Belle Results from e^+e^- annihilation in the vicinity of $\Upsilon(5S)$

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For the Belle Collaboration

Heavy Quarks & Leptons 2016
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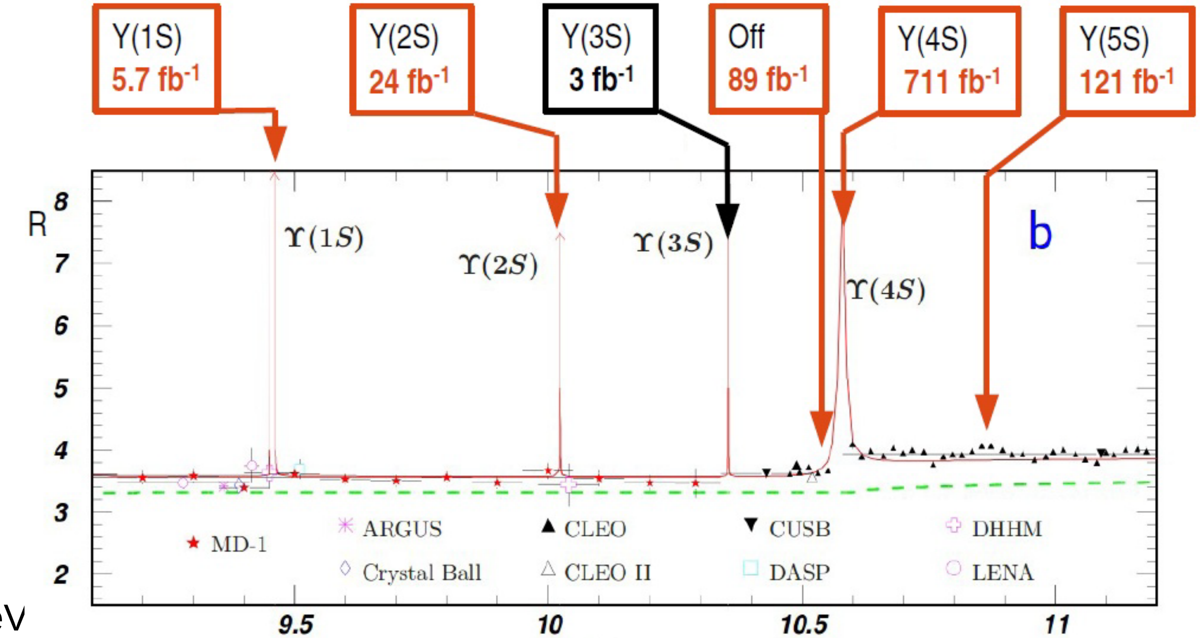
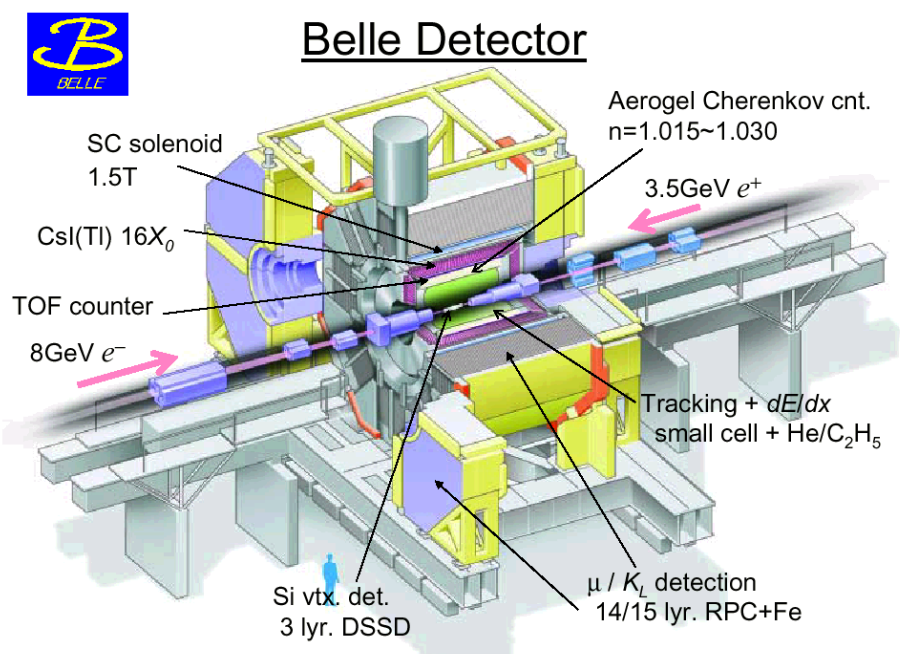
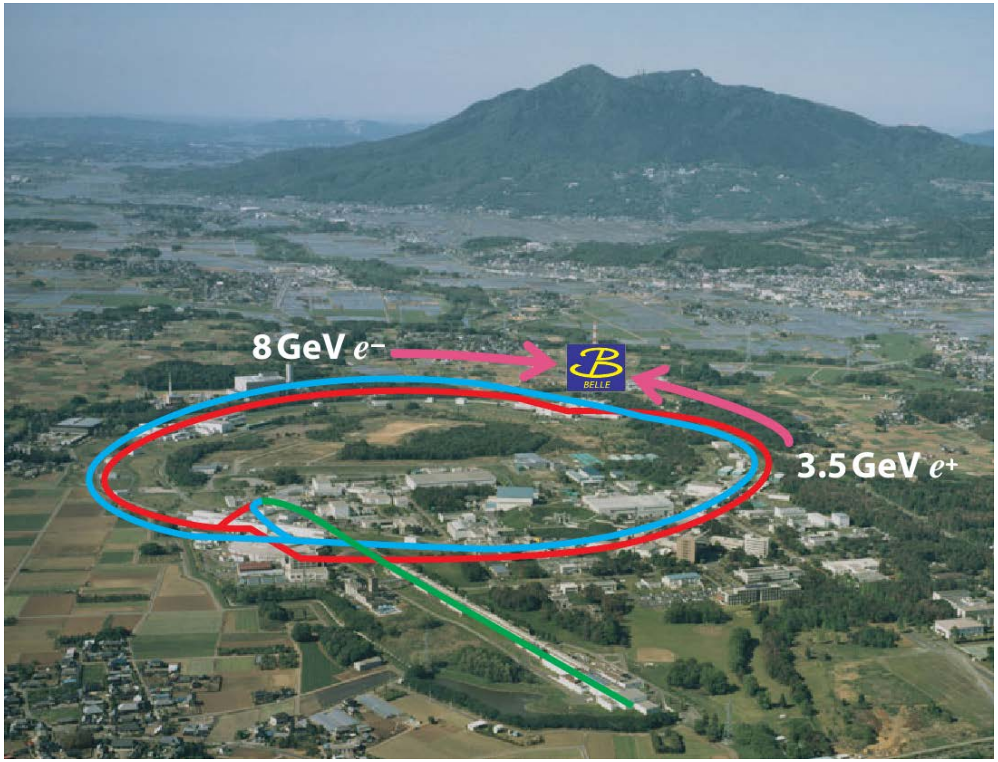
Belle @ KEK

- @KEKB Asymmetric e+e- collider
- Mainly operated at $\Upsilon(4S)$
- World's largest data samples at most bottomonium resonances



- Focus:
  - 121.4 fb^{-1} at $\Upsilon(5S)$
  - ~20 fb^{-1} of scan data from about 10.6 to 11.0 GeV





Topics for today's talk

- An unexpected and remarkable bounty of physics results have been obtained from studies at Belle of data taken above the ϒ(4S), especially near the ϒ(10860), usually identified as ϒ(5S)

- My task today is to give a tour of these results, and highlight the most recent results which shed new light on the nature of ϒ(5S) and the charged Z_b states

Advert: two other Belle talks which treat subjects closely related to the present talk:

Saurabh Sandilya, Transitions and Decays of Bottomonium States
(Spectroscopy II, today, 10:55)

Bilas Pal, Charmless B_s Decays
(Rare Decays II, Thursday, 16:55)

Topics for today's talk

- Brief synopsis of older results and historical developments using the $\Upsilon(5S)$ data sample at Belle
- Measurement of various cross sections as a function of energy in the range 10.63-11.02 GeV (the $\Upsilon(5S)$ and $\Upsilon(6S)$ region)
  - Measurement of R_b
  - Measurement of cross sections for $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$
  - And for $e^+e^- \to \pi^+\pi^- h_b(n\mathrm{P})$
- Measurement of $e^+e^- \to B^*\bar{B}^{(*)}\pi$ at the $\Upsilon(5S)$and the Z_b

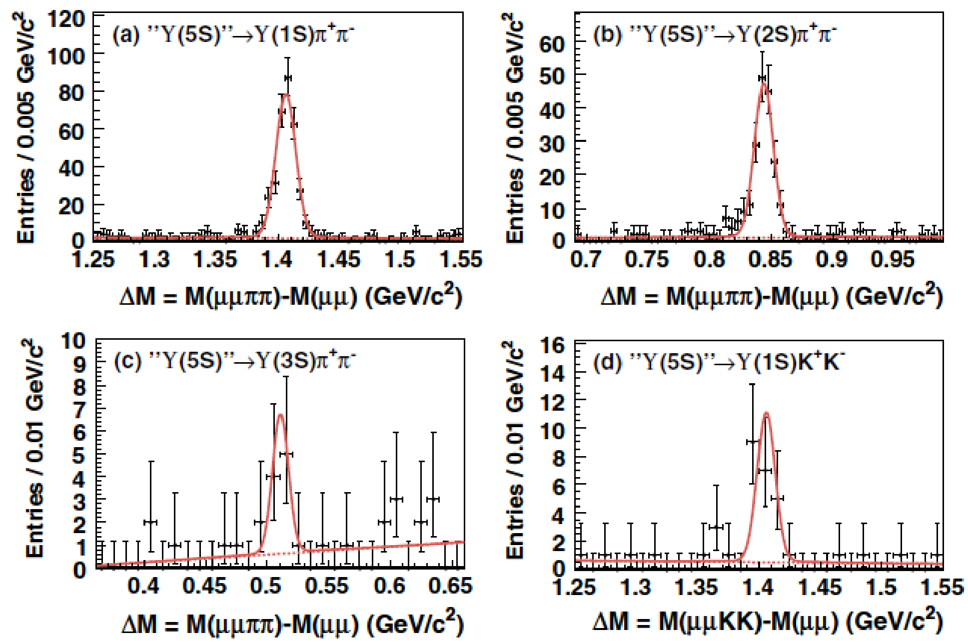
Observation of Anomalously Large Cross Sections

- The Υ(5S) has been the subject of interest in terms of its nature since its discovery by CUSB and CLEO in 1985

- In 2008 with ~24 fb^{-1} of e^+e^- annihilations taken at the Υ(5S), Belle reported a remarkable discovery – anomalously high rates for transitions to lower bottomonia

	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



K.-F. Chen, et al (Belle) PRL 100, 112001 (2008)

