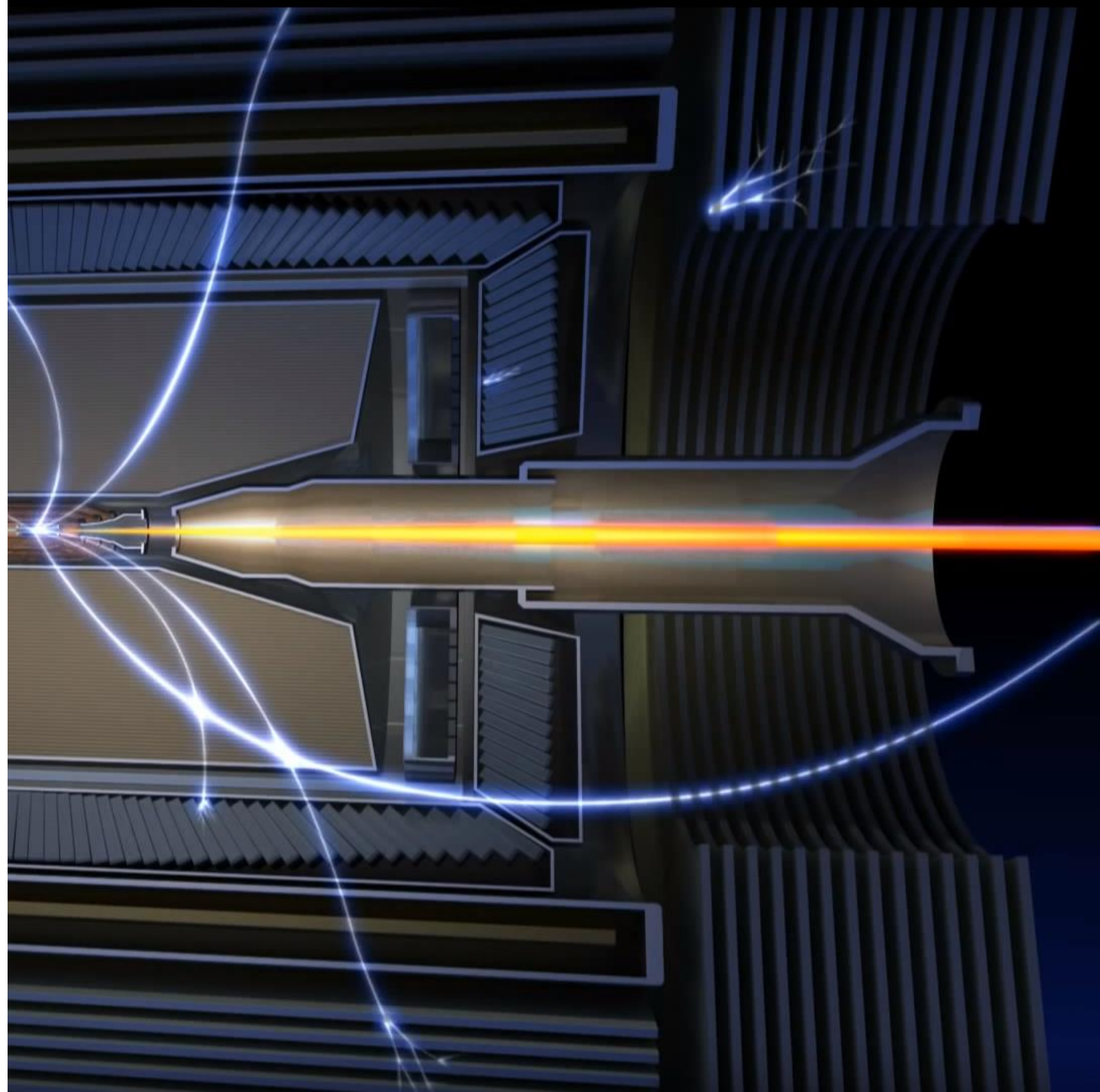


News from Belle II

Oct 25, 2021

Bryan Fulsom (PNNL)

Snowmass RF7 Meeting:
2021 Update on Hadron Spectroscopy



Reminder

- Belle II is the next generation B-Factory

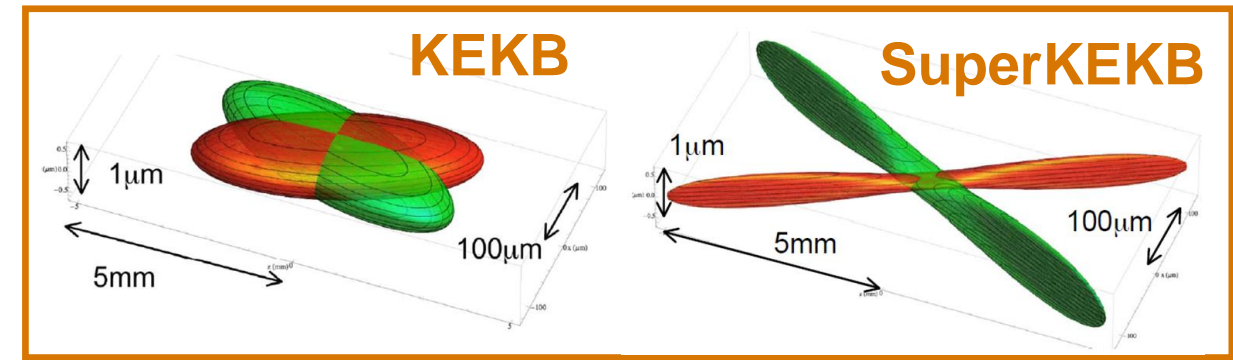
- Upgraded detector and accelerator
- ~10-year program ongoing since 2019

