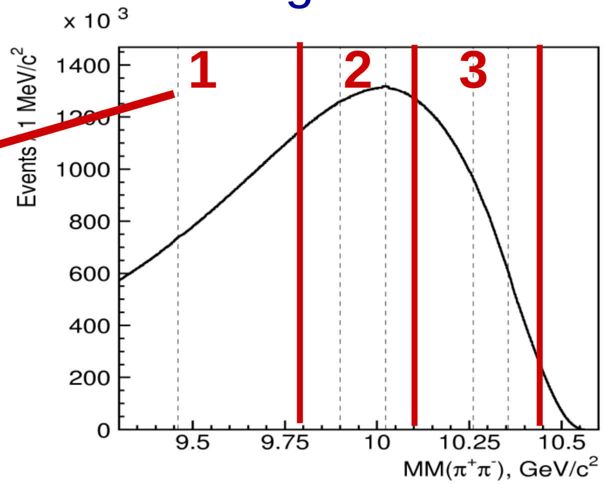
Off reson./scan :

~54 fb-1

Description of fit to MM($\pi^+\pi^-$)



Three fit regions

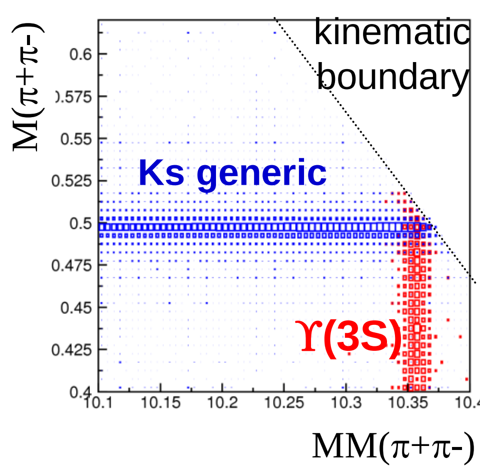


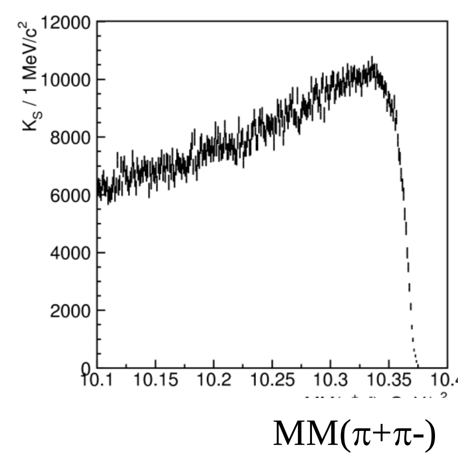
BG: Chebyshev polynomial, 6th or 7th order

Signal: shape is fixed from $\mu^+\mu^-\pi^+\pi^-$ data

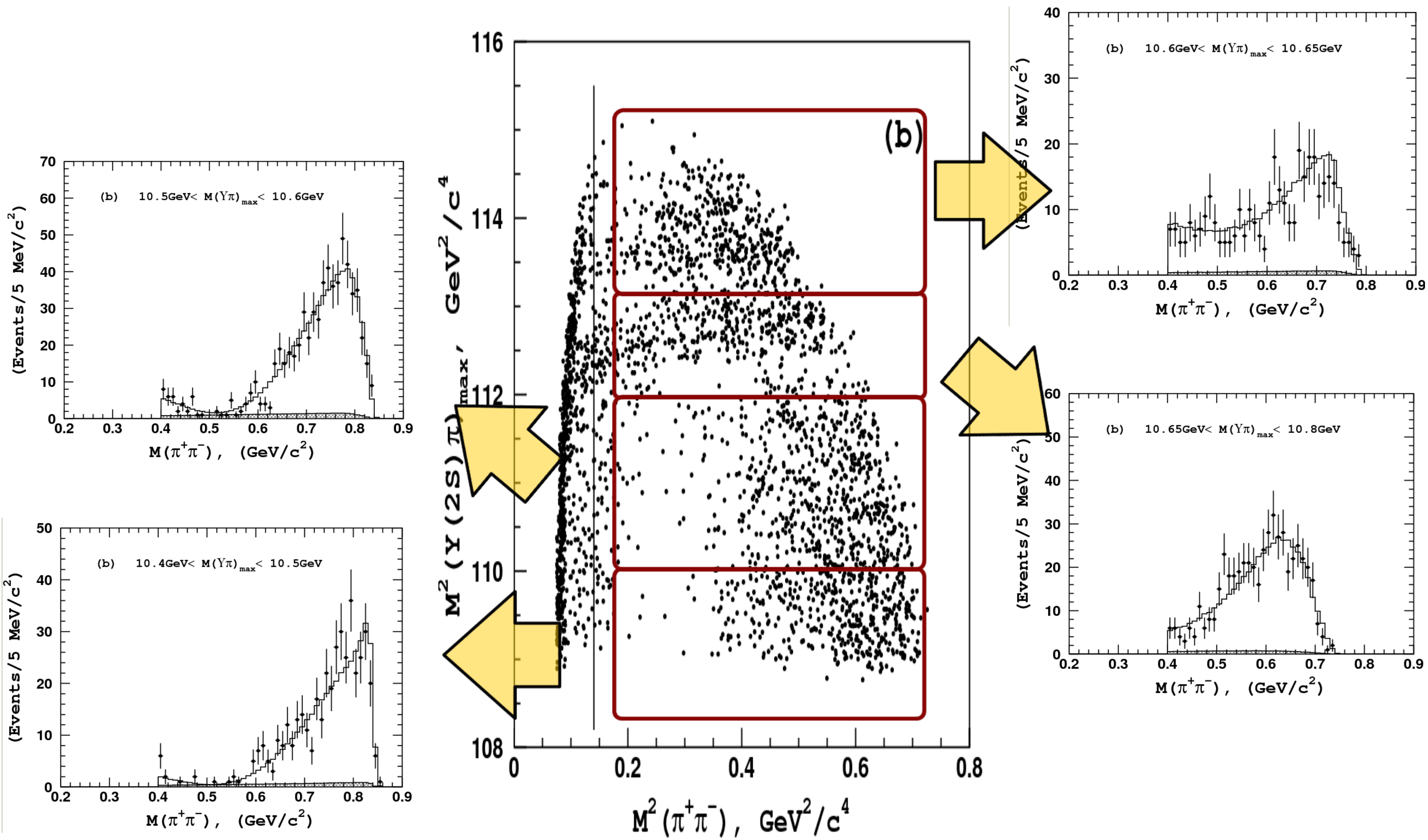
"Residuals" – subtract polynomial from data points

