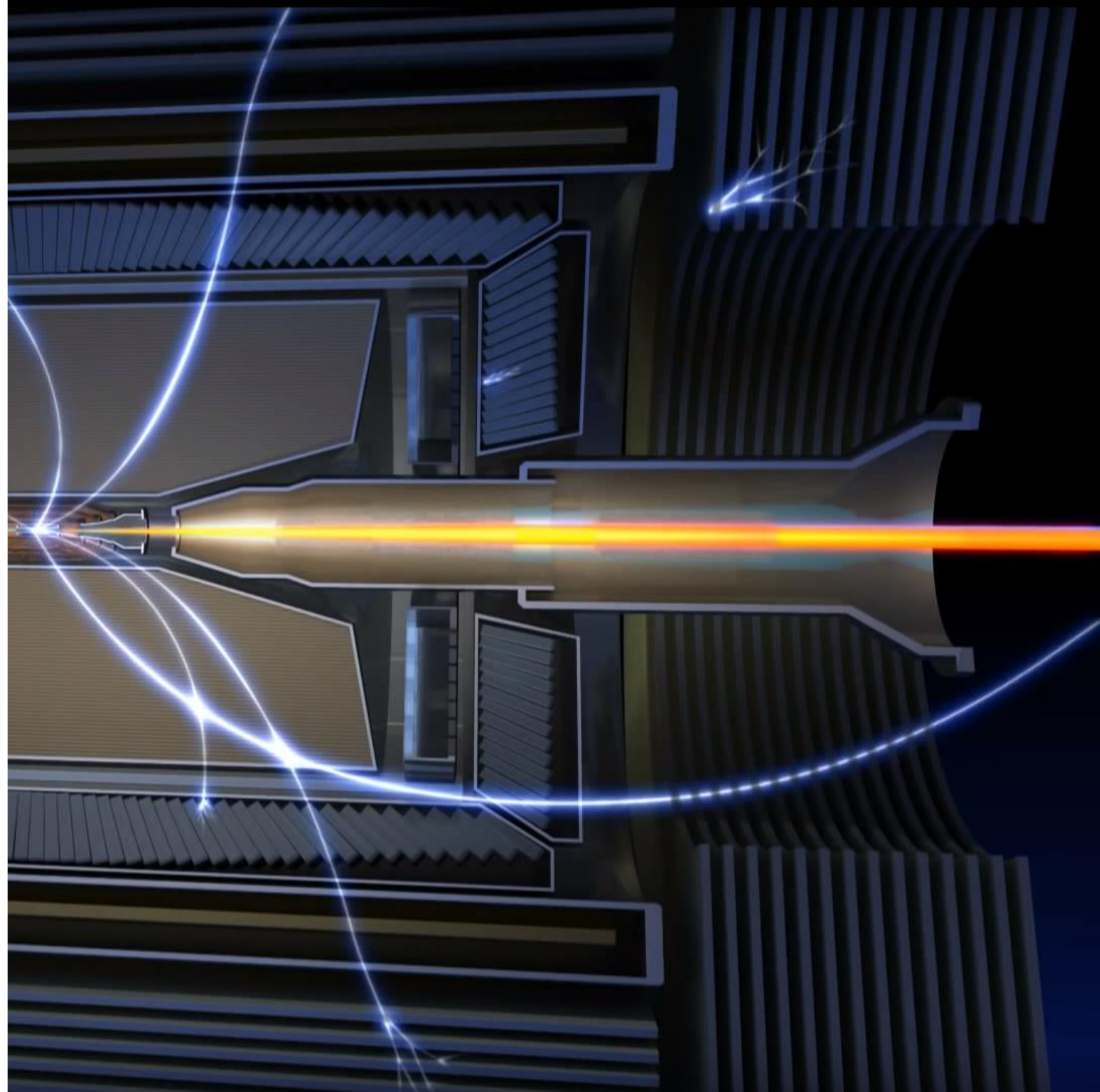


Beyond $\Upsilon(4S)$

November 09, 2020

**A. Bondar (BINP), B. Fulsom (PNNL),
A. Gaz (Nagoya), R. Mizuk (LPI),
U. Tamponi (INFN Torino), K. Trabelsi (IJCLab)**

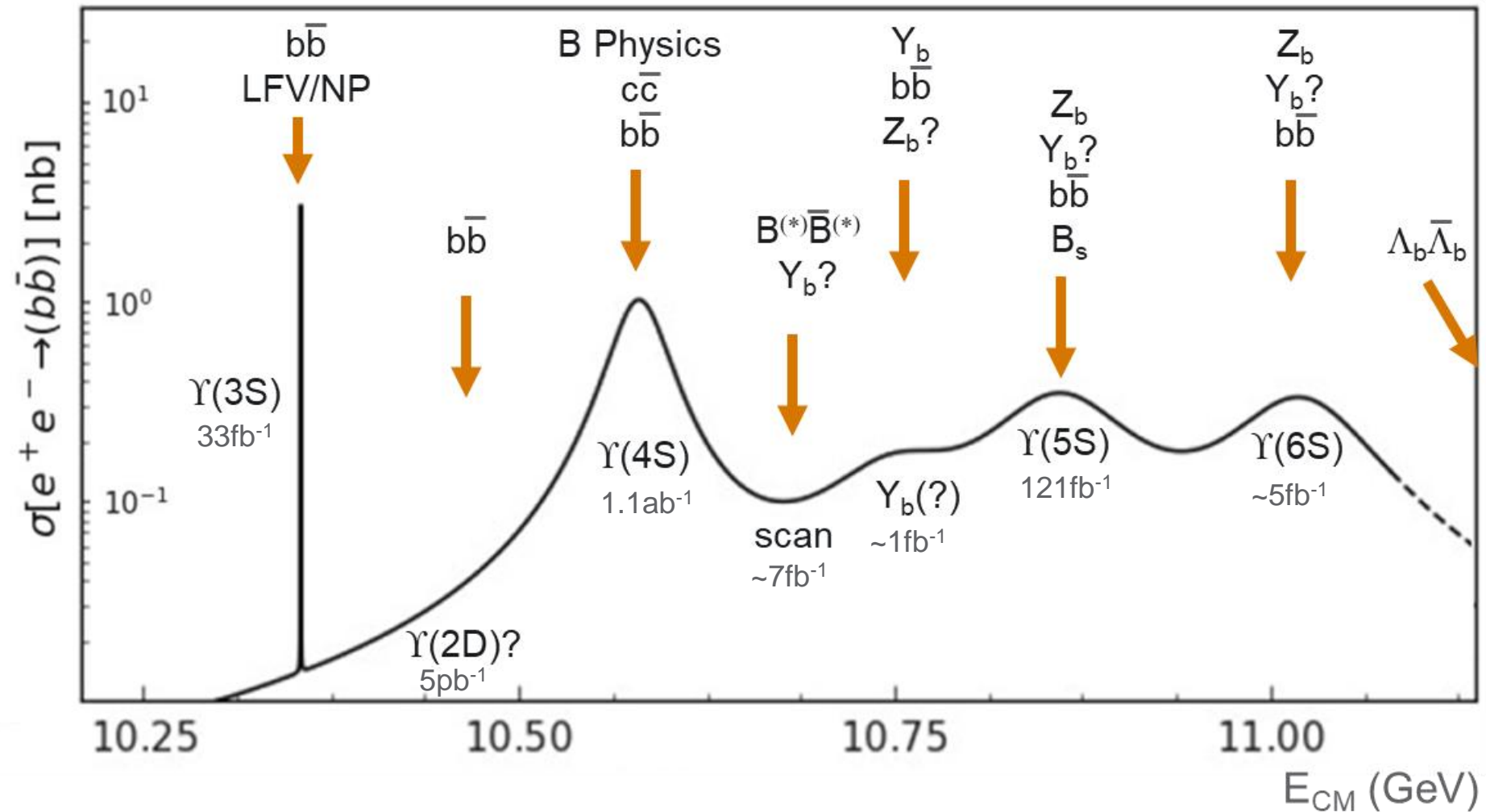
Belle II General Meeting



Introduction

- History
 - Under discussion since ~2014: Belle II Physics Book, Phase 2, ...
 - Feb 2020: **Task Force** requested by Executive Board to investigate options and **advantages of non- $\Upsilon(4S)$** energies
 - Opportunity for **unique physics** with **small luminosity**
- Possible Proposals
 - **$\sim 10 \text{ fb}^{-1}$ @ near 10.75 GeV**
 - **$\sim 30 \text{ fb}^{-1}$ @ $\Upsilon(6S)$ ($\sim 11 \text{ GeV}$), +100 fb^{-1} follow-up and $>11 \text{ GeV}$?**
 - $\Upsilon(4S)$ - $\Upsilon(5S)$ Scan: $\sim 1 \text{ fb}^{-1}$ steps of $\sim 20 \text{ MeV}$
 - Lower energies: $>100 \text{ fb}^{-1}$ @ $\Upsilon(3S, \dots)$
- Factors: beam energy, luminosity, physics

