Quarkonium Working Group meeting, 6-10 June 2016, PNNL

Z_b and energy scan results from Belle

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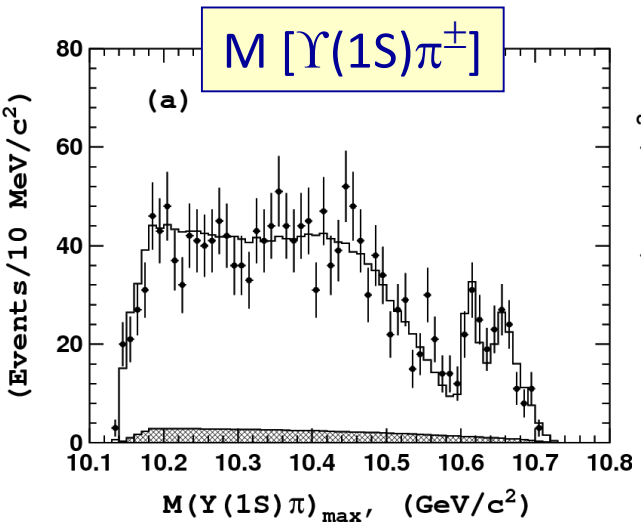
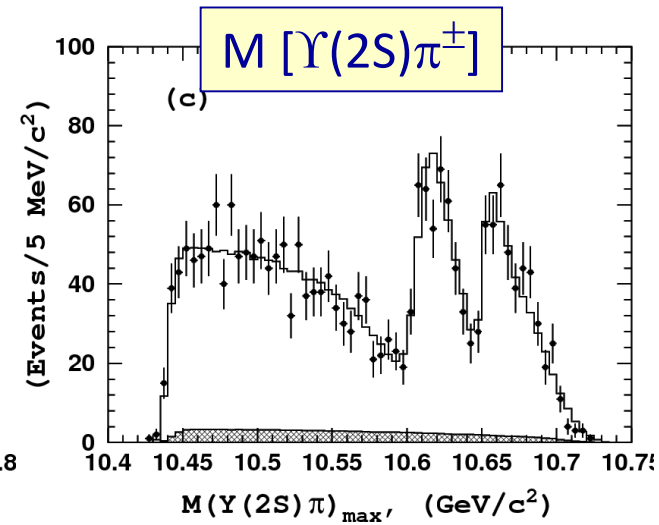
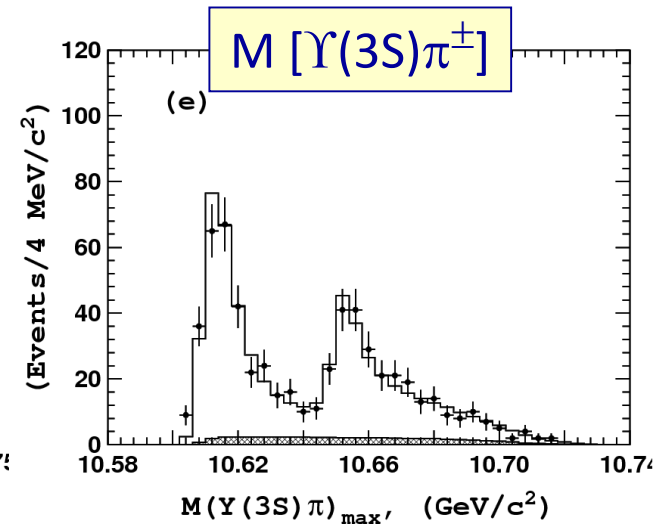
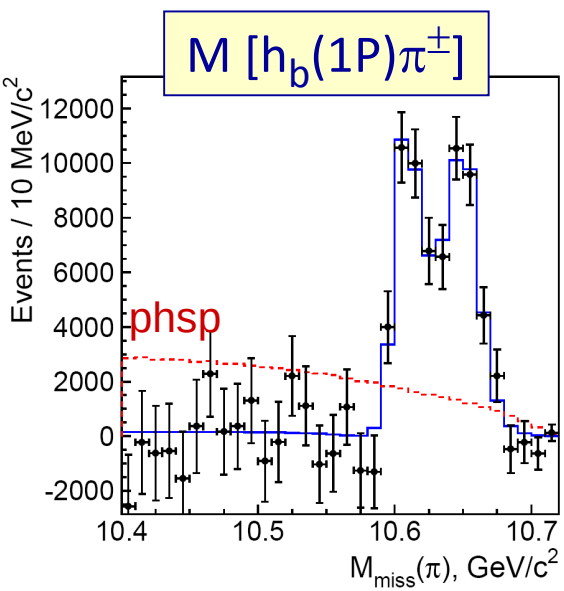
Z_b: intermediate states in $\Upsilon(5S) \to \Upsilon(nS)\ \pi^+\pi^-$
$\Upsilon(5S) \to h_b(mP)\ \pi^+\pi^-$

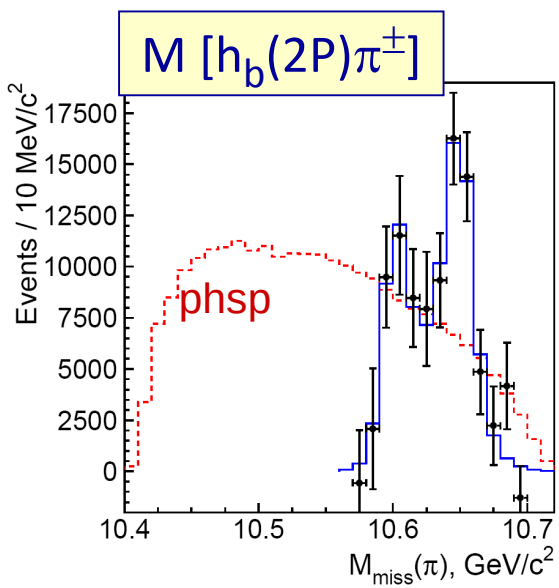
Belle PRL108,122001(2012)











$\Rightarrow$ **$Z_b(10610)$, $Z_b(10650)$**

minimal quark content:

$$|\, b\bar{b}u\bar{d}\,\rangle$$

Belle PRL108,122001(2012)

$Z_b(10610)$ M = 10607.2 ± 2.0 MeV near $B\bar{B}^*$ threshold
Γ = 18.4 ± 2.4 MeV δM = +2.6 ± 2.1 MeV

$Z_b(10650)$ M = 10652.2 ± 1.5 MeV near $B^*\bar{B}^*$ threshold
Γ = 11.5 ± 2.2 MeV δM = +1.8 ± 1.7 MeV

$J^P = 1^+$ Belle PRD91,072003(2015)

Molecular structure ⇒ decays into constituents should dominate: $Z_b(10610) \to B\bar{B}^*$
$Z_b(10650) \to B^*\bar{B}^*$

discrimination against hadrocharmonia & compact tetraquarks

Voloshin PRD87,091501(2013) Ali,.. PRD85,054011(2012)

Study resonant substructure in $\Upsilon(5S) \to (B\bar{B}^* + c.c.)\,\pi$ Belle PRL116,212001(2016)
$\Upsilon(5S) \to B^*\bar{B}^*\ \pi$

Full reconstruction of one B meson.

Update of Belle preliminary result: arxiv:1209.6450.