K_S contribution: subtract bin-by-bin

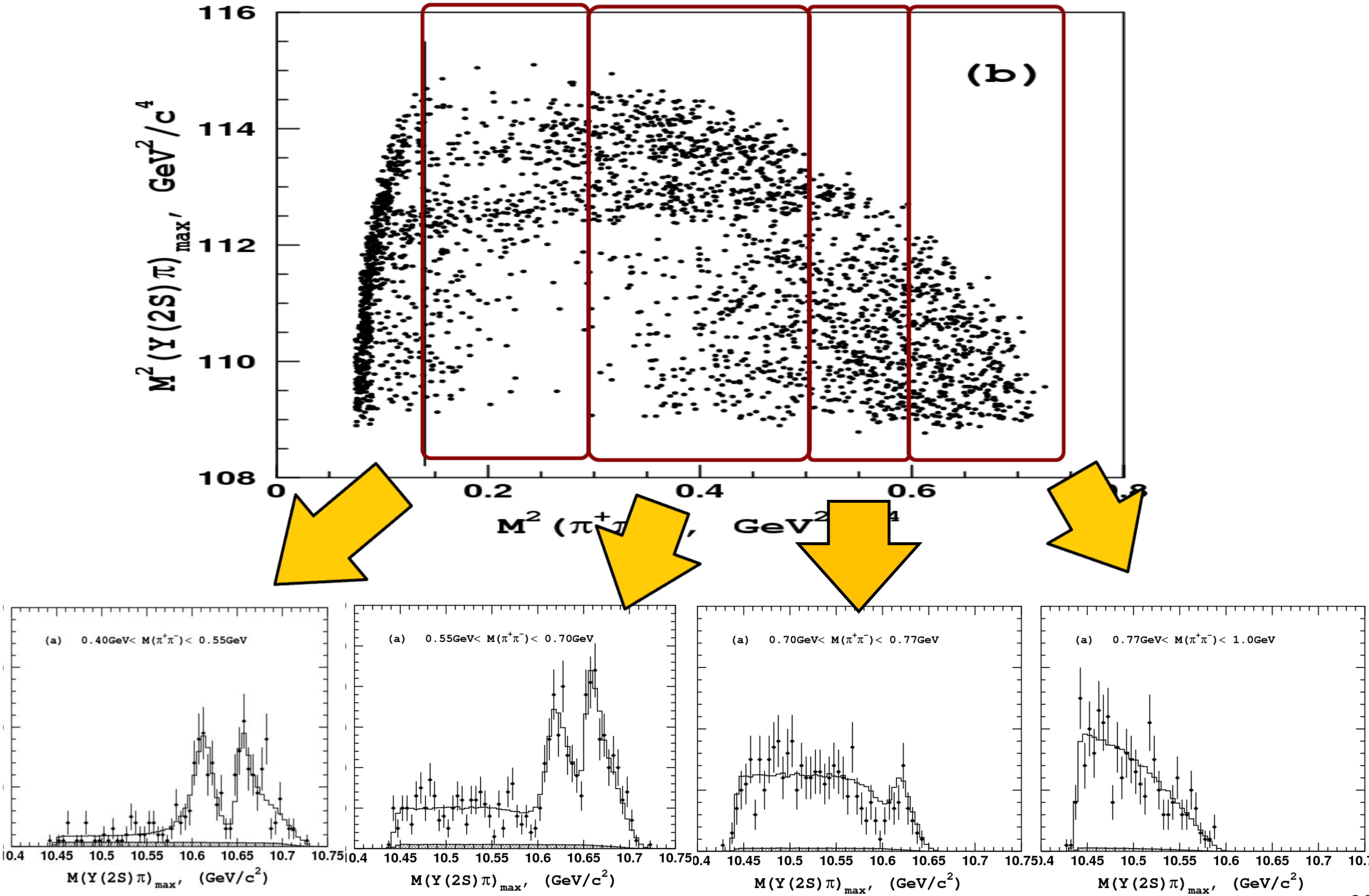