Physics Overview



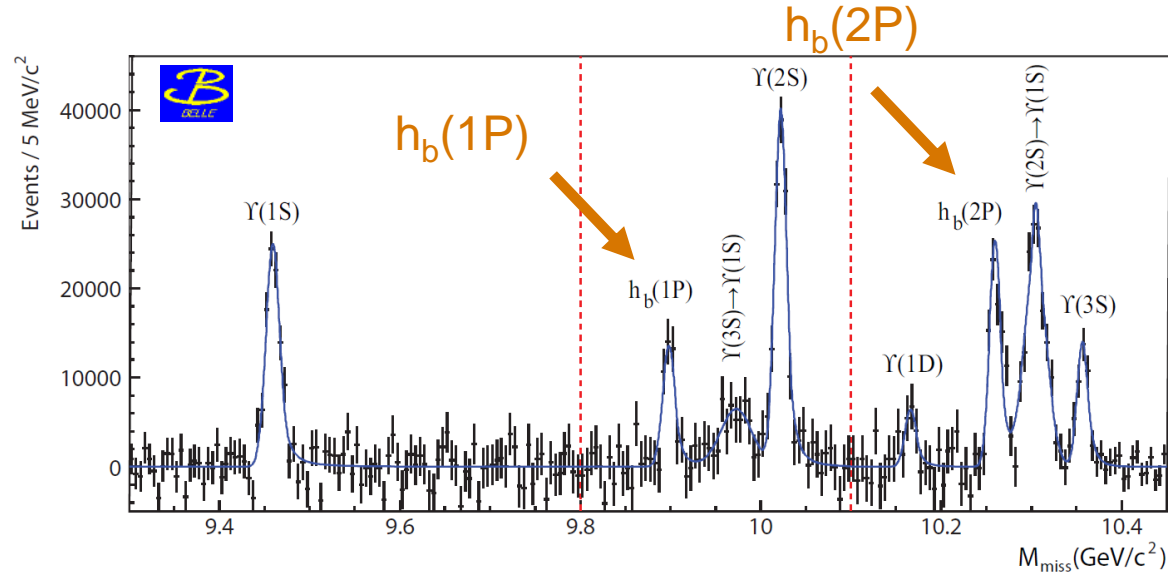
- In-depth references

- Bondar, Mizuk and Voloshin, “Bottomonium-like states: Physics case for energy scan above BB threshold at Belle-II”, Mod. Phys. Lett. A 32, 1750025 (2017)