Scan of Υ(5S) region to study these anomalies

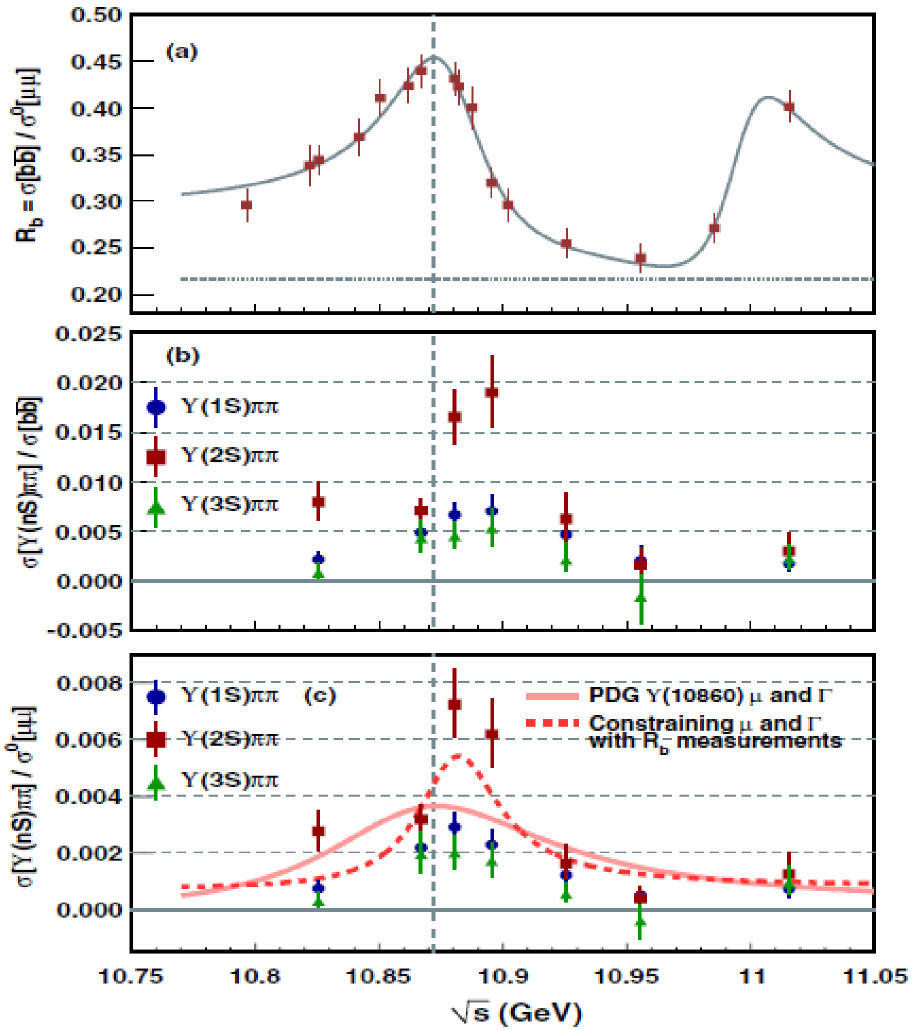
- Subsequently Belle undertook a scan of the region at and above ϒ(5S)

- A discrepancy observed between the peak of cross sections for bb vs ϒ ππ

  R_b : M = 10879 +/- 3 MeV

  $R_{\Upsilon\pi\pi}$: M = 10888 +/- 3 MeV

- Only a 2σ difference: 9 +/- 4 MeV, but led to speculation about a mixing of ϒ(5S) with a Y_b analogous to the Y(4260) in the charmonium region

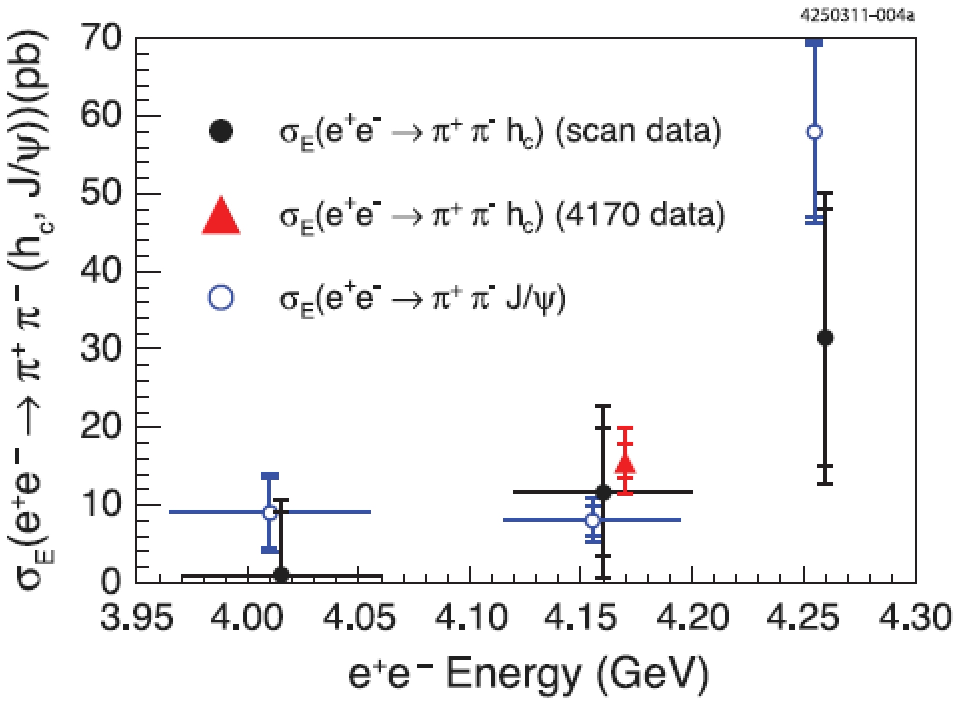


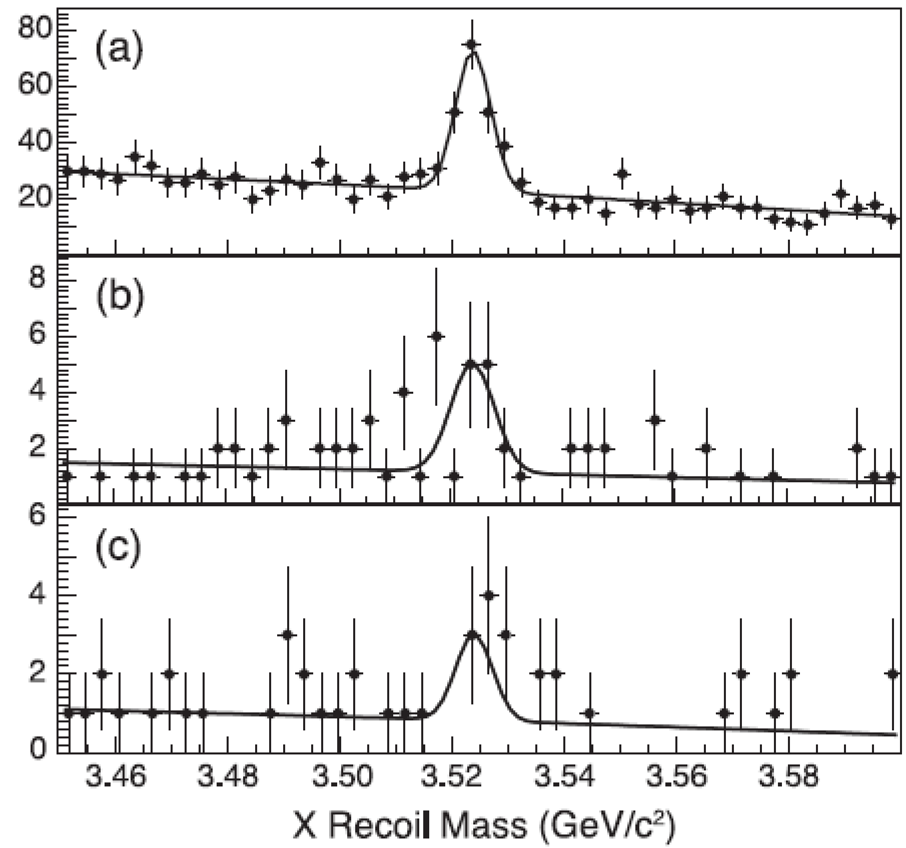
K.-F. Chen, et al (Belle) PRD 82, 091106 (2010)

These anomalies motivate a much increased data sample in the ϒ(10860) region (121.4 fb^{-1} plus scan data)

2010 observation by CLEO of $\pi\pi$ h_c in data taken above open charm threshold motivates h_b searches at Υ(5S)

- CLEO reported observation of $\pi\pi$ h_c at ψ(4160) and an indication of even higher rates at Y(4260)





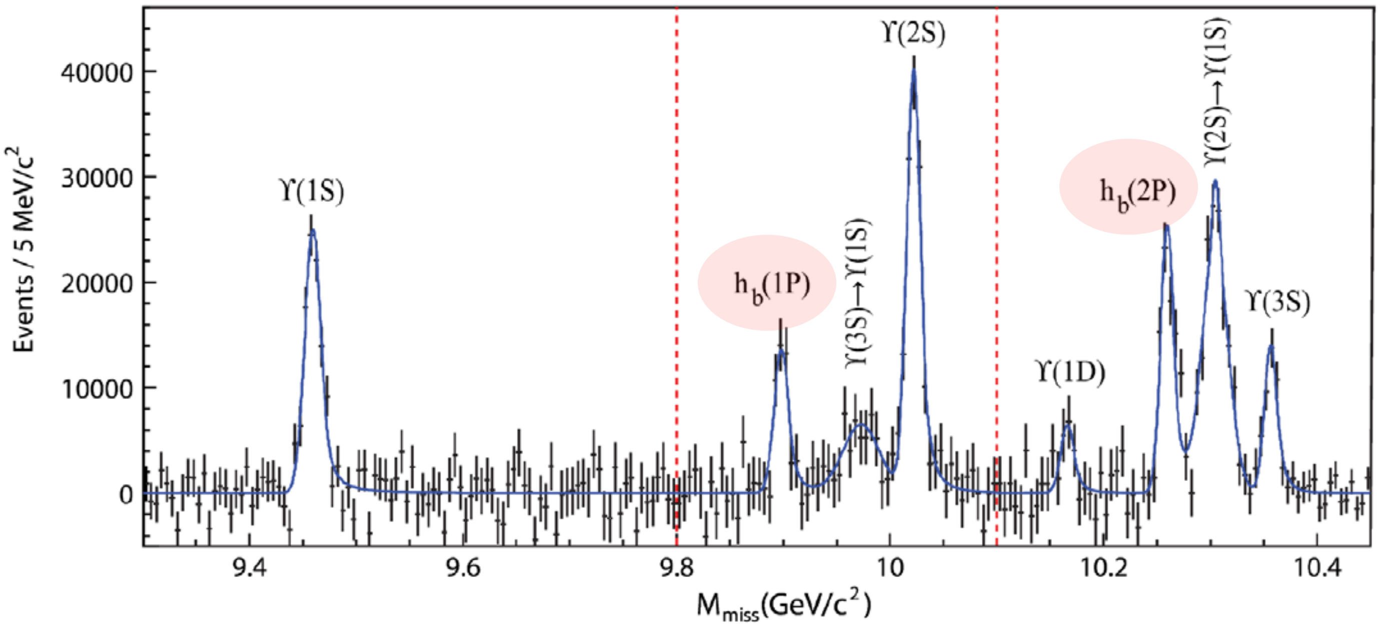
T. K. Pedlar et al (CLEO) PRL 107, 041803 (2011)

