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Energy scan results from Belle

Roman Mizuk

Lebedev Physical Institute,
Moscow Institute of Physics and Technology

Introduction

Belle data samples above $\Upsilon(4S)$:

$\Upsilon(5S)$ on-resonance: 121 fb^{-1} (3 points separated by 3 MeV : $23+50+48 \text{ fb}^{-1}$)

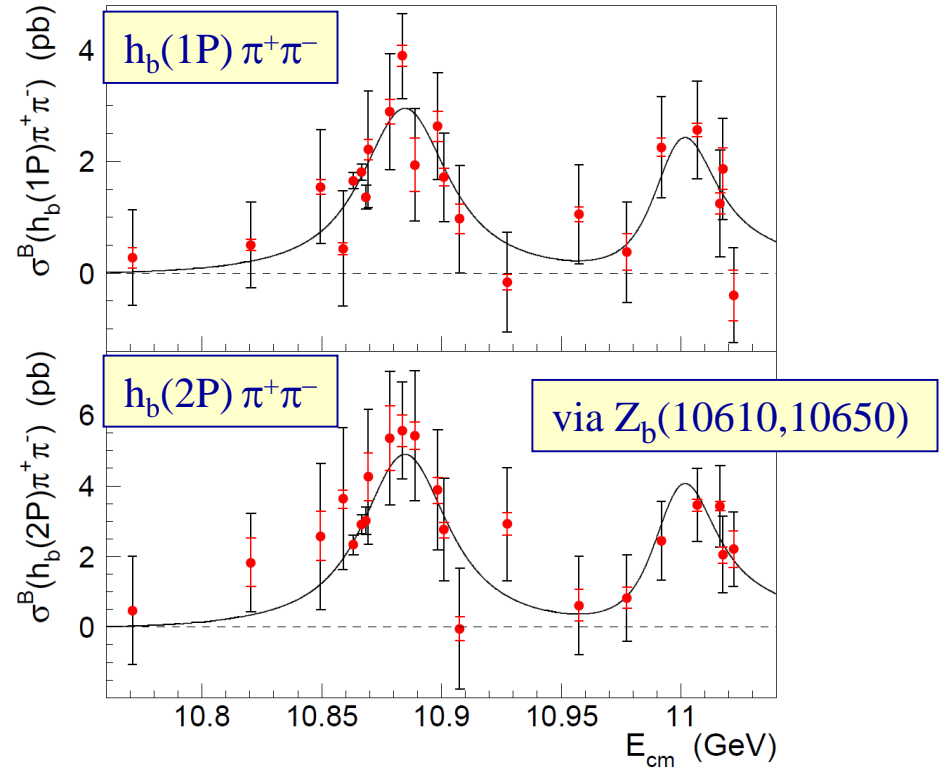
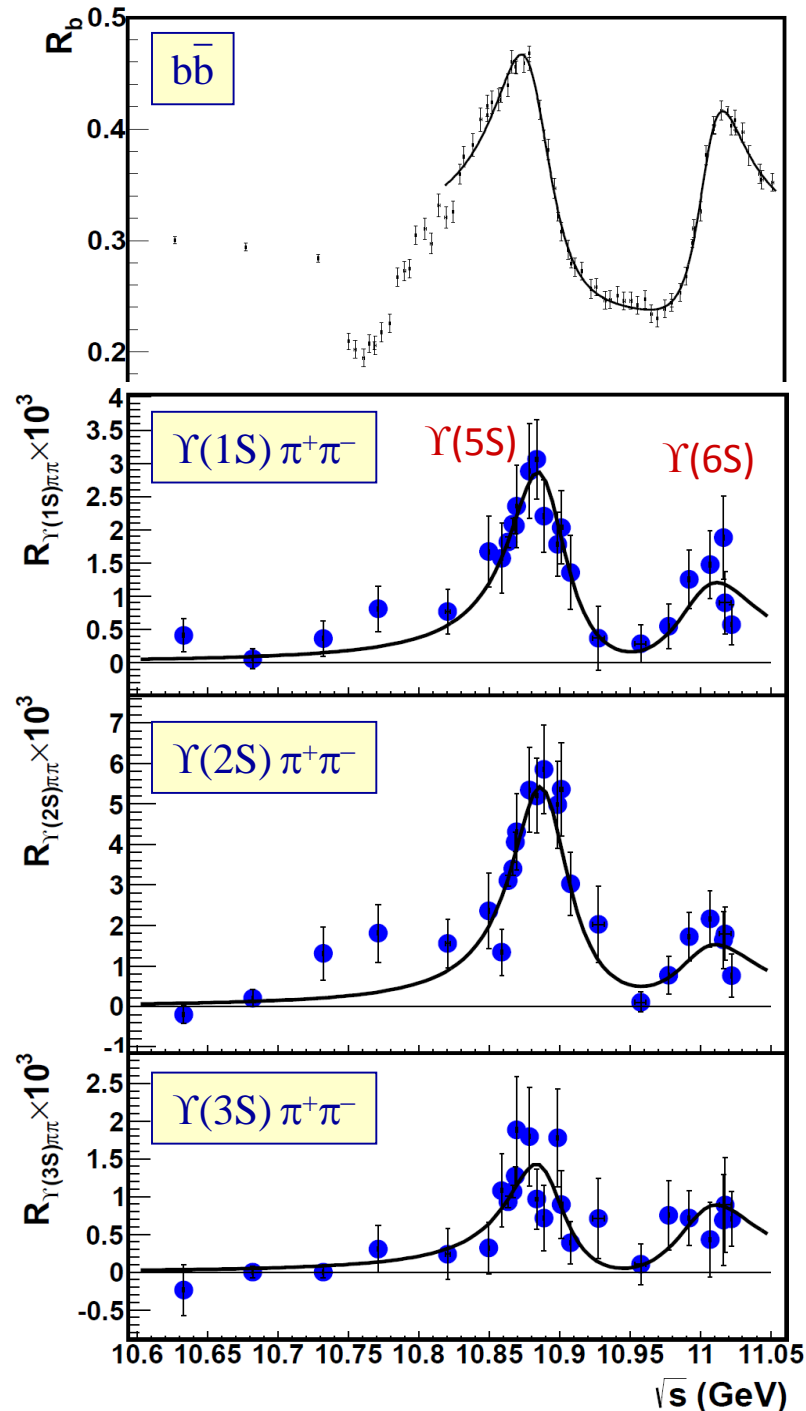
HILUM scan: 22 points $\sim 1 \text{ fb}^{-1}$ each