- Advantages

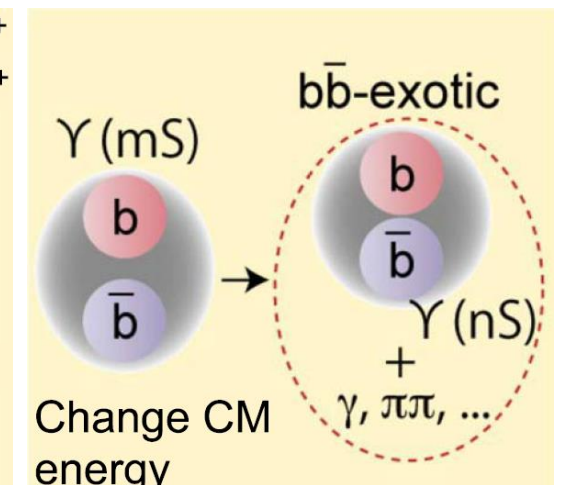
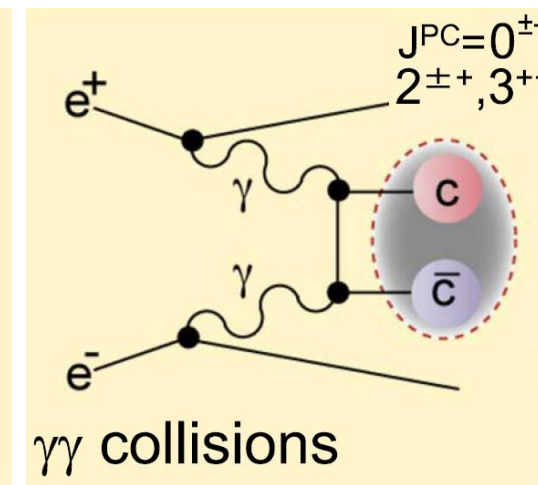
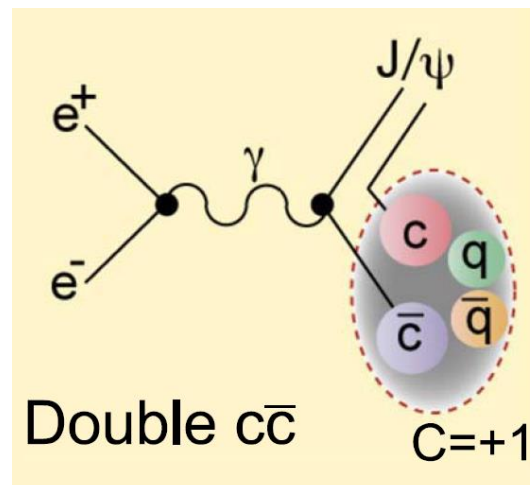
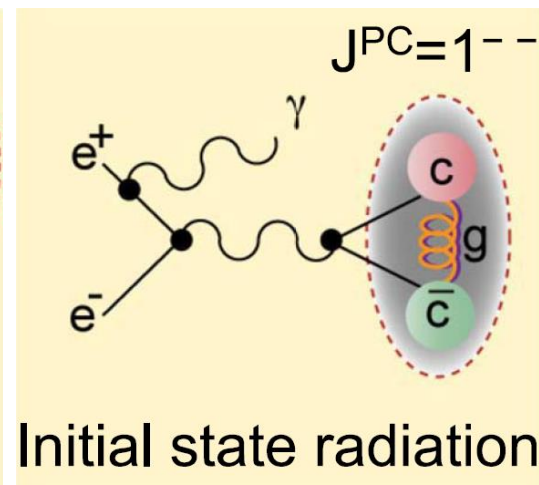
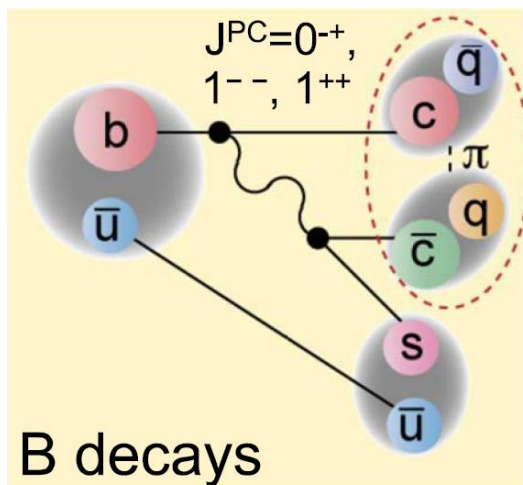
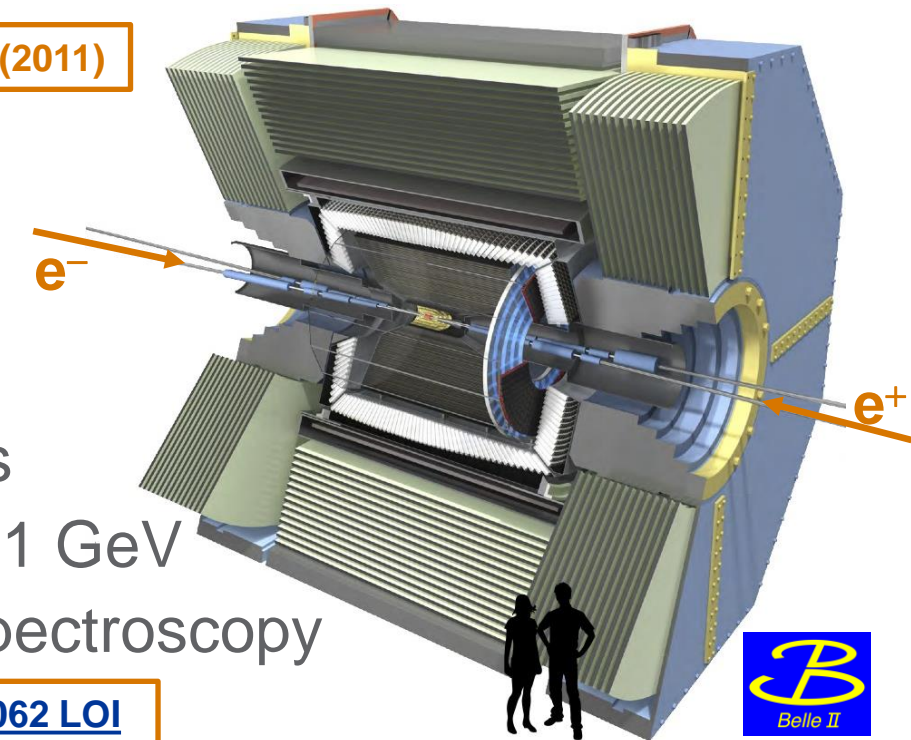
- Full event reconstruction, decays with neutral/soft particles
- Nominal $\sqrt{s} = 10.58 \text{ GeV} = m(\Upsilon(4S))$, potential to reach ~11 GeV
- Many flavor physics contributions, particularly in hadron spectroscopy

PTEP 2019 123C01 (2019)

SNOWMASS21-RF7 RF0 Fulsom-062 LOI



arXiv:1011.0352 (2011)