Naturally a search ensued at Belle, given the already known anomalies at Υ(10860) and this result

Discovery of h_b

I. Adachi et al (Belle) PRL 107, 041803 (2011)

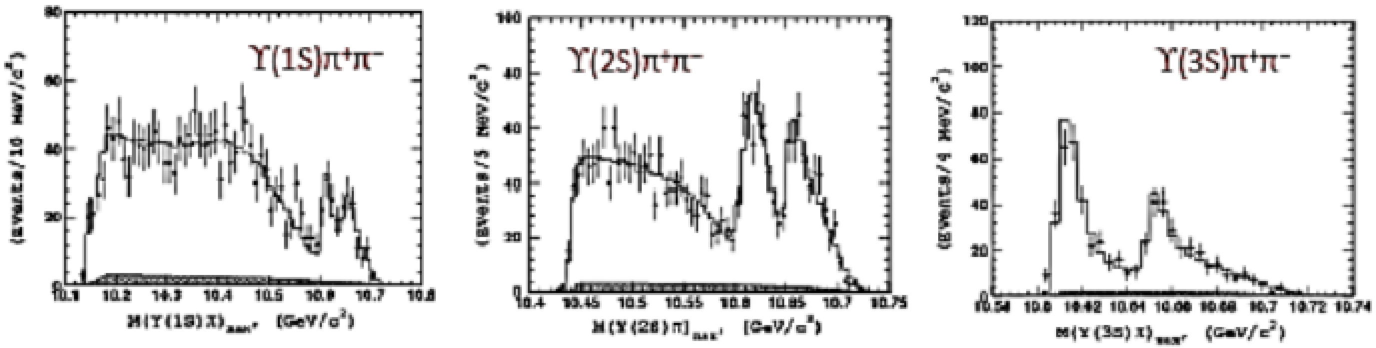
Searches in ππ missing mass spectrum lead to discovery of the two lowest lying singlet P states in bottomonium

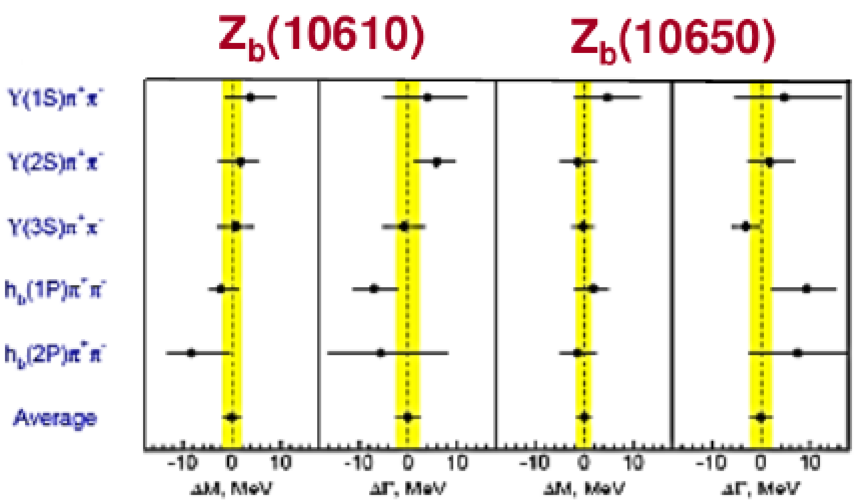


- The rates for these decays are even more intriguing than the rates of Υ(5S) to ππΥ(nS) (and very reminiscent of Y(4260))
- If these were direct three-body decays, these transitions require heavy quark spin flip, which must necessarily cause a suppression relative to ππΥ(nS)
- Natural to ponder the reason these transitions occur so readily

Anomalously large h_b production leads to study of resonant substructure: and another discovery

A. Bondar et al (Belle) PRL 109, 122001 (2012)





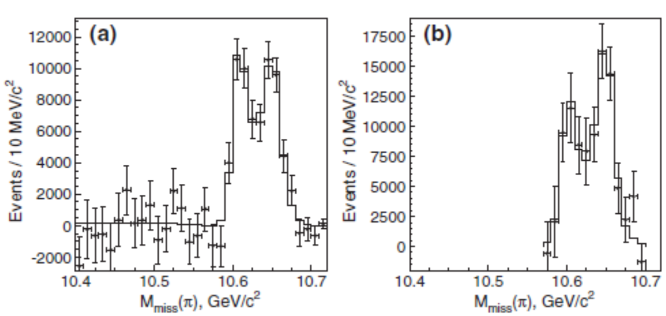
Average for $Z_b^{\pm}$:

$$\langle M_1 \rangle = 10607.2 \pm 2.0 \text{ MeV}$$
$$\langle \Gamma_1 \rangle = 18.4 \pm 2.4 \text{ MeV}$$

$$\langle M_2 \rangle = 10652.2 \pm 1.5 \text{ MeV}$$
$$\langle \Gamma_2 \rangle = 11.5 \pm 2.2 \text{ MeV}$$

Resonant substructure reveals that all $\Upsilon\pi\pi$ and $h_b\pi\pi$ processes show evidence of Z_b states

In the case of transitions to $h_b\pi\pi$ all production occurs through an intermediate Z_b



Min. 4-quark content (2 b quarks and charged)

Masses very near BB* and B*B* thresholds! Suggests relationship to them (Molecules?)

At this point we are left with (at least) the following interesting open questions

- Can the marginal discrepancy between the $b\bar{b}$ and the $\Upsilon\pi\pi$ cross sections be resolved?

- Can we learn anything about the $\Upsilon(5S)$ and $\Upsilon(6S)$ from studies of the $h_b\pi\pi$ cross section vs. $\sqrt{s}$? (and do the Z_b continue to saturate the rate for $h_b\pi\pi$ above $\Upsilon(5S)$?)

- Can we learn anything about the nature of the Z_b states as possibly molecular by looking at the $[B^{(*)}\ B^{(*)}]^{\mp}\pi^{\pm}$ cross sections in this region?

$b\bar{b}$ Cross Sections

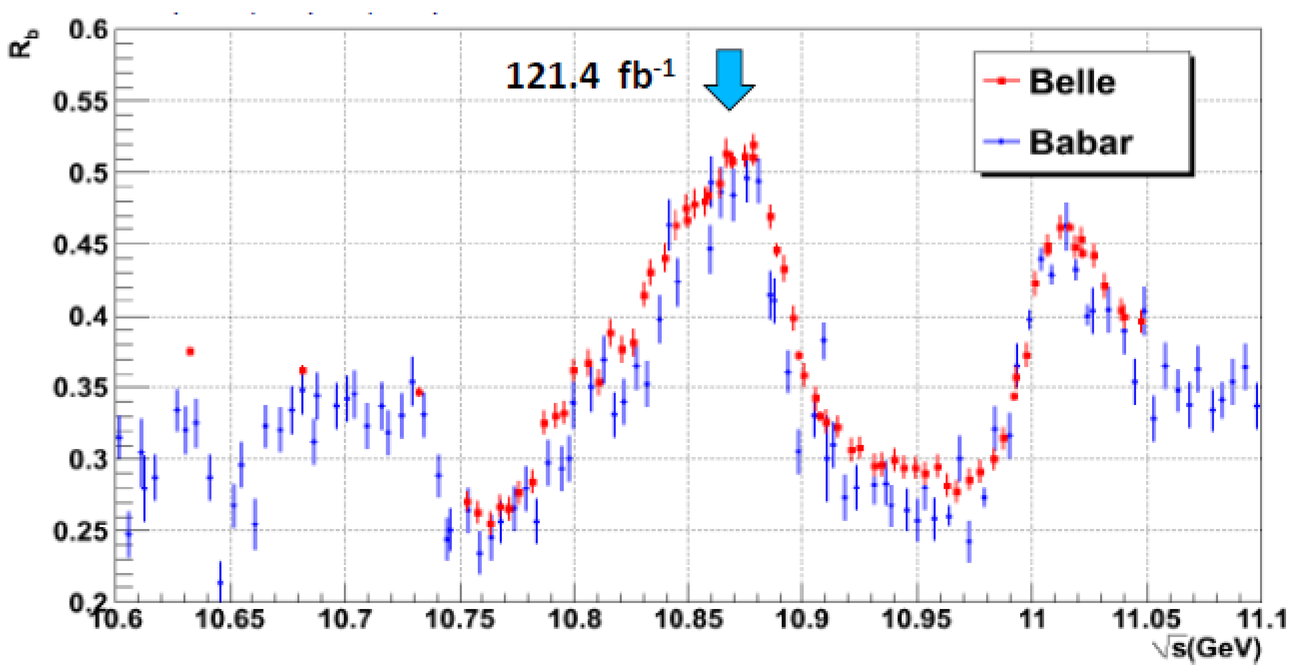
$$R_b \equiv \sigma(b\bar{b})/\sigma^0_{\mu\mu}$$

2010 energy scan:
16 points 1fb^{-1} for $\sigma[\Upsilon(nS)\,\pi\pi]$
61 point 50pb^{-1} 5MeV step for R_b
continuum point 1fb^{-1} @ 10.52GeV
Use also:

2007 energy scan: 6 points ~1fb^{-1}
Υ(5S) on-resonance point 121fb^{-1}

$$N_i = \mathcal{L}_i \times \left[\sigma_{b\bar{b},i}\epsilon_{b\bar{b},i} + \sigma_{q\bar{q},i}\epsilon_{q\bar{q},i} + \sum \sigma_{\mathrm{ISR},i}\epsilon_{\mathrm{ISR},i}\right]$$

