Seminar, Indiana University, October 13, 2014

Strange Beauty and Other Beasts in the $\Upsilon(5S)$ Neighborhood at Belle

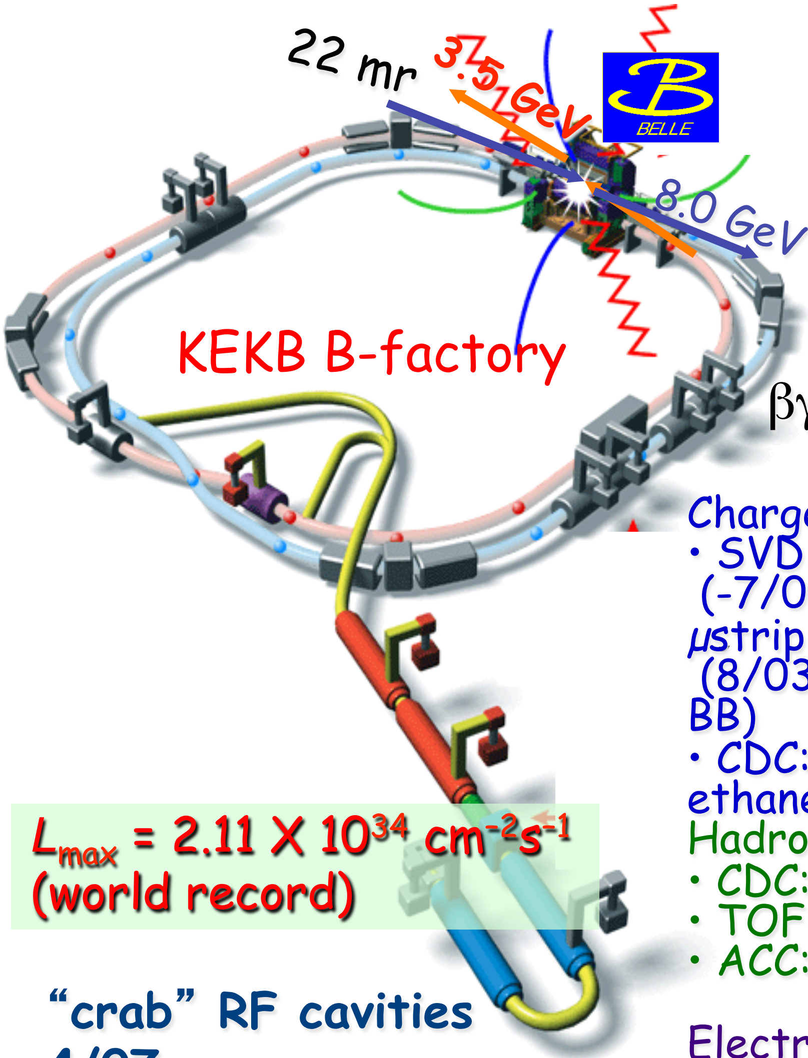
- Belle/KEKB: B-factory
  [$\Upsilon(4S)$ Resonance, B meson]
- $\Upsilon(10860)$ Resonance
  physics interest
  spectroscopic anomalies
  future

Kay Kinoshita
University of Cincinnati
Belle Collaboration

Belle/Belle II collaboration

International, ~400-600 collaborators

Belle hardware



$\beta\gamma$ = 0.425

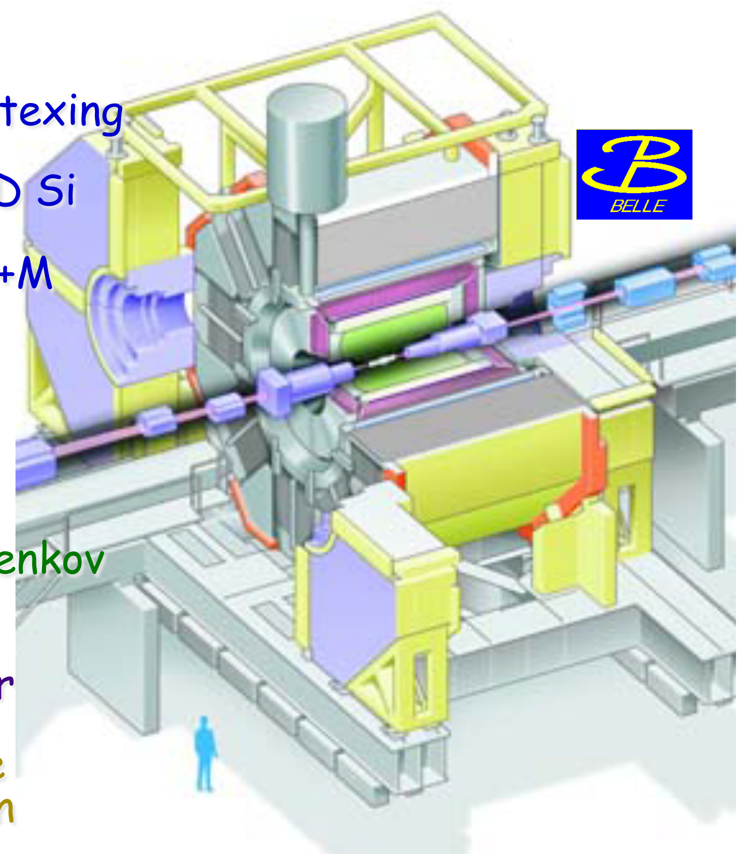
4/07- COPPER pipelined DAQ system

Charged tracking/vertexing
• SVD:
(-7/03) 3-layer DSSD Si μstrip (152M B pairs)
(8/03-) 4-layer (550+M BB)
• CDC: 50 layers (He-ethane)

Hadron identification
• CDC: dE/dx
• TOF: time-of-flight
• ACC: Threshold Cerenkov (aerogel)

Electron/photon
• ECL: CsI calorimeter

Muon/K_L
• KLM: Resistive plate counter/iron



Data (1999-2010)

> 1 ab^{-1} recorded by Belle

$\int Ldt$ since 6/1999

- •Υ(4S)
  711 fb^{-1}
- •sub-Υ(4S) continuum
  ~100 fb^{-1}
- •"Υ(5S)"
  ~121 fb^{-1}
- •Υ(3S), Υ(2S) , Υ(1S)
  ~34fb^{-1}
- •"Υ(5S)"+ scan
  ~31 fb^{-1}

- B pairs (7.7 x 10^8 events)
- charm (1.1 x 10^9 events)
- tau (~8 x 10^8 events)
- 2-photon events
- B_s (~7 x 10^6 events)
- Υ(5S) (~4 x 10^7 events)