Reconstruct

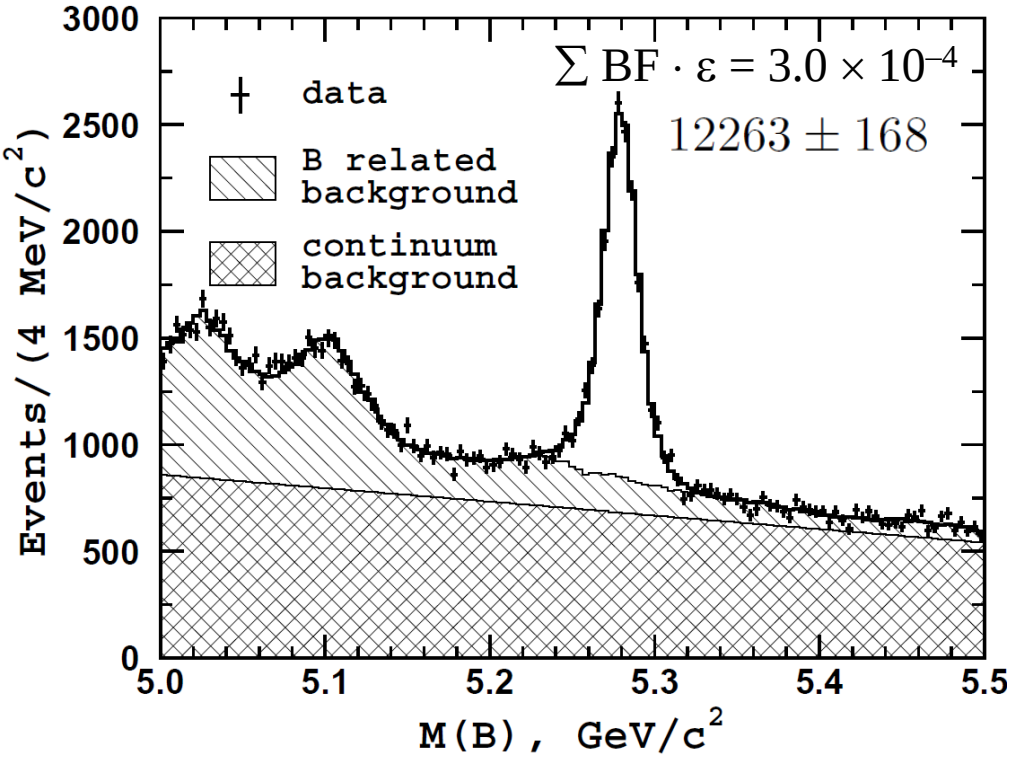
$$(B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+})\,\pi^- + \text{c.c.}$$
$$B^{*+} \bar{B}^{*0}\,\pi^-$$
$$B^* \to B\gamma$$

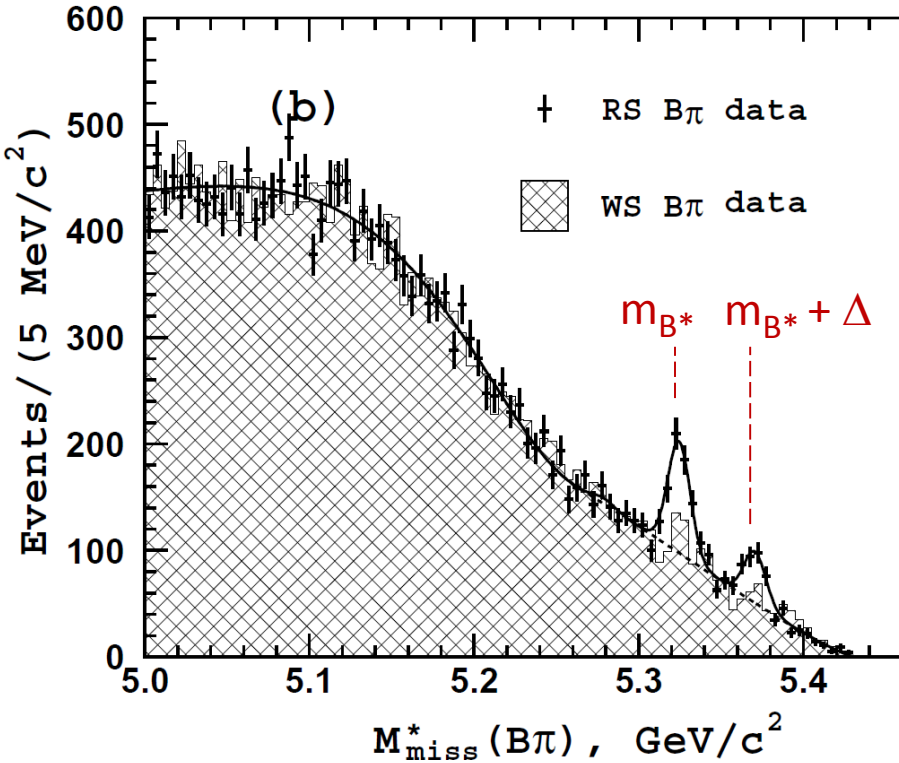
Reconstruct one B and π^+, use missing mass:

$$M_{miss}(B\pi) = \sqrt{(E_{e+e-} - E_{B\pi})^2 - (\vec{p}_{e+e-} - \vec{p}_{B\pi})^2}$$

$$B^+ \to J/\psi K^{(*)+},\ B^+ \to \bar{D}^{(*)0}\pi^+$$
$$B^0 \to J/\psi K^{(*)0},\ B^0 \to D^{(*)-}\pi^+$$

$$\Delta \equiv m_{B^*} - m_B$$





	Born cross sections	σ^B/σ_{bb}
$[B\bar{B}^* + \text{c.c.}]^{\pm}\pi^{\mp}$	$17.4 \pm 1.6 \pm 1.9$ pb	3.1 %
$[B^*\bar{B}^*]^{\pm}\pi^{\mp}$	$8.8 \pm 1.2 \pm 1.0$ pb	1.5 %

Reconstruct

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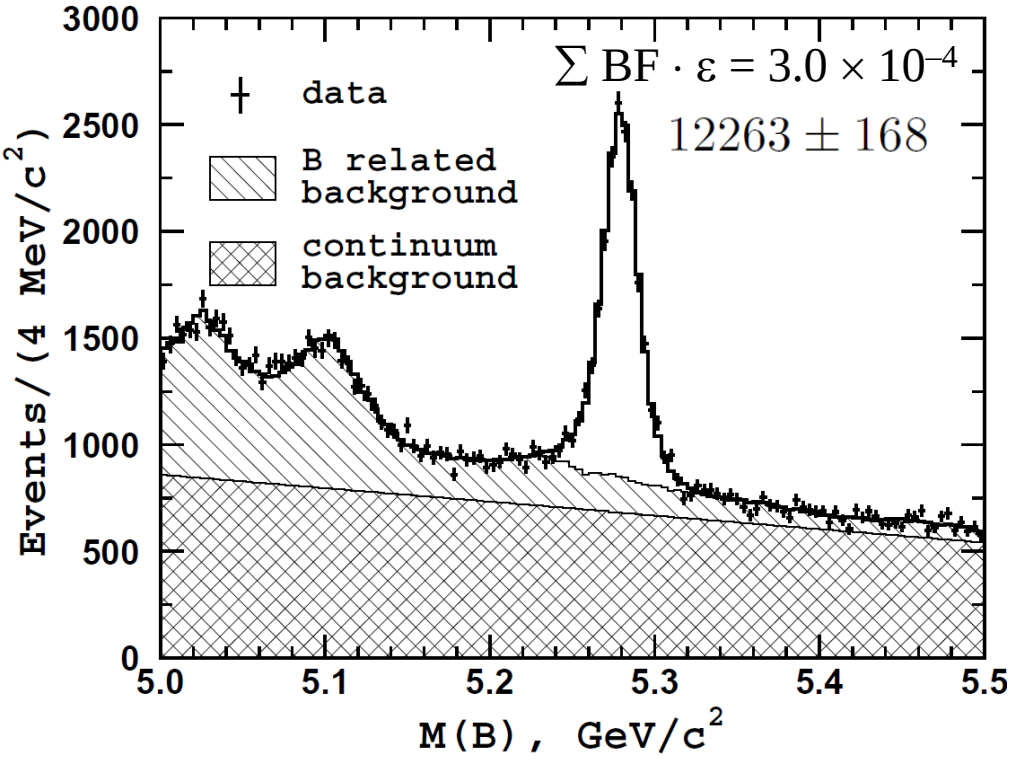