R_b : Remove qq using continuum data
R_b' : also remove ISR using simulation

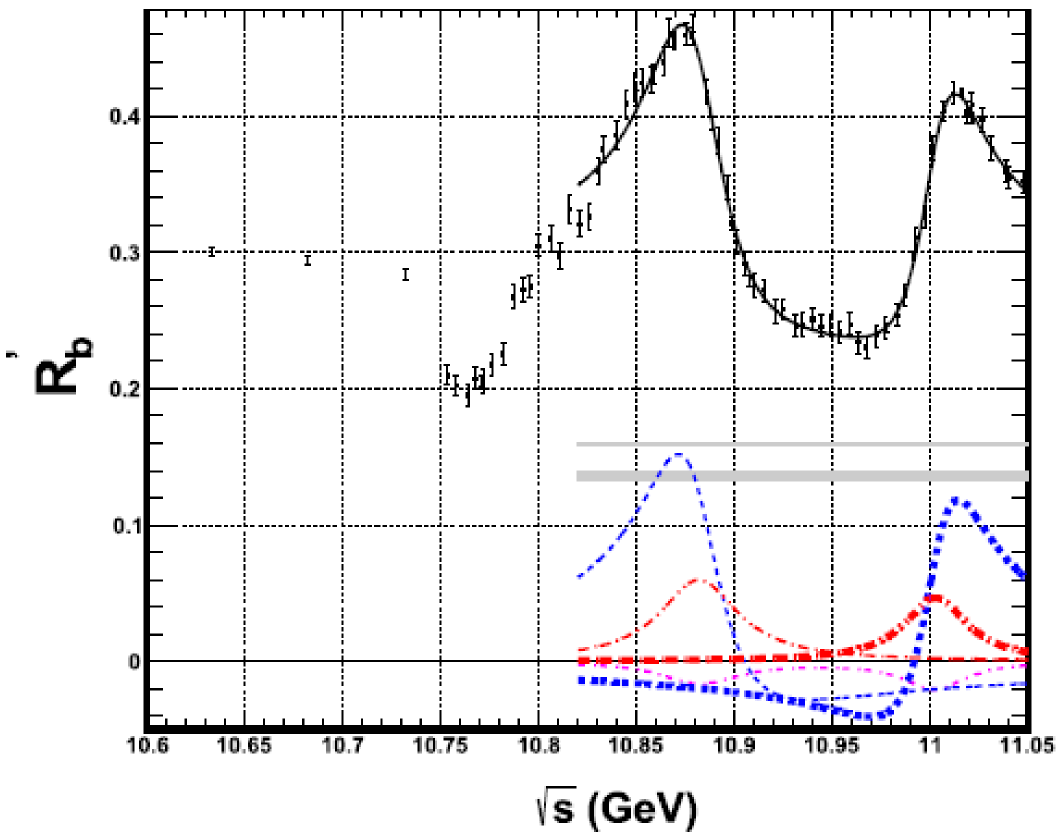


- BaBAR did not remove ISR contribution (so for comparison, we did not)
- Belle R_b slightly higher but consistent with BaBAR

D. Santel et al (Belle) PRD 93, 011101(R) (2016)

B. Aubert *et al.* (BABAR) PRL 102, 012001 (2009)

$b\bar{b}$ Cross Sections



- Fit the R_b' spectrum to

$$\mathcal{F}(\sqrt{s}) = |A_{\rm ic}|^2 + |A_{\rm c} + A_{5S}e^{i\phi_{5S}}f_{5S}(\sqrt{s}) + A_{6S}e^{i\phi_{6S}}f_{6S}(\sqrt{s})|^2,$$

- interference with flat continuum (A_c)
- Red dot-dot-dashed curve is the resonant Υ(5S) and Υ(6S) functions
- Reasonable agreement with BaBAR's resonance parameter results fromtheir similar analysis

Quantity	Belle R_b' Results	Babar R_b Results
M_5	$10881.8^{+1.0}_{-1.1} \pm 1.2$ MeV	10876 ± 2 MeV
Γ_5	$48.5^{+1.9}_{-1.8}{}^{+2.0}_{-2.8}$ MeV	37 ± 3 MeV
M_6	$10987.5 \pm 1.1{}^{+0.9}_{-1.0}$ MeV	10996 ± 2 MeV
Γ_6	$61^{+1.7}_{-1.6}{}^{+1.3}_{-2.4}$ MeV	37 ± 3 MeV

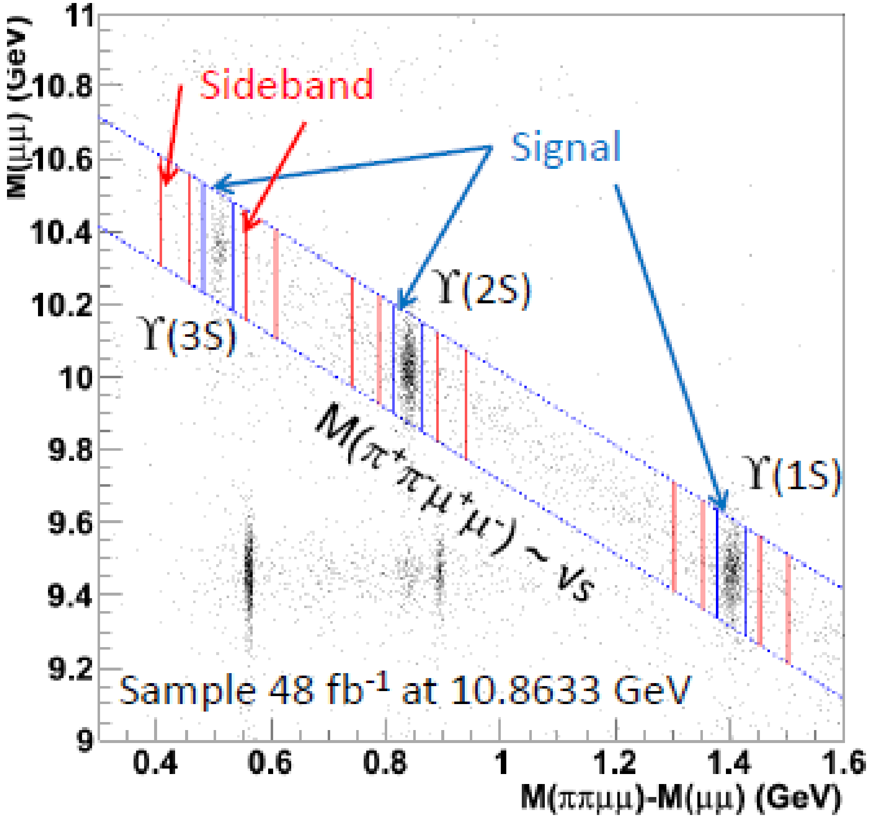
D. Santel et al (Belle) PRD 93, 011101(R) (2016)

B. Aubert *et al.* (BABAR) PRL 102, 012001 (2009)

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

- And now to consider the key motivating question for the new scan: the difference between the resonance peaks in $\pi^+\pi^-\Upsilon(nS)$ as compared to in R_b'
- Data sample: the 121.4 fb^{-1} sample near 10.866 GeV and 22 scan points each of ~1 fb^{-1} from 10.63-11.02 GeV
- Event selection includes the requirement of exactly four charged tracks (identified as $\pi^+\pi^-\mu^+\mu^-$)

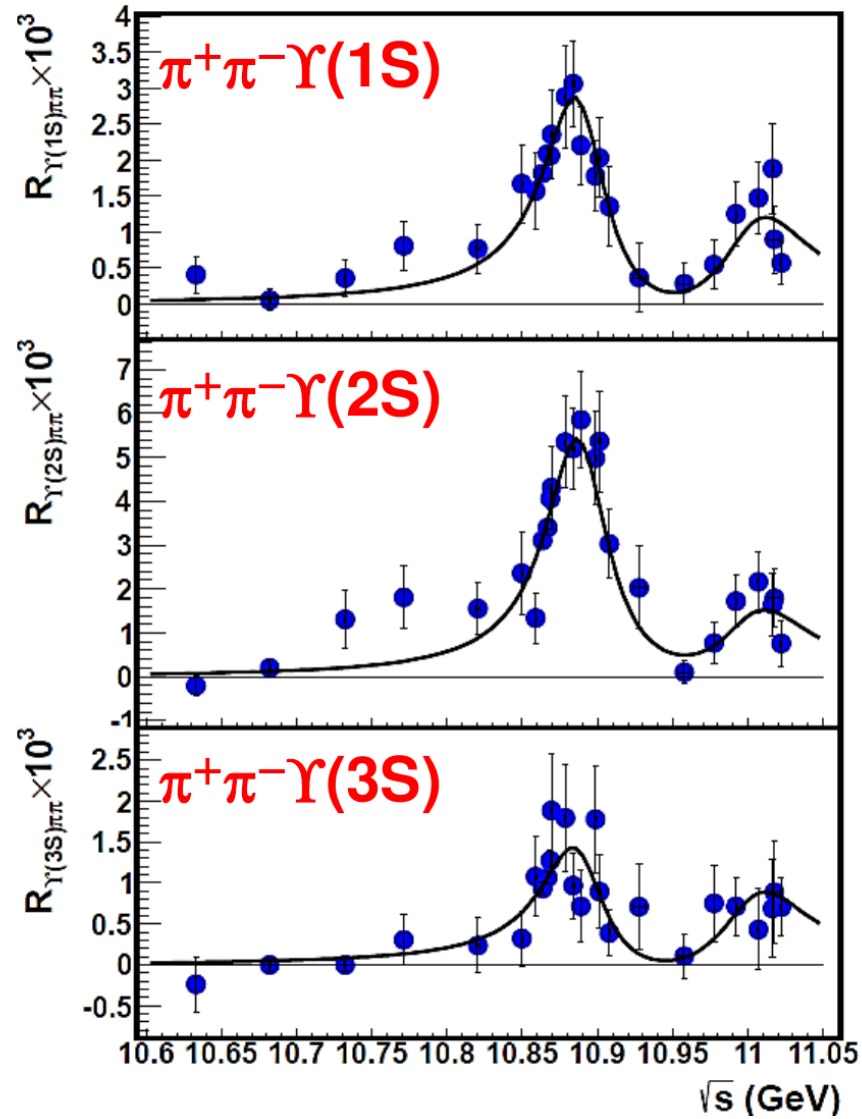
Event Selection



D. Santel et al (Belle) PRD 93, 011101(R) (2016)

$e^+e^- \rightarrow \pi^+\pi^-\Upsilon(nS)$

- At each $\sqrt{s}$ point, obtain the peak yield of $\pi^+\pi^-\Upsilon(nS)$; then plot $R_{\Upsilon(nS)\pi^+\pi^-}$ and fit to two BW amplitudes and possible continuum
- Continuum consistent with zero (marked contrast with R_b' – more on this at the end)
- Compare resonance parameters to those obtained with R_b'



Quantity	From $\pi^+\pi^-\Upsilon(nS)$	From $R_b{}'$
M_5	$10891.1\ 3.2^{+0.6}_{-1.7}$ MeV	$10881.8^{+1.0}_{-1.1} \pm 1.2$ MeV
Γ_5	$53.7^{+7.1}_{-5.6}{}^{+1.3}_{-5.4}$ MeV	$48.5^{+1.9}_{-1.8}{}^{+2.0}_{-2.8}$ MeV
M_6	$10987.5^{+6.4}_{-2.5}{}^{+9.0}_{-2.1}$ MeV	$10987.5 \pm 1.1{}^{+0.9}_{-1.0}$ MeV
Γ_6	$61^{+9}_{-19}{}^{+2}_{-20}$ MeV	$61^{+1.7}_{-1.6}{}^{+1.3}_{-2.4}$ MeV

Consistency between the two is about 2.5σ for $\Upsilon(5S)$ and < 2σ for $\Upsilon(6S)$