- E. Kou et al., “The Belle II Physics Book”, Prog. Theor. Exp. Phys. 2019 123C01 (2019)

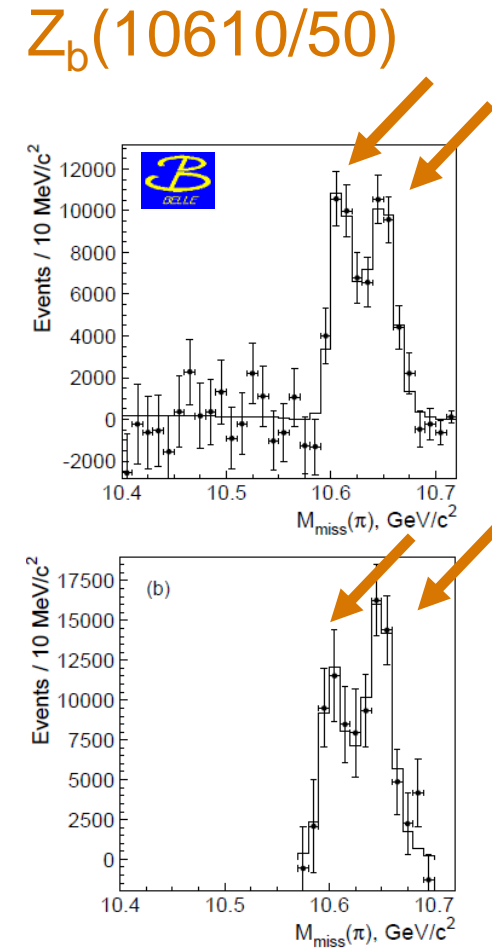
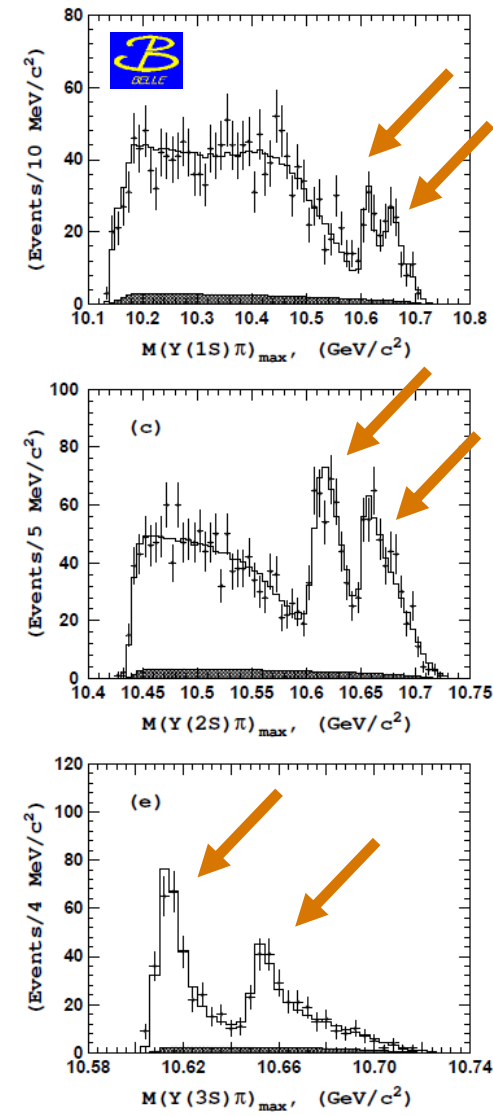
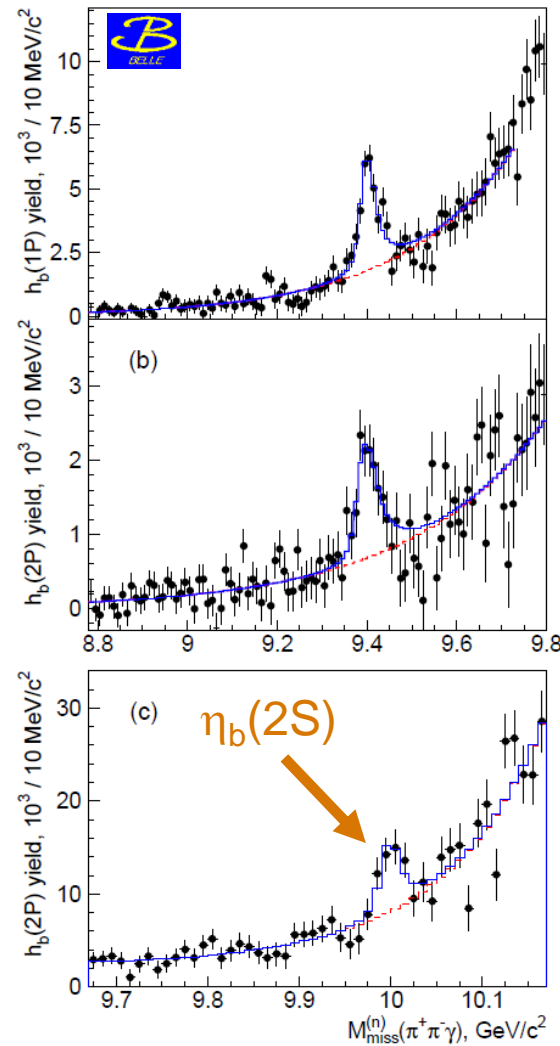
Reminder: $\Upsilon(5S)$ at Belle