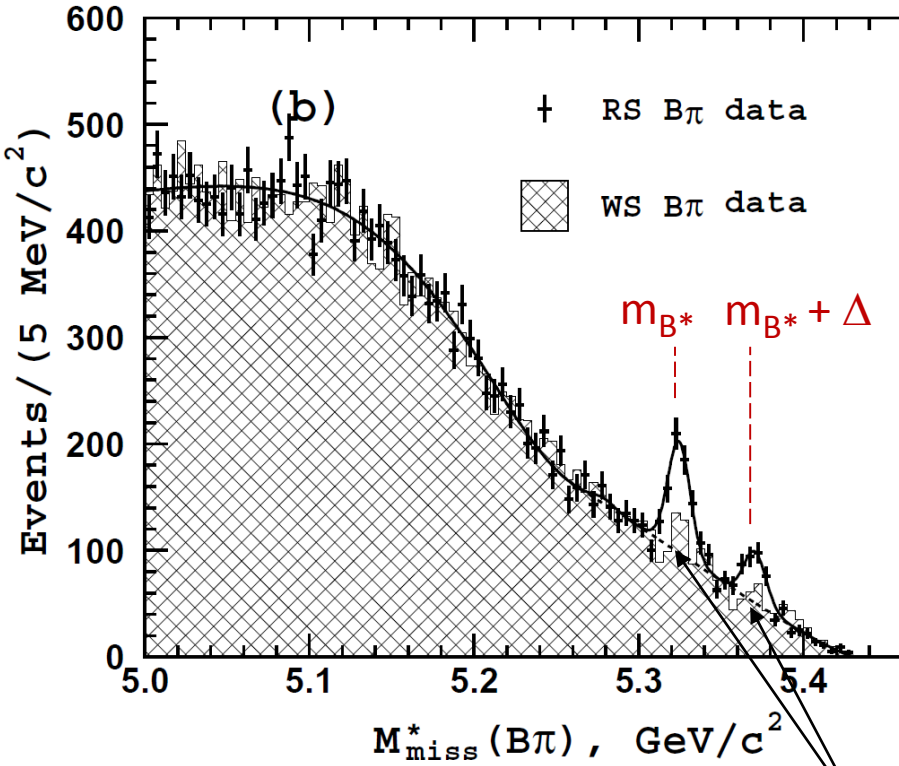

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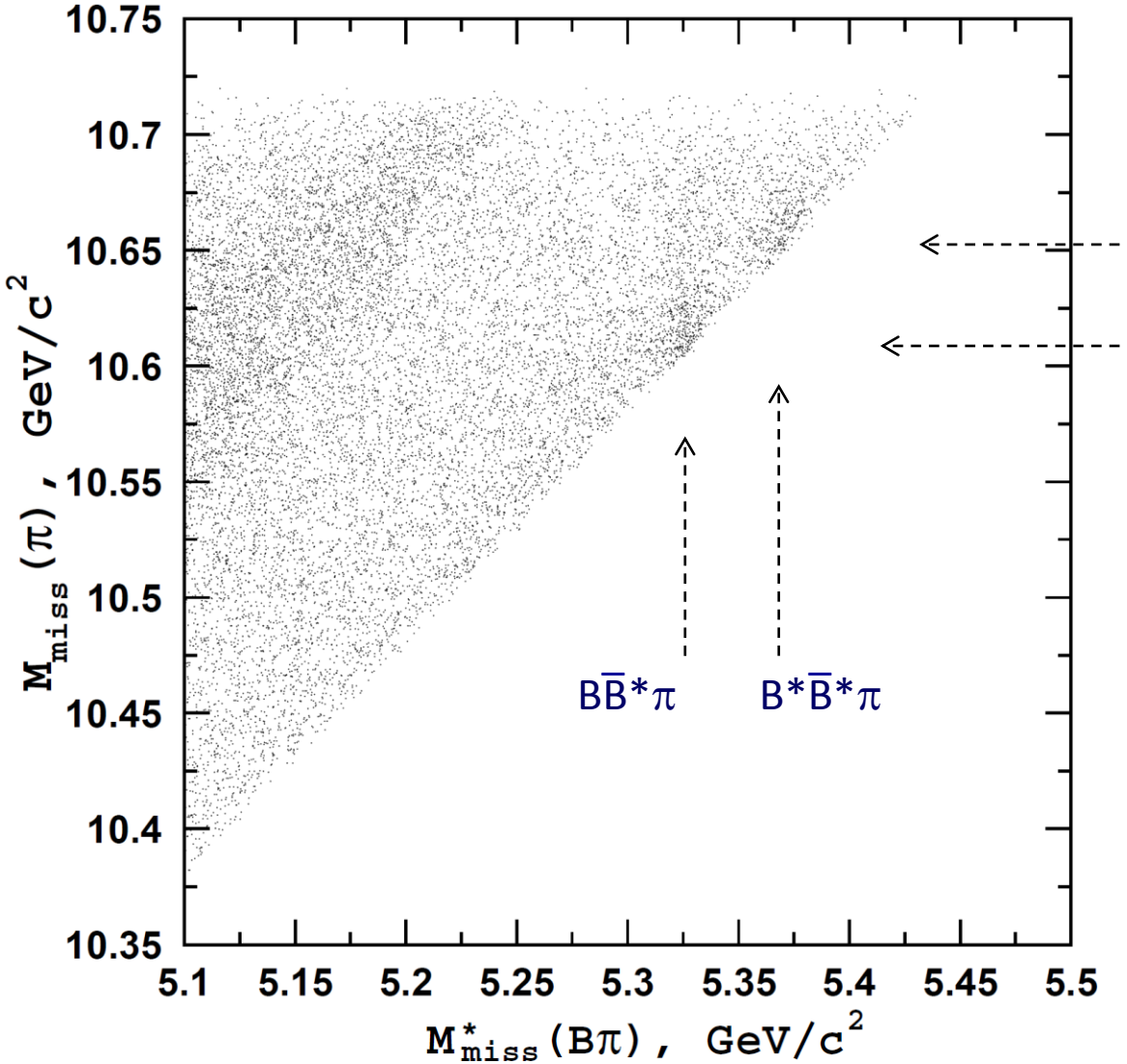
10% of signal leak into WS sample due to B^0 oscillations.