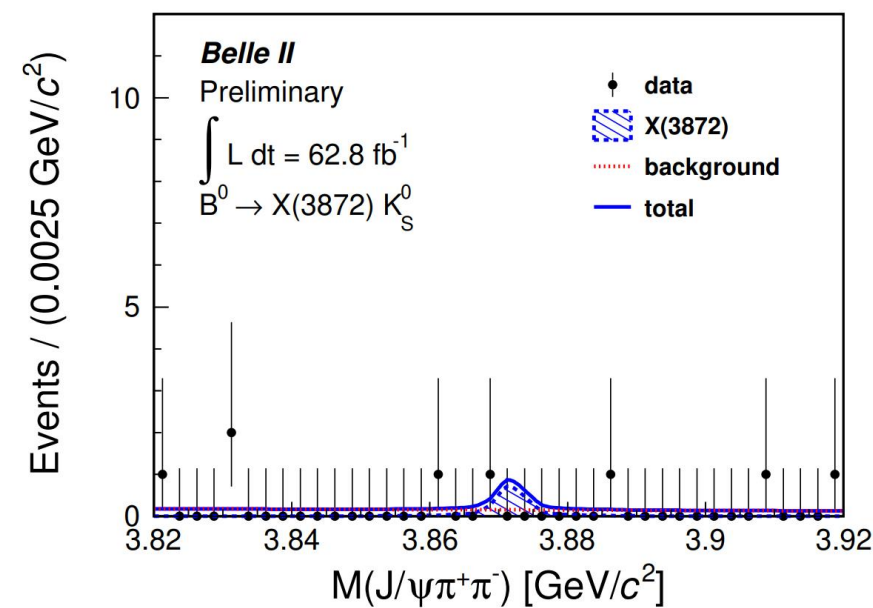
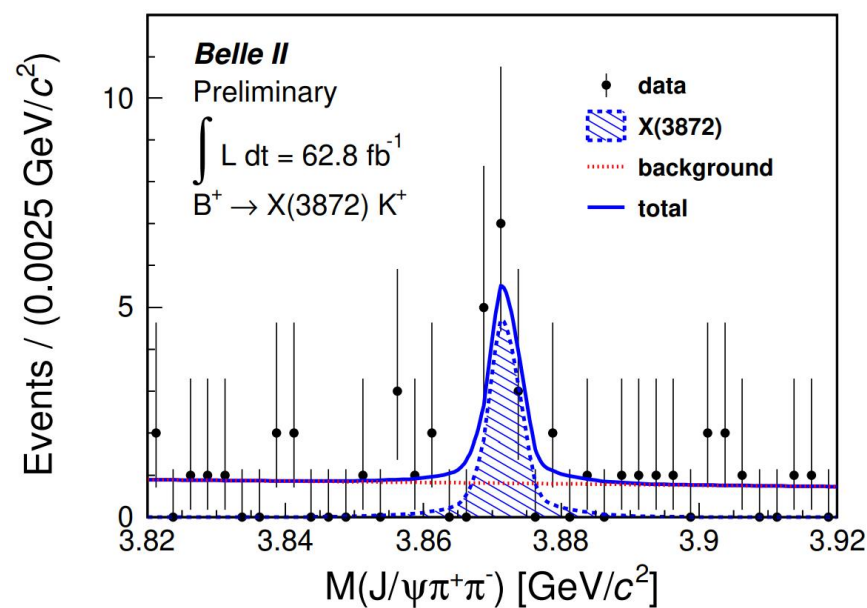
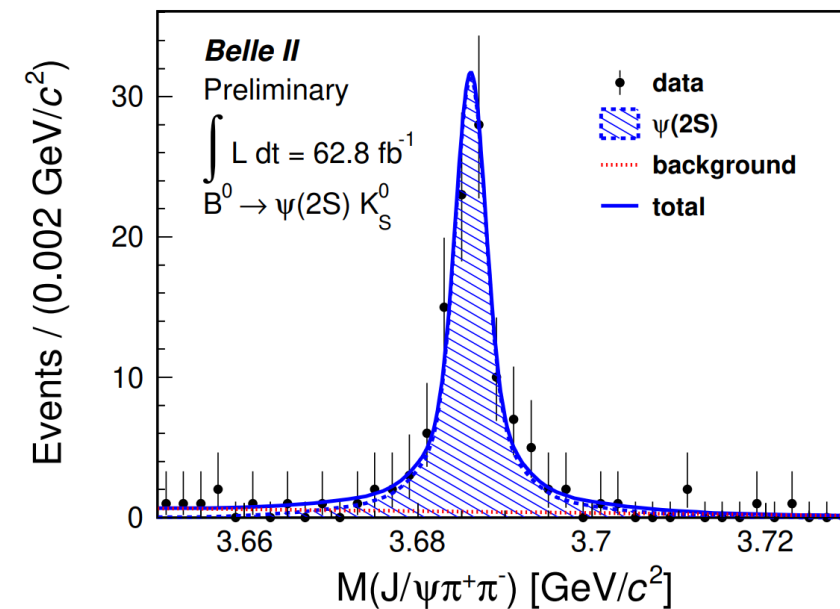
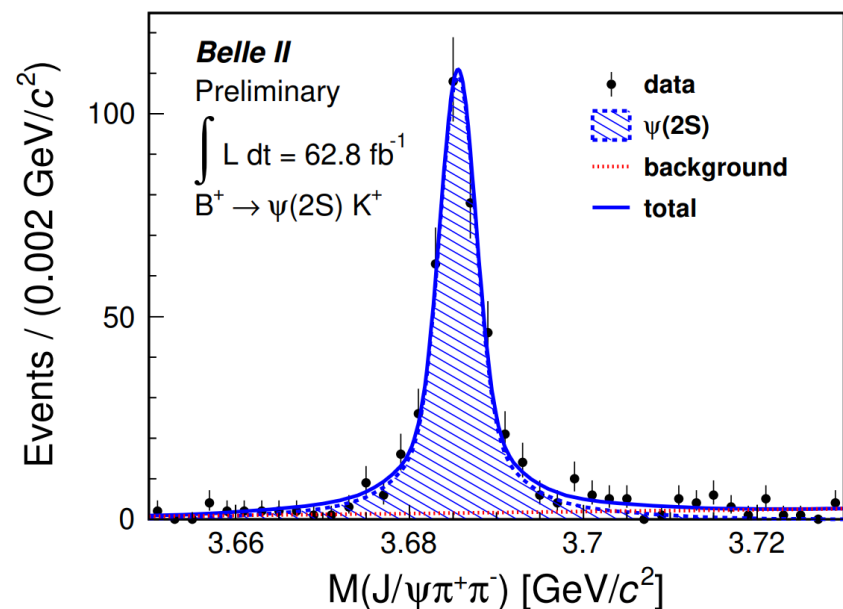


What's New since Oct. 2, 2020?

- Early results
- Overall operational situation
- Above $\Upsilon(4S)$ energy scan
- Snowmass/Future Plans

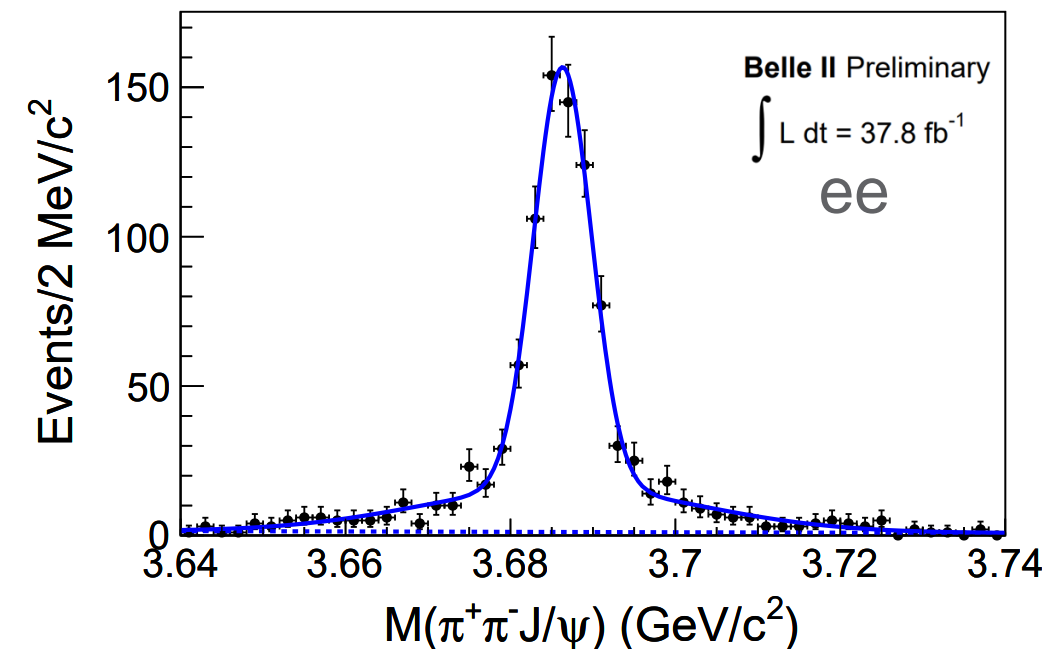
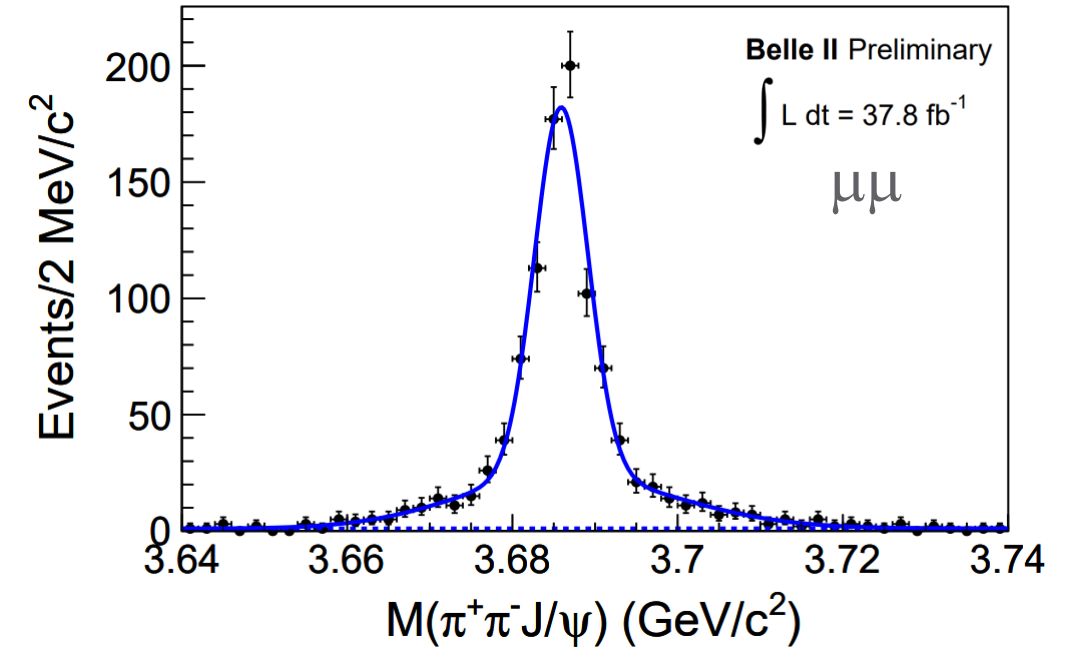
Belle II Progress – X(3872)

