



Belle II physics reach and plans for the next decade and beyond

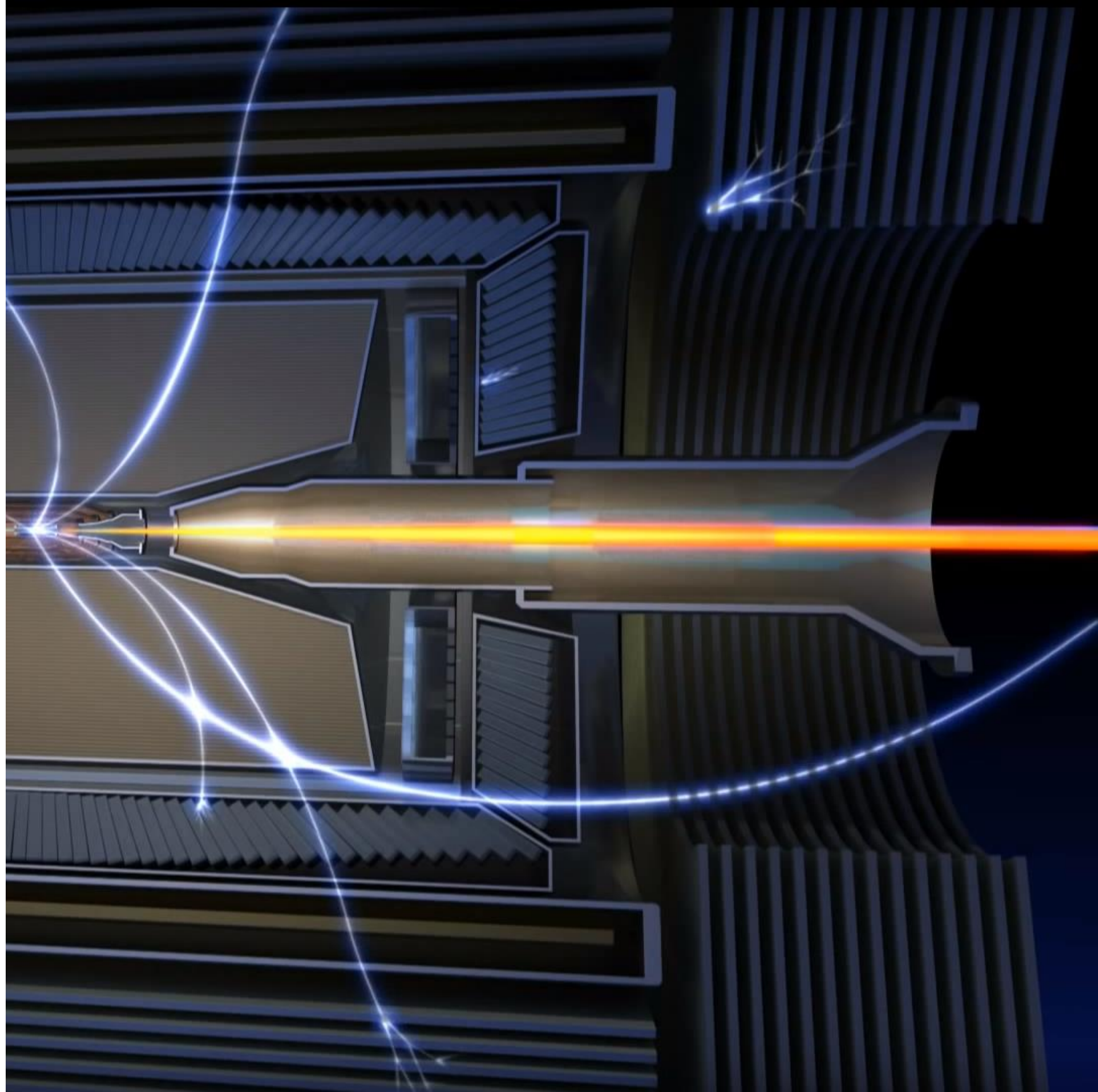
Mar 30, 2022

Bryan Fulsom (PNNL)