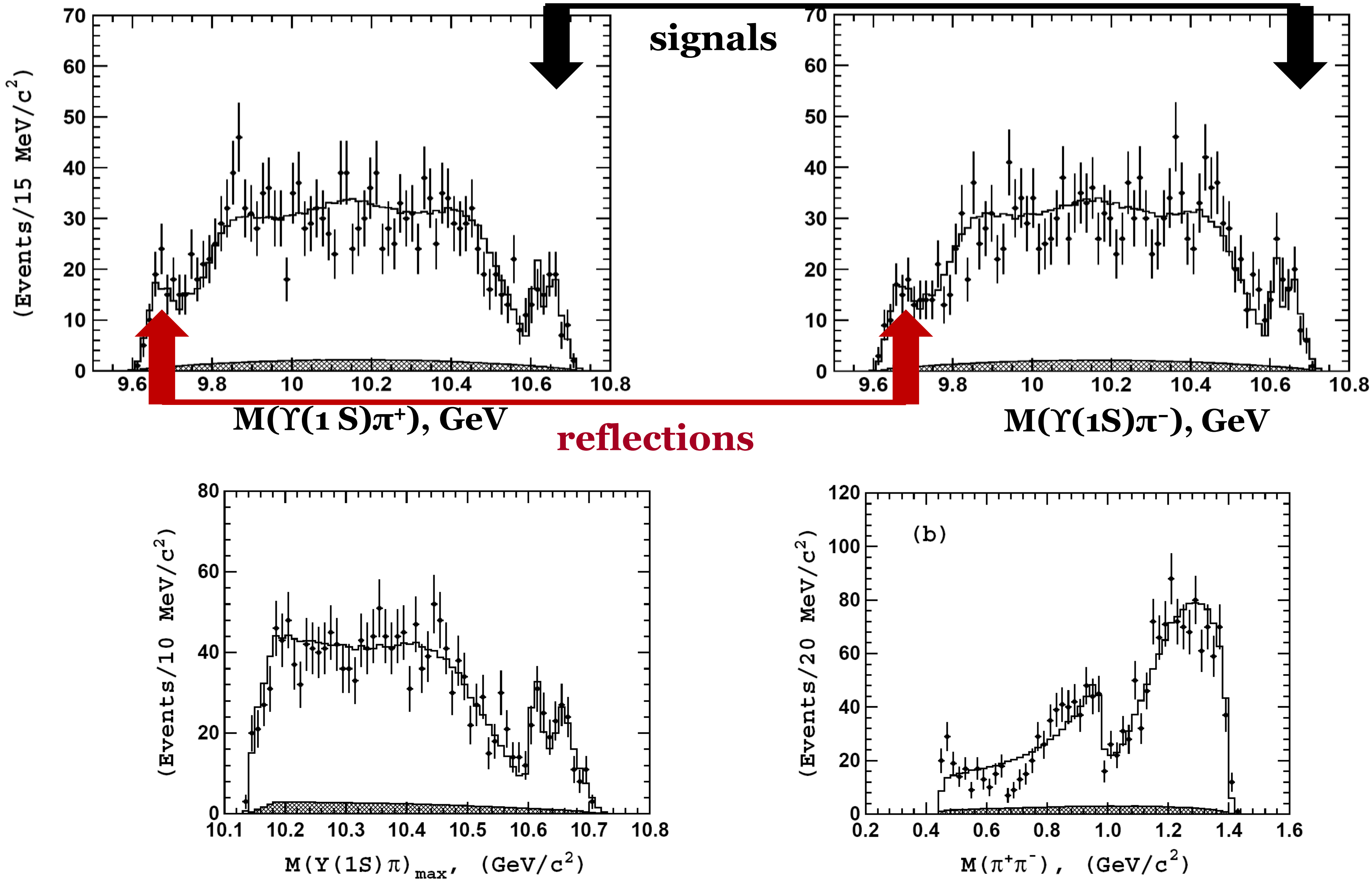
Results: $\Upsilon(5S)\to\Upsilon(2S)\pi^+\pi^-$