423 articles published/submitted
http://belle.kek.jp/bdocs/b_journal.html

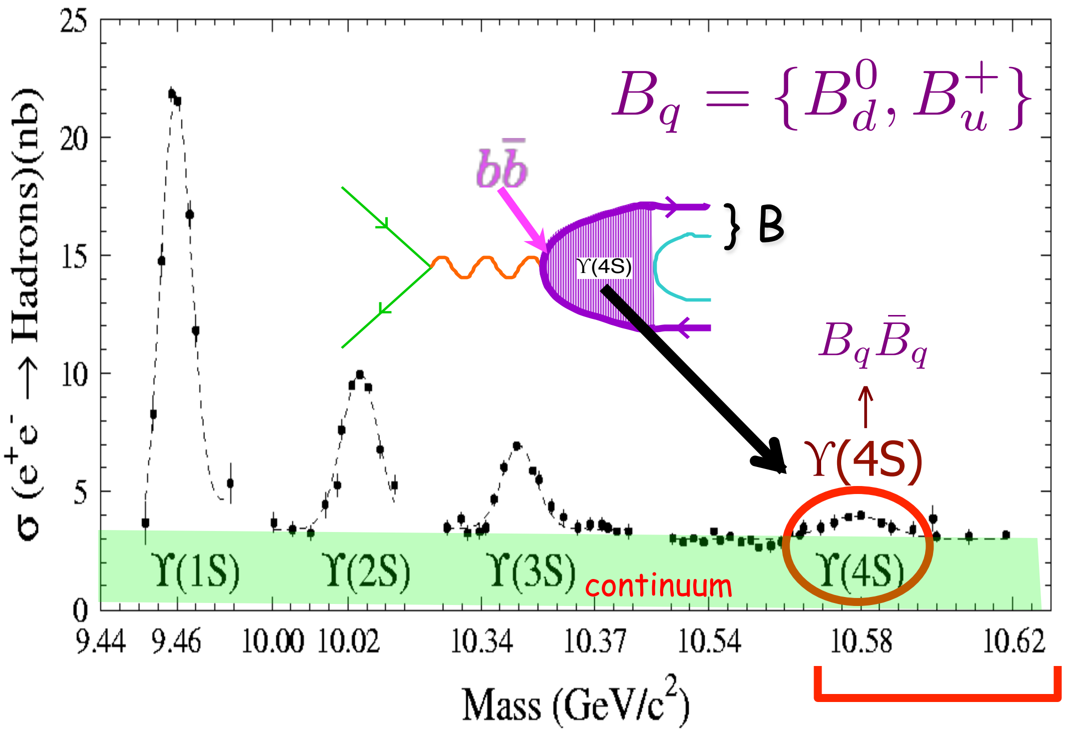
Highlights

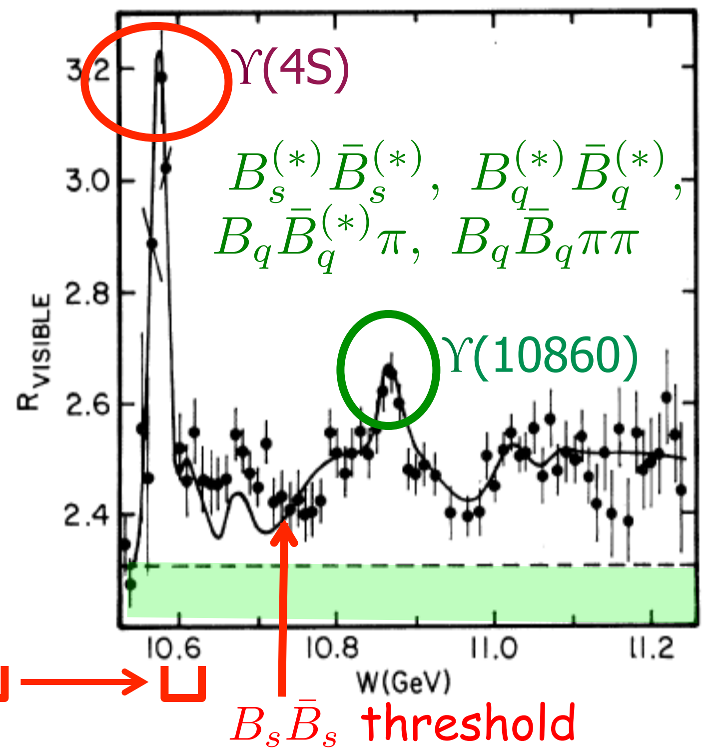
- CP violation in B decay
- Constraints on CKM; precision $\sin 2\varphi_1$, $|V_{cb}|$, $|V_{ub}|$
- overconstraints on CKM; limits/hints on New Physics
- evidence for D^0 mixing
- new charmonium-like states Z(4430), Y(4660), Y(4008), X(4160), Y(3940), X(3872)
- new bottomonia, bottomonium-like $Z_b(10610)$, $Z_b(10650)$
- Kobayashi & Maskawa 2008 Nobel

Future: Super KEKB /Belle II

- to start ~ 2016

The Upsilon Neighborhood





At/above the Υ(10860) ["Υ(5S)"]: B_s , bottomonium physics

- ✧ B-factory detector: high luminosity, established detector, Υ(4S) data for comparison; CLEAN events, energy definition, γ detection; high trigger efficiency
- ✧ on resonance – # events measured directly -> absolute BF's

Belle data above $\Upsilon(4S)$

2005: 3-day "engineering" run
- basic $\Upsilon(5S)$, $B_s^{(*)}$ properties,
- test KEKB at $\Upsilon(5S)$
- 1.86 fb^{-1} at peak (10869 MeV)
  = 4 x largest previous sample (CLEO)

A. Drutskoy et al., PRL 98, 052001 (2007)
A. Drutskoy et al., PRD 76, 012002 (2007)

2006: 20-day run
- + 21.7 fb^{-1} on resonance

K.F. Chen et al., PRL 100, 112001 (2008)
J. Wicht et al., PRL 100, 121801 (2008)
R. Louvot et al., PRL 102, 021801 (2009)
A. Drutskoy et al., PRD 81, 112003(R)(2010)
R. Louvot et al., PRL 104, 231801 (2010)
C.-C. Peng et al., PRD 82, 072007 (R) (2010)
S. Esen et al., PRL 105, 201802 (2010)
J. Li et al., PRL 106, 121802 (2011)

2007: scan 6 pts
- + 7.9 fb^{-1} above resonance

K.F. Chen et al., PRD 82, 091106(R) (2010)

10/08-12/10: extended run
- ~100 fb^{-1} on resonance

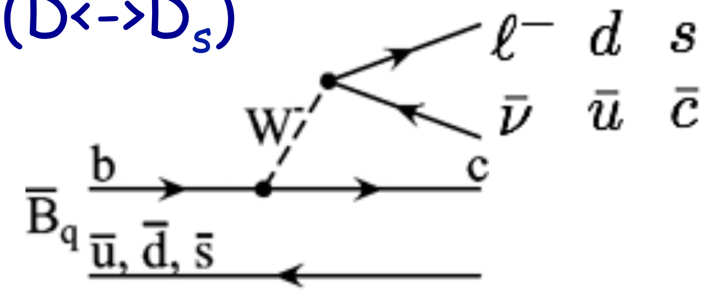
I. Adachi et al, PRL 108, 032001 (2012)
A. Bondar et al, PRL 108, 122001 (2012)
Y. Sato et al, PRL 108, 171801 (2012)
J. Li et al, PRL 108, 181808 (2012)
R. Mizuk at al, PRL 109, 232002 (2012)
S. Esen et al, PRD 87, 031101(R) (2013)
C. Oswald et al, PRD 87, 072008 (2013)
E. Solovieva et al, PLB 726, 206 (2013)
P. Krokovny et al, PRD 88, 052016 (2013)
F. Thorne et al, PRD 88, 114006 (2013)
A. Garmash et al, arXiv:1403.0992 [PRD]
X. He et al, accepted PRL

- ~30 fb^{-1} scan
  (D. Santel)

Υ(5S) physics

B_s decay in Standard Model

- similar to non-strange B
  spectator decay -> quark-hadron duality
  correspondence btw final particle (D<->D_s)
- dissimilarities
  $\Delta\Gamma/\Gamma_{CP}/\Gamma = O(10\%)$
  CP-asymmetry ~ 0
- In LHCb era: focus on final states w neutrals, absolute rates



spectroscopy

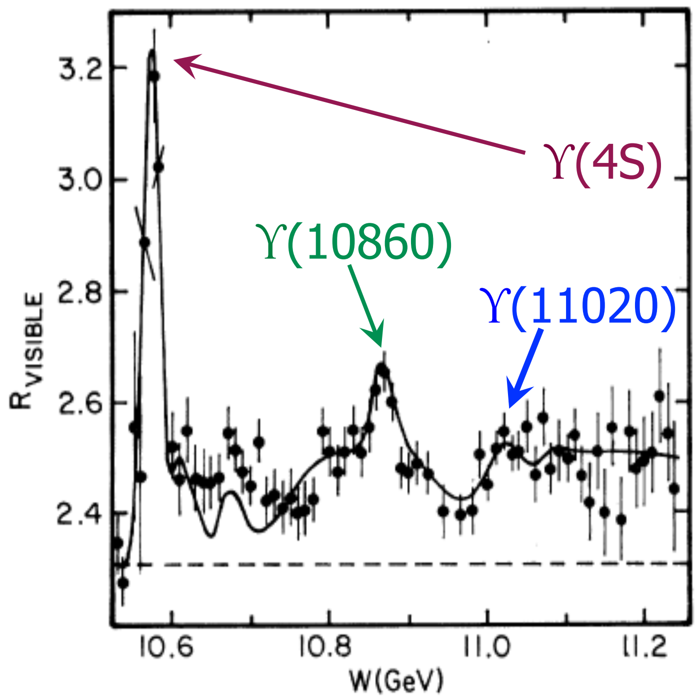
- $B_s^{(*)}$ mass
- $B_{(s)}^{(*)}(\pi)$ event fractions
- bottomonium, bottomonium-like states

Complexities above the $\Upsilon(4S)$:

- mass thresholds –

$$B_s^{(*)}\bar{B}_s^{(*)},\ \ B_q^{(*)}\bar{B}_q^{(*)},$$
$$B_q\bar{B}_q^{(*)}\pi,\ \ B_q\bar{B}_q\pi\pi$$
$$\Upsilon\pi\pi,\ldots$$

complex resonances, mixing/interference



Anomalies of the $\Upsilon(10860)$: some history

Speculation [W.S. Hou, PRD 74, 017504 (2006)]

- 2005: charmonium-like particle at 4260 GeV found in

$e^+e^- \to \gamma_{ISR}\,\pi^+\pi^- J/\psi \quad e^+e^- \to \pi^+\pi^- J/\psi$

Babar PRL 95, 142001 (2005)
Belle PRD 77, 011105 (R) (2008)
CLEO PRD 74, 091104(R) (2006)

$$Y(4260) \to \pi^+\pi^- J/\psi$$

+ many more! (now called X by PDG)

$$Y \to \pi^+\pi^-\psi(2S)$$

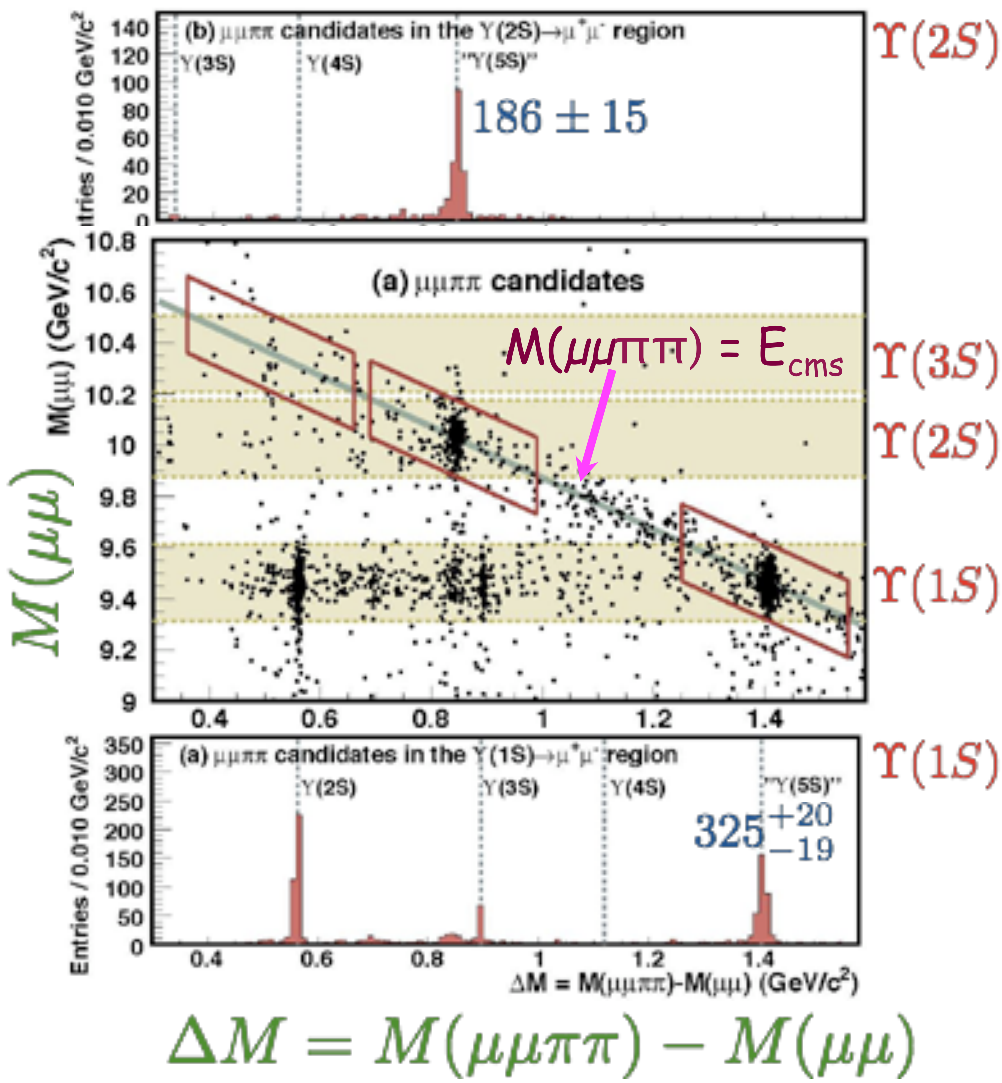
Does(do) analogous state(s) exist in Upsilon region, observable in Υ(5S) data?