Snowmass 2022 Energy Frontier Workshop

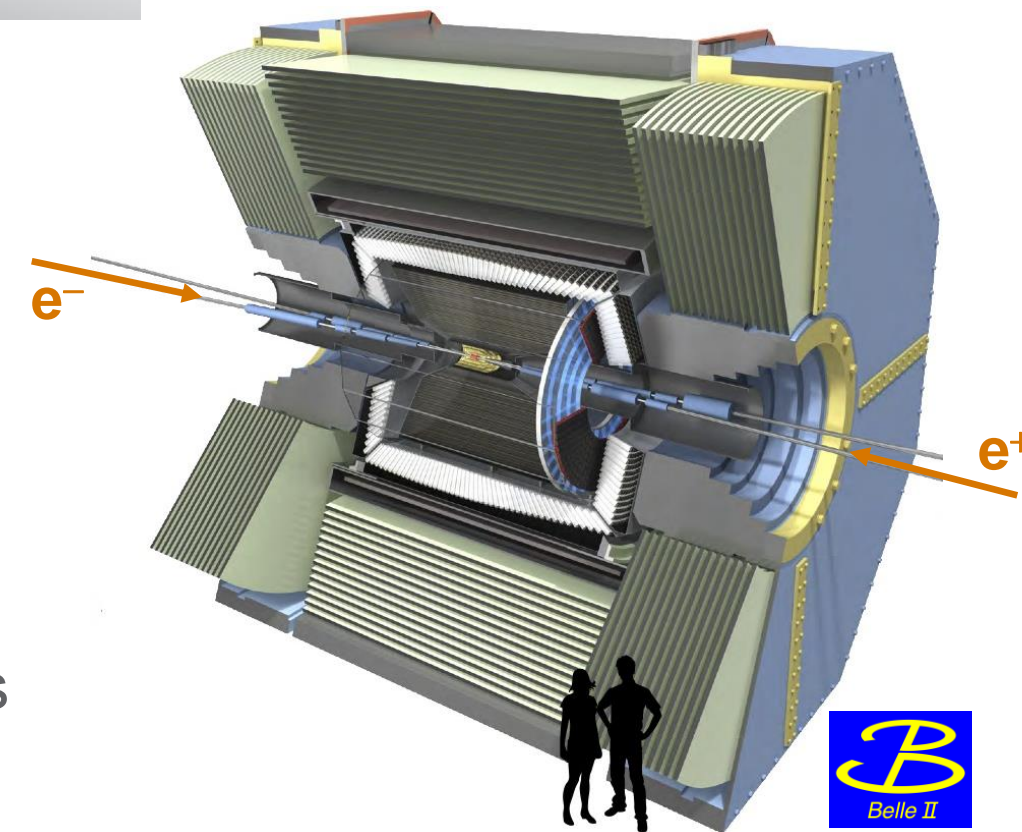
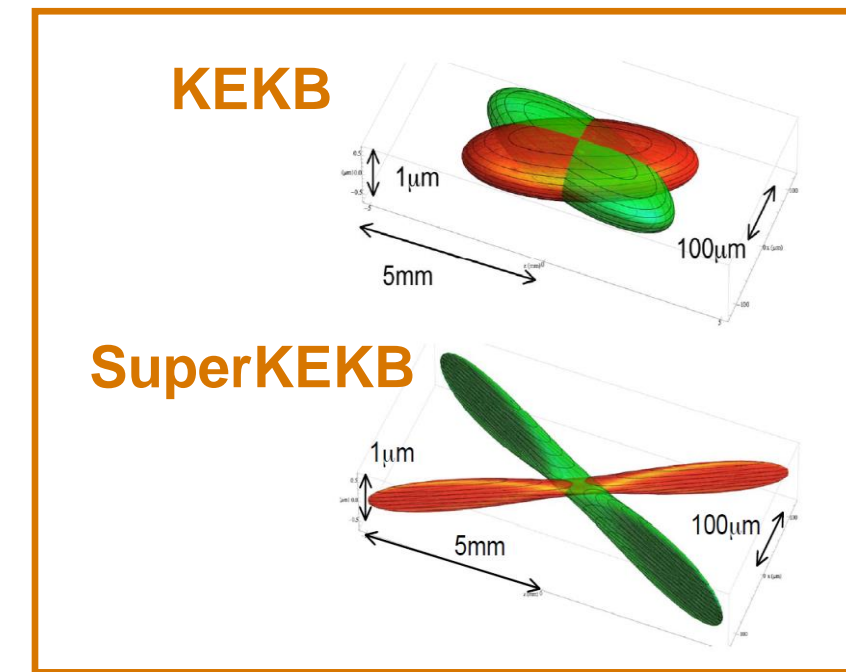
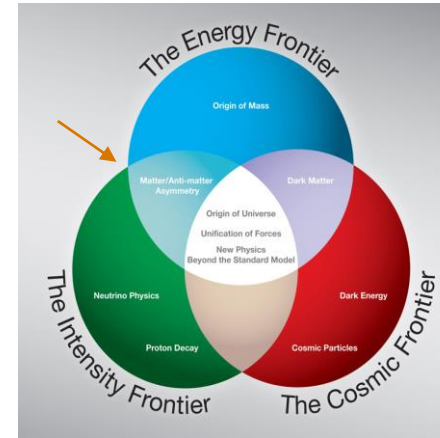