- Reconstruct final states:
 - $B^\pm \rightarrow \pi^+\pi^- J/\psi(\ell^+\ell^-) K^\pm$
 - $B^0 \rightarrow \pi^+\pi^- J/\psi(\ell^+\ell^-) K_S$
- “Standard” selection criteria
 - Particle identification
 - Continuum: nTracks, R_2
 - Kinematics: $M_{\pi^+\pi^-}$, M_{BC} , $|\Delta E|$
- Observe $B \rightarrow \psi(2S) K$
- First X(3872) at Belle II
 - 14.4 ± 4.6 events (4.6σ)



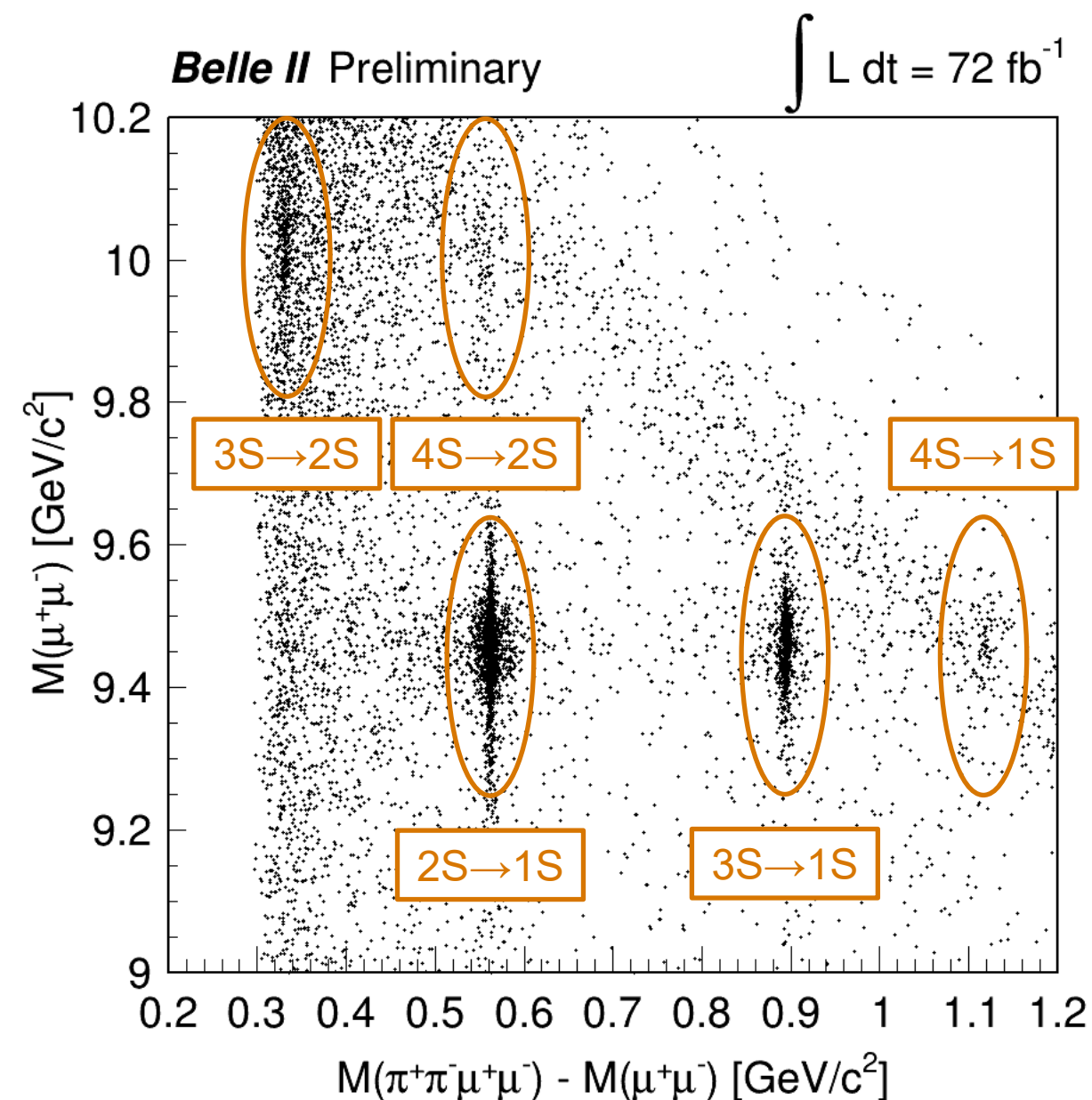
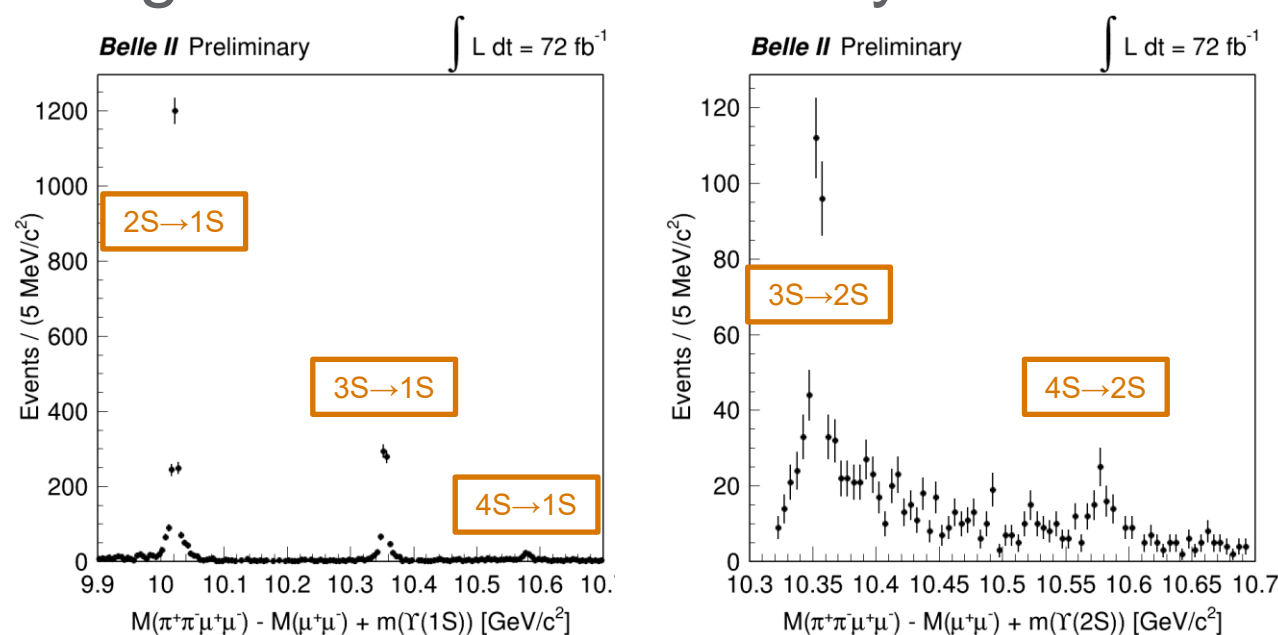
Belle II Progress – ISR $c\bar{c}$ Processes