✧ Search for

$$e^+e^- \to \Upsilon(1\mathrm{S}/2\mathrm{S}/3\mathrm{S})\pi^+\pi^-$$

$e^+e^- \to \Upsilon(1\mathrm{S}/2\mathrm{S}/3\mathrm{S})\pi^+\pi^-$ PRL 100, 112001 (2008)

$\Upsilon(1\mathrm{S}/2\mathrm{S}/3\mathrm{S}) \to \mu^+\mu^-$



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

PRL 100, 112001 (2008)

4 modes seen $\Upsilon(10860) \to \Upsilon(nS)h^+h^-$

Process	σ(pb)	$\mathcal{B}$(%)	Γ(MeV)
$\Upsilon(1S)\pi^+\pi^-$	$1.61 \pm 0.10 \pm 0.12$	$0.53 \pm 0.03 \pm 0.05$	$0.59 \pm 0.04 \pm 0.09$
$\Upsilon(2S)\pi^+\pi^-$	$2.35 \pm 0.19 \pm 0.32$	$0.78 \pm 0.06 \pm 0.11$	$0.85 \pm 0.07 \pm 0.16$
$\Upsilon(3S)\pi^+\pi^-$	$1.44^{+0.55}_{-0.45} \pm 0.19$	$0.48^{+0.18}_{-0.15} \pm 0.07$	$0.52^{+0.20}_{-0.17} \pm 0.10$
$\Upsilon(1S)K^+K^-$	$0.185^{+0.048}_{-0.041} \pm 0.028$	$0.061^{+0.016}_{-0.014} \pm 0.010$	$0.067^{+0.017}_{-0.015} \pm 0.013$

ϒ(5S) expectation: width comparable to ϒ(2S/3S/4S)

Process	$\Gamma_{\rm total}$	$\Gamma_{e^+e^-}$	$\Gamma_{\Upsilon(1S)\pi^+\pi^-}$
$\Upsilon(2S) \to \Upsilon(1S)\pi^+\pi^-$	0.032 MeV	0.612 keV	0.0060 MeV
$\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-$	0.020 MeV	0.443 keV	0.0009 MeV
$\Upsilon(4S) \to \Upsilon(1S)\pi^+\pi^-$	20.5 MeV	0.272 keV	0.0019 MeV
$\Upsilon(10860) \to \Upsilon(1S)\pi^+\pi^-$	110 MeV	0.31 keV	0.59 MeV

larger by > 10^2

ϒ(10860) = ϒ(5S), Y_b, or something else?

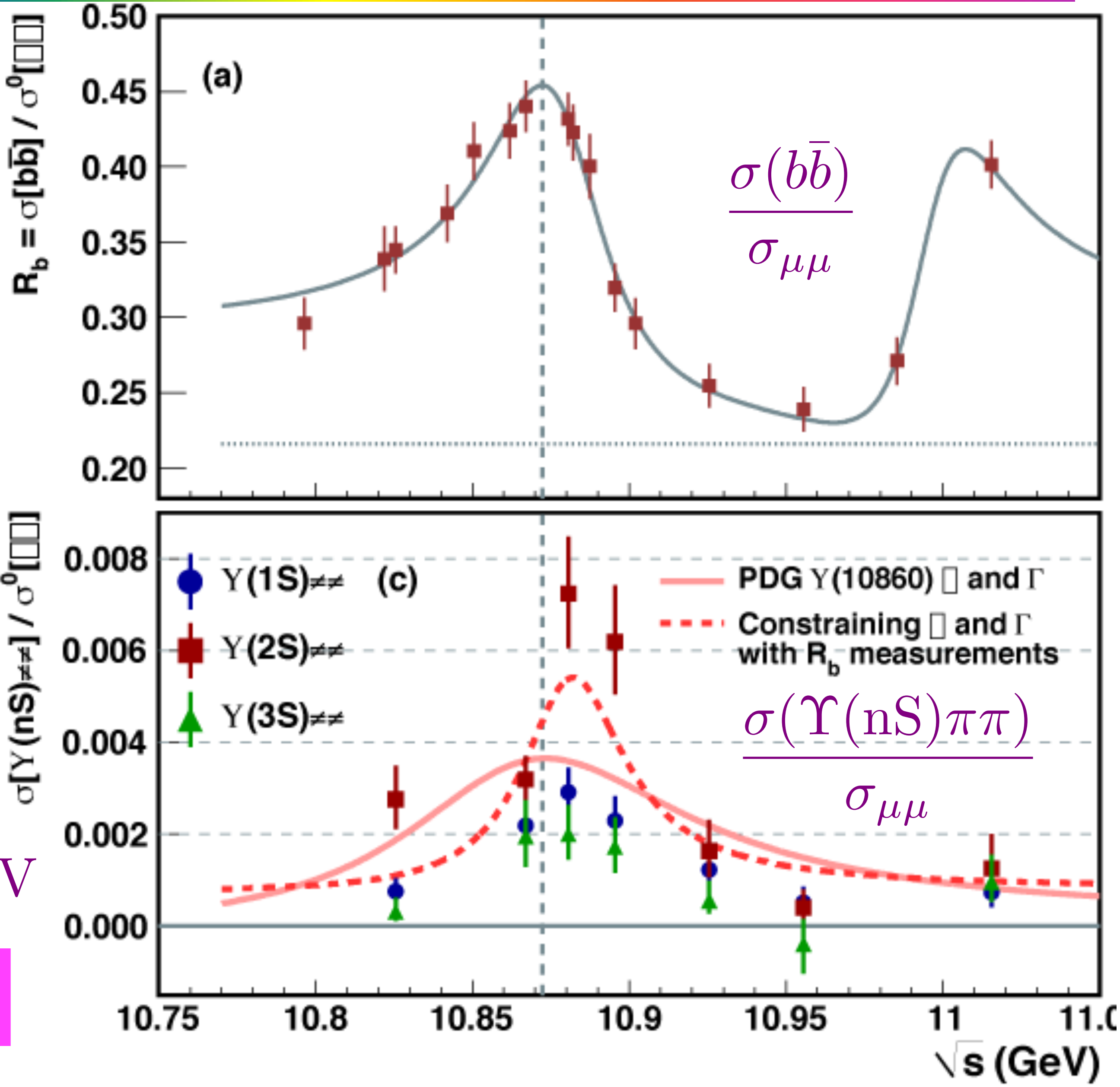
→ 12/07: energy scan, for $e^+e^- \to \Upsilon(nS)h^+h^-$

scan near $\Upsilon(10860)$ [PRD82, 091106 (2010)]

$\sqrt{s}$(GeV)	$\mathcal{L}(\mathrm{fb}^{-1})$
10.8275	1.68
10.8825	1.83
10.8975	1.41
10.9275	1.14
10.9575	1.01
11.0175	0.86