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Belle II Capabilities

- Belle II is the next generation B-Factory
 - Flavor physics anomalies in B decays
 - NP in rare processes
 - DM searches in e^+e^-/B meson processes
 - Spectroscopy (“XYZ” states) and QCD studies
 - ~1000 members (~100 US @ 18 institutions)
 - ~10-year program ongoing since 2019
- Upgraded detector and accelerator
- Advantages
 - 30x instantaneous and integrated luminosity
 - Full event reconstruction and decays involving neutrals
 - Multiple production mechanisms for exotics
 - Nominal $\sqrt{s} = 10.58 \text{ GeV} = \Upsilon(4S)$, potential to reach ~11.2 GeV



arXiv:1011.0352 (2011)

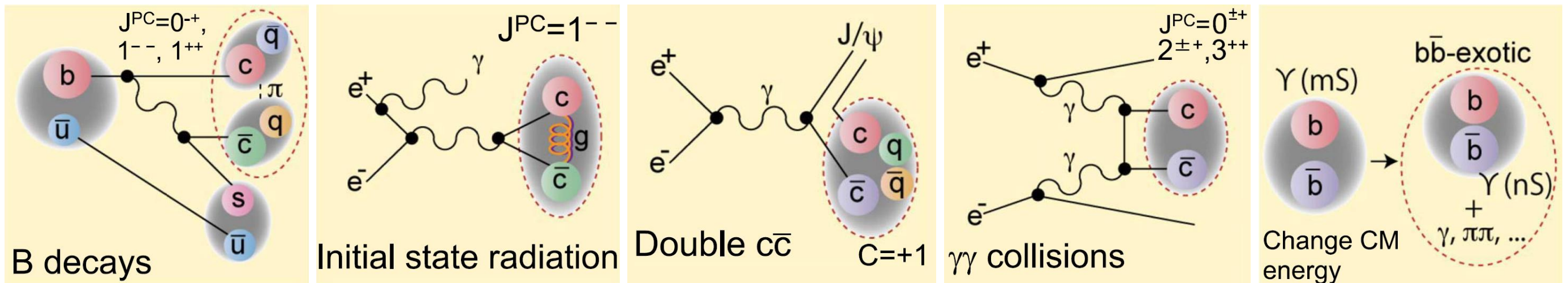
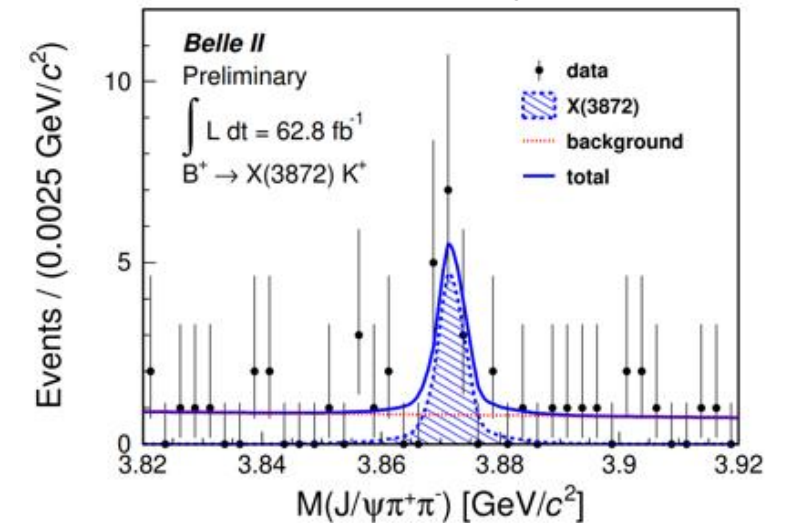
Belle II in the Snowmass Process