- $e^+e^-\gamma_{\text{ISR}} \rightarrow \pi^+\pi^-J/\psi(\ell^+\ell^-)$ final states
 - Nominal PID requirements
 - $|M(J/\psi) - M(\text{PDG})| < 75 \text{ MeV}$
 - ISR photon not required (high efficiency)
 - $|MM^2(\pi^+\pi^-J/\psi)| < 2 \text{ GeV}^2$
- Clear observation of ISR $\psi(2S)$ signals
- Next step: “Y(4260)” rediscovery
 - Expect ~ 60 total events per 100 fb^{-1}



Belle II Progress – Bottomonium

- Initial State Radiation production:
 - $\gamma_{\text{ISR}} \Upsilon(2S) \rightarrow \pi^+ \pi^- \Upsilon(1S) (\ell^+ \ell^-)$
 - $\gamma_{\text{ISR}} \Upsilon(3S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S) (\ell^+ \ell^-)$
- Direct transitions: $\Upsilon(4S) \rightarrow \pi^+ \pi^- \Upsilon(1S, 2S)$
- All signals observed in early Belle II data

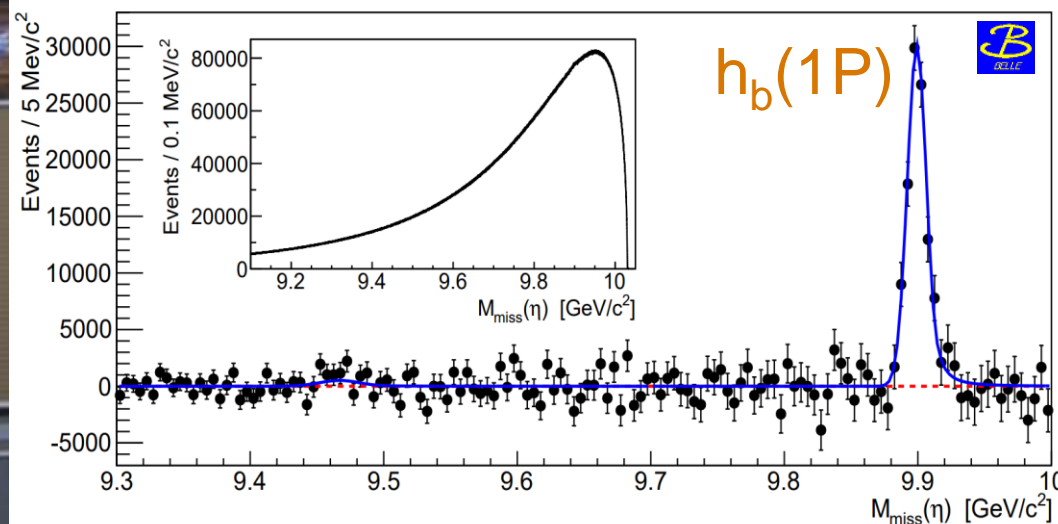


- Future studies: $M(\pi^+ \pi^-)$ in $\Upsilon(4S)$ transitions

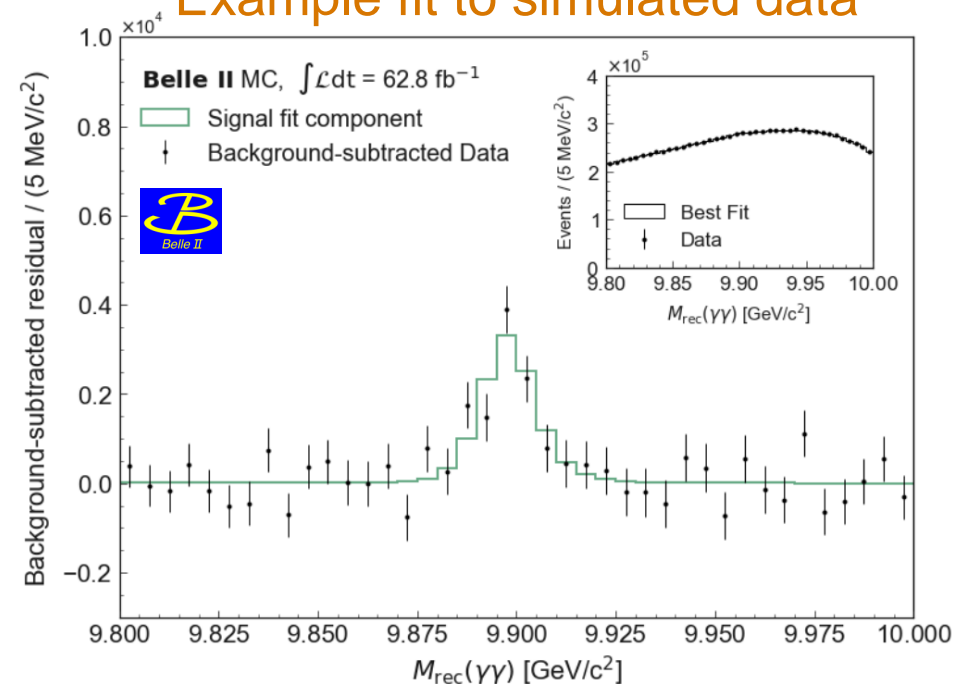
Belle II Progress – Eta transitions

- Surprisingly enhanced η transition rates in Belle
- Apply advanced selection criteria and improved analysis technique

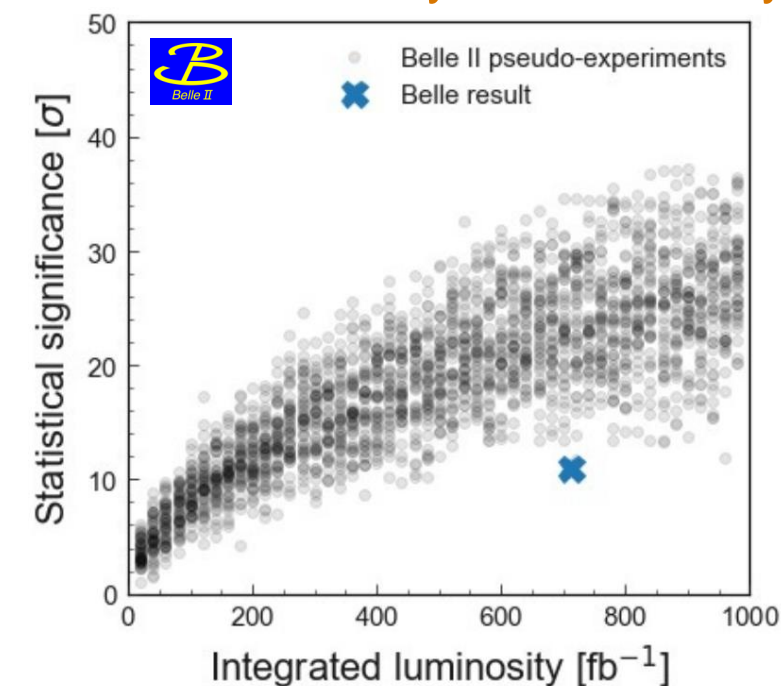
Belle analysis PRL 115, 142001 (2015)



