Future of Hadron Spectroscopy at Belle II

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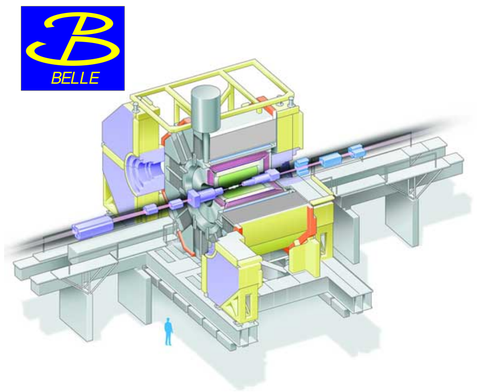
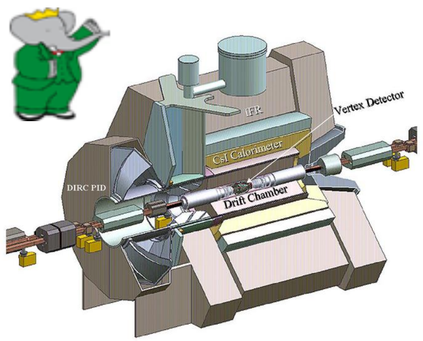
Snowmass CSS - July 20, 2022

https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF7_RF0_Fulsom-062.pdf
Belle II executive summary: https://arxiv.org/abs/2203.10203