LOLUM scan: 61 points 50 pb^{-1} each

Belle measured energy dependence of total and exclusive cross sections:

$$e^+e^- \rightarrow \Upsilon(nS) \pi^+\pi^- \quad (n=1,2,3)$$

$$e^+e^- \rightarrow h_b(mP) \pi^+\pi^- \quad (m=1,2) \quad \text{via intermediate } Z_b(10610,10650) \text{ states}$$



\Rightarrow $\Upsilon(5S)$ and $\Upsilon(6S)$ in all final states,
no other significant structures

Shapes of exclusive cross sections are similar
(unlike in charmonium region)

Properties of $\Upsilon(5S)$ and $\Upsilon(6S)$

Partial widths $\Gamma [\Upsilon(5S,6S) \rightarrow \Upsilon(nS) \pi^+ \pi^-] \sim 1 \text{ MeV}$ are anomalously high
 $\Upsilon(5S)$, $\Upsilon(6S)$ have exotic structure ?

Using $\Upsilon(5S)$ on-resonance data Belle observed more transitions:

$$\Upsilon(5S) \rightarrow \Upsilon(1S) K^+ K^-$$

$$\Upsilon(5S) \rightarrow \Upsilon(nS) \eta$$

$$\Upsilon(5S) \rightarrow \chi_{bJ}(1P) \omega$$

$$\Upsilon(5S) \rightarrow \Upsilon_J(1D) \pi^+ \pi^-$$

} talk by Xiaolong Wang

To understand $\Upsilon(5S,6S) \Rightarrow$ energy dependence of open flavor cross sections:

$$B\bar{B}, B\bar{B}^*, B^*\bar{B}^*, B^{(*)}\bar{B}^{(*)}\pi, B_s^{(*)}\bar{B}_s^{(*)}, \dots$$

My talk: study of $e^+e^- \rightarrow B_s\bar{B}_s, B_s\bar{B}_s^* + \text{c.c.}, B_s^*\bar{B}_s^*$