121 fb⁻¹

- High-rate $\Upsilon(5S)$ dipion transitions led to discovery of h_b , η_b , $Z_b(10610, 10650)$

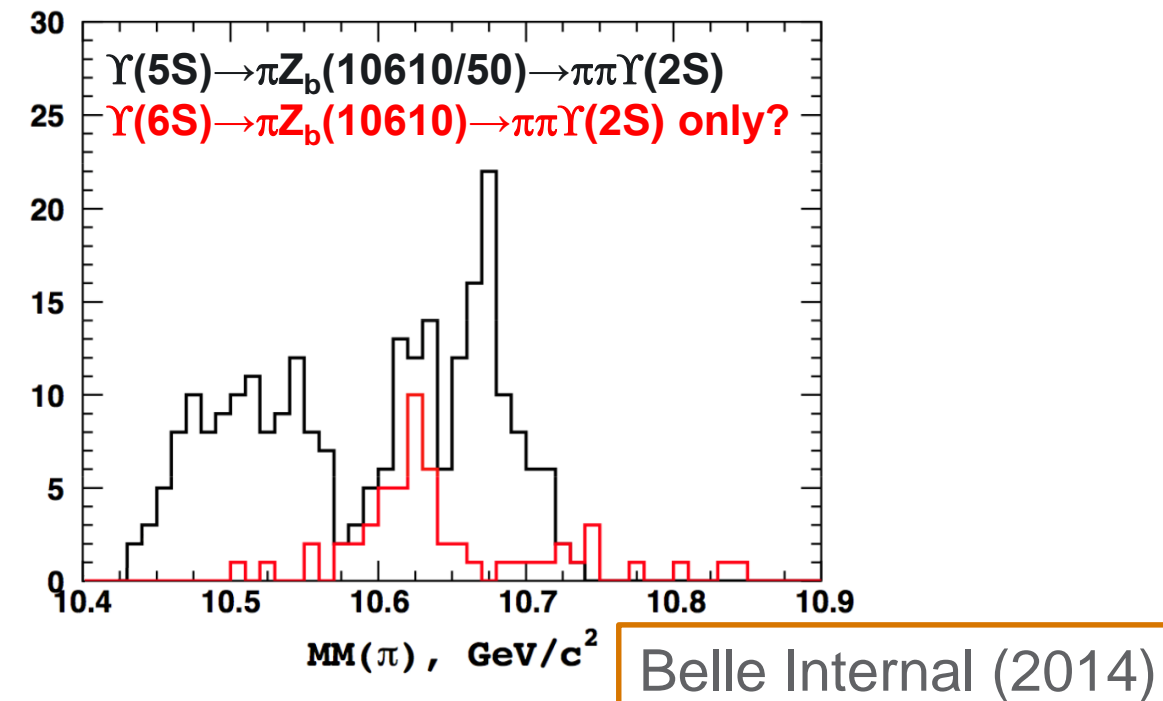
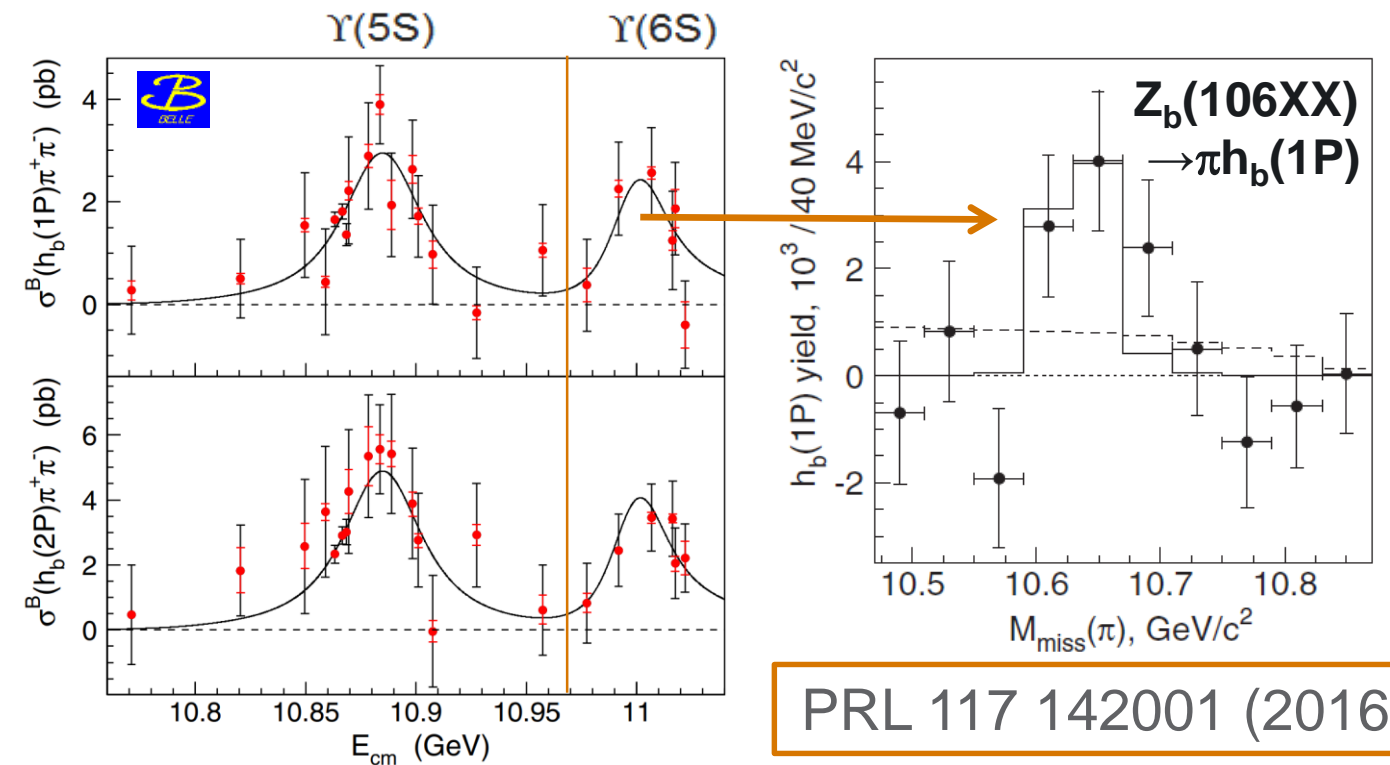


PRL 108, 032001 (2012) ← ~200 citations
 PRL 108, 122001 (2012) ← >500 citations
 PRL 109, 232002 (2012) ← ~100 citations



Motivation: $\Upsilon(6S)$

- Belle limited by statistics
- $<1 \text{ fb}^{-1}$ per scan point $\sim 4.6 \text{ fb}^{-1}$
- Not on σ peak, $L_{\text{eff}} \sim 3 \text{ fb}^{-1}$
- $\Upsilon(6S) \rightarrow \pi^+\pi^- X$
 - h_b : evidence for Z_b
 - $\Upsilon(pS)$ exclusive: unpublished
- Pending questions:
 - Z_b : how many states, neutral partners?
 - Is $\Upsilon(6S)$ quarkonium or a four-quark state?
 - Potential pathway to other bottomonium states