D. Santel et al (Belle) PRD 93, 011101(R) (2016)

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

A. Abdsselam et al (Belle)
arXiv:1508.06562

- Until now, no evidence for such transitions except in the large data sample taken at 10.866 GeV, on the $\Upsilon(5S)$ resonance
- Our initial Z_b study showed that while the $\pi^+\pi^-\Upsilon(nS)$ cross section has a large contribution from intermediate Z_b states, $\pi^+\pi^- h_b(n\mathrm{P})$ at 10.866 GeV, **is all due to $\boldsymbol{Z_b}$**
- Enhance $\pi^+\pi^- h_b(n\mathrm{P})$ sample through requirement of consistency with intermediate Z_b :

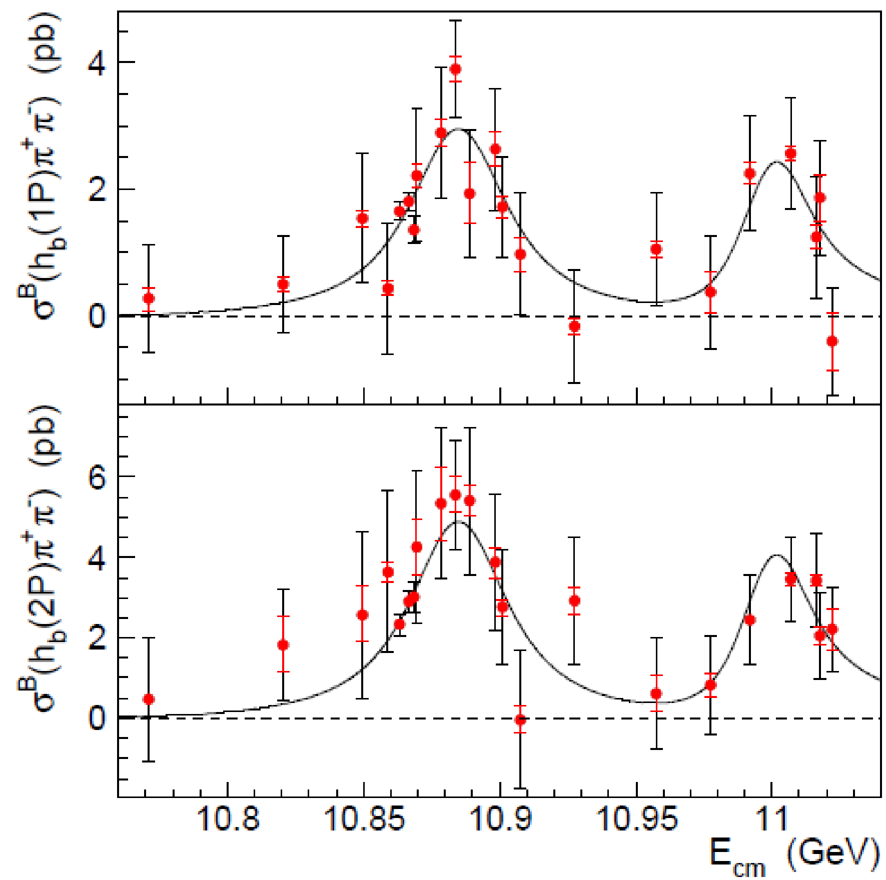
$$10.59\,\mathrm{GeV}/c^2 < M_{\mathrm{miss}}(\pi^{\pm}) < 10.67\,\mathrm{GeV}/c^2$$

- Reconstruct $\pi\pi$ missing mass and fit for yield of h_b at each $\sqrt{s}$ point
- Produce the cross section as a function of $\sqrt{s}$

$e^+e^- \to \pi^+\pi^- h_b(nP)$

A. Abdsselam et al (Belle)
arXiv:1508.06562

- Fit the spectrum of $\pi^+\pi^- h_b(nP)$ cross sections to Breit-Wigner amplitudes for the two resonances and continuum
- Continuum contribution in resulting fit is $< 1.5\sigma$; the default fit does not use it
- Results are consistent with results for the previously described cross sections for $\pi^+\pi^-\Upsilon(nS)$



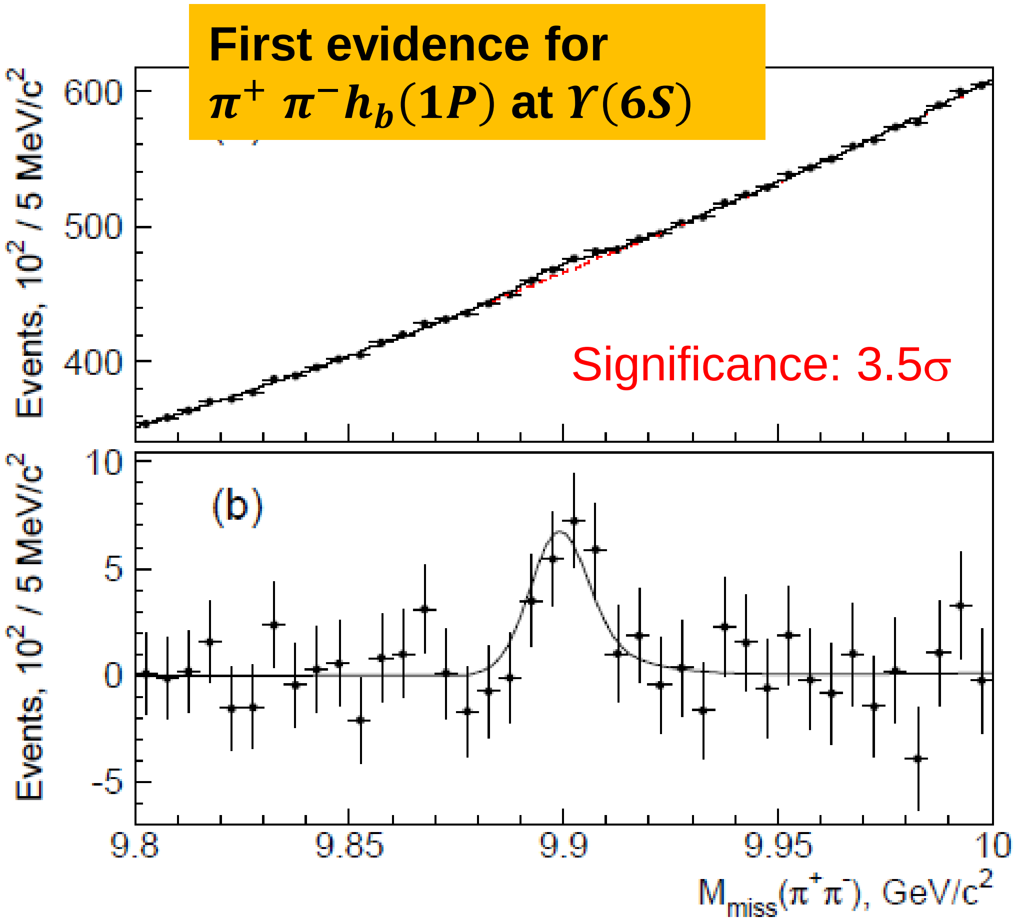
Quantity	From $\pi^+\pi^-\Upsilon(nS)$	From $\pi^+\pi^- h_b(nP)$
M_5	$10891.1\ 3.2^{+0.6}_{-1.7}$ MeV	$10884.7^{+3.6+8.9}_{-3.4-1.0}$ MeV
Γ_5	$53.7^{+7.1}_{-5.6}{}^{+1.3}_{-5.4}$ MeV	$40.6^{+12.7}_{-8.0}{}^{+1.1}_{-19.1}$ MeV
M_6	$10987.5^{+6.4}_{-2.5}{}^{+9.0}_{-2.1}$ MeV	$10999.0^{+7.3}_{-7.8}{}^{+16.9}_{-1.0}$ MeV
Γ_6	$61^{+9}_{-19}{}^{+2}_{-20}$ MeV	$27^{+27}_{-11}{}^{+5}_{-12}$ MeV

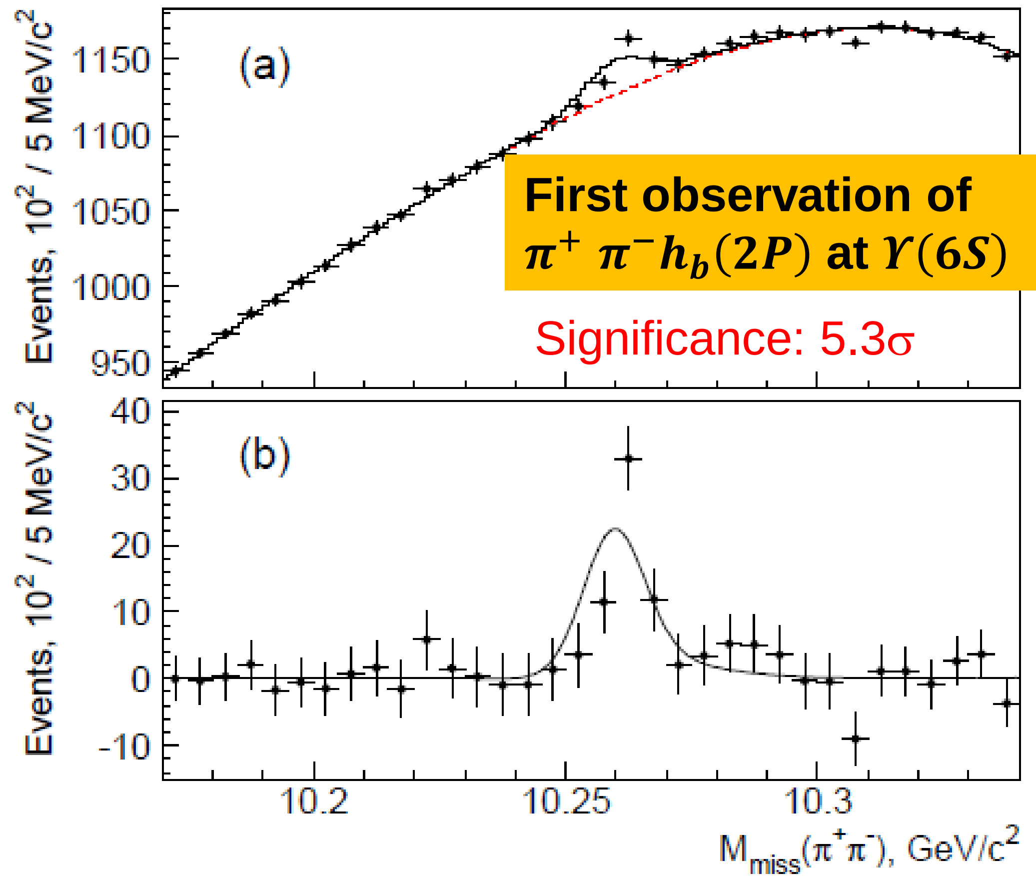
Clear (first) evidence of $\pi^+\pi^- \boldsymbol{h_b}(\boldsymbol{nP})$ at $\Upsilon(6S)$