$$M_{5S}c^2 = [10888^{+2.7}_{-2.6} \pm 1.2]\mathrm{MeV}$$

$\boxed{\Delta Mc^2 = 9 \pm 4 \text{ MeV}}$



resonant substructure in

$$e^+e^- \to \Upsilon(n\mathrm{S})\pi^+\pi^-$$

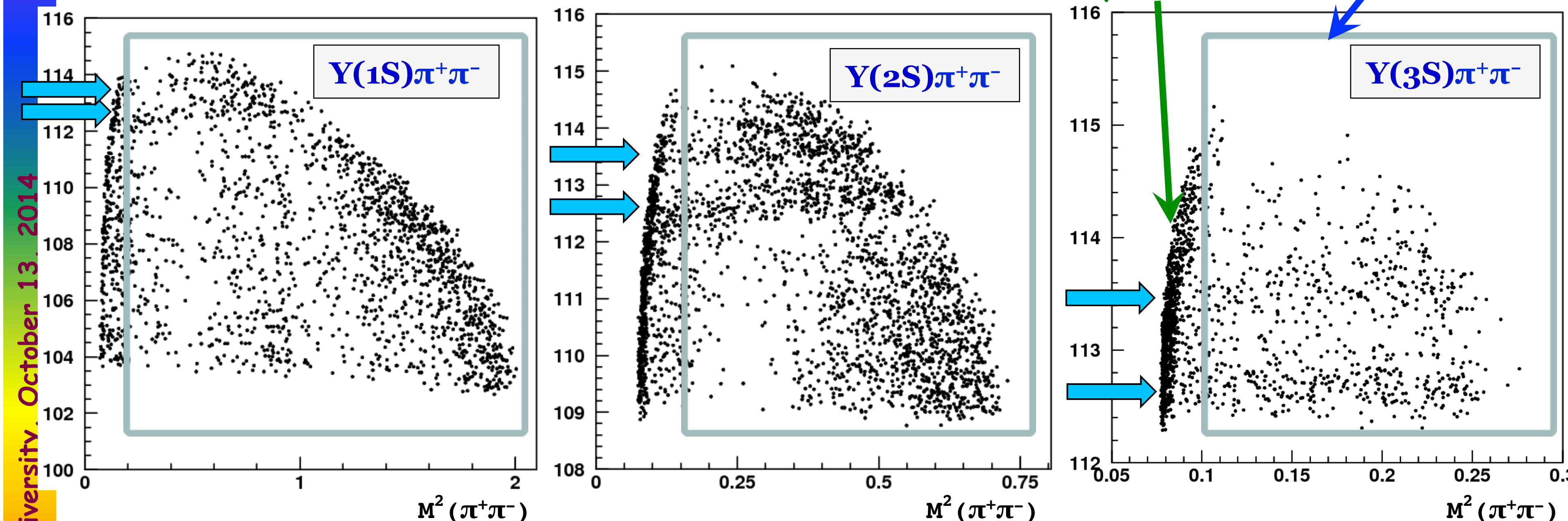
$$e^+e^- \to h_b(m\mathrm{P})\pi^+\pi^-$$

121 fb^{-1} at Υ(10860) peak

[PRL 108, 122001 (2012)]

Resonant substructure $\Upsilon(5S) \to \Upsilon(nS)\pi^{\pm}\pi^{\mp}$

Dalitz Plots 121.4 fb^{-1} $M^2(\Upsilon\pi)$ vs $M^2(\pi\pi)$



Fit function:

$$S(s_1, s_2) = |A_{Z_{b1}} + A_{Z_{b2}} + A_{\rm NR} + A_{f_0(980)} + A_{f_2(1275)}|^2$$

$$s_i = M^2_{\pi_i\Upsilon} \quad A_{Z_{bk}} = \frac{\sqrt{M_k\Gamma_k}}{M_k^2 - s_1 + iM_k\Gamma_k} + \frac{a_k e^{i\phi_k}\sqrt{M_k\Gamma_k}}{M_k^2 - s_2 + iM_k\Gamma_k}$$

$$A_{\rm NR} = c_1 + c_2 M^2_{\pi\pi}$$

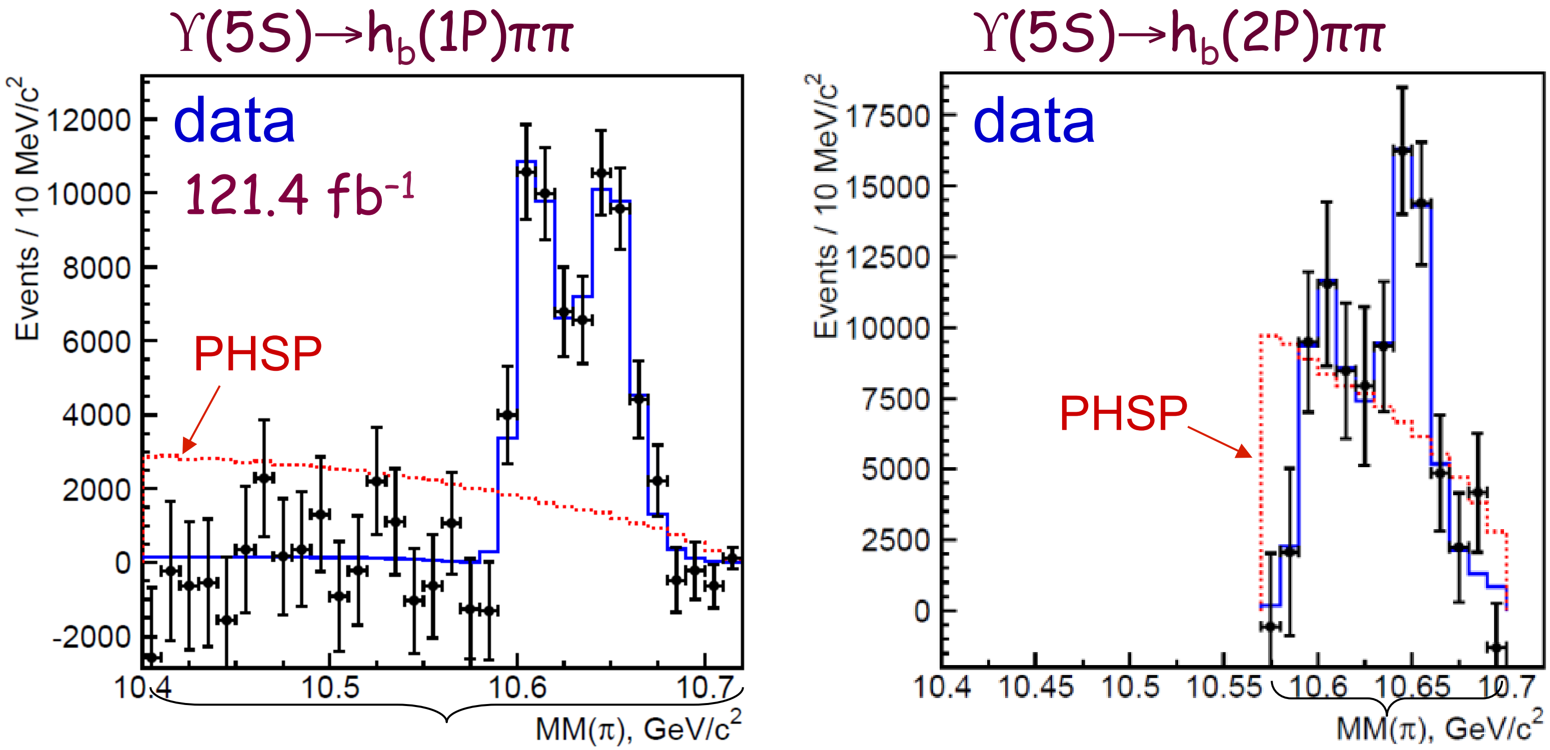
A. Voloshin, PRD74, 054022 (2006);
Prog. Part. Nucl. Phys. 61, 455 (2008)

Resonant substructure $h_b(\mathrm{nP})\pi^\pm\pi^\mp$

probe: missing mass $e^+e^- \to \underbrace{h_b(\mathrm{nP})\pi^\pm}_{\text{“Z”}}\pi^\mp$