$\Upsilon(5S) \to (B\bar{B}^* + c.c.)\,\pi$

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

$M(B^{(*)}\bar{B}^*) = M_{miss}(\pi)$



Clear signals

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

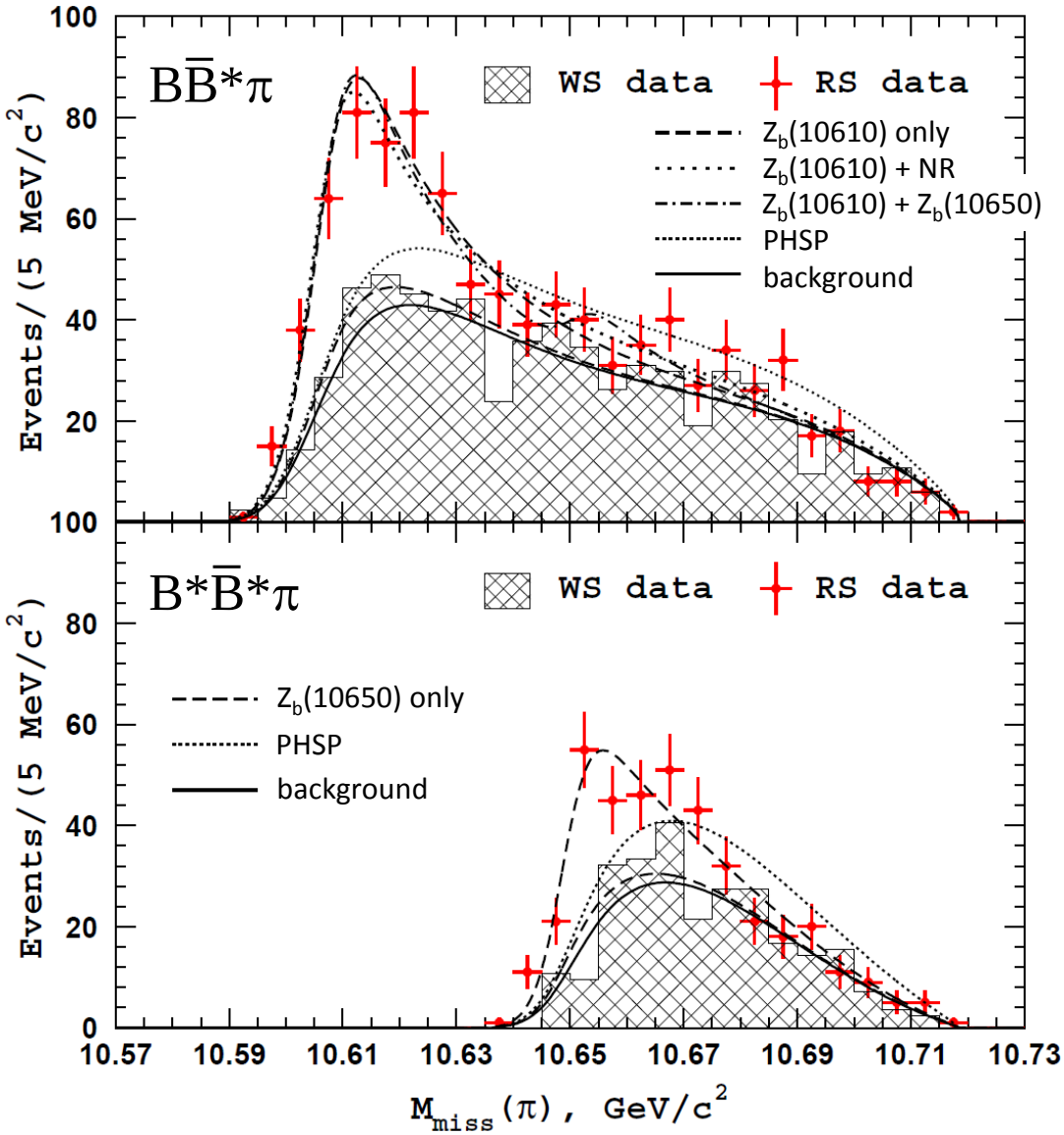
$Z_b(10650) \to B^*\bar{B}^*$

No signal of

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

Resonant structure of $\Upsilon(5S) \to B^{(*)}\bar{B}^*\pi^{\pm}$

Simultaneous fit to RS (signal + BG) and WS (0.10*signal + BG) samples.



Fit function $\propto$

$$|\mathcal{A}_{Z_b(10610)} + \mathcal{A}_{Z_b(10650)} + \mathcal{A}_{\rm nr}|^2$$

$B\bar{B}^*\pi$

	exclusion level
$Z_b(10610)$ only vs. PHSP	6.3σ
non-resonant significance	1.5σ
$Z_b(10650)$ significance	1.3σ

$B^*\bar{B}^*\pi$

	exclusion level
$Z_b(10650)$ only vs. PHSP	5.2σ
non-resonant significance	0.1σ

Decay table of Z_b ⇒

assume all major decay channels are known

Channel	Fraction, %	
	$Z_b(10610)$	$Z_b(10650)$
$\Upsilon(1S)\pi^+$	$0.60 \pm 0.17 \pm 0.07$	$0.17 \pm 0.06 \pm 0.02$
$\Upsilon(2S)\pi^+$	$4.05 \pm 0.81 \pm 0.58$	$1.38 \pm 0.45 \pm 0.21$
$\Upsilon(3S)\pi^+$	$2.40 \pm 0.58 \pm 0.36$	$1.62 \pm 0.50 \pm 0.24$
$h_b(1P)\pi^+$	$4.26 \pm 1.28 \pm 1.10$	$9.23 \pm 2.88 \pm 2.28$
$h_b(2P)\pi^+$	$6.08 \pm 2.15 \pm 1.63$	$17.0 \pm 3.74 \pm 4.1$
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	$82.6 \pm 2.9 \pm 2.3$	–
$B^{*+}\bar{B}^{*0}$	–	$70.6 \pm 4.9 \pm 4.4$

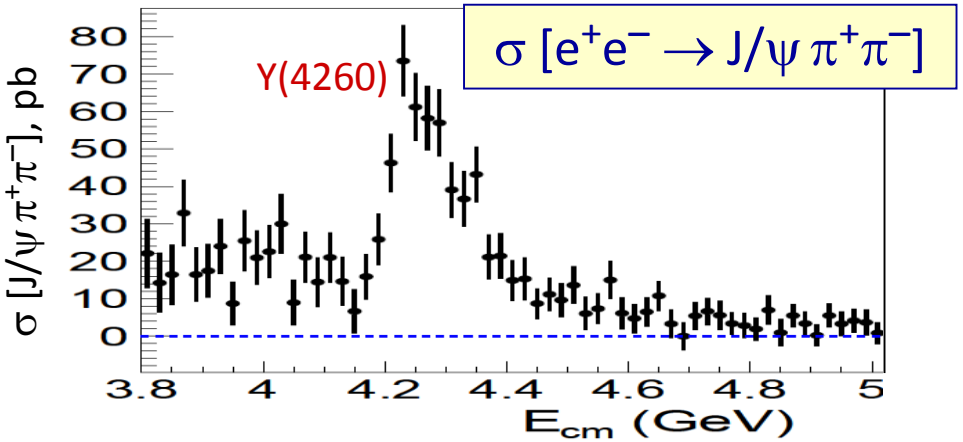
PRD93,011101(2016)
arXiv:1508.06562
PRL116,212001(2016)