arXiv:1609.08749

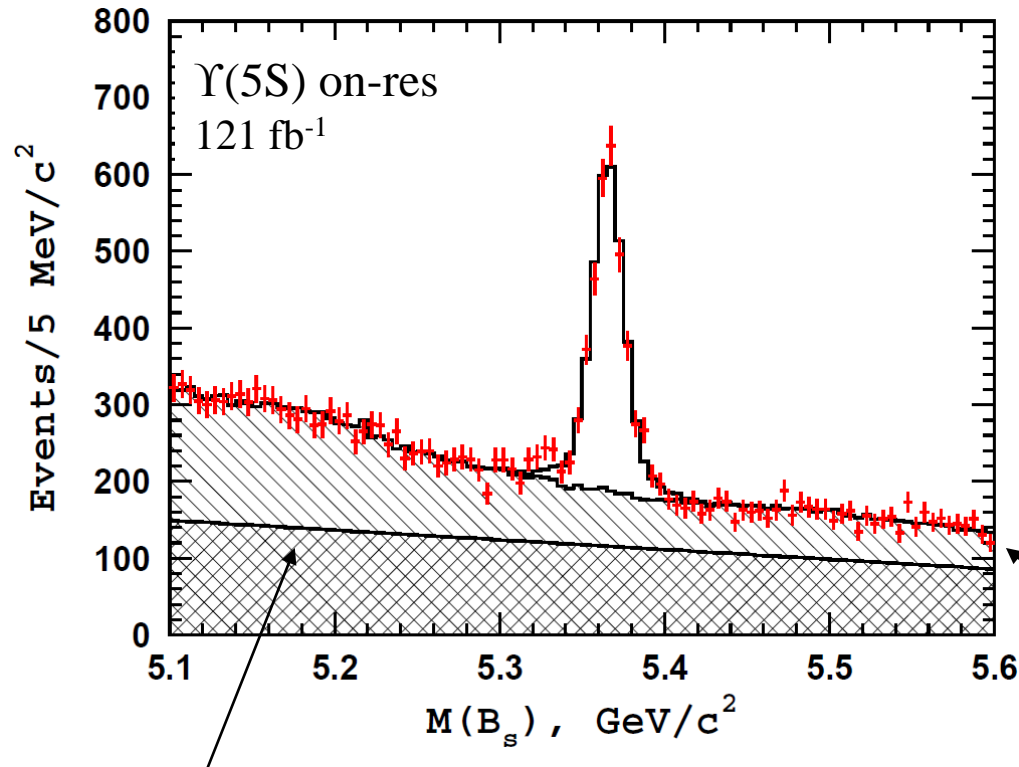
cross section energy dependence
angular analysis of $B_s^*\bar{B}_s^*$

Reconstruction of B_s

arXiv:1609.08749

Decay channels

$$D_s^{(*)-} \pi^+, J/\psi K^+ K^-, J/\psi \pi^+ \pi^-, \psi(2S) K^+ K^-$$



B_s yield: 2283 ± 63

B and B_s related bg
shape, fraction from MC

Continuum $e^+e^- \rightarrow \text{udsc}$ background

suppressed using event topology:

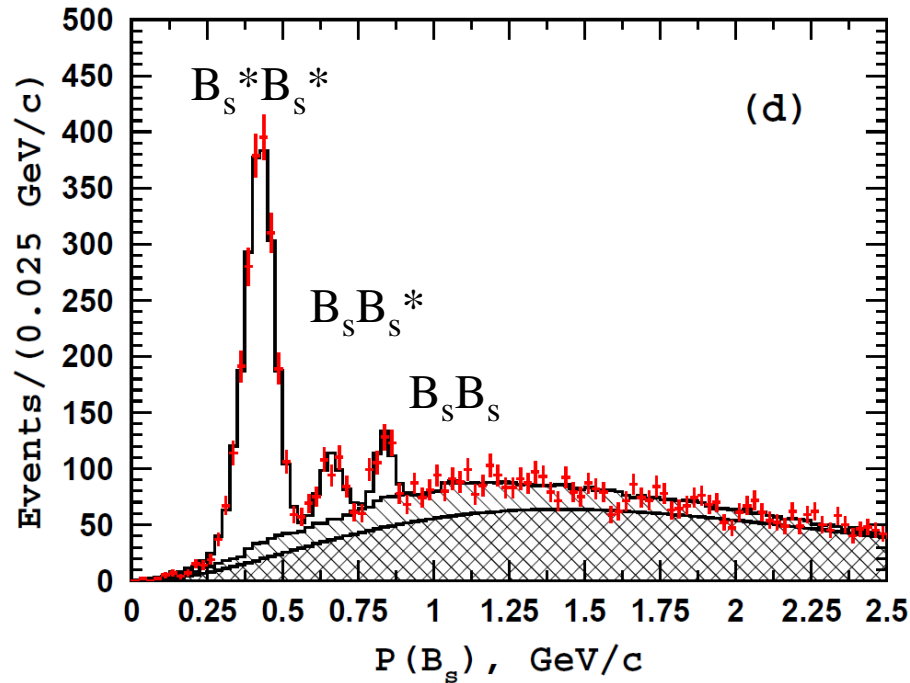
$$|\cos \theta(\text{thrust})| < 0.8$$

Reconstruction of $e^+e^- \rightarrow B_s \bar{B}_s, B_s \bar{B}_s^*, B_s^* \bar{B}_s^*$