- **Belle II Physics Program White Paper**
(<https://www.slac.stanford.edu/~mpeskin/Snowmass2021/BelleIIPhysicsforSnowmass.pdf>)
 - **Chapter 8: Quantum chromodynamics**
 - **8.1 Quarkonium, exotics, and hadron spectroscopy (RF07, EF06)**
 - **8.2 Constraining hadronic vacuum-polarization in muon g-2 and opportunities for precision QCD in hadronization (EF05)**
- Belle II Detector Upgrades White Paper (<https://arxiv.org/abs/2203.11349>)
- Belle II User-based GRID analysis (<https://arxiv.org/abs/2203.07564>)
- Beam Background Expectations for Belle II at SuperKEKB (<http://arxiv.org/abs/2203.05731>)
- SuperKEKB Electron Polarization Upgrade White Paper (in progress)
- SuperKEKB Upgrades White Paper (in progress)
- Future HEP Computing Challenges (Belle II/DUNE joint paper, <https://arxiv.org/abs/2203.07237>)
- Physics reach of a long-lived particle detector at Belle II (<https://arxiv.org/abs/2105.12962>)

The New Alphabet: X, Y, Z

- Belle opened new era in -onia studies
- Belle II expects to continue this success
- $X(3872) \rightarrow D^0 \bar{D}^0 \pi^0$: accurate lineshape determination
- Find exotic partners (Z_c , $X \rightarrow \phi J/\psi$)
- Unique e^+e^- production mechanisms provide information (e.g. J^{PC} , type)