Example fit to simulated data



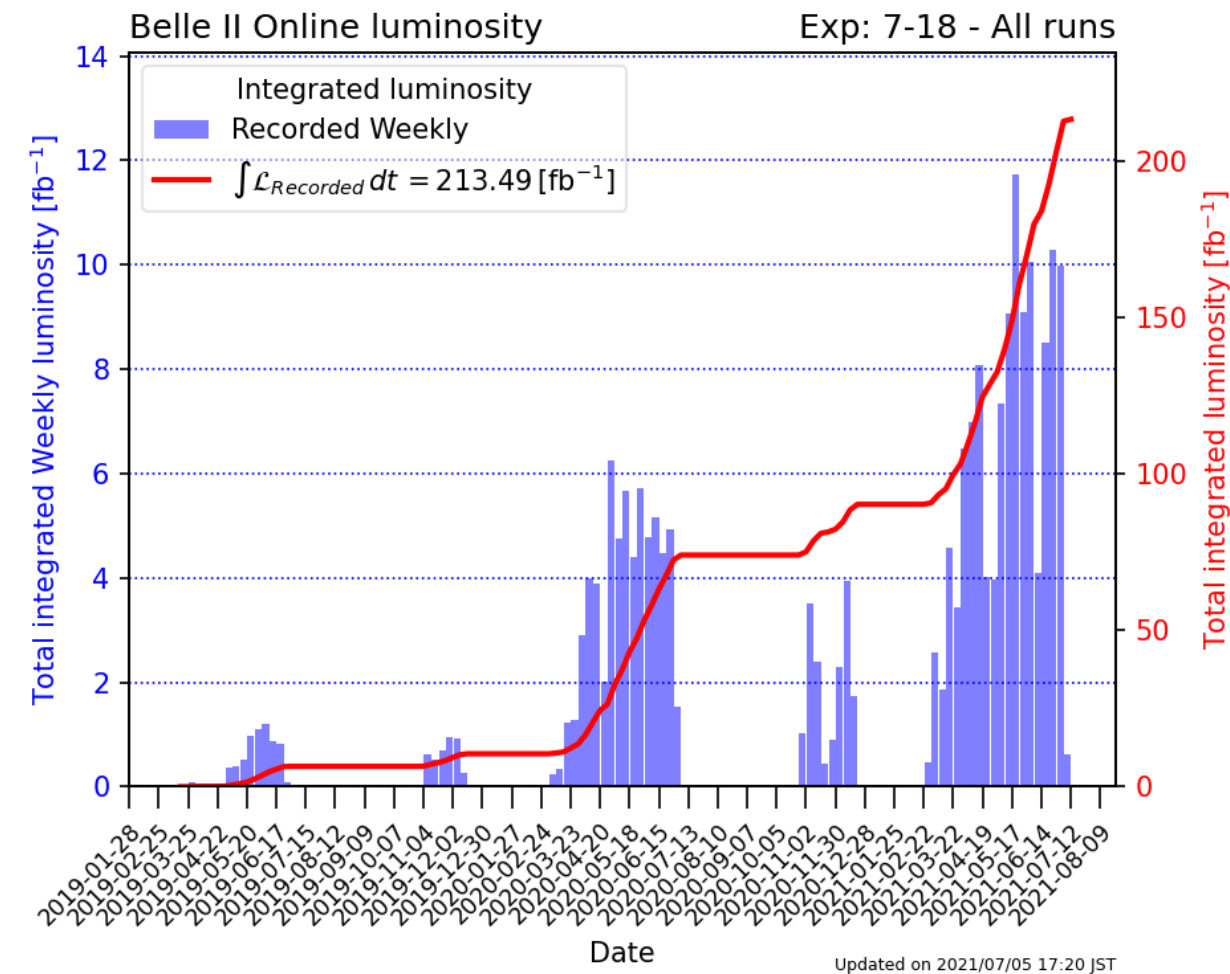
Predicted sensitivity vs. luminosity



- Toy experiments indicate better sensitivity expected
- Internal review of analysis underway

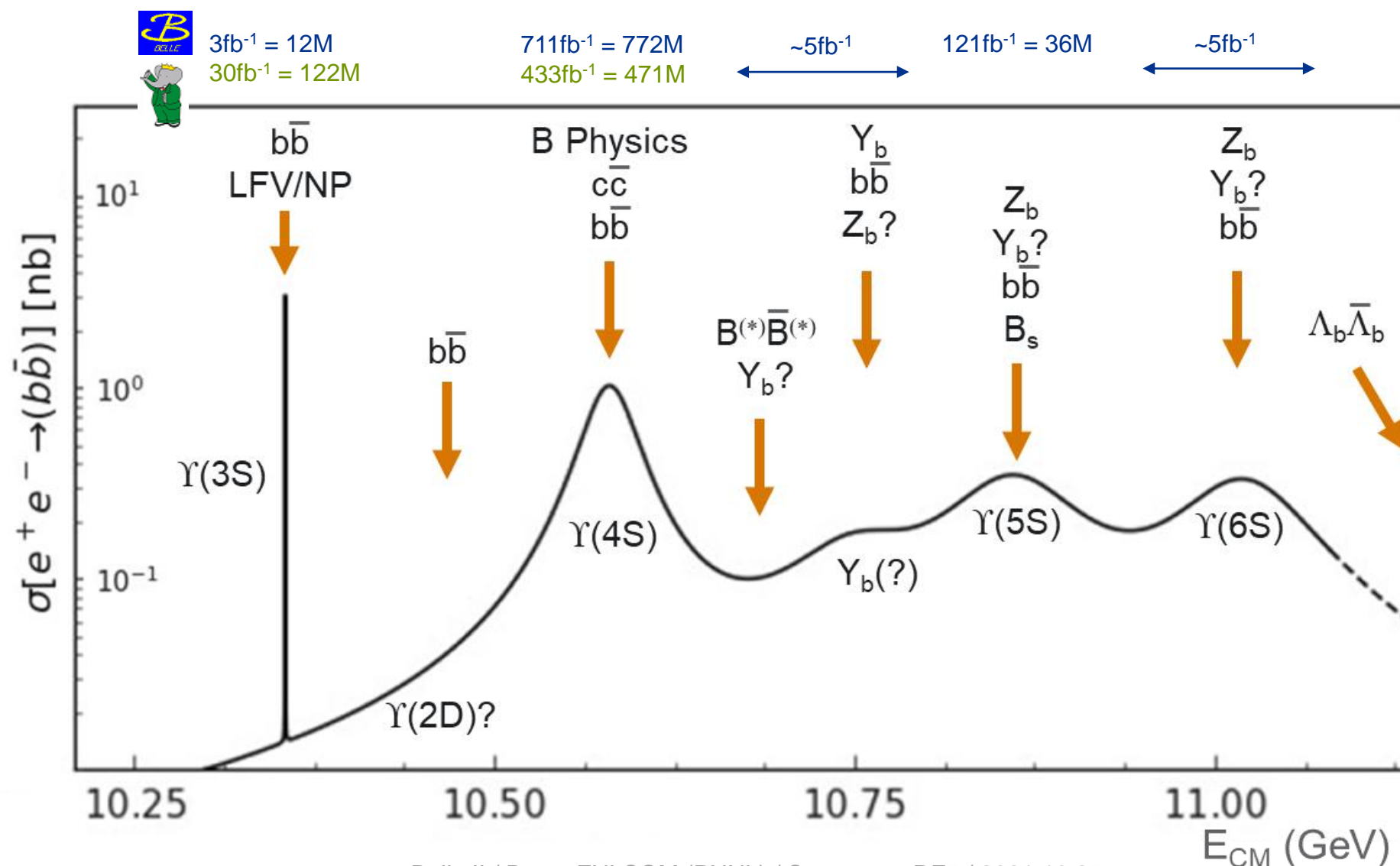
Experiment Operational Status

- Successes
 - Instantaneous luminosity record: $3.12 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - Continued full operations through pandemic
- Challenges
 - Ramp-up a bit slower than anticipated
 - Luminosity, backgrounds, infrastructure
- Near-term news
 - 2022 detector upgrade postponed due to COVID
 - International task force formed to understand and mitigate accelerator issues
- Luminosity projections
 - Expect ~Belle luminosity in 2022
 - Long-term projection details uncertain, though target remains 50 ab^{-1}