arXiv:1609.08749

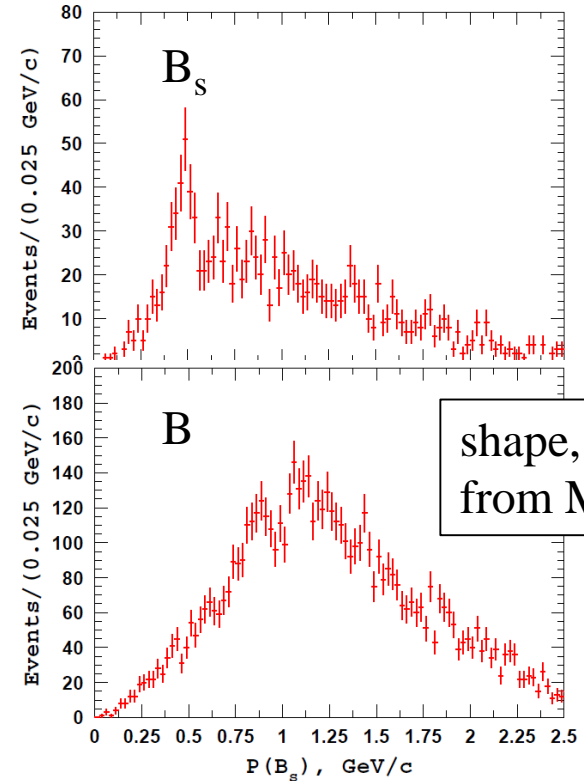
Reconstruct one B_s , do not reconstruct γ from $B_s^* \rightarrow B_s \gamma$

Use B_s momentum \Rightarrow



Signal shape – from MC, accounts for ISR

B and B_s related bgs have structures:



$$B_s^* \bar{B}_s^*$$

$$B_s \bar{B}_s^*$$

$$B_s \bar{B}_s$$

Yields 1854 ± 51 226 ± 27 169 ± 24

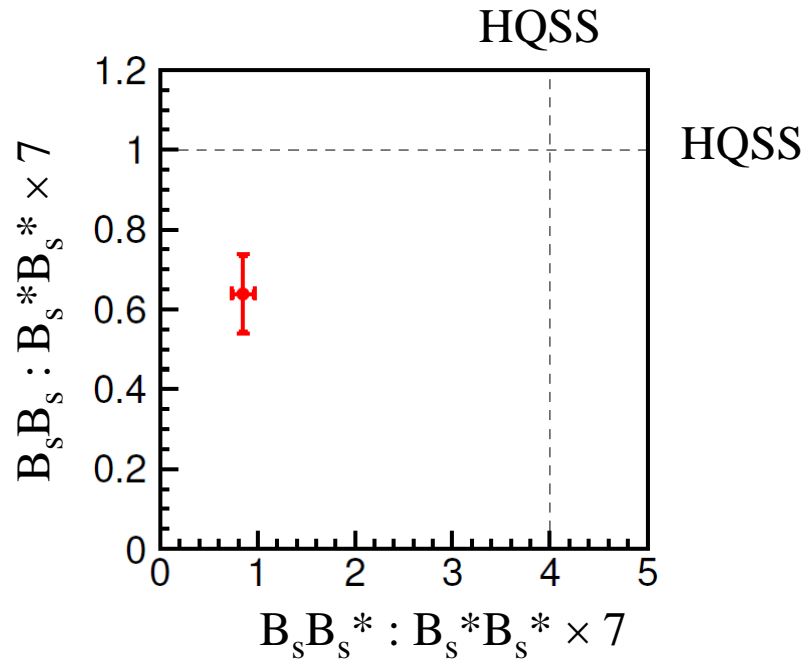
Ratio of $e^+e^- \rightarrow B_s^{(*)}\bar{B}_s^{(*)}$ cross sections

arXiv:1609.08749

Ratio of cross sections:

$$B_s^*\bar{B}_s^* : B_s\bar{B}_s^* : B_s\bar{B}_s = 7 : (0.853 \pm 0.106 \pm 0.053) : (0.638 \pm 0.094 \pm 0.033)$$

HQSS expectations: $7 : 4 : 1$ Voloshin PRD87,094033(2012)



\Rightarrow Strong violation of HQSS.