$$M_Z = MM(\pi) = \sqrt{E_Z^2 - p_Z^2}$$

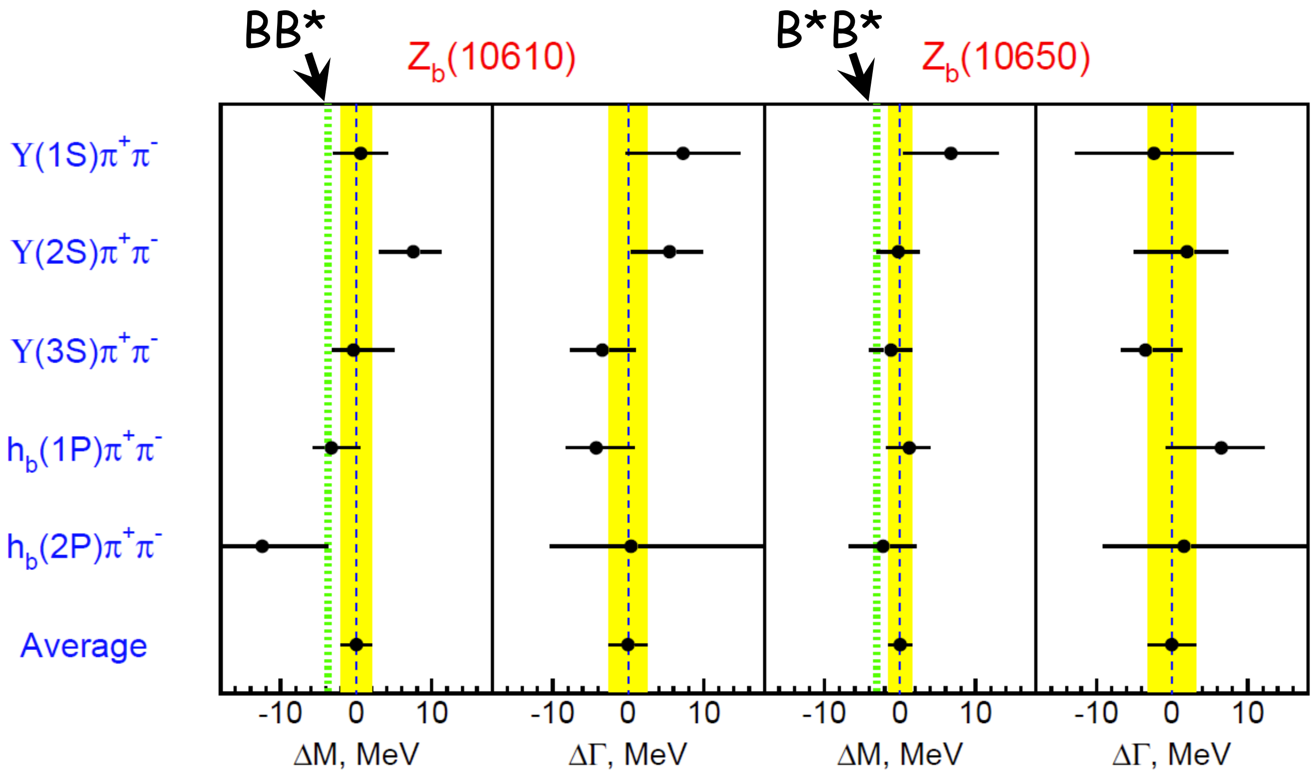
yield in MM(π) bins



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

Nearly all resonant

2 new resonances: $Z_b^{\pm}(10610)$, $Z_b^{\pm}(10650)$, 5 modes ea



Good agreement among all 5 modes

$M=10608.4\pm2.0$ MeV/c^2
$\Gamma=15.6\pm2.5$ MeV

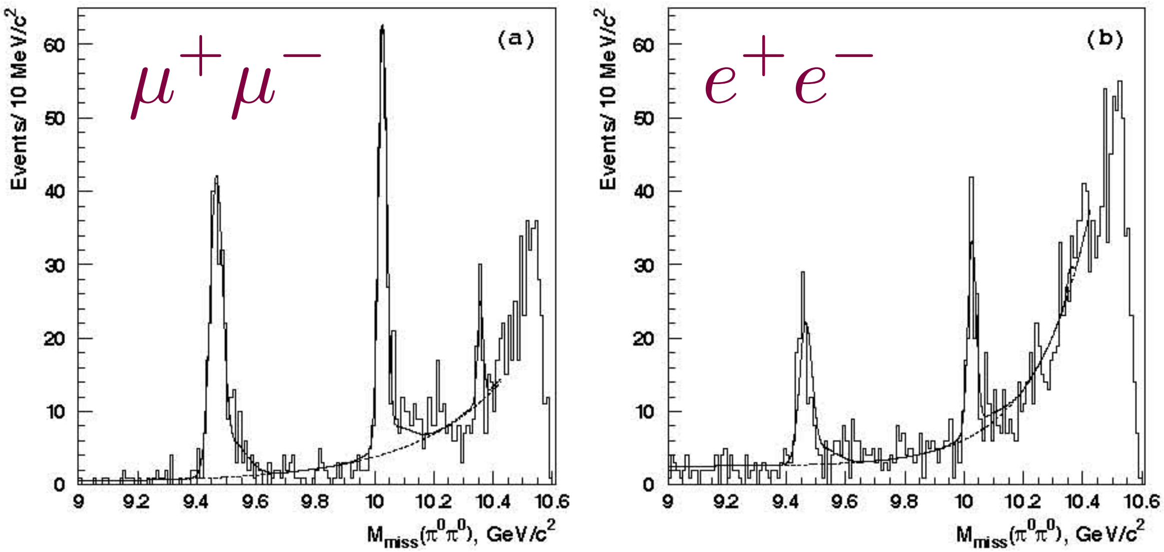
$M=10653.2\pm1.5$ MeV/c^2
$\Gamma=14.4\pm3.2$ MeV

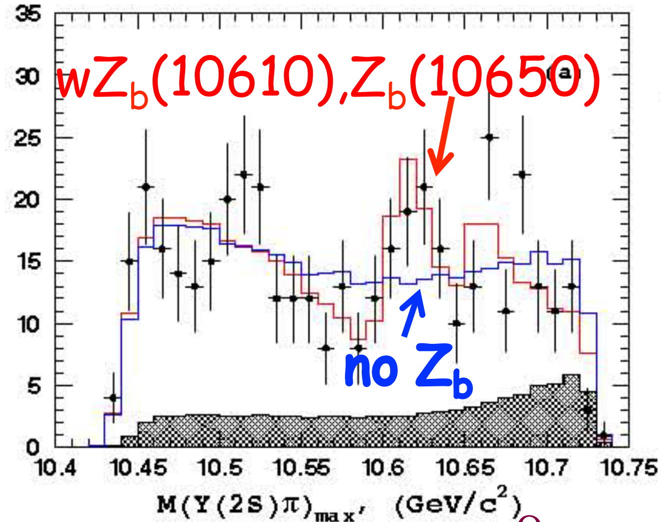
- Relative phases: Υ (~0°), h_b (~180°)
- Masses just above B*B and B*B* thresholds
- angular analysis favors $J^P=1^+$ [arXiv:1403.0992]

Favors "meson molecule" hypothesis of Z_b's

Further evidence: neutral partner

121.4 fb^{-1}





$$M(\Upsilon(2S)\pi^0)$$

$$e^+e^- \to \Upsilon(nS)\pi^0\pi^0$$

$$Z_b^0 \to \Upsilon(nS)\pi^0$$

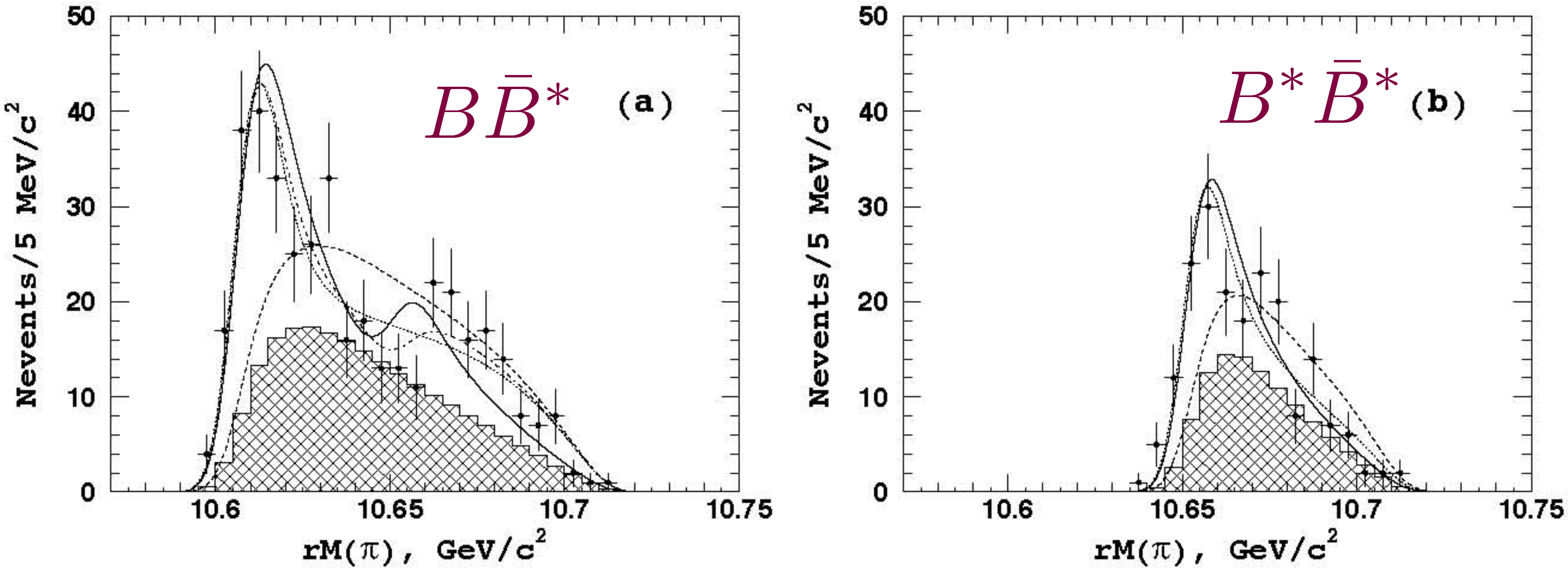
Z_b^0(10610) observed with 6.5σ significance

[PRD 88, 052016 (2013)]

Further evidence $Z_b \to B^* B^{(*)}$

121.4 fb^{-1}

$$e^+e^- \to B^* B^{(*)} \pi^\pm$$



arXiv:1209.6450 [hep-ex]

What IS Z_b?

many theories

- Meson molecule
  [A.Bondar, et al., PRD 84, 054010 (2011)]
- Coupled channel resonances
  [I.V.Danilkin et al, arXiv:1106.1552]
- Cusp
  [D.Bugg, Europhys.Lett. 96, 11002 (2011)]
- Tetraquark
  [M.Karliner & H.Lipkin, arXiv:0802.0649]

Similar pattern in charmonium region

Heavy quark exotica

PDG13

Many are unconfirmed
Primary characteristic:
high rate to quarkonia

Charmonium -like

Z(3900)

Z(3885)

Z(4025)

Z(4020)