A Question of Beam Energy

- Physics reach potentially extended by running at non- $\Upsilon(4S)$ energies

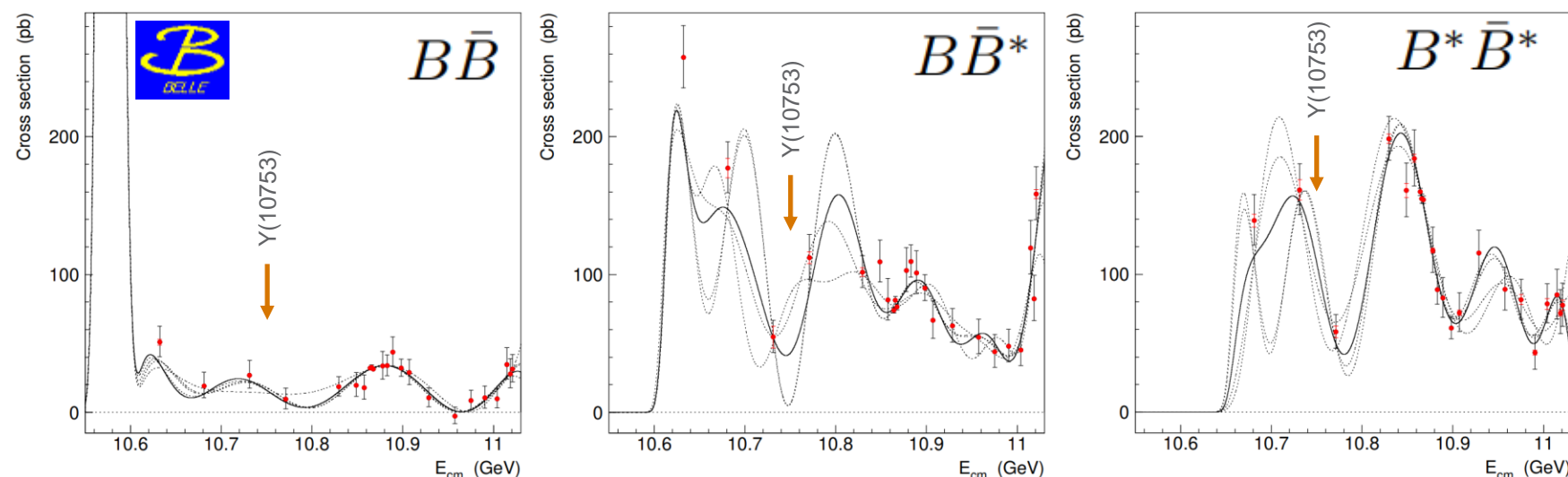


Reminder of Past Results

- Belle: seven $\sim 1\text{fb}^{-1}$ scan points below $\Upsilon(5S)$
- New structure observed in $\pi^+\pi^-\Upsilon(\ell^+\ell^-)$ transitions

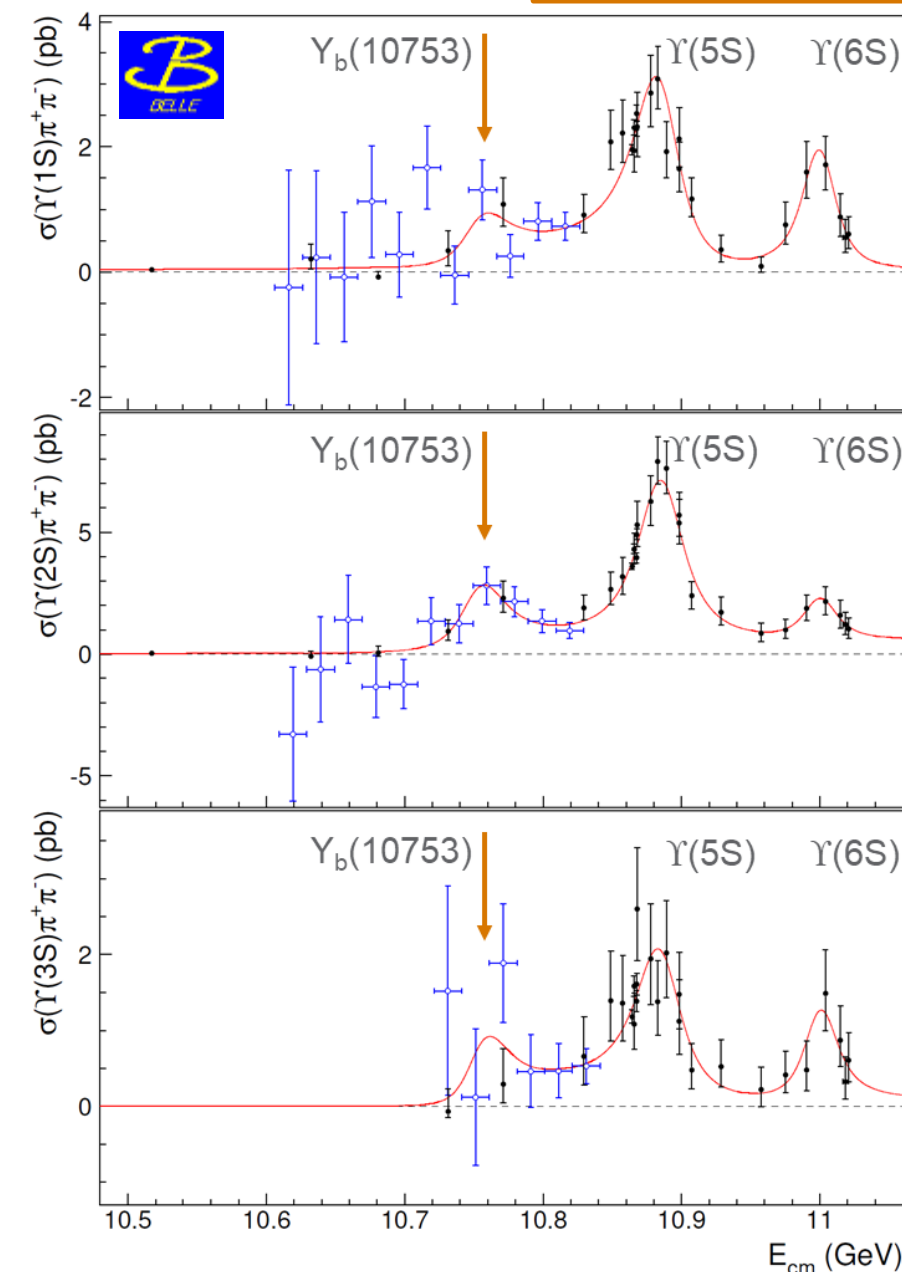
	$\Upsilon(10860)$	$\Upsilon(11020)$	New structure
$M \text{ (MeV/c}^2\text{)}$	$10885.3 \pm 1.5^{+2.2}_{-0.9}$	$11000.0^{+4.0+1.0}_{-4.5-1.3}$	$10752.7 \pm 5.9^{+0.7}_{-1.1}$
$\Gamma \text{ (MeV)}$	$36.6^{+4.5+0.5}_{-3.9-1.1}$	$23.8^{+8.0+0.7}_{-6.8-1.8}$	$35.5^{+17.6+3.9}_{-11.3-3.3}$