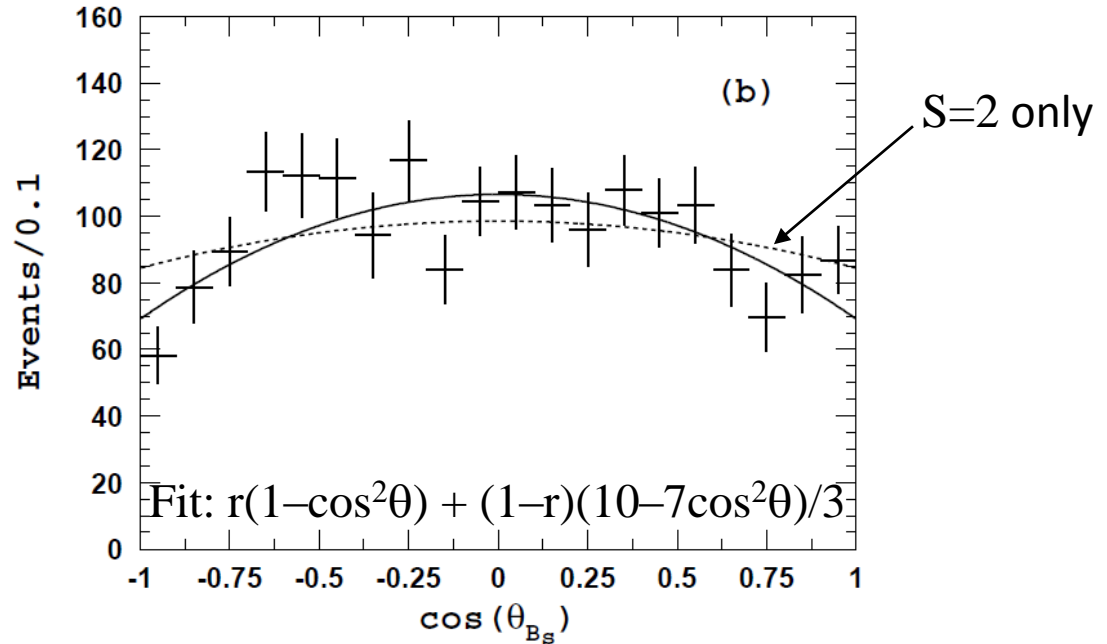
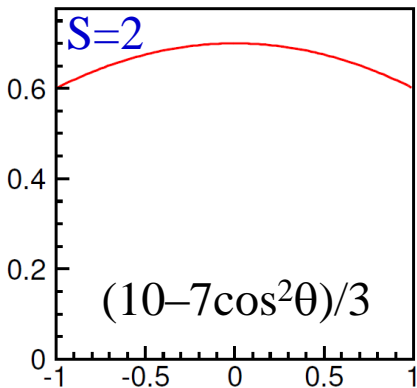
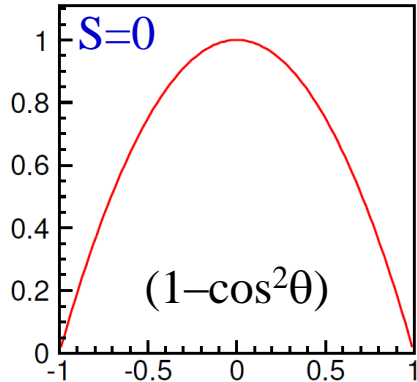
Angular analysis of $e^+e^- \rightarrow B_s^* \bar{B}_s^*$

arXiv:1609.08749

$B_s^* \bar{B}_s^*$ are in P-wave $\Rightarrow S=0$ or $S=2$

F-wave is suppressed, $S=1$ has wrong C-parity

θ – angle btw B_s^* and beam



Fraction of $S=0$: $r = 0.175 \pm 0.057^{+0.022}_{-0.018}$

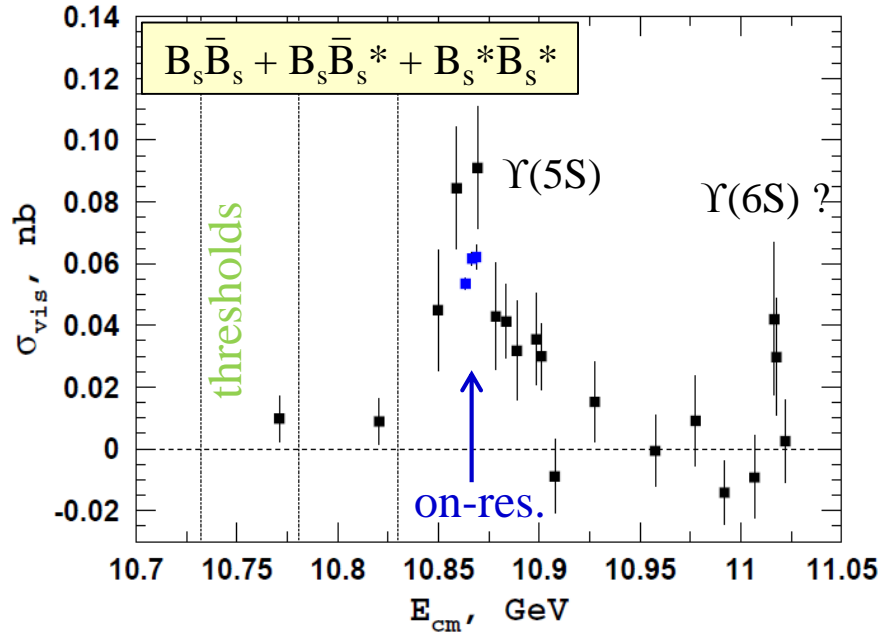
Significance of $r \neq 0$: 3.1σ (2.6σ including systematics)