Bottomonium-like

$Z_b^0(10610)$

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment (#σ)	Year	Status
$X(3872)$	3871.68 ± 0.17	<1.2	$1^{++}/2^{-+}$	$B\to K(\pi^+\pi^-J/\psi)$	Belle [36,37] (12.8), BABAR [38] (8.6)	2003	OK
				$p\bar{p}\to(\pi^+\pi^-J/\psi)+...$	CDF [39–41] (np), D0 [42] (5.2)		
				$B\to K(\omega J/\psi)$	Belle [43] (4.3), BABAR [23] (4.0)		
				$B\to K(D^{*0}\bar{D}^0)$	Belle [44,45] (6.4), BABAR [46] (4.9)		
				$B\to K(\gamma J/\psi)$	Belle [47] (4.0), BABAR [48,49] (3.6)		
				$B\to K(\gamma\psi(2S))$	BABAR [49] (3.5), Belle [47] (0.4)		
				$pp\to(\pi^+\pi^-J/\psi)+...$	LHCb [50] (np)		
$X(3915)$	3917.4 ± 2.7	28^{+10}_{-9}	$0/2^{?+}$	$B\to K(\omega J/\psi)$	Belle [51] (8.1), BABAR [52] (19)	2004	OK
				$e^+e^-\to e^+e^-(\omega J/\psi)$	Belle [53] (7.7), BABAR [23] (np)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [54] (6.0)	2007	NC!
				$e^+e^-\to J/\psi(...)$	Belle [20] (5.0)		
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^-\to\gamma(D\bar{D})$	BABAR [55] (np), Belle [56] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-J/\psi)$	Belle [57] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (1.1)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [60,61] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [54] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [58] (5.0), BABAR [59] (2.0)	2008	NC!
$Y(4260)$	4263^{+8}_{-9}	95 ± 14	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-J/\psi)$	BABAR [62,63] (8.0)	2005	OK
					CLEO [64] (5.4), Belle [57] (15)		
				$e^+e^-\to(\pi^+\pi^-J/\psi)$	CLEO [65] (11)		
				$e^+e^-\to(\pi^0\pi^0J/\psi)$	CLEO [65] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [61] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$e^+e^-\to e^+e^-(\phi J/\psi)$	Belle [66] (3.2)	2009	NC!
$Y(4360)$	4361 ± 13	74 ± 18	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	BABAR [67] (np), Belle [68] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B\to K(\pi^+\psi(2S))$	Belle [69,70] (6.4), BABAR [71] (2.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^-\to\gamma(\Lambda_c^+\Lambda_c^-)$	Belle [72] (8.2)	2007	NC!
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	Belle [68] (5.8)	2007	NC!
$Z_b(10610)^+$	10607.2 ± 2.0	18.4 ± 2.4	1^+	$\Upsilon(5S)\to\pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Z_b(10650)^+$	10652.2 ± 1.5	11.5 ± 2.2	1^+	$\Upsilon(5S)\to\pi^-(\pi^+[b\bar{b}])$	Belle [73,74] (16)	2011	NC!
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^-\to(\pi^+\pi^-\Upsilon(nS))$	Belle [75,76] (2.0)	2010	NC!

Anomalies of the Υ(10860)

High rates to $\Upsilon(n\mathrm{S})\pi\pi$

$h_b\pi\pi$

$B^* B^{(*)}\pi$

Large fraction as $Z_b\pi$ (X in PDG as of 2014)

-> reprise energy scan

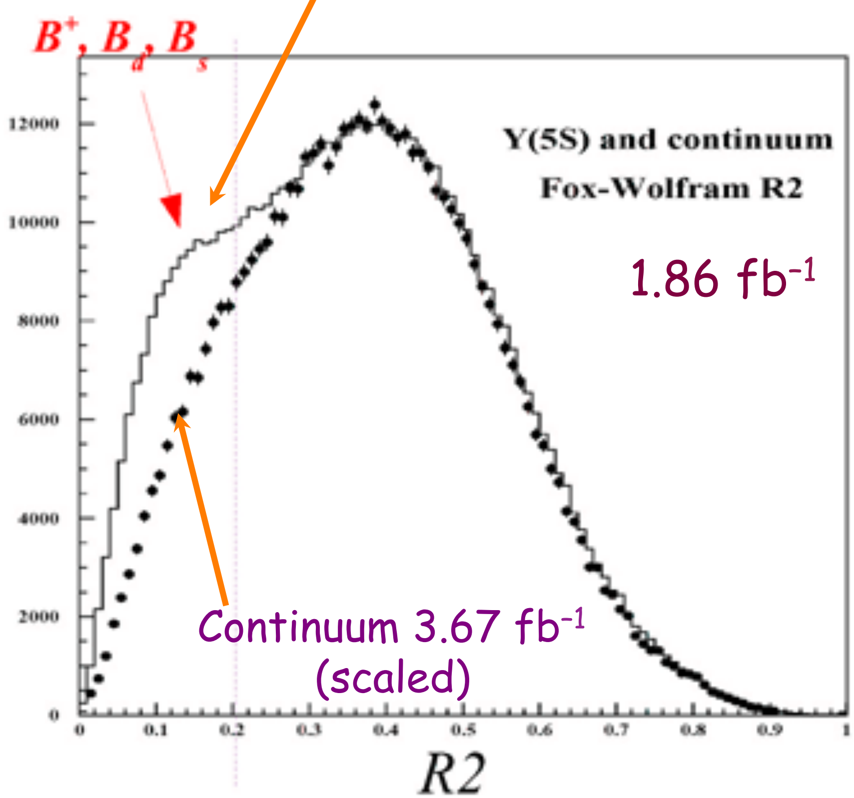
121.4 fb^{-1} @ 10.865±1GeV

+15 x 1 fb^{-1}, +61 x 50 pb^{-1} @10.68-10.11.02

$\sigma(b\bar{b})$

Event count

$(3.40\pm0.16)\times10^{5}$ events/fb^{-1} (121.4 fb^{-1})



Event shape parameter
(Fox-Wolfram moments)

$$R_2 = \frac{\sum_{i,j} |p_i||p_j| \underbrace{P_2(\cos\theta)}_{3x^2-1}}{\sum_{i,j} |p_i||p_j| \underbrace{P_0(\cos\theta)}_{1}}$$

2-jet $e^+e^- \to q\bar{q}$ $R_2 \to 1$

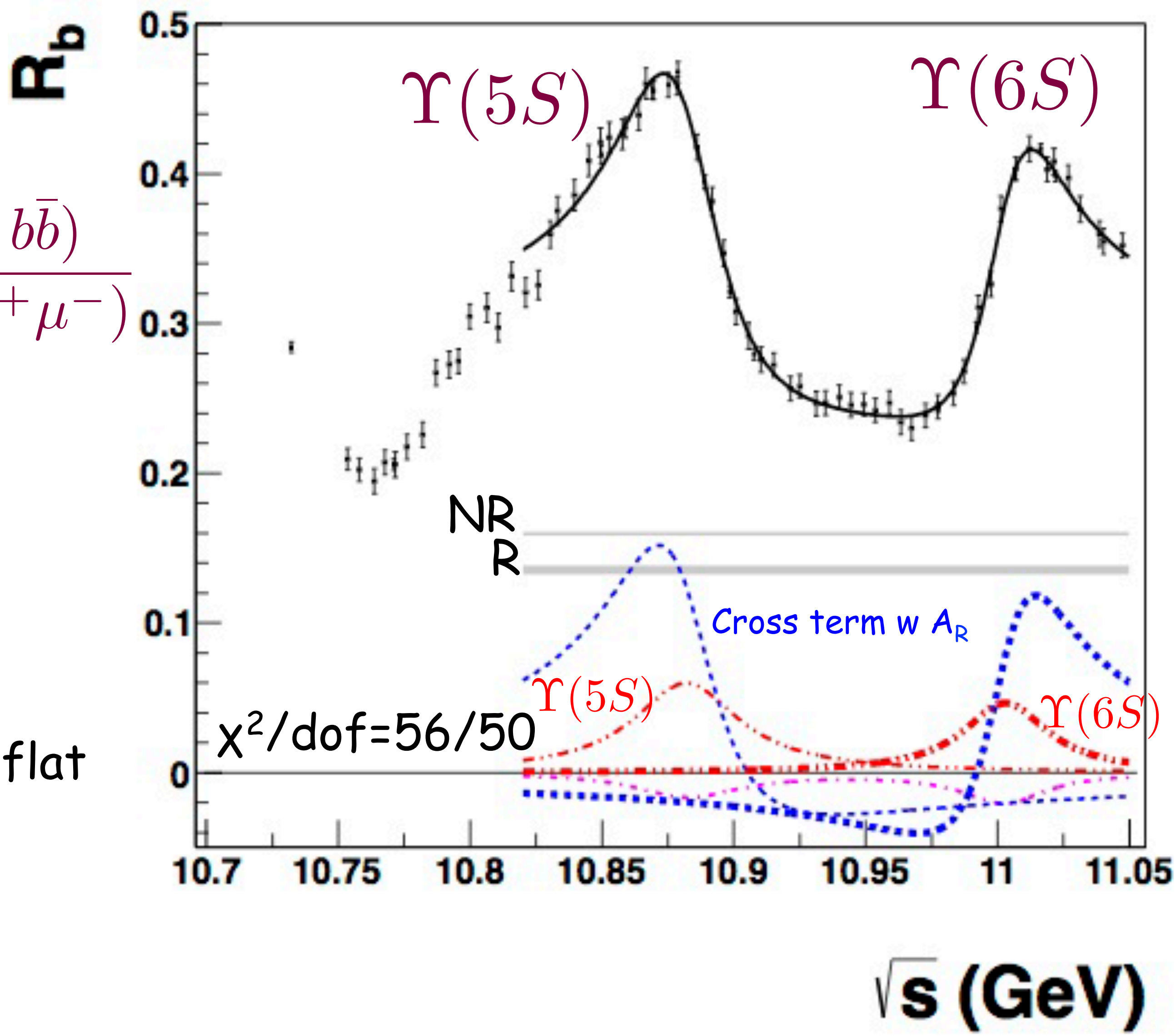
$e^+e^- \to B\bar{B}$ $R_2 \to 0$

Contributions of initial-state radiation calculated, subtracted

$$e^+e^- \to \gamma\gamma^*$$
$$\gamma^* \to \Upsilon(1/2/3S)$$

$\sigma(b\bar{b})$

$$R_b \equiv \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



Fitted for 2 BW's + flat "continuum" w/wo interference

$$|A_{NR}|^2 +$$
$$|A_R + A_{5S}e^{i\phi_{5S}}BW(M_{5S},\Gamma_{5S}) + A_{6S}e^{i\phi_{6S}}BW(M_{6S},\Gamma_{6S})|^2$$