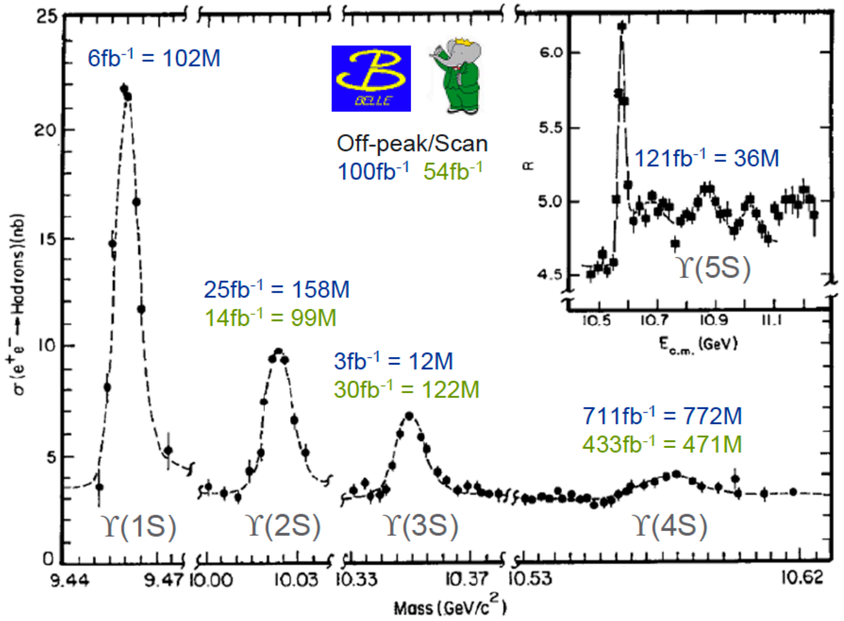
B factories

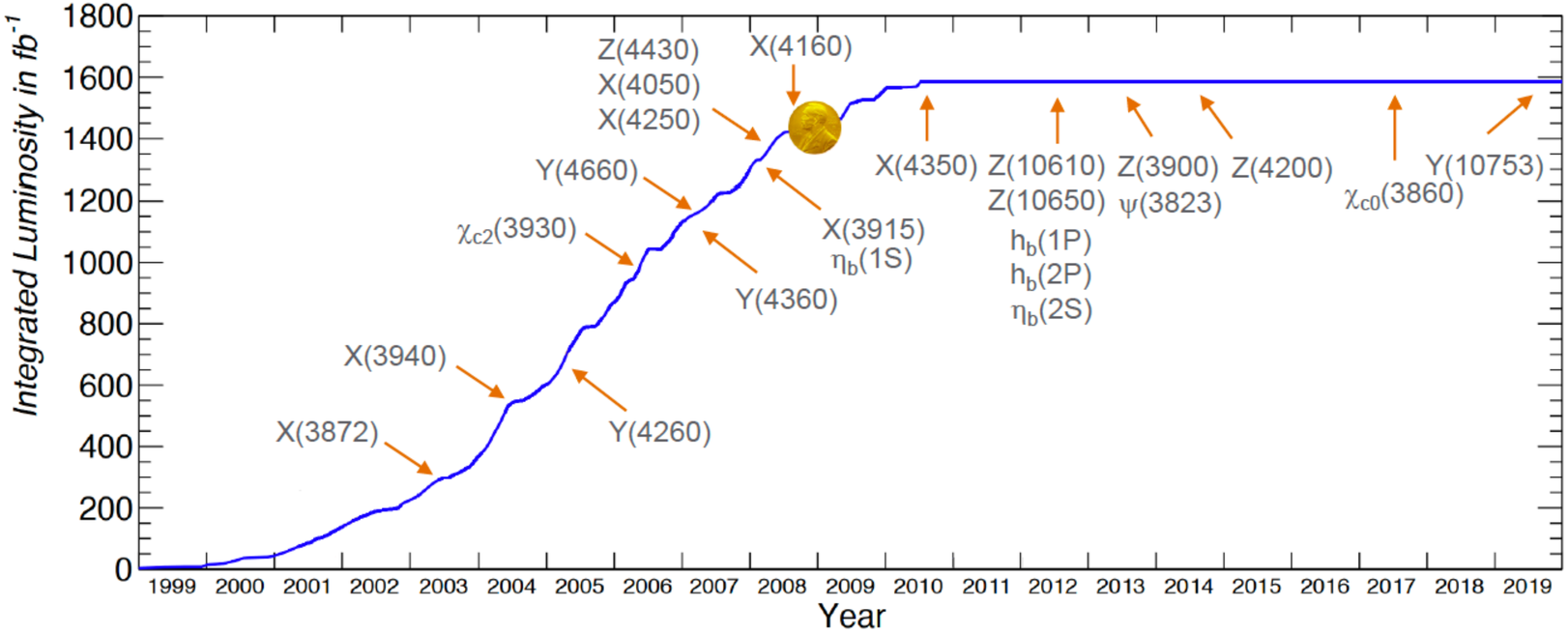




- Belle/KEKB (KEK) and BaBar/PEP-II (SLAC)
  - Very successful physics programs with a total recorded sample over 1.5 ab^{-1} (1.25×10^9 $B\bar{B}$ pairs)
  - Flavor physics (CKM/UT, CPV), NP in rare processes, new particle discoveries

More details in "The Physics of the B Factories", EPJC 74, 3026 (2014)



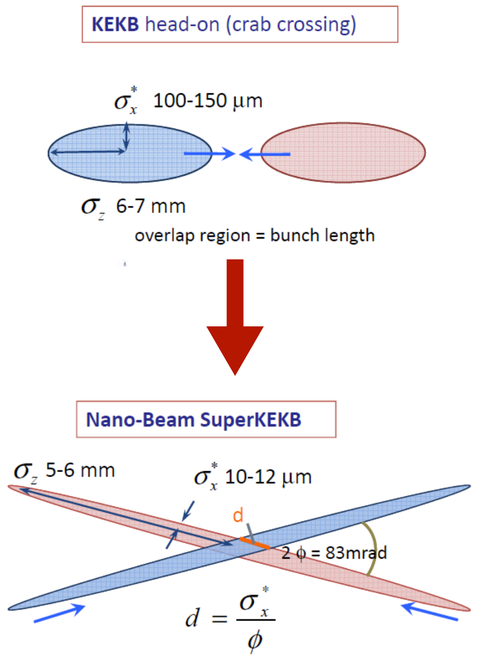


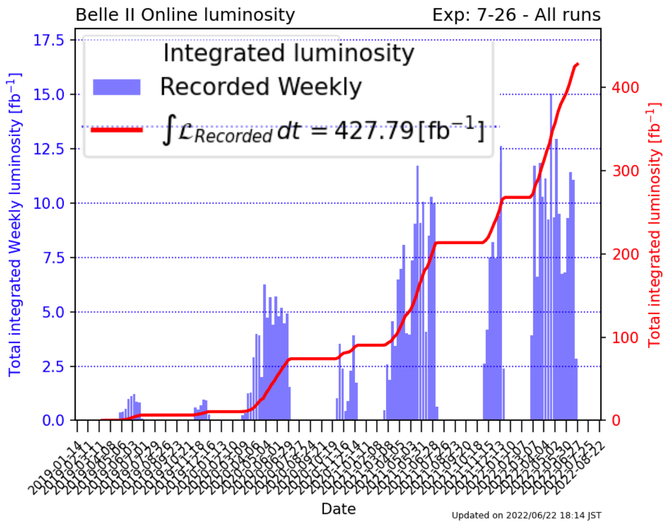
Even >10 years after data taking, still producing new results in hadron spectroscopy

>350 papers published since shutdown!