HQSS expectation: $(S=0) : (S=2) = 1 : 20$ \leftarrow violation

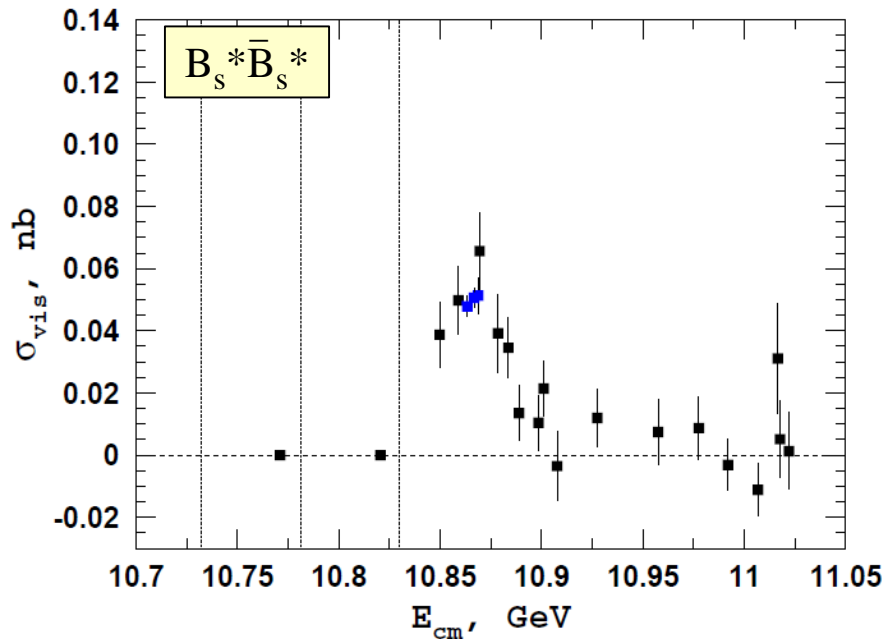
Voloshin PRD87,094033(2012)