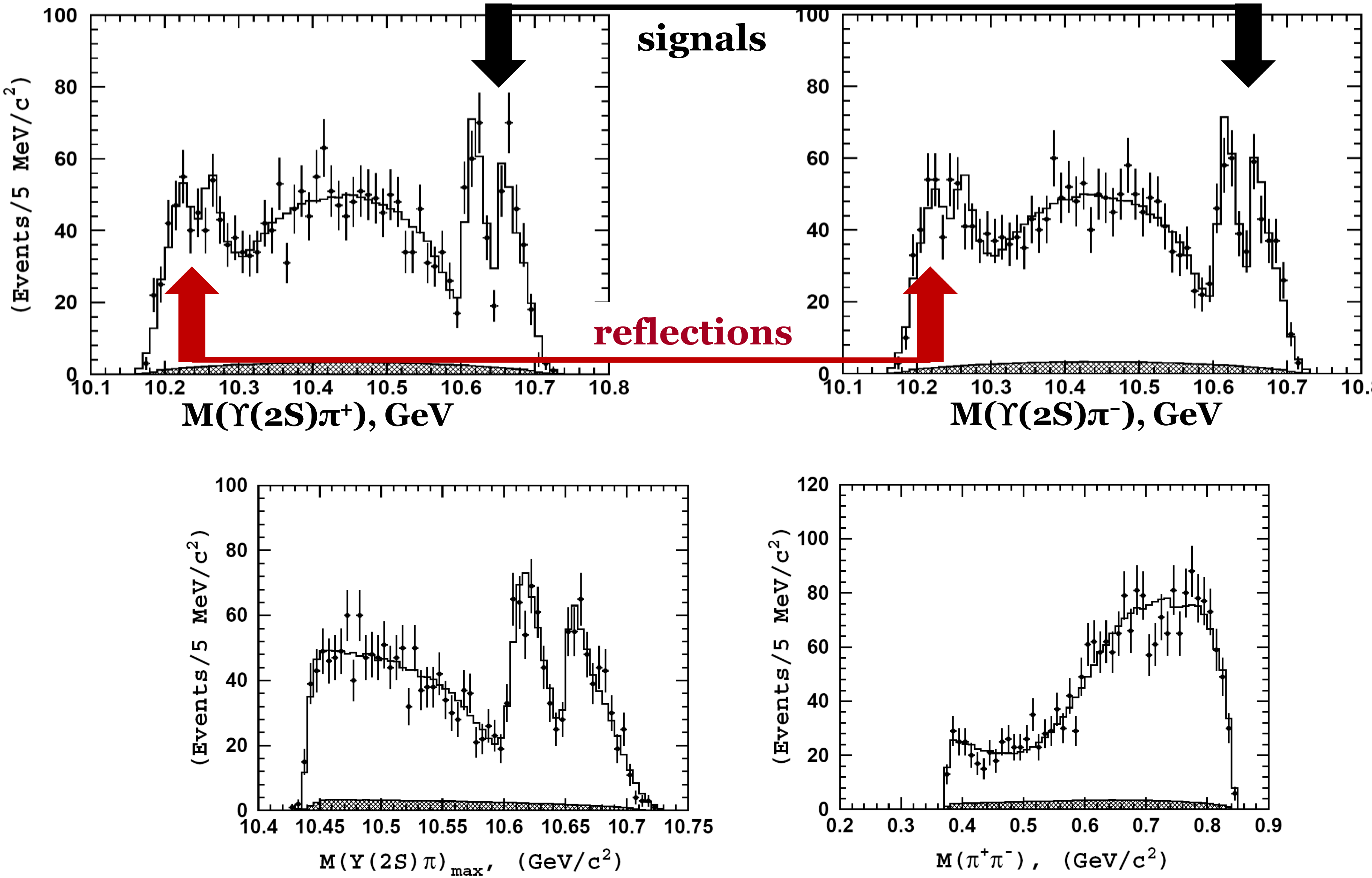
Results: Υ(5S)→Υ(2S)π⁺π⁻



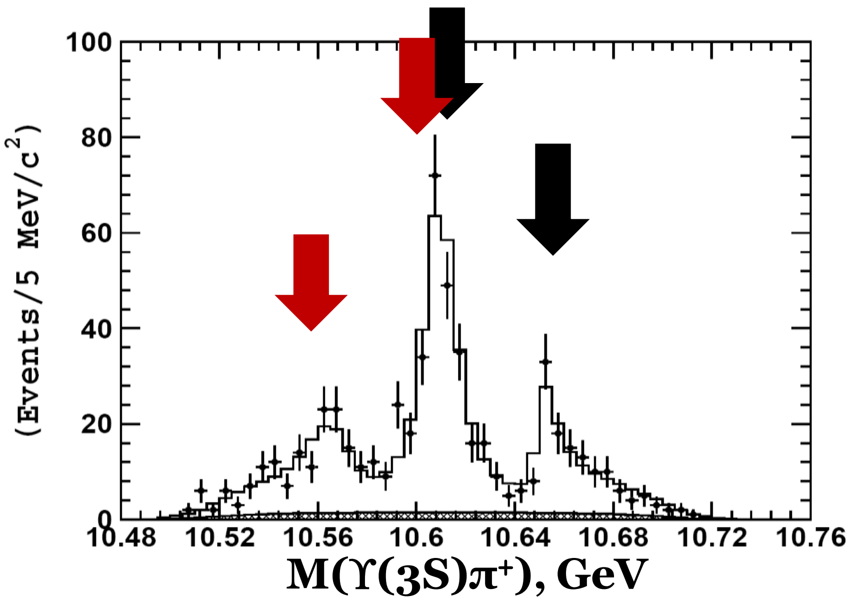
Results: $\Upsilon(1S)\pi^+\pi^-$

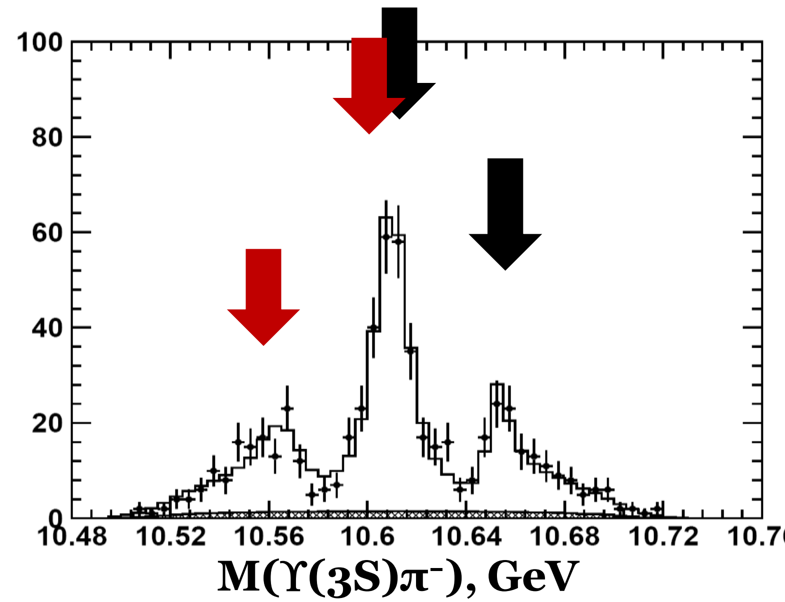


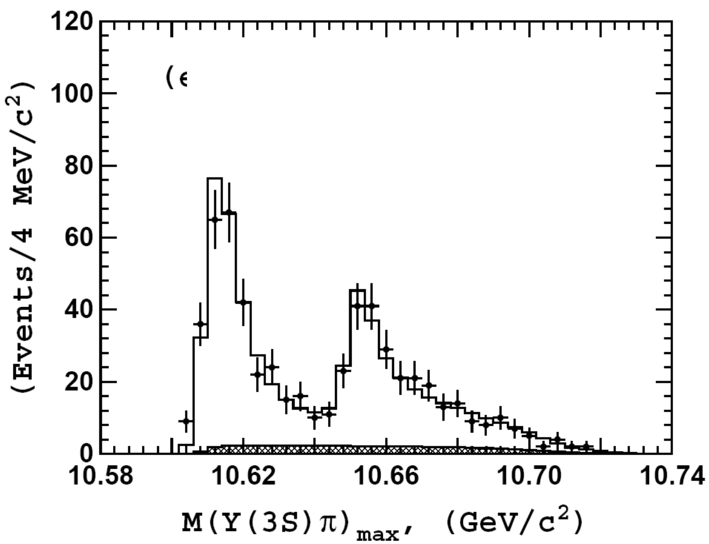
Results: $\Upsilon(2S)\pi^+\pi^-$

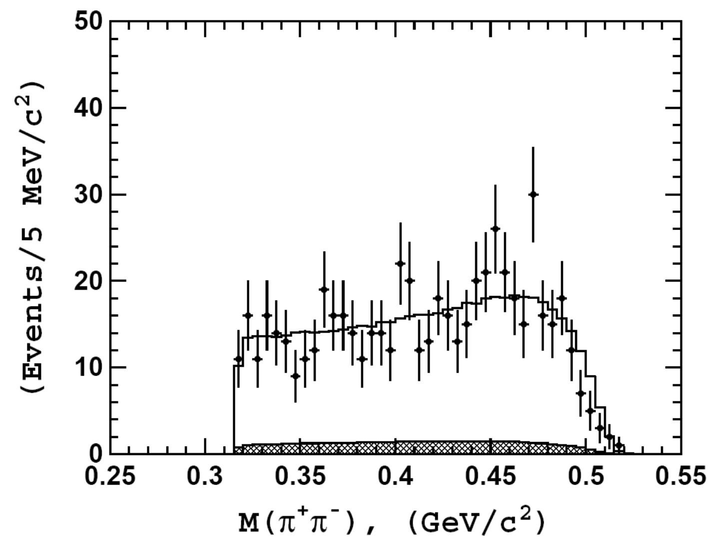


Results: $\Upsilon(3S)\pi^+\pi^-$

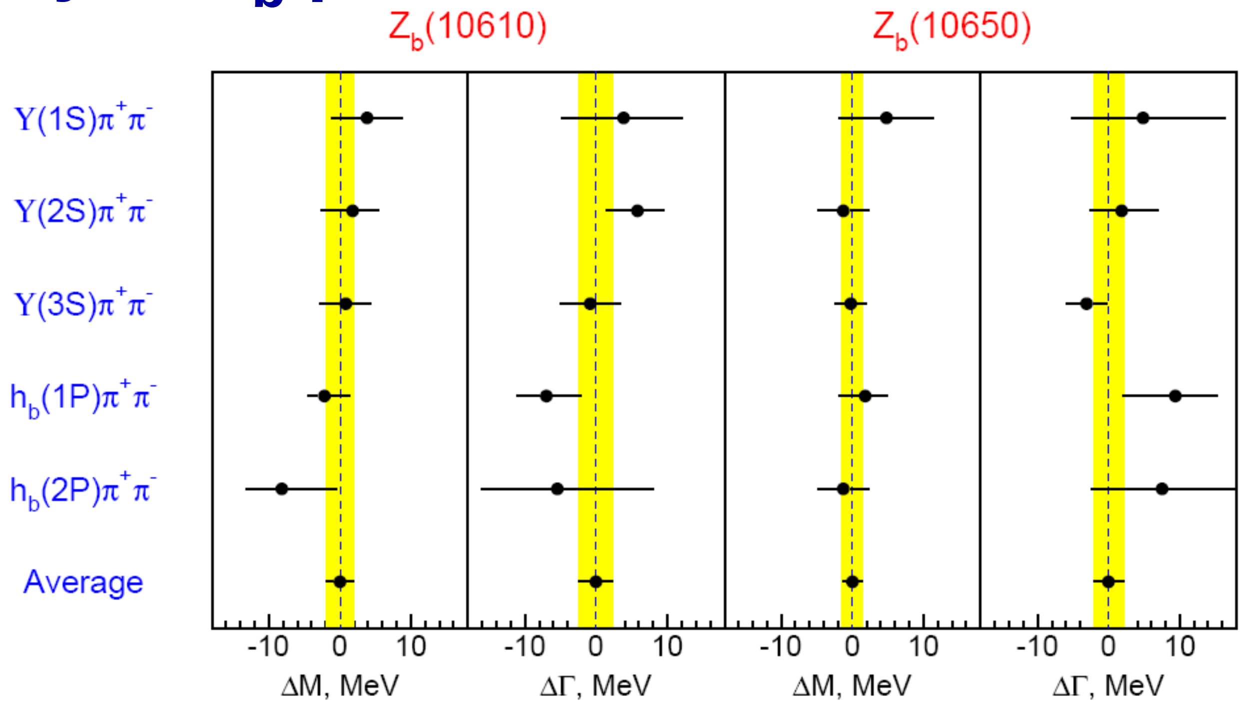








Summary of Z_b parameters



Average over 5 channels