$e^+e^- \rightarrow \pi^+ \pi^- h_b(n\mathrm{P})$

A. Abdsselam et al (Belle)
arXiv:1508.06562

- When we sum the data in several points on the $\Upsilon(6S)$ resonance, we find:



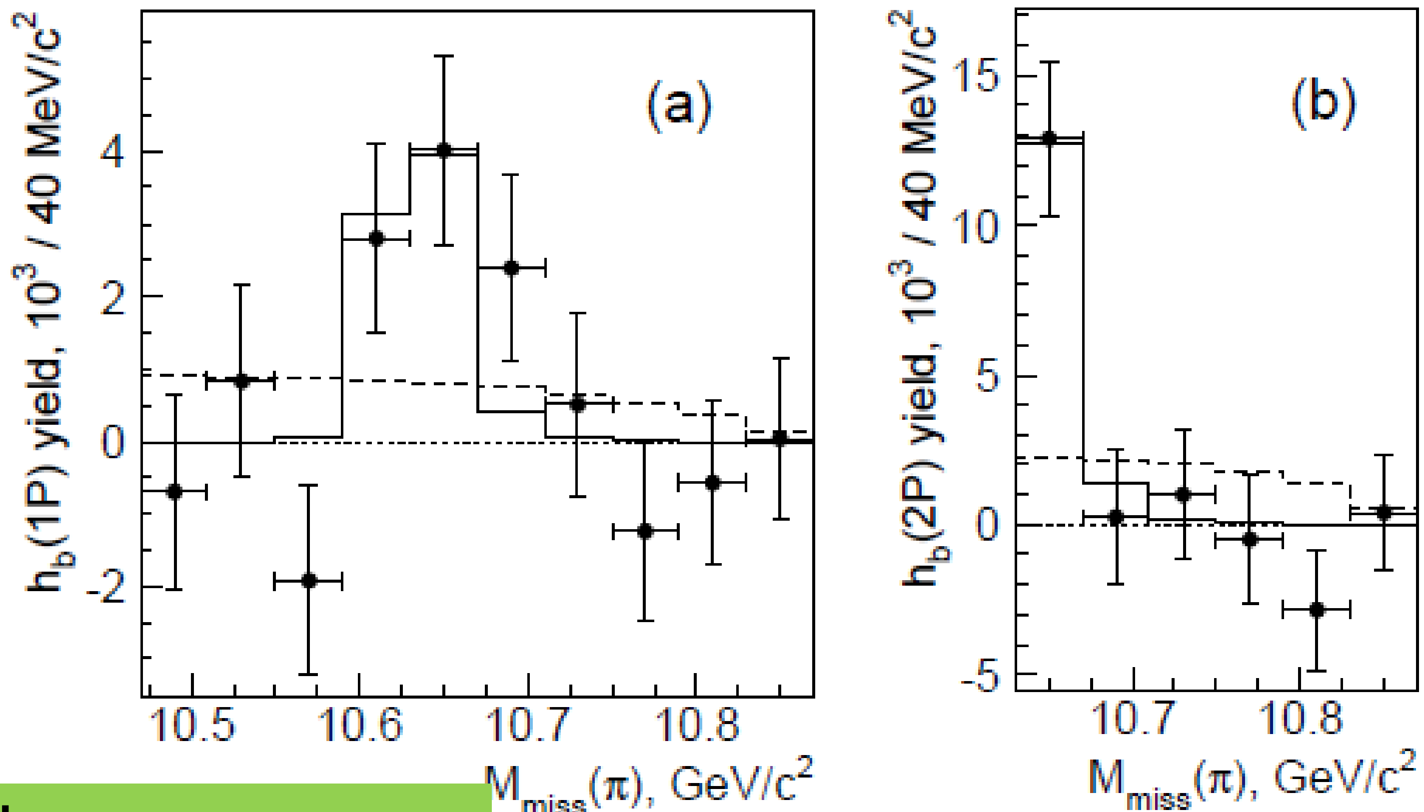


Significance figures include syst errors

$e^+e^- \rightarrow \pi^+ \pi^- h_b(n\mathrm{P})$

A. Abdsselam et al (Belle)
arXiv:1508.06562

To test the cross sections for $\pi^+ \pi^- h_b(n\mathrm{P})$ for contribution from the intermediate charged Z_b states, we again construct the missing mass against single charged pions:



Consistent with dominance of Z_b but statistics insufficient to distinguish contributions from one or both states

For more specificity, must (unfortunately) wait for Belle II

Phase space hypothesis excluded at 3.6σ and 4.5σ

A. Garmash et al (Belle)
arXiv:1512.07419
(accepted, PRL)

Study of $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$

- Our measurements of $e^+e^- \to \pi^+\pi^- h_b(n\mathrm{P})$ are dominated by $e^+e^- \to Z_b^{\pm}\pi^{\mp}$ and we'd like to know more about the nature of these states as potential molecular states of $B^*B^{(*)}$
- This analysis utilizes the full 121 fb^{-1} data sample at 10.866 GeV
- Method: reconstruct a B and π, and examine the missing mass spectrum of $B\pi$:
  - *B* reconstructed in the following modes:
    $$B^+ \to J/\psi K^{(*)+}, \bar{D}^{(*)0}\pi^+;\ B^0 \to J/\psi K^{(*)0}, D^{(*)-}\pi^+$$
  - Signal $BB^*\pi$ events produce a peak in the spectrum at $m(B^*) \approx 5.325\ GeV$
  - Signal $B^*B^*\pi$ events produce a peak in the spectrum at $m(B^*) + (m(B^*) - m(B)) \approx 5.370\ GeV$ due to the fact that a photon from $B^* \to B\gamma$ is not reconstructed

A. Garmash et al (Belle)
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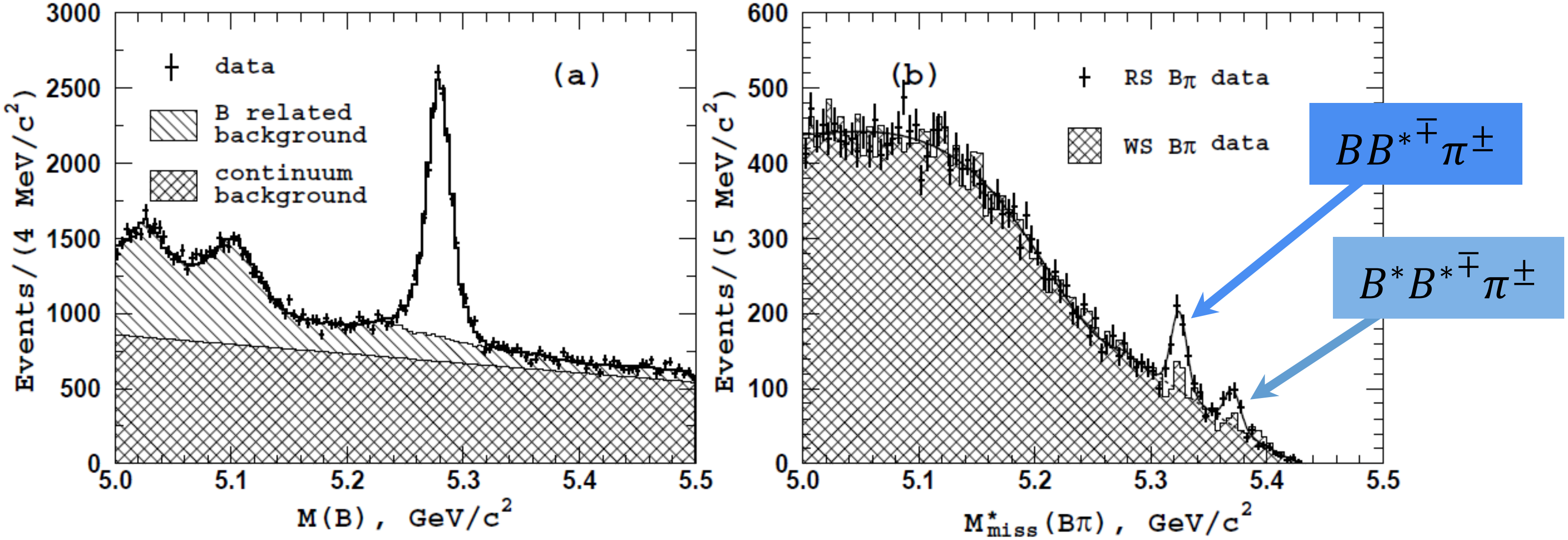
Study of $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$



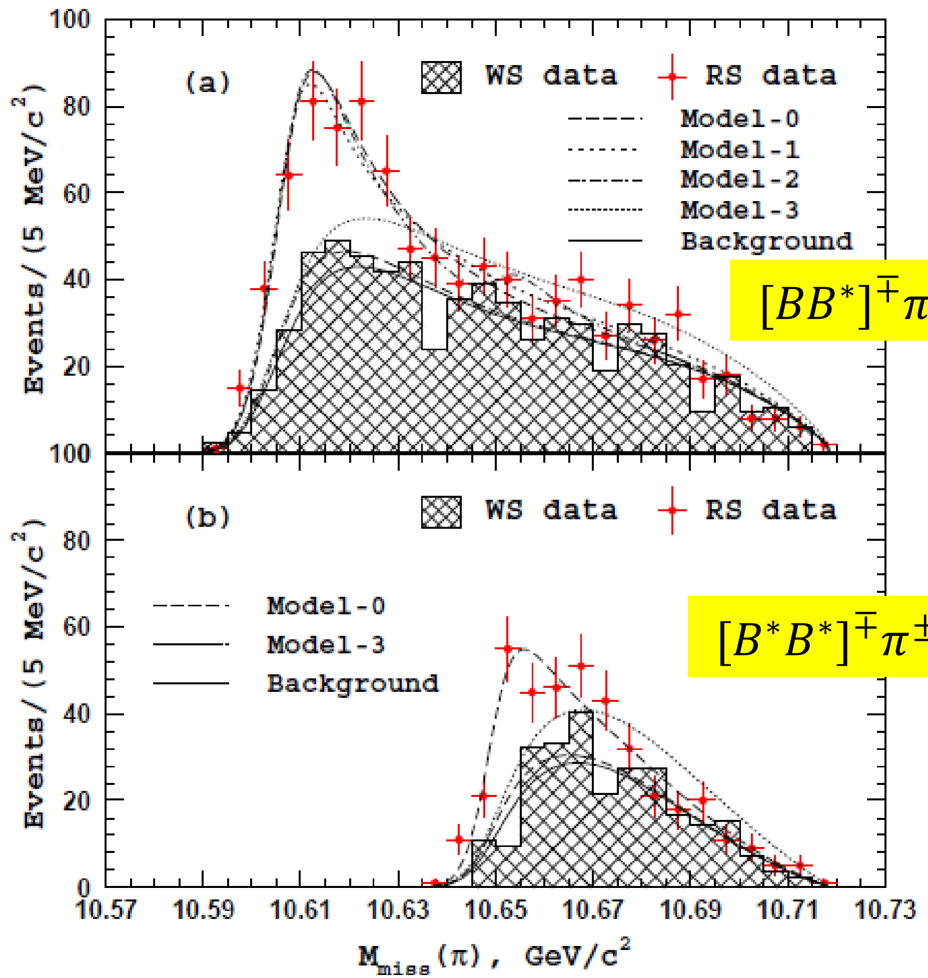
- (Left) Invariant mass of B meson daughters
- (Right) Rescaled missing mass against $B\pi$ combinations ($M^*_{miss}(B\pi) = M_{miss}(B\pi) + M(B) - m_{B,PDG}$, used to improve resolution)
- Wrong sign data models background well in $M^*_{miss}(B\pi)$

These represent the first observation of $e^+e^- \to [B^{(*)}\,B^{(*)}]^{\mp}\pi^{\pm}$ with the significance for $[BB^*]^{\mp}\pi^{\pm}$ being 9.3σ and for $[B^*B^*]^{\mp}\pi^{\pm}$, 8.1σ

A. Garmash et al (Belle)
arXiv:1512.07419
(accepted, PRL)

Study of $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$

- At right are plots of $M_{miss}(\pi)$ which will show excesses at Z_b masses if $Z_b \to [B^*\ B^{(*)}]$.
- Again, WS data provides background estimate
- Fits to the data done for four model
  - Model-0 One Z_b amplitude
  - Model-1 One Z_b amplitude + NR
  - Model-2 Two Z_b amplitudes
  - Model-3 NR only



Interestingly, though kinematically favored, no BB* component in the decays of Z_b (10650)!