Energy dependence of $\sigma[e^+e^- \rightarrow B_s^{(*)}\bar{B}_s^{(*)}]$

arXiv:1609.08749

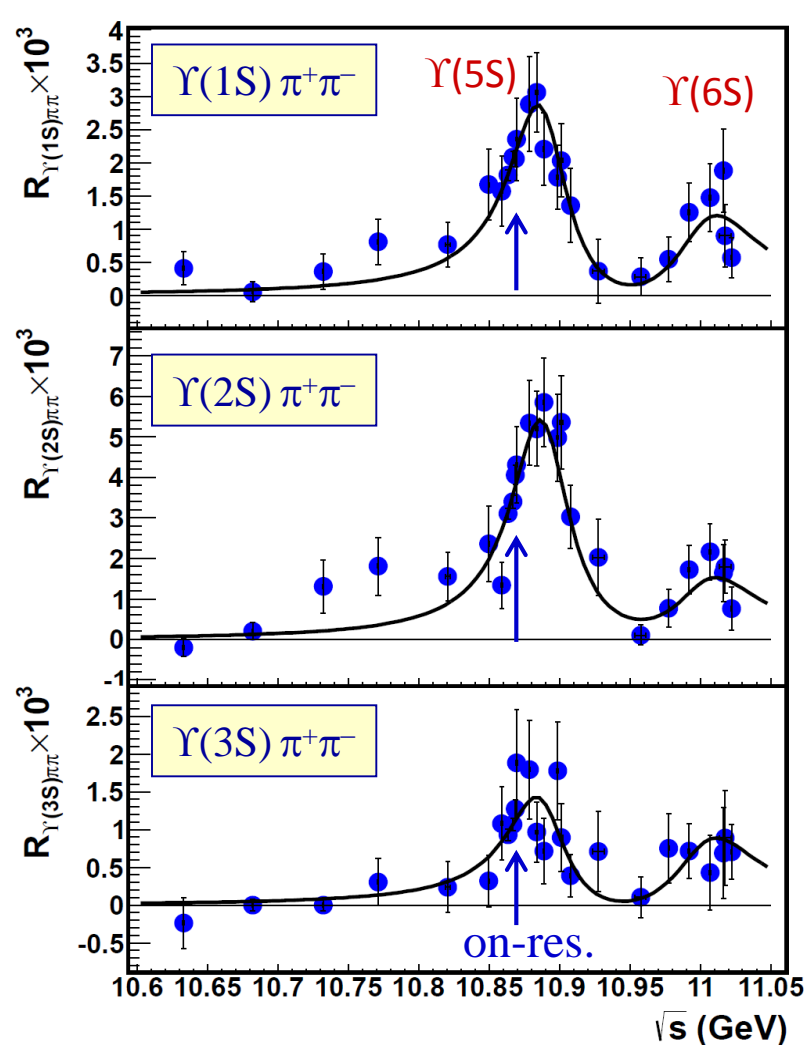


Clear signal of $\Upsilon(5S)$,
no significant $\Upsilon(6S)$,
no significant continuum.



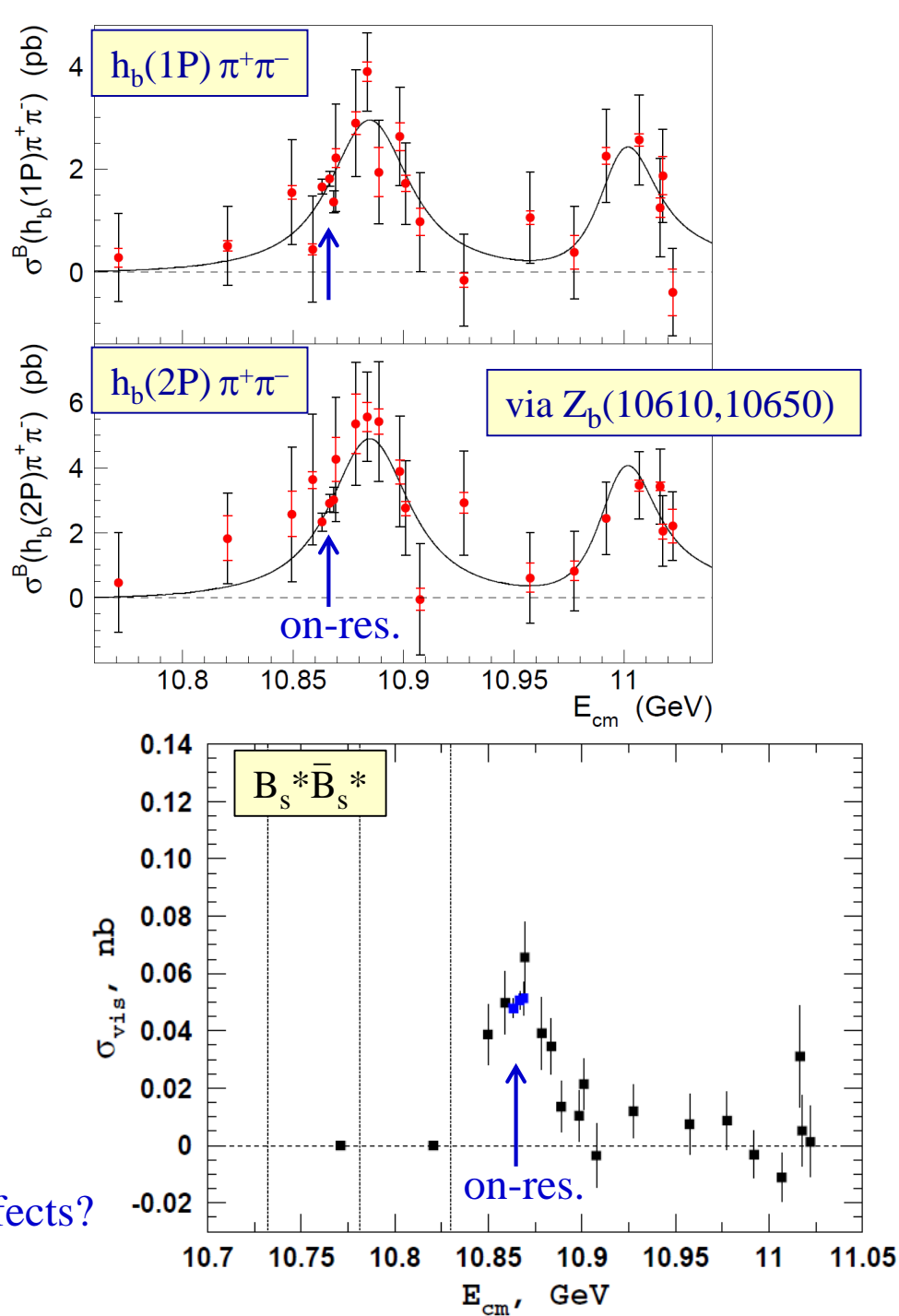
$B_s^* \bar{B}_s^*$ is peaking at $\Upsilon(5S)$,
 $B_s \bar{B}_s^*$ and $B_s \bar{B}_s$ are small at all energies