$\sigma(b\bar{b})$

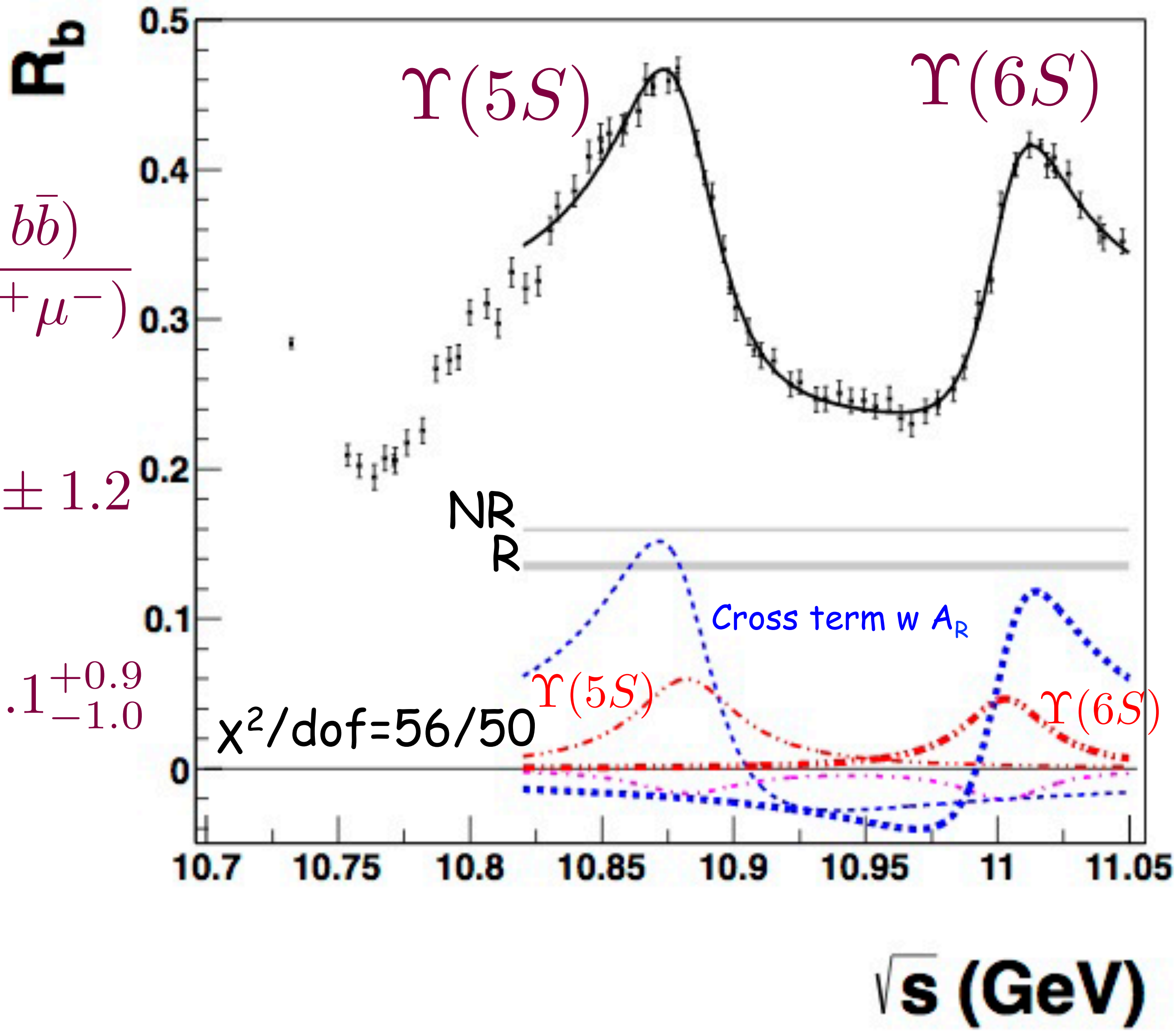
$$R_b \equiv \frac{\sigma(e^+e^- \to b\bar{b})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

$$M_{5S} = 10881.8^{+1.0}_{-1.1} \pm 1.2$$

$$\Gamma_{5S} = 48.5^{+1.9+2.0}_{-1.8-2.8}$$

$$M_{6S} = 11003.0 \pm 1.1^{+0.9}_{-1.0}$$

$$\Gamma_{6S} = 39.3^{+1.7+1.3}_{-1.6-2.4}$$



$$|A_{NR}|^2 +$$
$$|A_R + A_{5S}e^{i\phi_{5S}}BW(M_{5S},\Gamma_{5S}) + A_{6S}e^{i\phi_{6S}}BW(M_{6S},\Gamma_{6S})|^2$$

$\sigma(e^+e^- \to \Upsilon(nS)\pi^+\pi^-)$

- event-by-event efficiency correction over Dalitz space, (reduce model-dependence)

first fit: as w R_b

$$\underline{PHSP}(E_{CM}) \times (|A_{NR}|^2 + |A_R + A_{5S}e^{i\phi_{5S}}BW(M_{5S},\Gamma_{5S}) + A_{6S}e^{i\phi_{6S}}BW(M_{6S},\Gamma_{6S})|^2)$$

Final fit (simultaneous for 3 Υ's)

- find $|A_{NR}|$, $|A_R|$ small -> set = 0
- possible differences in substructure btw Υ(5S), Υ(6S)
  -> "decoherence coeffficient" = $ke^{i\delta}$ (0<k<1)

$$PHSP(E_{CM}) \times |A_{5\mathrm{S}}BW_{5\mathrm{S}}|^2 + |A_{6\mathrm{S}}BW_{6\mathrm{S}}|^2 + 2kA_{5\mathrm{S}}A_{6\mathrm{S}}\Re[e^{i\delta}BW_{5\mathrm{S}}BW^*_{6\mathrm{S}}]$$

- (k consistent w 1)

$\sigma(e^+e^- \to \Upsilon(nS)\pi^+\pi^-)$

$$R_{\Upsilon\pi\pi} \equiv \frac{\sigma(e^+e^- \to \Upsilon(nS)\pi^+\pi^-)}{\sigma(e^+e^- \to \mu\mu)}$$

$$M_{5S} = 10891.1 \pm 3.2^{+0.6}_{-1.5}$$

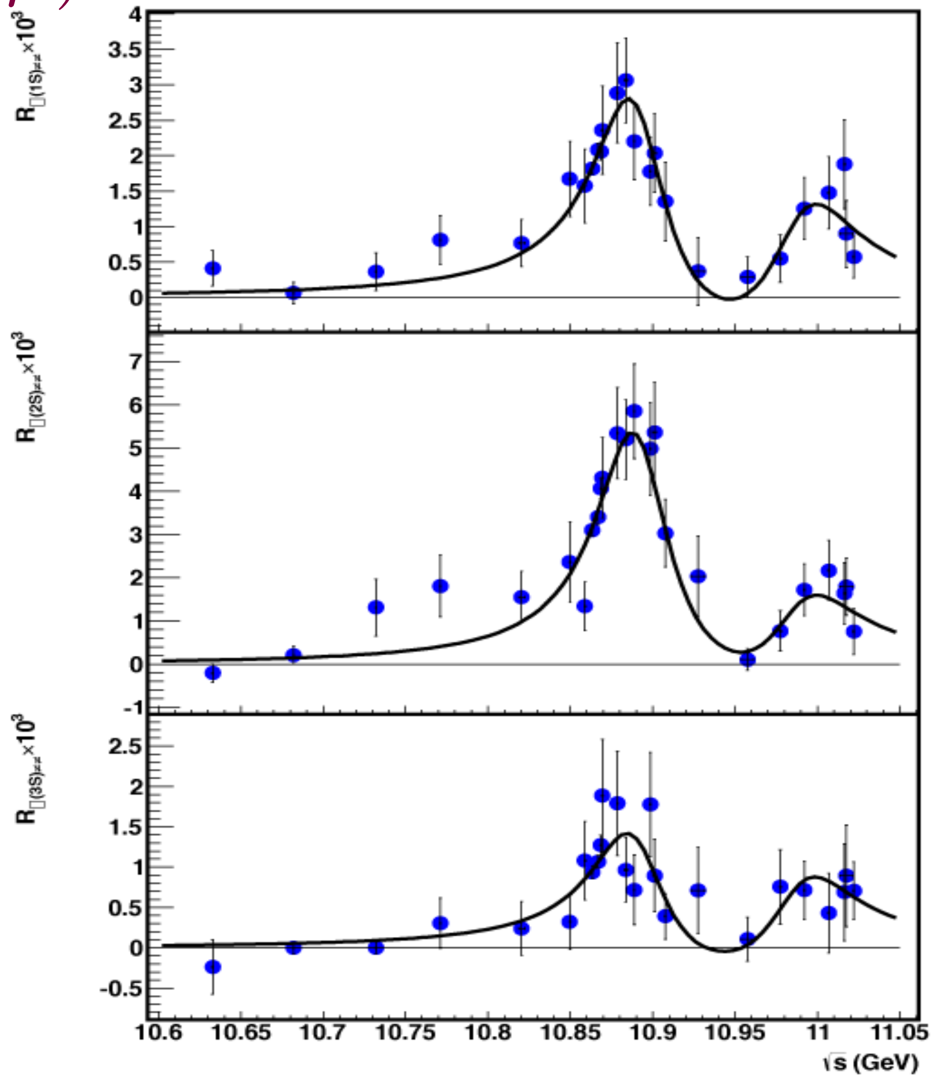
$$\Gamma_{5S} = 53.7^{+7.1+0.9}_{-5.6-5.4}$$

$$M_{6S} = 10987.5^{+6.4+9.0}_{-2.5-2.1}$$

$$\Gamma_{6S} = 61^{+9}_{-19}{}^{+2}_{-20}$$

$\Upsilon\pi\pi$ *vs* $b\bar{b}$

$\boxed{\Delta Mc^2 = 9.3 \pm 3.9 \text{ MeV}}$



Reconcile results $R_b, \ R_{\Upsilon\pi\pi}$

Contribution of bottomonium modes to Υ(10860) resonance

$$PHSP(E_{CM}) \times |A_{5\mathrm{S}} BW_{5\mathrm{S}}|^2 + |A_{6\mathrm{S}} BW_{6\mathrm{S}}|^2$$
$$+2kA_{5\mathrm{S}} A_{6\mathrm{S}} \Re[e^{i\delta} BW_{5\mathrm{S}} BW^*_{6\mathrm{S}}]$$