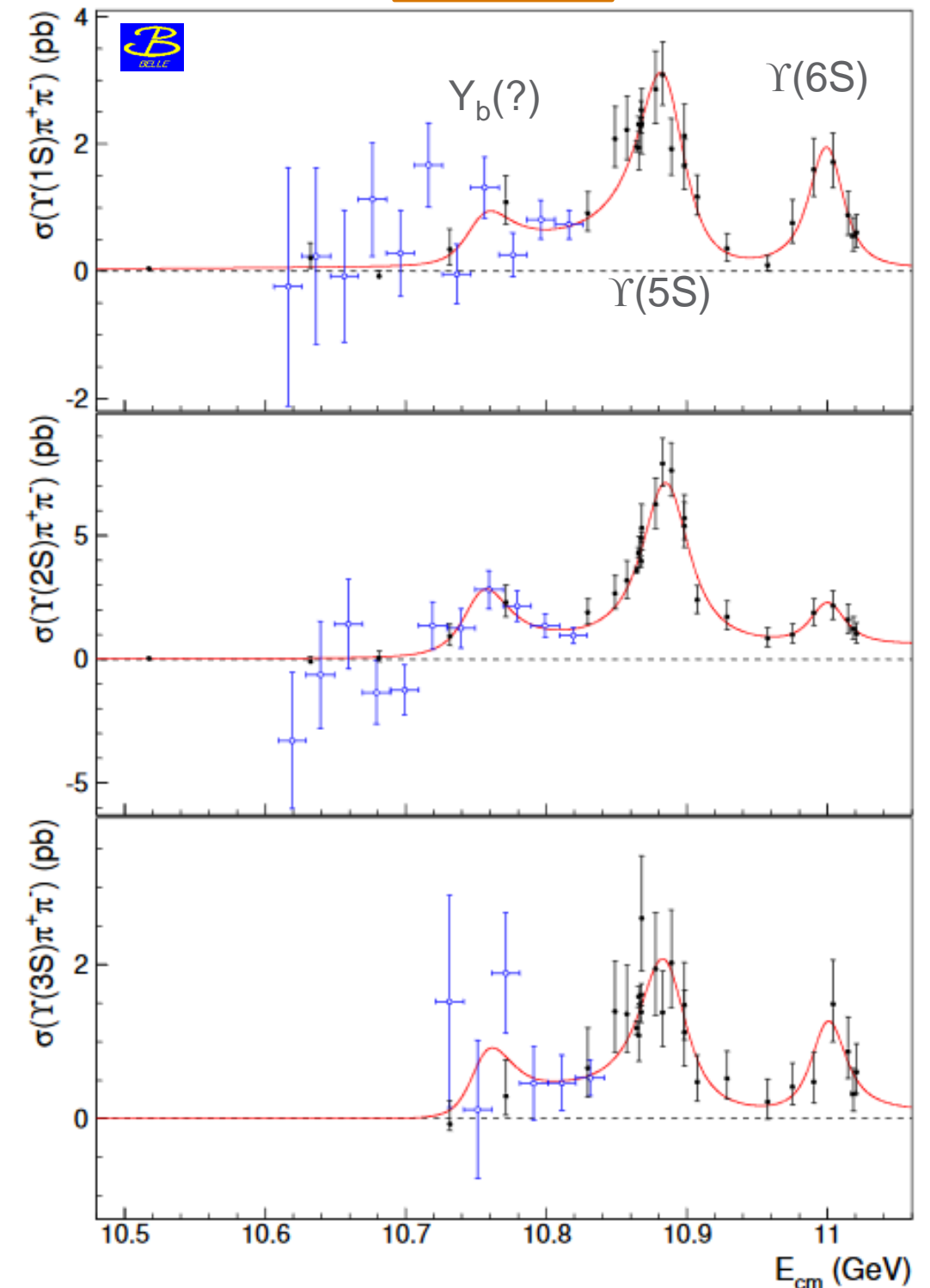
Motivation: “ $\Upsilon_b(10750)$ ”

- Recent Belle analysis of $\pi^+\pi^-\Upsilon(\ell\ell)$ transitions
JHEP 10 (2019) 220
- Observation of enhancement @ 10.75 GeV
- Decays similar to $\Upsilon(56S) \rightarrow \pi^+\pi^-\Upsilon(123S)$
 - Could there be a Z_b enhancement?
 - Could it be $\Upsilon(3D)$ bottomonium or a tetraquark?
 - Near $B^{(*)}B^*\pi$ threshold regions

Wang, CPC 43, 123102 (2019)
 Ali et al., PLB 802, 135217 (2020)
 Bicudo, Cardoso & Wagner, arXiv:2008.05605 (2020)
 Chen, Zhang & He, PRD 101, 014020 (2020)
 Giron & Lebed, PRD 102, 014036 (2020)
 Li et al., EPJC 80, 59 (2020)
 Liang, Ikeno & Oset, PLB 803, 135340 (2020)

...