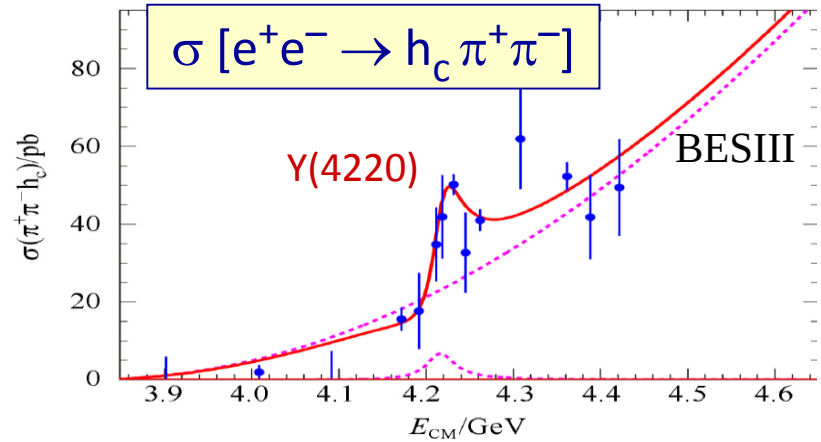
Dominant decay channels ⇒

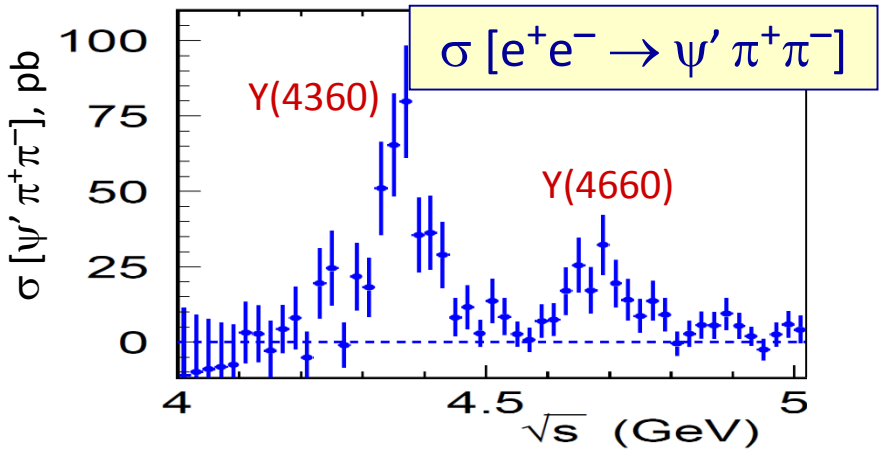
$Z_b(10610) \to B\bar{B}^*$
$Z_b(10650) \to B^*\bar{B}^*$

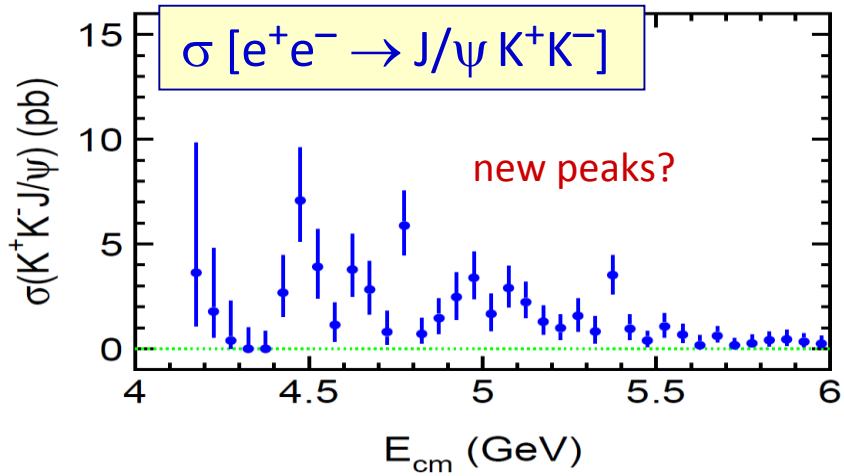
Smoking gun of molecular structure.