$\langle M_1 \rangle = 10607.2 \pm 2.0$ MeV

$\langle \Gamma_1 \rangle = 18.4 \pm 2.4$ MeV

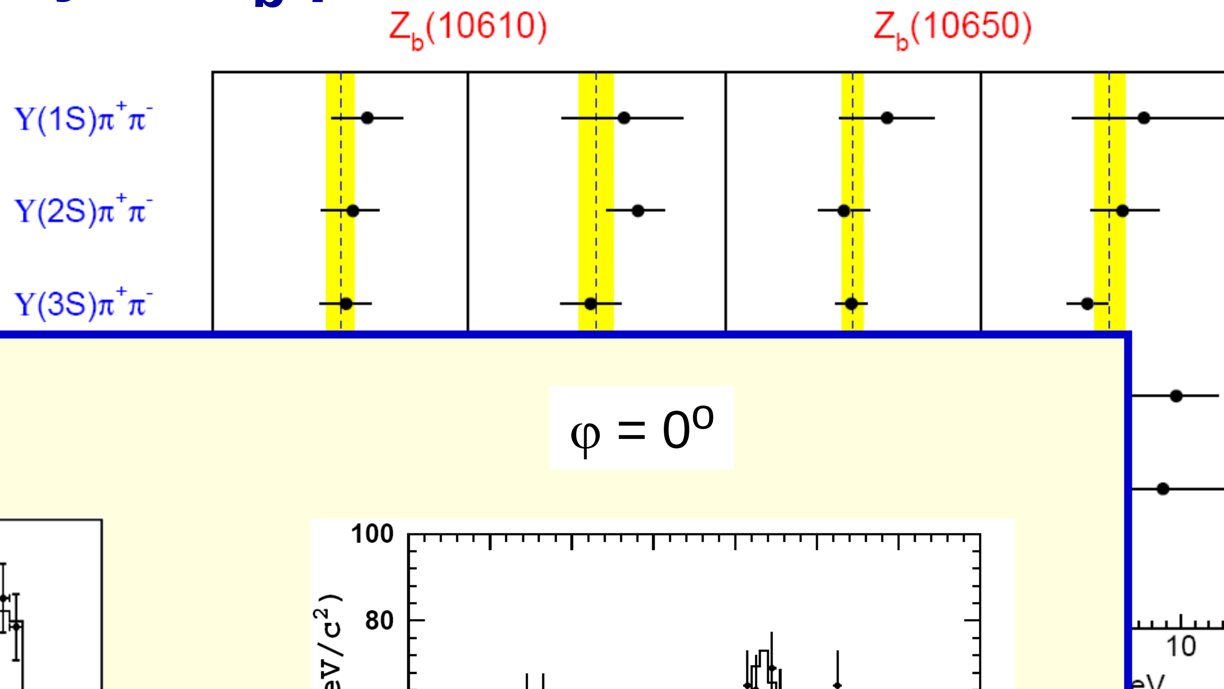
$\langle M_2 \rangle = 10652.2 \pm 1.5$ MeV

$\langle \Gamma_2 \rangle = 11.5 \pm 2.2$ MeV

Final state	$\Upsilon(1S)\pi^+\pi^-$	$\Upsilon(2S)\pi^+\pi^-$	$\Upsilon(3S)\pi^+\pi^-$	$h_b(1P)\pi^+\pi^-$	$h_b(2P)\pi^+\pi^-$
$M[Z_b(10610)]$, MeV/c^2	$10611 \pm 4 \pm 3$	$10609 \pm 2 \pm 3$	$10608 \pm 2 \pm 3$	$10605 \pm 2^{+3}_{-1}$	10599^{+6+5}_{-3-4}