- Varying $B\bar{B}$ cross sections



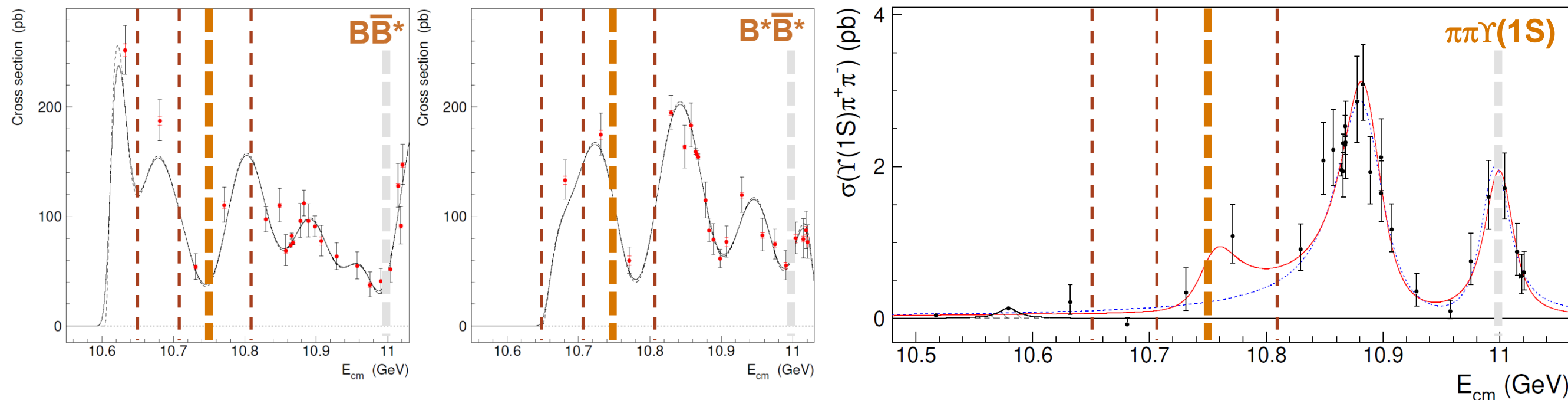
JHEP 06 (2021) 137

JHEP 10 (2019) 220



Above- $\Upsilon(4S)$ Energy Scan

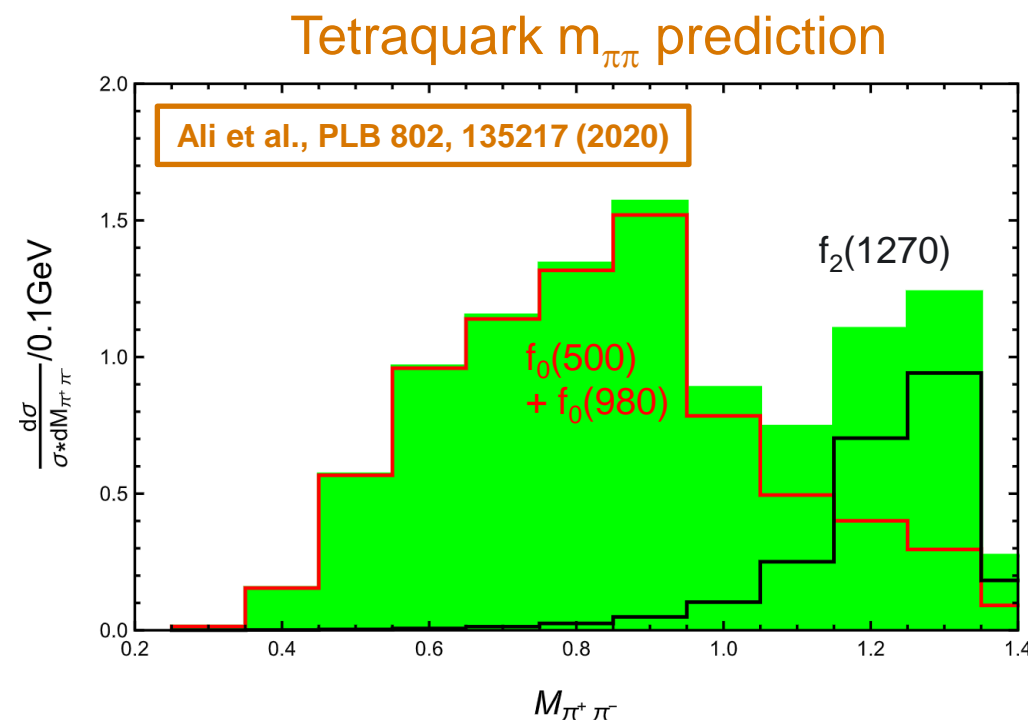
- Scheduled for Nov. 2021
- **10.751 GeV (9.5 fb⁻¹)**: to study $\Upsilon_b(10753)$ on-peak
- **10.657, 10.706, 10.810 (1.5+3.5+2 fb⁻¹)**: additional points for $B\bar{B}$ decomposition
- **11 GeV (30+ fb⁻¹)**: post-upgrade to study $\Upsilon(6S)$ on-peak



Theoretical Predictions and Planned Analyses

- Physics goal: study nature of $Y_b(10753)$
- Distinguish between tetraquark/bottomonium models

Mode	$\mathcal{B}(4q)$ (%)	$\mathcal{B}(b\bar{b})$ (%)
$B\bar{B}$	$39.3^{+38.7}_{-22.9}$	21.3
$B\bar{B}^*$	~ 0.2	14.3
$B^*\bar{B}^*$	$52.3^{+54.9}_{-31.7}$	64.1
$B_s\bar{B}_s$	-	0.3
$\omega\eta_b$	$7.9^{+14.0}_{-5.0}$	-
$\omega\chi_{bJ}$	-	~ 0.3
$f_0(1370)\Upsilon$	$0.2^{+0.6}_{-0.2}$	-
$\eta\Upsilon$	-	~ 0.2
$\eta'\Upsilon$	-	~ 0.06
ηh_b	-	~ 0.2



Wang, CPC 12, 123102 (2019), Ali et al., PLB 802, 135217 (2020)
 Chen et al., PRD 101, 014020 (2020), Giron & Lebed, PRD 102, 014036 (2020)
 Li et al., EPJC 80, 59 (2020), Liang et al., PLB 803, 135340 (2020)
 Bicundo et al., PRD 103, 074507 (2021), Li et al., arXiv:2106.14123 (2021)

Golden Modes

$e^+e^- \rightarrow \pi^+\pi^-\Upsilon(pS)(\rightarrow \ell^+\ell^-)$
 $B\bar{B}$ decomposition
 $\pi^+\pi^-$ Dalitz
 $Y_b \rightarrow \omega\eta_b(1S)$
 $Y_b \rightarrow \omega\chi_{bJ}(1P)$

Silver Modes

$Y_b \rightarrow \pi^+\pi^-X$ (inclusive)
 $Y_b \rightarrow \eta X$ (inclusive)
 $Y_b \rightarrow \eta\Upsilon(1S, 2S)(\rightarrow \ell^+\ell^-)$
 $Y_b \rightarrow \eta'\Upsilon(1S)(\rightarrow \ell^+\ell^-)$
 $Y_b \rightarrow \Upsilon(1S)$ (inclusive)

Bronze Modes

$Y_b \rightarrow \gamma X_b$
 $Y_b \rightarrow \pi^0\pi^0\Upsilon(pS)(\rightarrow \ell^+\ell^-)$
 $Y_b \rightarrow K K(\phi)\Upsilon(pS)(\rightarrow \ell^+\ell^-)$
 $Y_b \rightarrow \pi^0\pi^0X$ (inclusive)
 $Y_b \rightarrow \pi^0X$ (incl. or excl.)
 ...

Summary and Snowmass Context

- Belle II Status
 - Initial quarkonium physics rediscoveries as performance benchmarks
 - Confronting challenges of the ramp-up phase
 - Operation through 2022 followed by eventual “Long Shutdown” for detector upgrades
 - Imminent above- $\Upsilon(4S)$ scan for spectroscopy studies
- Next Steps / Desired Outcomes
 - Convert Belle II LOIs into white papers (including Hadron Spectroscopy)
 - Use success of energy scan to promote $\Upsilon(6S)$ and other runs
 - Focus on long-term luminosity goals for 10-year Snowmass process
 - Ensure continued support for US program

Thank you