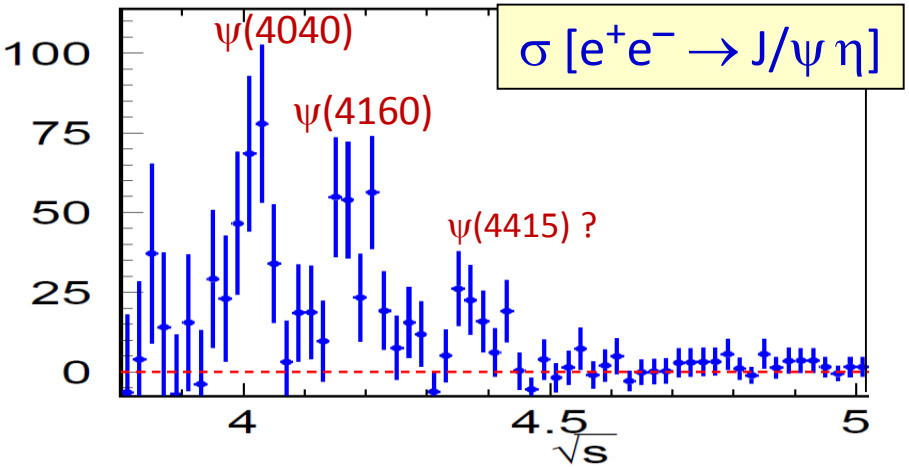
Energy scan results







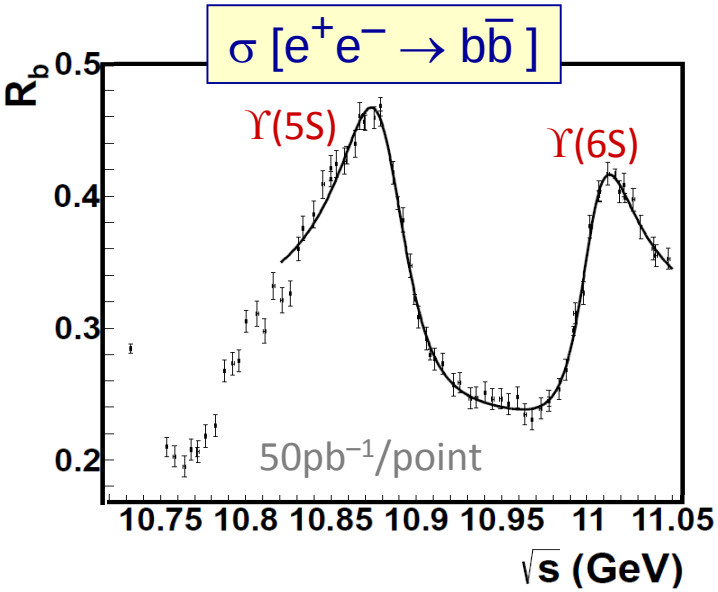


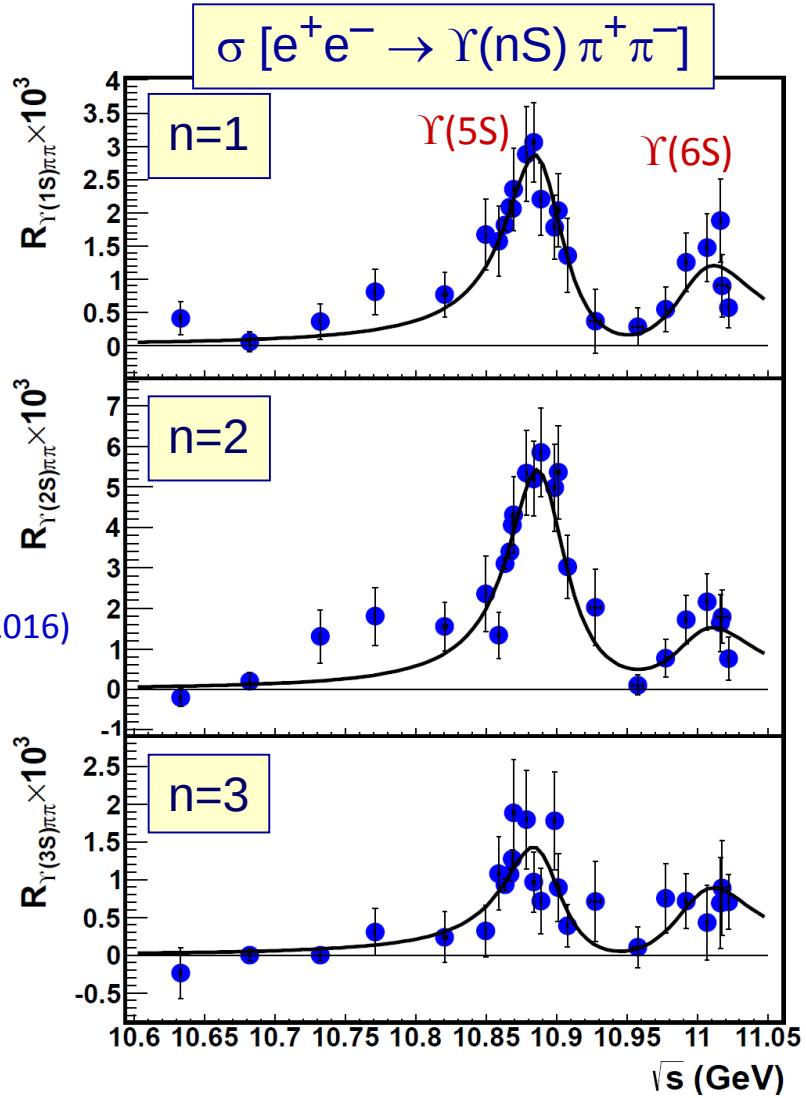


Different cross sections have different peaks.

Each Y or ψ state decays to only one channel. puzzling

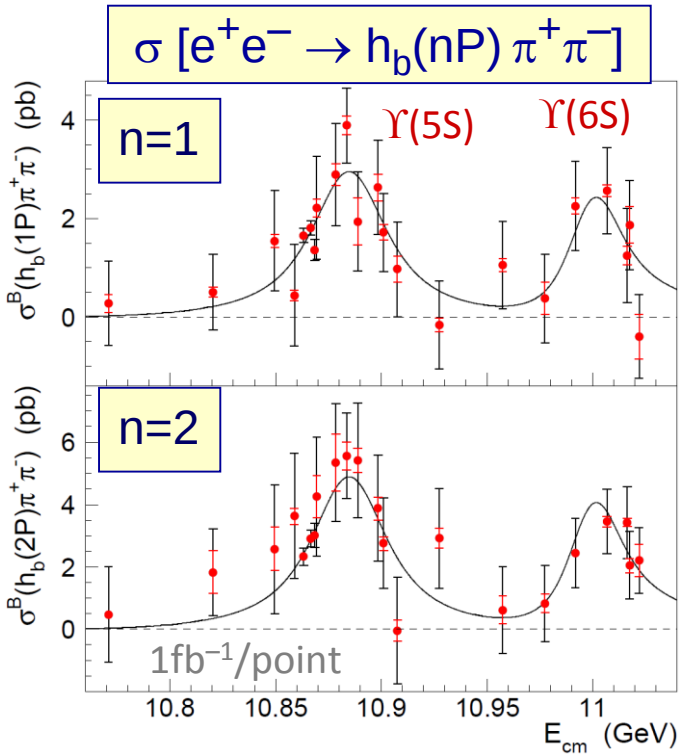
Belle ⇒
energy scan





arXiv:1508.06562 → PRL

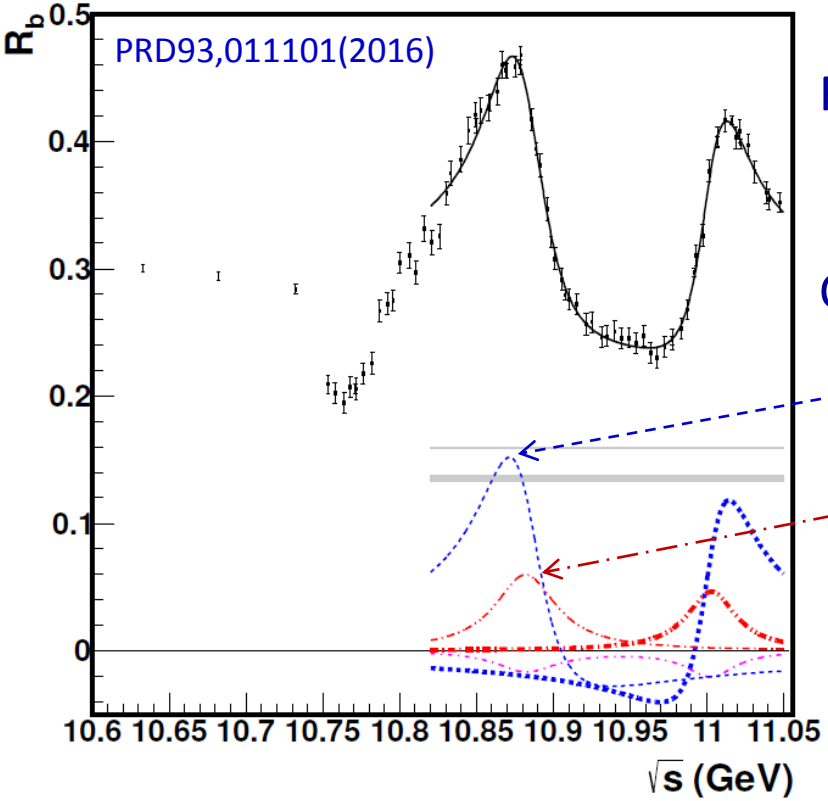
PRD93,011101(2016)



⇒ Only Υ(5S) and Υ(6S) peaks in all cross sections.

Difference btw decay patterns of charmonium-like and bottomonium-like states is not understood.