$\Gamma[Z_b(10610)]$, MeV	$22.3 \pm 7.7^{+3.0}_{-4.0}$	$24.2 \pm 3.1^{+2.0}_{-3.0}$	$17.6 \pm 3.0 \pm 3.0$	$11.4\,^{+4.5+2.1}_{-3.9-1.2}$	$13\,^{+10+9}_{-8-7}$
$M[Z_b(10650)]$, MeV/c^2	$10657 \pm 6 \pm 3$	$10651 \pm 2 \pm 3$	$10652 \pm 1 \pm 2$	$10654 \pm 3\,^{+1}_{-2}$	10651^{+2+3}_{-3-2}
$\Gamma[Z_b(10650)]$, MeV	$16.3 \pm 9.8^{+6.0}_{-2.0}$	$13.3 \pm 3.3^{+4.0}_{-3.0}$	$8.4 \pm 2.0 \pm 2.0$	$20.9\,^{+5.4+2.1}_{-4.7-5.7}$	$19 \pm 7\,^{+11}_{-7}$
Rel. normalization	$0.57 \pm 0.21^{+0.19}_{-0.04}$	$0.86 \pm 0.11^{+0.04}_{-0.10}$	$0.96 \pm 0.14^{+0.08}_{-0.05}$	$1.39 \pm 0.37^{+0.05}_{-0.15}$	$1.6^{+0.6+0.4}_{-0.4-0.6}$
Rel. phase, degrees	$58 \pm 43^{+4}_{-9}$	$-13 \pm 13^{+17}_{-8}$	$-9 \pm 19^{+11}_{-26}$	187^{+44+3}_{-57-12}	$181^{+65+74}_{-105-109}$

$Z_b(10610)$ yield ~ $Z_b(10650)$ yield in every channel
Relative phases: 0^o for $\Upsilon\pi\pi$ and 180^o for $h_b\pi\pi$