A. Garmash et al (Belle)
arXiv:1512.07419
(accepted, PRL)

Study of $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$

- Finally, with the present results using Model-0 one can also determine branching fractions for the two Z_b states, assuming that the observed decays of the Z_b saturate the total rates

TABLE III: B branching fractions for the $Z_b^+(10610)$ and $Z_b^+(10650)$ decays. The first quoted uncertainty is statistical; the second is systematic.

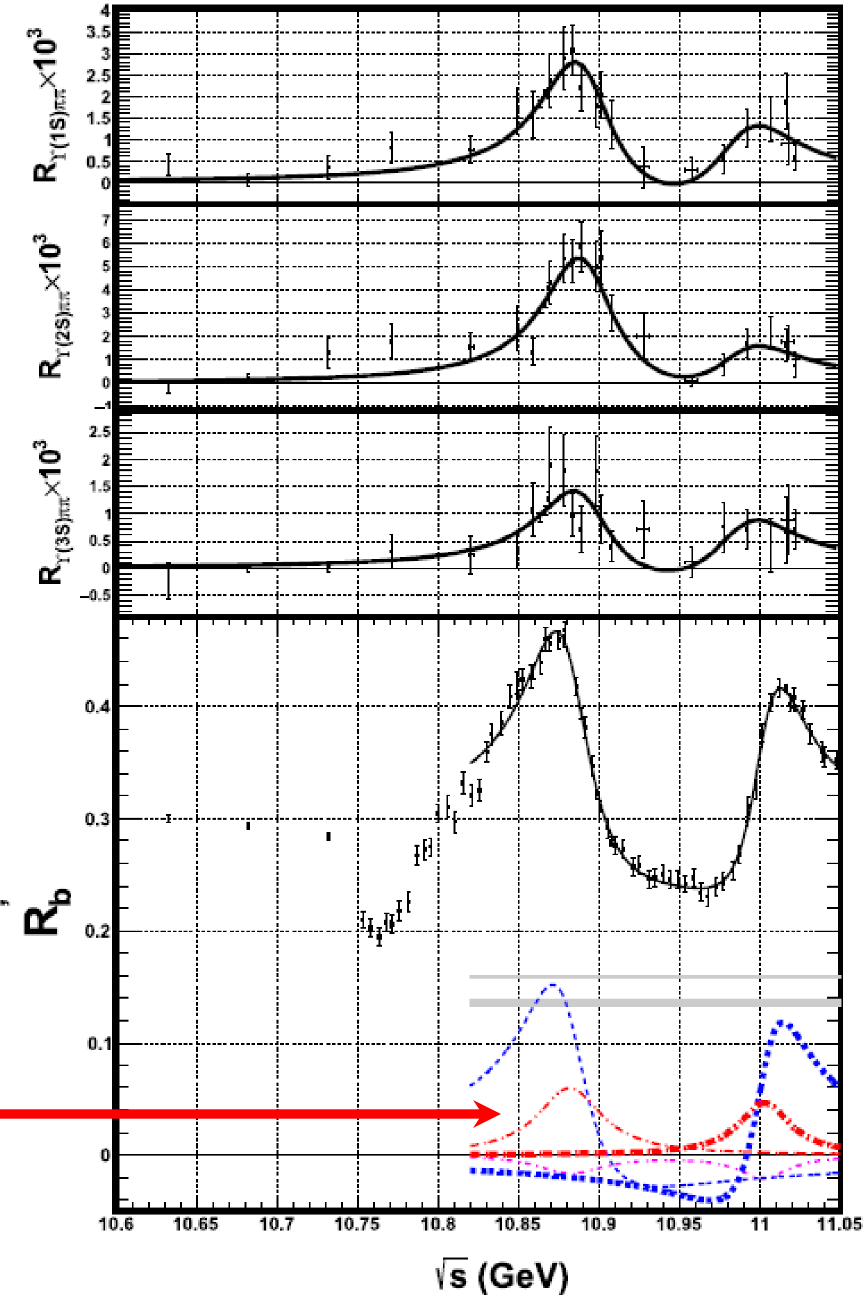
Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.54^{+0.16+0.11}_{-0.13-0.08}$	$0.17^{+0.07+0.03}_{-0.06-0.02}$
$\Upsilon(2S)\pi^+$	$3.62^{+0.76+0.79}_{-0.59-0.53}$	$1.39^{+0.48+0.34}_{-0.38-0.23}$
$\Upsilon(3S)\pi^+$	$2.15^{+0.55+0.60}_{-0.42-0.43}$	$1.63^{+0.53+0.39}_{-0.42-0.28}$
$h_b(1P)\pi^+$	$3.45^{+0.87+0.86}_{-0.71-0.63}$	$8.41^{+2.43+1.49}_{-2.12-1.06}$
$h_b(2P)\pi^+$	$4.67^{+1.24+1.18}_{-1.00-0.89}$	$14.7^{+3.2+2.8}_{-2.8-2.3}$
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	$85.6^{+1.5+1.5}_{-2.0-2.1}$	–
$B^{*+}\bar{B}^{*0}$	–	$73.7^{+3.4+2.7}_{-4.4-3.5}$

As expected, dominant decay modes of the Z_b are the $[B^{(*)}B^{(*)}]^{\mp}$ modes

No BB* component in the decays of Z_b (10650)!

One final summary point concerning $\Upsilon(5S)$

- R_b' fit showed VERY strong interference between the resonances and continuum
- The $\pi^+ \pi^- \Upsilon(nS)$ and $\pi^+ \pi^- h_b(nP)$ show evidence of no continuum contribution
- Another process expected to have little continuum contribution is $[B^{(*)} \bar{B}^{(*)}]^{\mp}\pi^{\pm}$, and the rates for this at $\Upsilon(5S)$ and $\Upsilon(6S)$ are saturated by $Z_b^{\mp}\pi^{\pm}$
- This all leads us to question the makeup of the resonant part of the R_b' fit



D. Santel et al (Belle) PRD 93, 011101(R) (2016)

One final summary point concerning $\Upsilon(5S)$

- If we compare amplitudes (sum of the squares times relevant phase space factors) from the fits for the various $\Upsilon(5S)$ transitions reported today to the resonance amplitude from the R_b' study, and compute the ratio, we find:

Process (x)	Cumulative fraction $\mathcal{P}$
$\pi^+\pi^-\Upsilon(nS)$	0.170 ± 0.009
$\pi^+\pi^- h_b(nP)$, $\pi^0\pi^0\Upsilon(nS)$, $\pi^0\pi^0 h_b(nP)$	0.420 ± 0.004
$[B^* B^{(*)}]^{\mp}\pi^{\pm}$ and $[B^* B^{(*)}]^0\pi^0$	1.09 ± 0.15

- If $\mathcal{P}$ = 1, the R_b' resonant amplitude is saturated by these observed amplitudes
- little room for the ~20% known for $B_s^{(*)}B_s^{(*)}$ at the resonance…(yes, errors are large)
- …and calls into question the use of a flat continuum as is used in R_b' measurements, and our understanding of the massive interference that is observed (many bb thresholds are crossed in this region, too)

Upshot: Mass/width obtained from R_b' fits seem unreliable; best to use continuum-free processes such as $\pi^+\pi^-\Upsilon(nS)$ and $\pi^+\pi^- h_b(nP)$.

D. Santel et al (Belle) PRD 93, 011101(R) (2016)

Conclusions

- 2008-2016 have been very productive for Belle in bottomonium-related physics at and above $\Upsilon(5S)$, and we continue to study the Belle data, looking forward to Belle II

- Recent results presented here today include

  - New measurements of R_b' and cross sections for $e^+e^- \to \pi^+\pi^-\Upsilon(nS), \pi^+\pi^-h_b(n\mathrm{P})$ near $\Upsilon(5S)$ and $\Upsilon(6S)$
    - First evidence for $\pi^+\pi^-\Upsilon(nS)$ at $\Upsilon(6S)$
    - First evidence for $\pi^+\pi^-h_b(1\mathrm{P})$ at $\Upsilon(6S)$
    - First observation of $\pi^+\pi^-h_b(2\mathrm{P})$ at $\Upsilon(6S)$
    - Questions re: validity of resonance parameter evaluation via R_b'

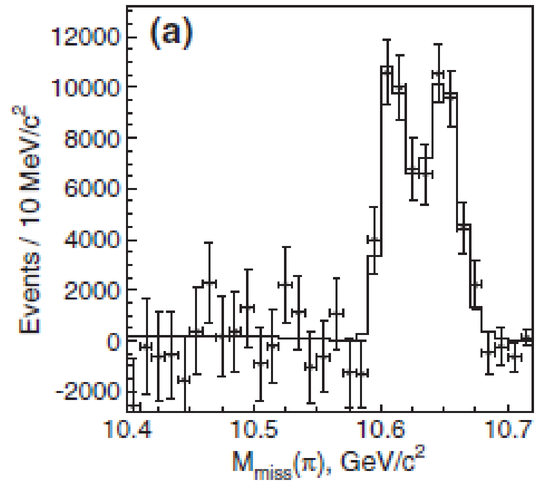
  - Confirmation of the dominance of the $e^+e^- \to \pi^+\pi^-h_b(n\mathrm{P})$ process by intermediate Z_b at $\Upsilon(6S)$ just as at $\Upsilon(5S)$

  - First observation of the processes $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$, showing dominance by amplitudes for $Z_b \to [B^*B^{(*)}]^{\mp}$ and strengthening the molecular hypothesis for Z_b