Decomposition of R_b



Fit to R_b:

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

Conclusions:

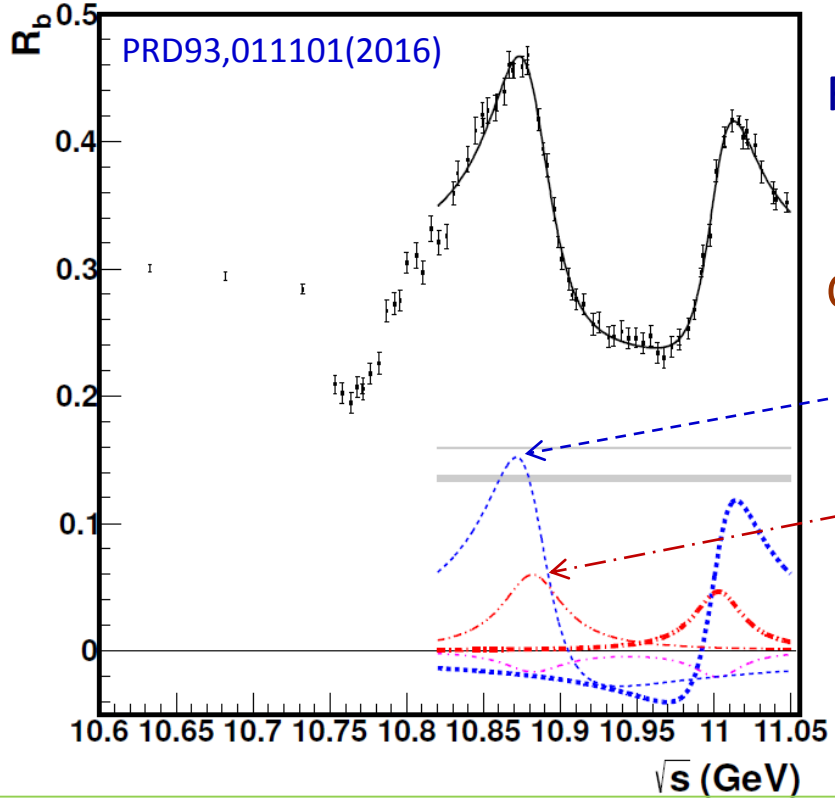
Strong interference btw Υ(5S) & continuum

Υ(5S) peak is saturated by

$B^{(*)}\bar{B}^*\pi$, $\Upsilon(nS)\pi\pi$, $h_b(mP)\pi\pi$

$B\bar{B}/B\bar{B}^*/B^*\bar{B}^*$ do not resonate $\Rightarrow$ continuum

Decomposition of R_b



Fit to R_b:

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Conclusions:

inconsistency

~~Strong interference btw $\Upsilon(5S)$ & continuum~~

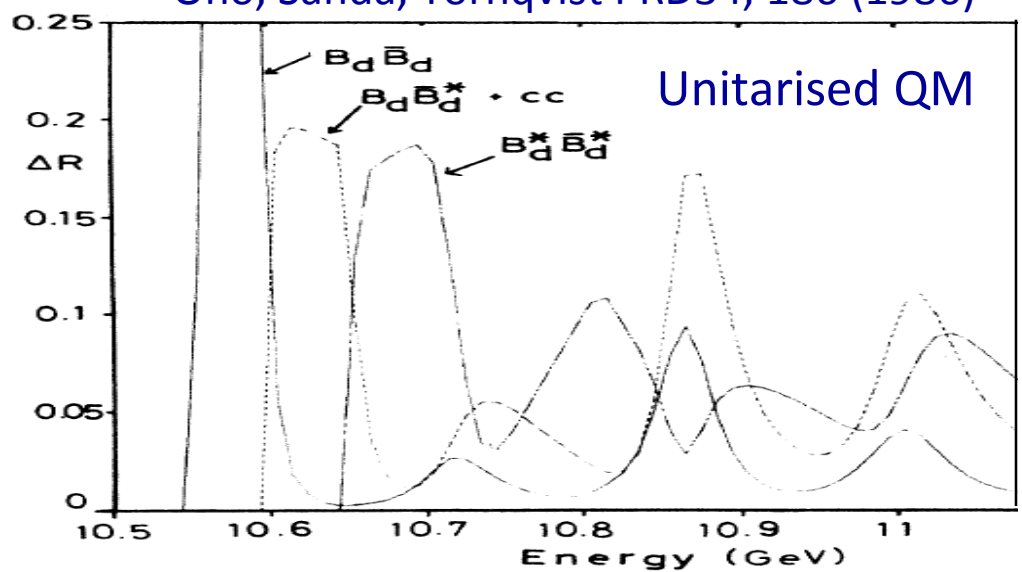
~~$\Upsilon(5S)$ peak is saturated by~~

~~$B^{(*)}\bar{B}^*\pi$, $\Upsilon(nS)\pi\pi$, $h_b(mP)\pi\pi$~~

~~$B\bar{B}/B\bar{B}^*/B^*\bar{B}^*$ do not resonate $\Rightarrow$ continuum~~

Simple fit model for R_b should not be used.

Ono, Sanda, Tornqvist PRD34, 186 (1986)



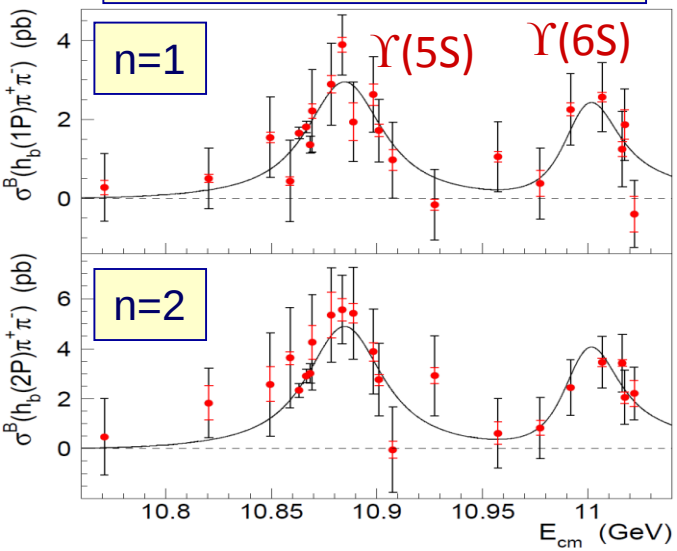
Many peaks in $B\bar{B}/B\bar{B}^*/B^*\bar{B}^*$ cross sections $\Rightarrow$ important information

Belle can measure this.