$X(3872)$: discovered by Belle
“rediscovered” in early Belle II data

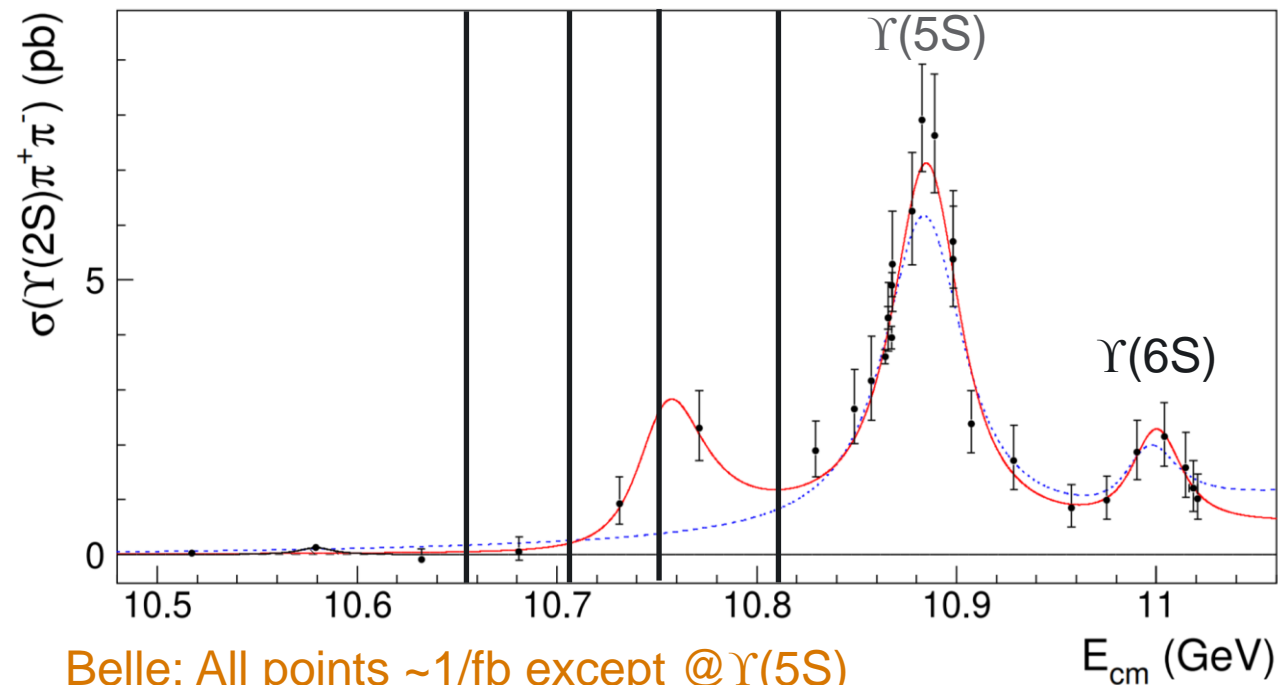


Belle II opportunities in the bottom sector

- Data above $\Upsilon(4S) = 10.58$ GeV: discovery of $Z_b(10610/50)$, $Y_b(10750)$, η_b , h_b
- Belle II opportunities: increased luminosity, energy range up to ~ 11.2 GeV
- Data already collected in 2021!

4 new points at Belle II

3.5/fb 1.6/fb 9.6/fb 4.6/fb



Belle: All points $\sim 1/\text{fb}$ except @ $\Upsilon(5S)$

- Explore multiple final states to confirm/determine nature of Y_b
- Revisit $\Upsilon(6S)$ with 10x statistics
- Higher statistics scan of entire region
- LFV in $\Upsilon(2S,3S)$ decays