Summary of Z_b parameters

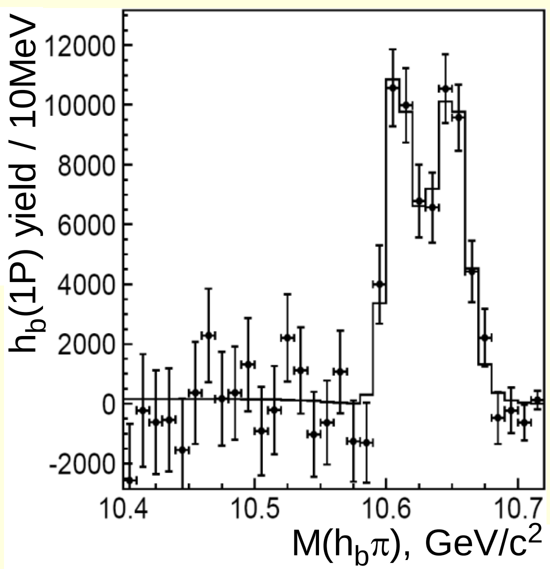


Average over 5 channels

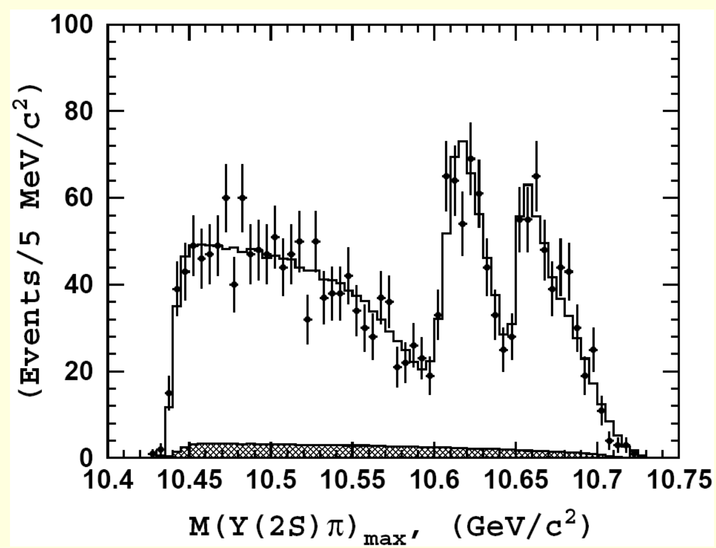
$\langle M_1 \rangle = 10607.2 \pm 2.0$ MeV

$\langle \Gamma_1 \rangle = 18.4 \pm 2.4$ MeV

$\varphi = 180^o$



$\varphi = 0^o$



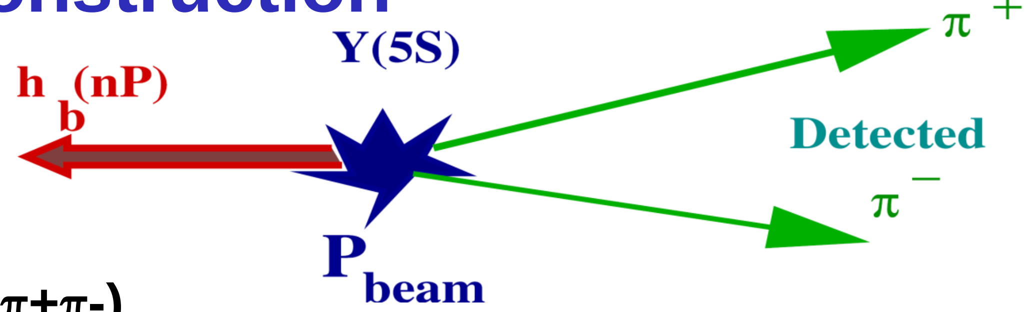
Fina... $)\pi^+\pi^-$
$M[Z$ ... $+6+5$ $-3-4$
$\Gamma[Z_b$ ... $10+9$ $8-7$
$M[Z$ ... $+2+3$ $-3-2$
$\Gamma[Z_b$ ... $7\ {}^{+11}_{-7}$
Rel. ... $.6+0.4$ $.4-0.6$
Rel. ... $5+74$ $05-109$

$Z_b(10610)$ yield ~ $Z_b(10650)$ yield in every channel

Relative phases: 0^o for $\Upsilon\pi\pi$ and 180^o for $h_b\pi\pi$

h_b reconstruction

Missing mass to ππ system



$$M_{hb(nP)} = \sqrt{(P_{\Upsilon(5S)} - P_{\pi+\pi-})^2} \equiv MM(\pi+\pi-)$$

Simple selection :

$\pi^+\pi^-$: good quality, positively identified

Suppression of continuum events
FW R2<0.3

⇒ Search for $h_b(nP)$ peaks in $MM(\pi^+\pi^-)$ spectrum