Signals of $\Upsilon(6S) \to h_b(nP)\,\pi^+\pi^-$

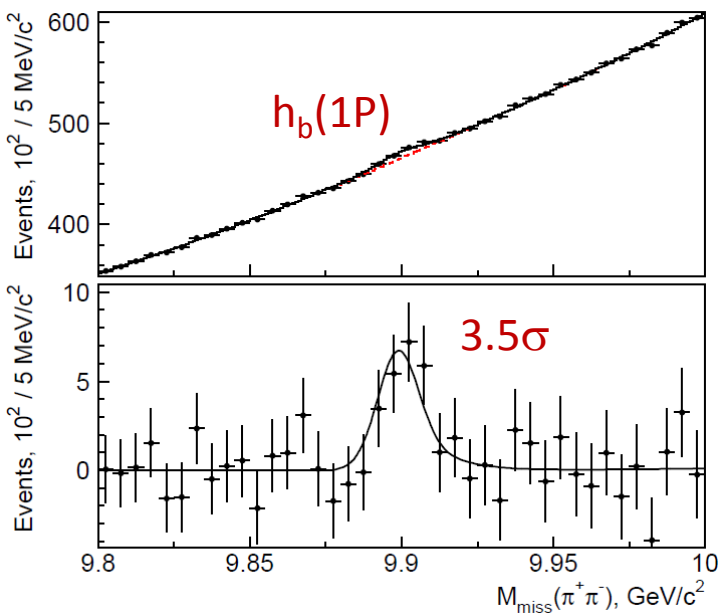
Belle arXiv:1508.06562 → PRL

$\sigma\,[e^+e^- \to h_b(nP)\,\pi^+\pi^-]$

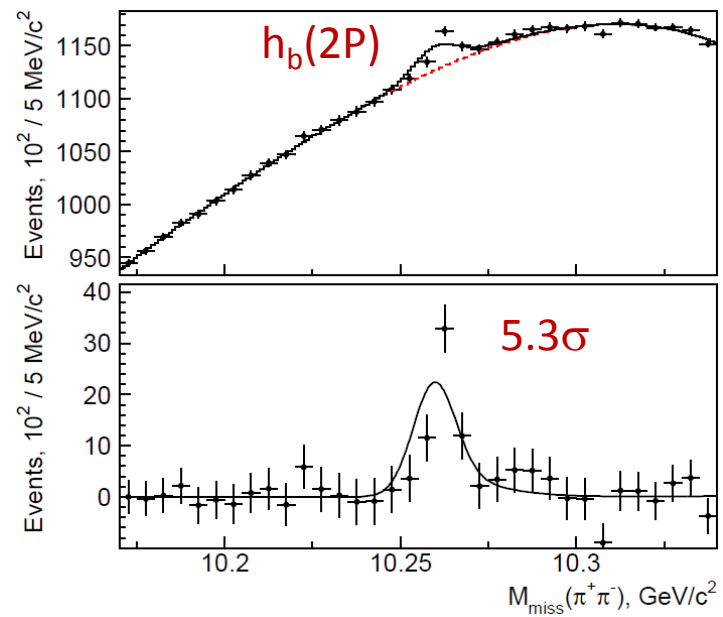


Combine five scan points in the $\Upsilon(6S)$ region, plot $M_{miss}(\pi^+\pi^-)$ ⇒

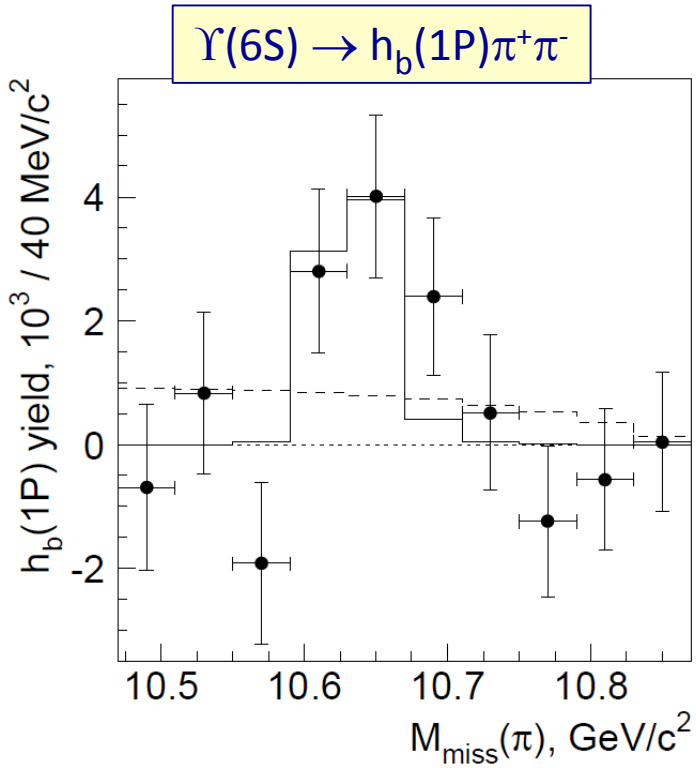
$\Upsilon(6S) \to h_b(1P)\pi^+\pi^-$

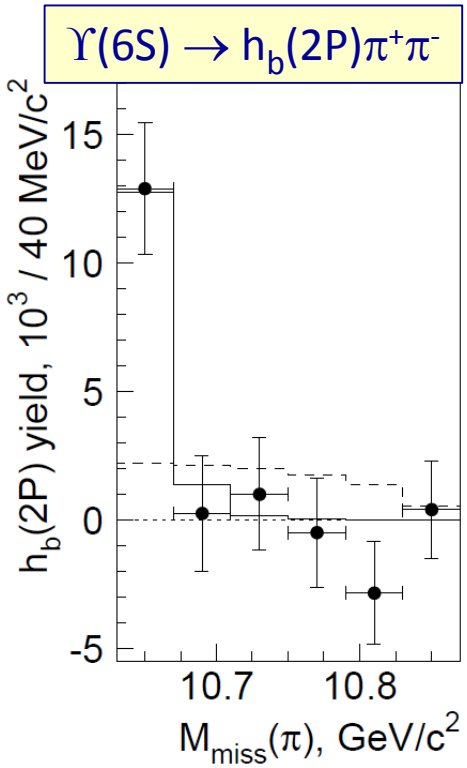


$\Upsilon(6S) \to h_b(2P)\pi^+\pi^-$

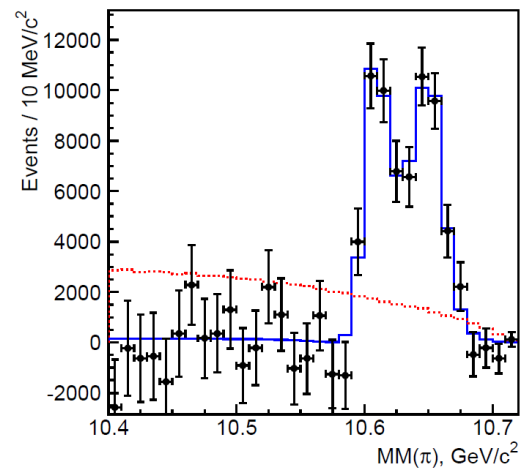


Resonant substructure of $\Upsilon(6S) \to h_b(nP)\pi^+\pi^-$





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



$\Rightarrow$ Transitions proceed entirely via Z_b states without non-resonant contribution.

Relative fraction of $Z_b(10610)$ and $Z_b(10650)$ is loosely constrained:

single $Z_b(10610)$ hypothesis is excluded at 3.3σ level,
single $Z_b(10650)$ hypothesis is not excluded at a significant level.

Conclusions

Data are consistent with:

$\Upsilon(5S) \to B\bar{B}^*\pi$ proceeds entirely via $Z_b(10610)$

$\Upsilon(5S) \to B^*\bar{B}^*\pi$ proceeds entirely via $Z_b(10650)$

$$\left.\begin{array}{l} Z_b(10610) \to B\bar{B}^* \\ Z_b(10650) \to B^*\bar{B}^* \end{array}\right\}$$ dominant decay channels $\Rightarrow$ molecular structure

Line-shapes are sensitive to Z_b nature $\to$ talk by Christoph Hanhart

Cross sections $e^+e^- \to \Upsilon(nS)\pi^+\pi^-$ and $e^+e^- \to h_b(mP)\pi^+\pi^-$ show clear $\Upsilon(5S)$ and $\Upsilon(6S)$ peaks without significant continuum contribution.

$\Rightarrow$ different from charmonium

$\Upsilon(6S) \to h_b(mP)\pi^+\pi^-$ proceed entirely via Z_b states.

$\Rightarrow h_b(mP)\pi^+\pi^-$ cross section = $Z_b\pi$ cross section

Results on $B\bar{B}$, $B\bar{B}^*$, $B^*\bar{B}^*$,.. cross sections are coming.