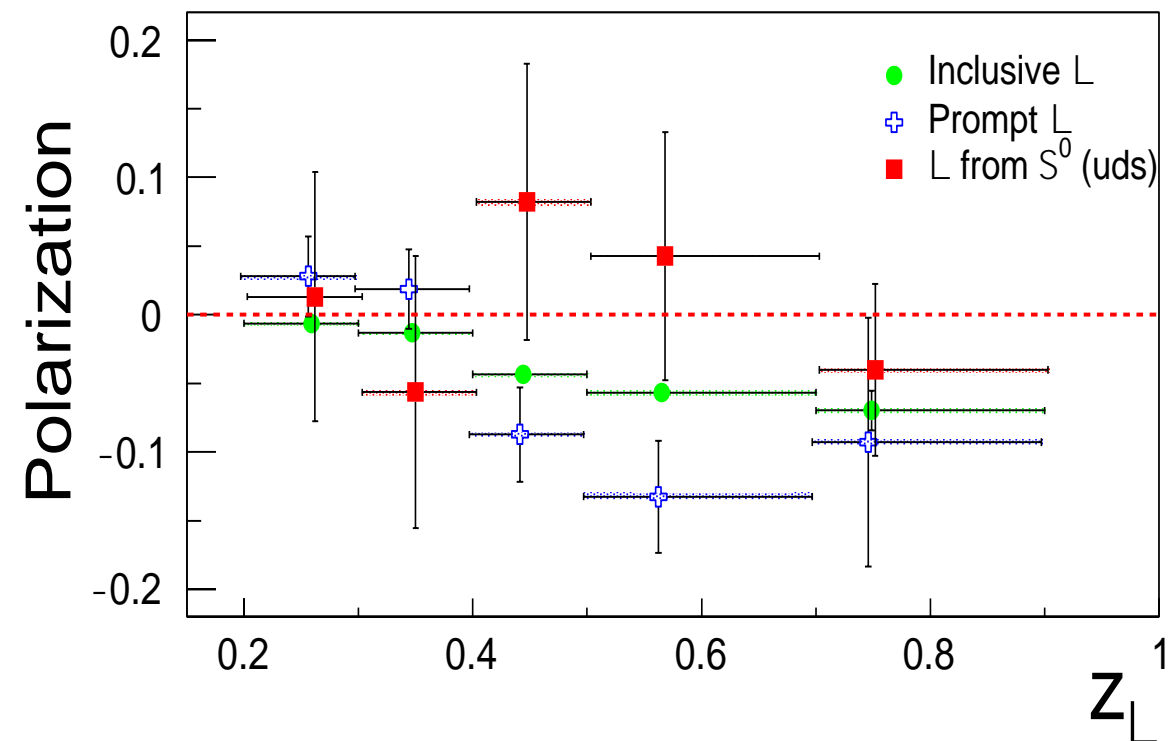
- Range of possibilities up to $\Lambda_b\Lambda_b$ (beyond requires SuperKEKB upgrades)

Hadronization Studies at Belle II

- Dedicated Snowmass White Paper on precision QCD in hadronization to appear on arXiv
- Constraints from hadronization studies at Belle II needed to tune hadronization unpolarized/polarized hadronization models (e.g. MCEGs) essential for physics programs at Jlab/EIC and important for LHC
 - Charge/baryon number/strangeness compensations
 - Energy dependence in conjunction with LEP data
 - Polarization dependent hadron correlations
 - ...
- Synergy/complementarity with hadron structure studies in SIDIS and pp
 - Precision jet studies at Belle II energies will access an unexplored phase space
 - ✓ Explore transition from jets to hadrons → boundaries of perturbative QCD
 - ✓ Vacuum energy loss
 - Probe of TMD framework at N3LL
 - Jet mass generation
 - Study of string fragmentation model in flavor correlations of leading-hadron energy energy-correlations
 - ...

Fragmentation Studies at Belle II

- Extraction of fragmentation functions (FF) of final states with additional degrees of freedom (compared to available FFs) needed as tools to extract nucleon structure from EIC and JLab
 - Sensitive to dynamics in hadronization
 - Allow more targeted access to proton structure (e.g. Disentangle twist-3 effects (quark-gluon correlations)) PRL 126 152501 (2019)
 - Full multi-dimensional measurements needed to reduce systematics from model assumptions
 - **Belle II statistics needed!**
- Example FFs in need of Belle II dataset
 - Polarized di-hadron TMD FFs
 - Polarized Λ FFs



Feed-down unfolded Λ^\uparrow observation from PRL **122**, 042001 (2019)
 → More statistics needed for precision measurement

Summary and Snowmass Context

- Belle II Status
 - Initial quarkonium physics rediscoveries as performance benchmarks
 - Operation through the next 10 years with detector/accelerator upgrades
 - Above- $\Upsilon(4S)$ scan available for spectroscopy studies
- Next Steps / Desired Outcomes
 - Use success of energy scan to promote $\Upsilon(6S)$ and other runs
 - Focus on long-term luminosity goals for 10-year Snowmass process
 - Discoveries/precision measurements of quarkonium(-like) particles
 - Hadronization/fragmentation as essential inputs to other (LHC/JLab/EIC) programs
 - Ensure continued support for US program

Thank you