P

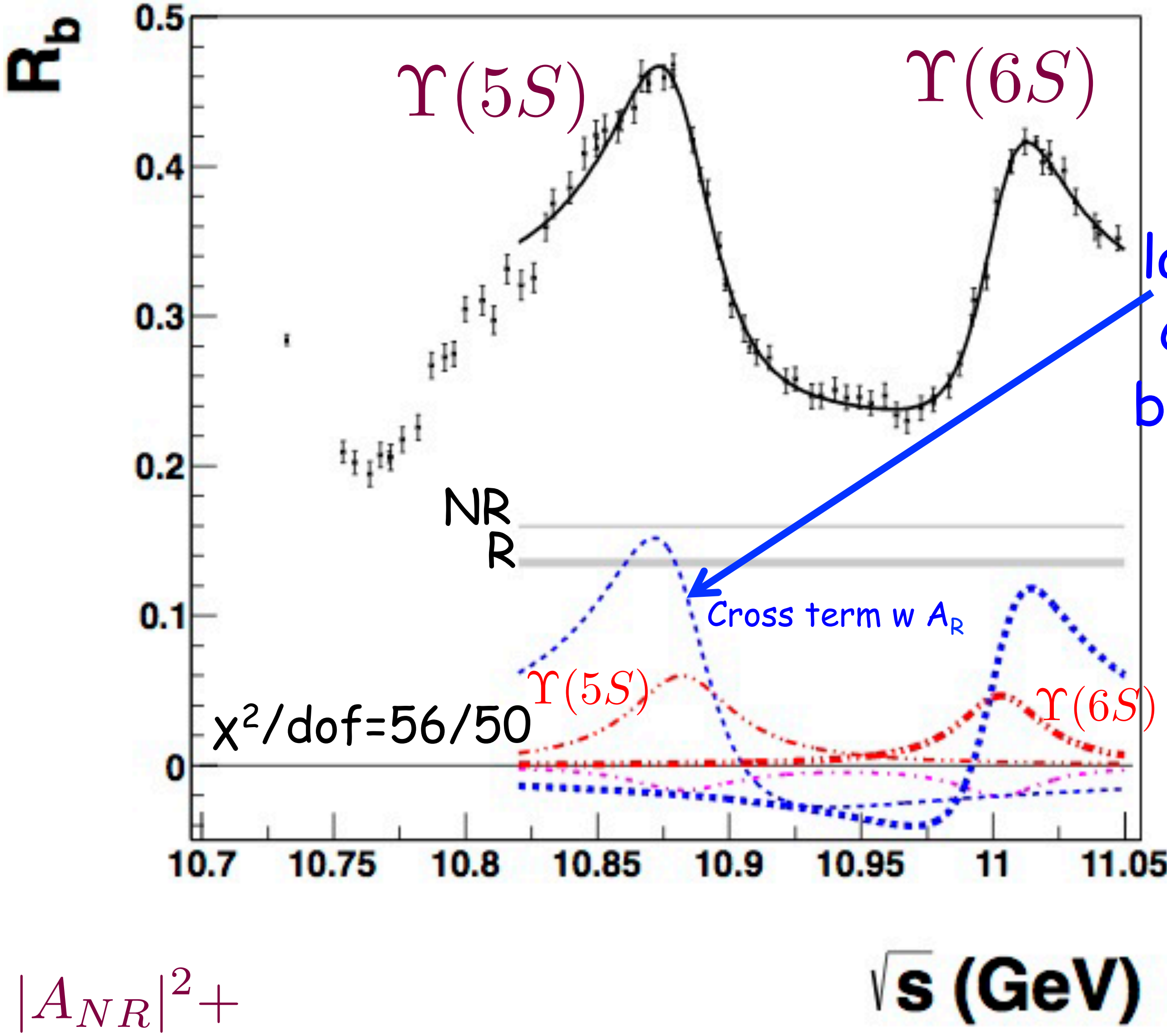
$$\mathcal{P} \equiv \frac{\sum_n P_n}{P_b}$$

= 0.42±0.04 all $\Upsilon\pi\pi$, $h_b\pi\pi$

= 1.09±0.15 with $B^*B^{(*)}\pi$

??Appears to saturate b cross section w/o $B^{(*)}$, $B_s^{(*)}$ pairs

Look again at fit R_b



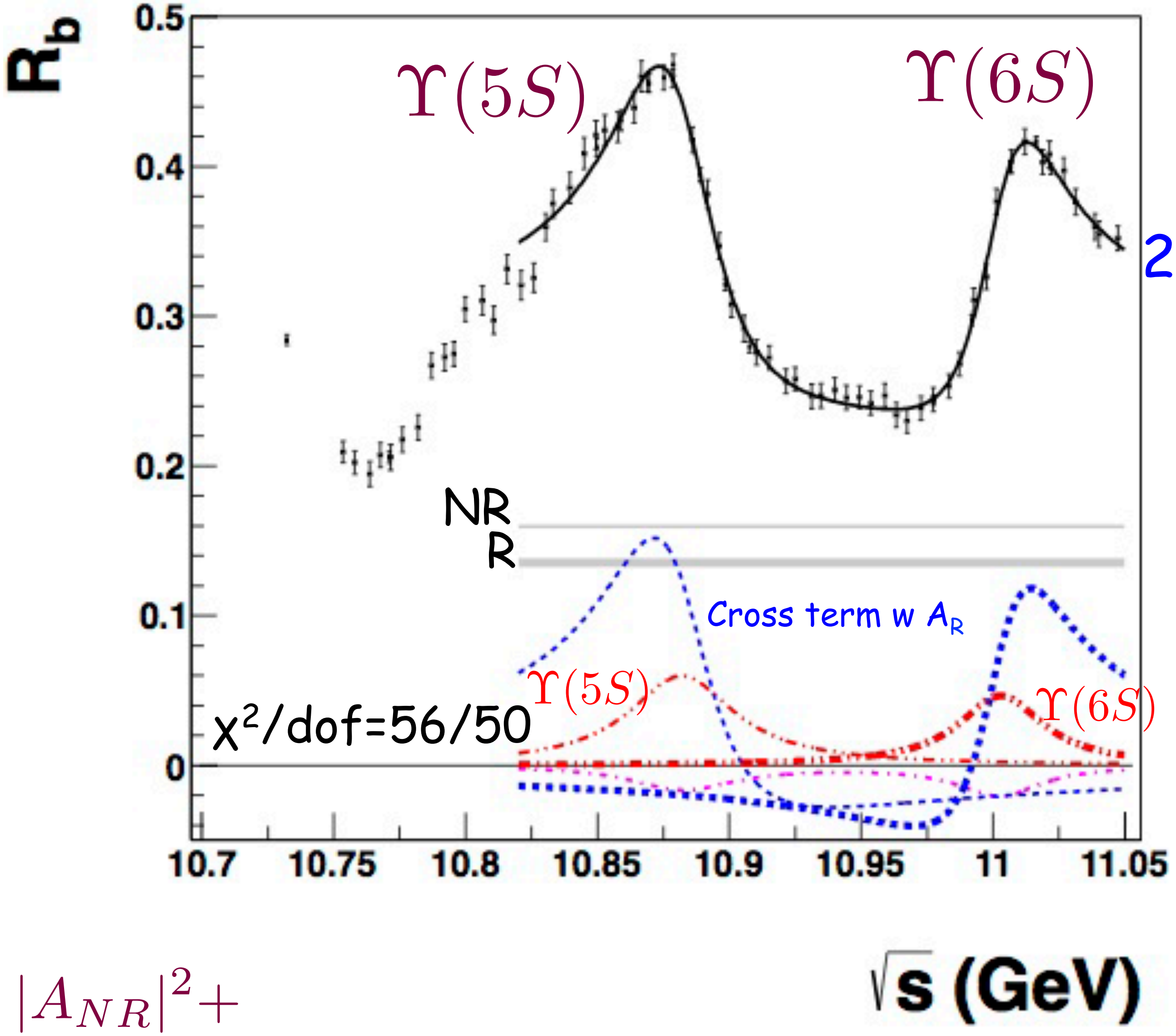
Paradox?

large interference, cannot come from bottomonium modes

but bottomonium saturate amplitude?!

$$|A_{NR}|^2 +$$
$$|A_R + A_{5S} e^{i\phi_{5S}} BW(M_{5S}, \Gamma_{5S}) + A_{6S} e^{i\phi_{6S}} BW(M_{6S}, \Gamma_{6S})|^2$$

Look again at fit R_b



Paradox?

2 resonances + flat continuum is probably too simple to describe R_b in this region

$$|A_{NR}|^2 +$$
$$|A_R + A_{5S} e^{i\phi_{5S}} BW(M_{5S}, \Gamma_{5S}) + A_{6S} e^{i\phi_{6S}} BW(M_{6S}, \Gamma_{6S})|^2$$

K. Kinoshita

Summary

Rich structure in region of $\Upsilon(10860)$

- $e^+e^- \to \{b\bar{b}\}\pi\pi$

  New states $Z_b^+(10610)$, $Z_b^+(10650)$
  Seen to decay to BB*, B*B*
  Evidence for neutral Z_b

- new questions raised by R_b, $R_{\Upsilon\pi\pi}$ vs E_{CM}
  what is $\Upsilon(10860)$?
  - High rate to bottomonia, Z_b's -> Y_b?
  - masses from R_b, $R_{\Upsilon\pi\pi}$ marginally consistent
    are the "$\Upsilon(5S)$" the same?
  - apparent paradox in rates -> doubt on R_b "model"
- to be continued…
  $B^{(*)}{}_{(s)}$ modes vs E_{CM}