Peak position \Rightarrow

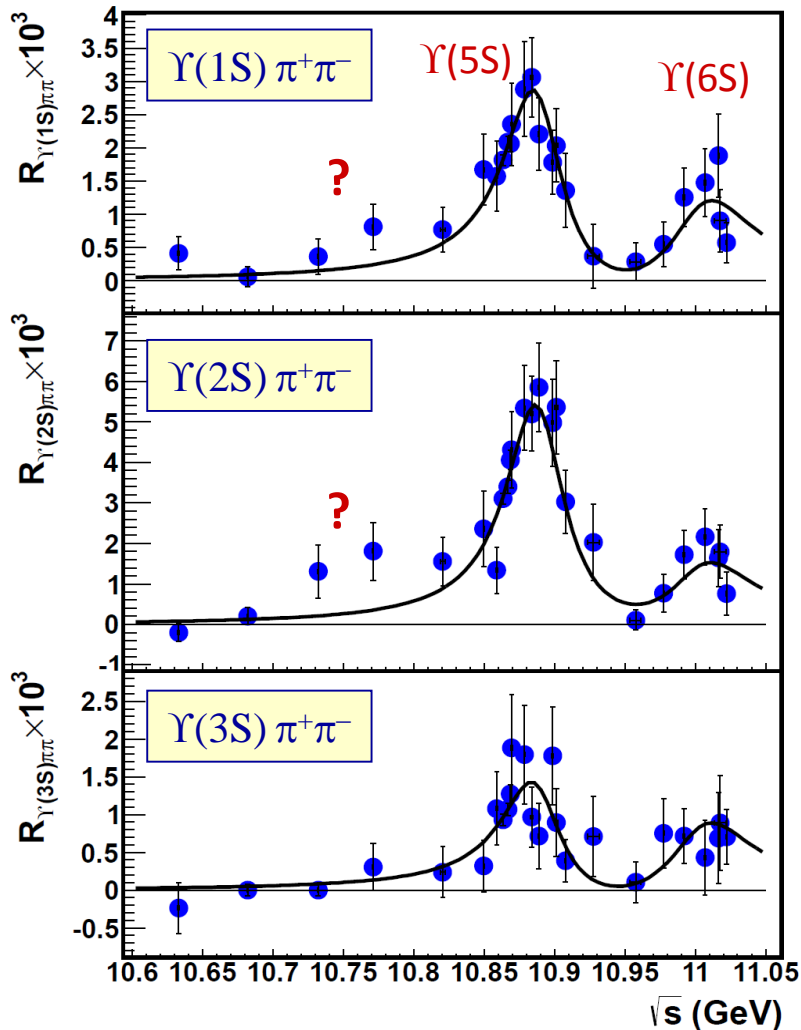


$\Upsilon(5S)$ peak in $\Upsilon\pi\pi / h_b\pi\pi$ is shifted
 by +15 MeV relative to $B_s^* \bar{B}_s^*$

Can this be explained by coupled-channel effects?



Belle plans on energy scan analyses



New structure near 10.77 GeV ?
 \Rightarrow Update $e^+e^- \rightarrow \Upsilon(nS) \pi^+\pi^-$

Study more final states:
 $e^+e^- \rightarrow \chi_{bJ}(1P) \omega, \chi_{bJ}(1P) \phi$

Measure energy dependence of $e^+e^- \rightarrow B\bar{B}, B\bar{B}^*, B^*\bar{B}^*, B^{(*)}\bar{B}^{(*)}\pi$

Conclusions

$\Upsilon(5S)$ on-resonance:

$$\sigma[B_s^* \bar{B}_s^*] : \sigma[B_s \bar{B}_s^*] : \sigma[B_s \bar{B}_s] = 7 : (0.85 \pm 0.12) : (0.64 \pm 0.10)$$

HQSS: 7 : 4 : 1

$$\text{Fraction of } S=0 \text{ in } B_s^* \bar{B}_s^* : r = 0.175 \pm 0.057 \begin{matrix} +0.022 \\ -0.018 \end{matrix}$$

HQSS: $r = 0.05$

Violation of HQSS $\Leftarrow B_s^* \bar{B}_s^*$ threshold is only 35MeV below $\Upsilon(5S)$

Energy dependence of $e^+e^- \rightarrow B_s^{(*)} \bar{B}_s^{(*)}$ cross sections:

peak at $\Upsilon(5S)$, no significant $\Upsilon(6S)$, no significant continuum

$B_s \bar{B}_s$ and $B_s \bar{B}_s^*$ are relatively small at all energies

More energy scan results from Belle are coming soon.