$\sim 1 \text{ fb}^{-1}$

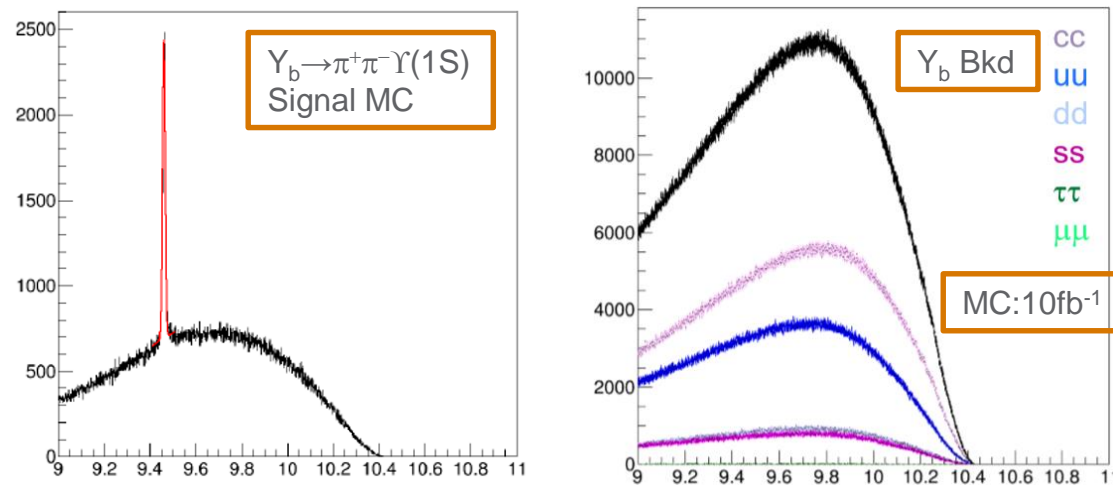


Analysis Preparations (Preliminary)

- $Y_b(10750)$, $\Upsilon(6S)$ MC sensitivity studies:

Inclusive and exclusive $\pi^+\pi^-bb$

Feb 2020 B2GM

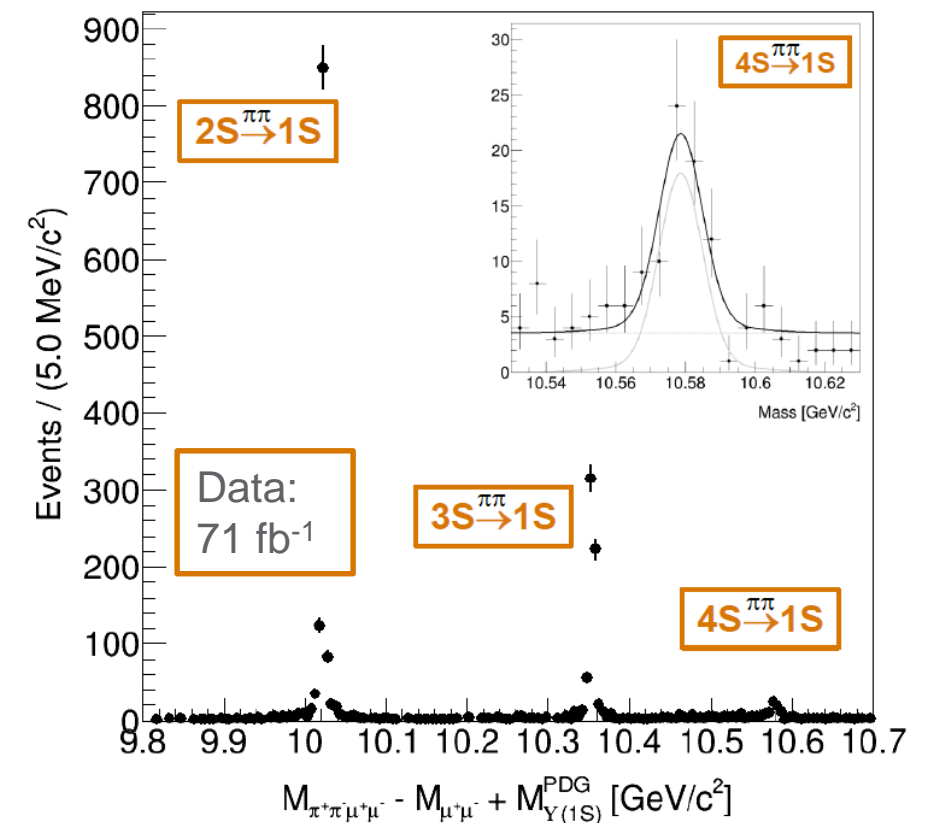


Mode	σ (pb)	S (/fb ⁻¹)	B (/fb ⁻¹)	$\mathcal{L}(5\sigma)$
$\Upsilon(6S)$				
$\pi^+\pi^-\Upsilon(1S)(\mu\mu)$	1.7	9.1	0.8	3.0
$\pi^+\pi^-\Upsilon(2S)(\mu\mu)$	2.2	9.2	3.0	3.6
$\pi^+\pi^-h_b(1P)(all)$	2.5	1476	446747	5.2
$\pi^+\pi^-h_b(2P)(all)$	4.0	2126	436449	2.5
Y_b				
$\pi^+\pi^-\Upsilon(1S)(\mu\mu)$	1.1	5.6	1.2	5.5
$\pi^+\pi^-\Upsilon(2S)(\mu\mu)$	2.3	7.7	2.8	4.4

- Proof of principle:

Oct 2020 B2GM

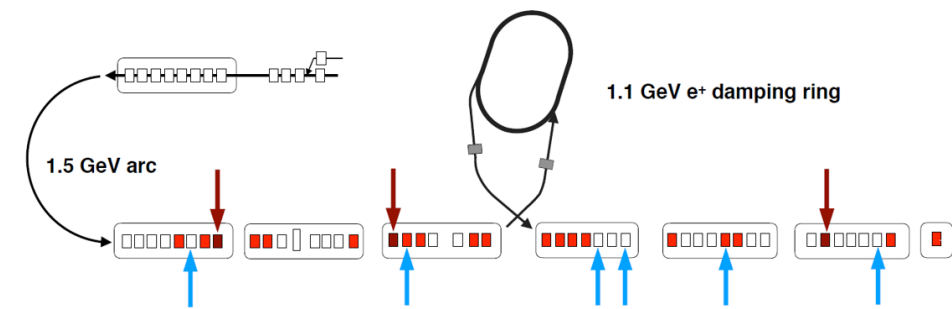
$\Upsilon(234S) \rightarrow \pi^+\pi^-\Upsilon(1S)(\mu\mu)$ in Belle II data



- Underway: η bottomonium transitions in early Belle II data
- Bottomonium Working Group meetings: every 2nd Friday

Some Accelerator Considerations

- Above $\Upsilon(4S)$ Task Force input from SuperKEKB colleagues
- Ongoing linac RF upgrade
 - Improve operational stability
 - Might reach energies up to ~ 11.26 GeV
- $\Upsilon(6S)$ / 11 GeV
 - Potentially possible (linac) in 2021
 - Situation better after shutdown?
- Y_b / 10.75 GeV
 - Possible (linac) in 2021
 - Tuning/stability/luminosity TBD



FY 2018	FY 2019	FY 2020	FY 2021	FY 2022
New S-band structure				
Completed ! R & D	Completed ! Fabrication of four structures	High-power test & installation Material procurement for 12 structures	10.75 GeV ? Fabrication of 12 structures	Belle II Long Shutdown Conditioning Installation
				$\Upsilon(6S)$?

- Further discussion needed, see other talks today

Conclusion

- Task Force studying near-term plans for above $\Upsilon(4S)$ data collection
- Information available in [BELLE2-NOTE-PH-2020-066](#)
- Useful initial dataset size $O(10 \text{ fb}^{-1})$ at $\sim 10.75 \text{ GeV}$ and $O(30 \text{ fb}^{-1})$ at $\sim 11 \text{ GeV}$
- Long list of potential analyses
 - $\Upsilon(6S/b) \rightarrow \pi\pi X$ inclusive
 - $\Upsilon(6S/b) \rightarrow \pi\pi\Upsilon(pS)$ exclusive
 - Also $\pi^0\pi^0$ modes
 - $\Upsilon(6S) \rightarrow \gamma W_b \rightarrow \omega\Upsilon(1S)$
 - $\Upsilon(6S/b) \rightarrow \gamma \chi_b$ exclusive
 - $\Upsilon(6S/b) \rightarrow \gamma X$ inclusive
 - Each represents a **publication unique to Belle II**
 - $\Upsilon(6S/b) \rightarrow \eta X$ inclusive
 - $\Upsilon(6S/b) \rightarrow \eta\Upsilon(pS)$ exclusive
 - $\Upsilon(6S/b) \rightarrow \eta'\Upsilon(pS)$ exclusive
 - $\Upsilon(6S/b) \rightarrow \omega X$ exclusive
 - $\Upsilon(6S) \rightarrow \phi\chi_b(1P)$ exclusive
 - $\Upsilon(6S/b) \rightarrow BB$
 - ...probably more...
- Potential to increase our physics output...hopefully we can make it possible!

Thank you