Backup Slides

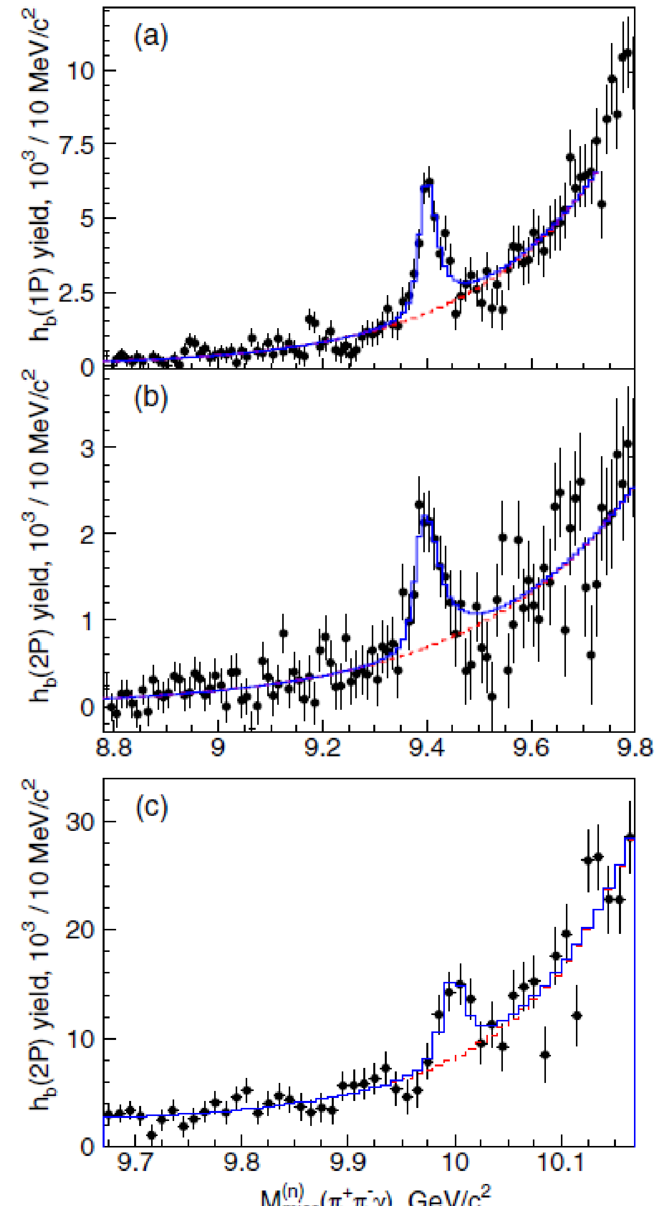
Z_b intermediate states saturate the rates for h_b production from Υ(5S)

All of the h_b production from Υ(5S) proceeds through the Z_b



- While interesting of itself, this led importantly to an excellent selector for h_b – which made observations of radiative decays of h_b possible:

$$\mathcal{B}[h_b(1P) \to \eta_b(1S)\gamma] = (49.2 \pm 5.7^{+5.6}_{-3.3})\%$$
$$\mathcal{B}[h_b(2P) \to \eta_b(1S)\gamma] = (22.3 \pm 3.8^{+3.1}_{-3.3})\%$$
$$\mathcal{B}[h_b(2P) \to \eta_b(2S)\gamma] = (47.5 \pm 10.5^{+6.8}_{-7.7})\%$$

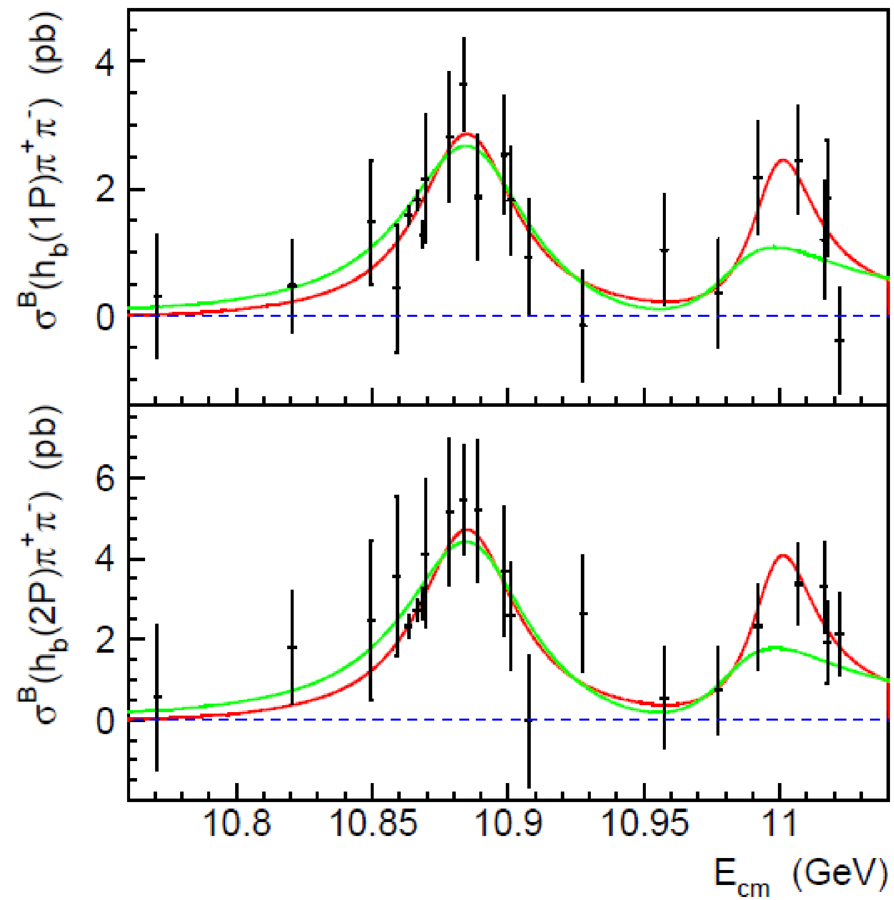


R. Mizuk et al (Belle) PRL 109, 232002 (2012)

A. Abdsselam et al (Belle)
arXiv:1508.06562

$e^+e^- \rightarrow \pi^+\pi^- h_b(n\text{P})$

- Fit the spectrum of $\pi^+\pi^- h_b(n\text{P})$ cross sections to Breit-Wigner amplitudes for the two resonances and continuum
- Continuum contribution in resulting fit is < 1.5σ ; the default fit does not use it
- Results are consistent with results for the previously described cross sections for $\pi^+\pi^-\Upsilon(nS)$



Quantity	From $\pi^+\pi^-\Upsilon(nS)$	From $\pi^+\pi^- h_b(nP)$
M_5	$10891.1\ 3.2^{+0.6}_{-1.7}$ MeV	$10884.7^{+3.6+8.9}_{-3.4-1.0}$ MeV
Γ_5	$53.7^{+7.1}_{-5.6}{}^{+1.3}_{-5.4}$ MeV	$40.6^{+12.7}_{-8.0}{}^{+1.1}_{-19.1}$ MeV
M_6	$10987.5^{+6.4}_{-2.5}{}^{+9.0}_{-2.1}$ MeV	$10999.0^{+7.3}_{-7.8}{}^{+16.9}_{-1.0}$ MeV
Γ_6	$61^{+9}_{-19}{}^{+2}_{-20}$ MeV	$27^{+27}_{-11}{}^{+5}_{-12}$ MeV

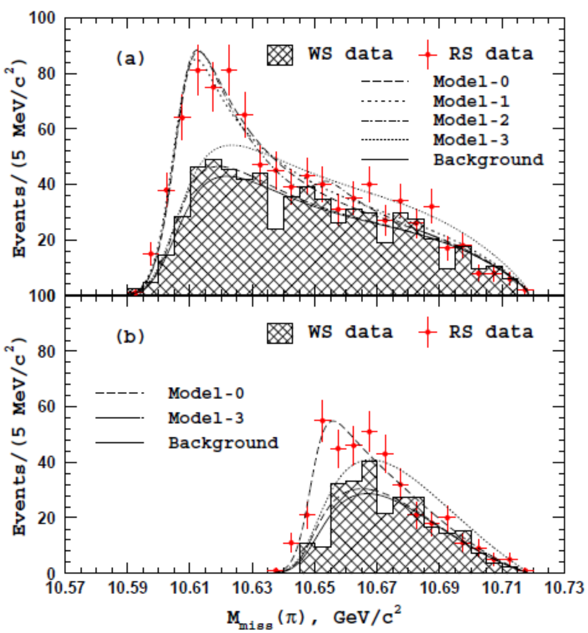
Clear (first) evidence of $\pi^+\pi^- \boldsymbol{h_b}(\boldsymbol{nP})$ at $\Upsilon(6S)$

A. Garmash et al (Belle)
arXiv:1512.07419
(accepted, PRL)

Study of $e^+e^- \to [B^*B^{(*)}]^{\mp}\pi^{\pm}$

TABLE I: Summary of fit results to the $M_{\rm miss}(\pi)$ distributions for the three-body $BB^*\pi$ and $B^*B^*\pi$ final states.

Mode	Parameter	Model-0	Model-1 Solution 1	Model-1 Solution 2	Model-2 Solution 1	Model-2 Solution 2	Model-3
$BB^*\pi$	$f_{Z_b(10610)}$	1.0	1.45 ± 0.24	0.64 ± 0.15	1.01 ± 0.13	1.18 ± 0.15	–
	$f_{Z_b(10650)}$	–	–	–	0.05 ± 0.04	0.24 ± 0.11	–
	$\phi_{Z_b(10650)}$, rad.	–	–	–	-0.26 ± 0.68	-1.63 ± 0.14	–
	$f_{\rm nr}$	–	0.48 ± 0.23	0.41 ± 0.17	–	–	1.0
	$\phi_{\rm nr}$, rad.	–	-1.21 ± 0.19	0.95 ± 0.32	–	–	–
	$-2\log\mathcal{L}$	-304.7	-300.6	-300.5	-301.4	-301.4	-344.5
$B^*B^*\pi$	$f_{Z_b(10650)}$	1.0	1.04 ± 0.15	0.77 ± 0.22			–
	$f_{\rm nr}$	–	0.02 ± 0.04	0.24 ± 0.18			1.0
	$\phi_{\rm nr}$, rad.	–	0.29 ± 1.01	1.10 ± 0.44			–
	$-2\log\mathcal{L}$	-182.4	-182.4	-182.4			-209.7



- Model-3 (non-resonant amplitude only) is ruled out
- Model-0 is kept as nominal fit; addition of either an NR component or allowance of second Z_b only marginally improves results (and adds multiple solutions in likelihood function)

$e^+e^- \to [BB^*]^{\mp}\pi^{\pm}$ dominated by Z_b (10610)
$e^+e^- \to [B^*B^*]^{\mp}\pi^{\pm}$ dominated by Z_b (10650)