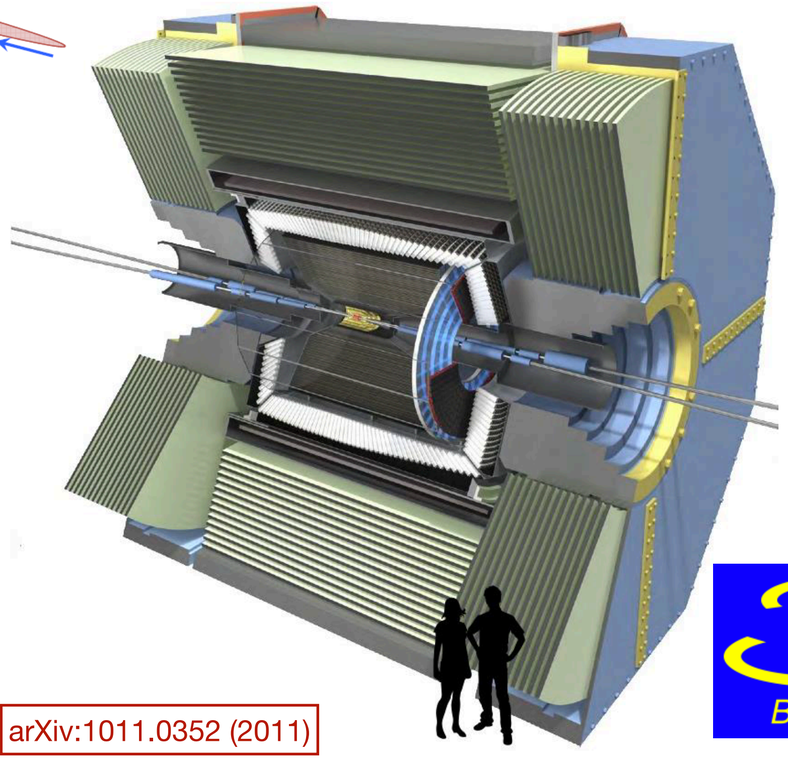
Belle II capabilities

- Belle II is the next generation B-factory
  - Upgraded detector and accelerator
  - ~1000 members (~100 US @ 18 institutions)
  - ~15-year program ongoing since 2019





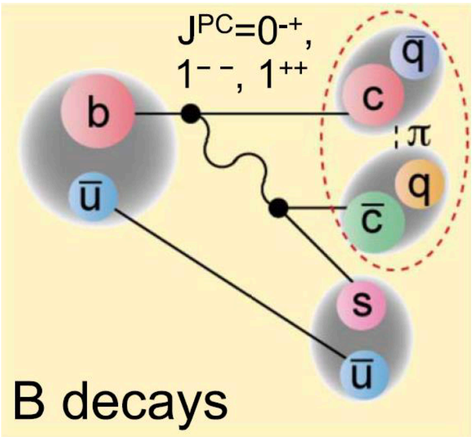
- <u>Advantages for quarkonium physics program</u>
  - World record instantaneous luminosity (aiming for 50x Belle integrated luminosity)
  - High resolution, hermetic detector, good PID capability
  - Efficient reconstruction of neutrals (π^0, η, …)
  - Reconstruct single resonance to explore recoiling system (e.g. $e^+e^- \to J/\psi\, X$)
  - Using tagged events (i.e. with a fully reconstructed partner B) to measure absolute branching fractions
  - Variety of production mechanisms accessible

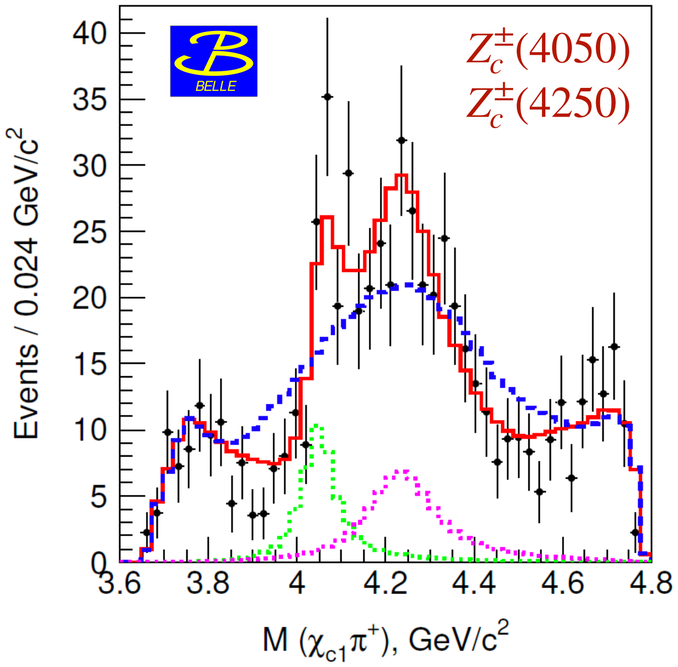


arXiv:1011.0352 (2011)

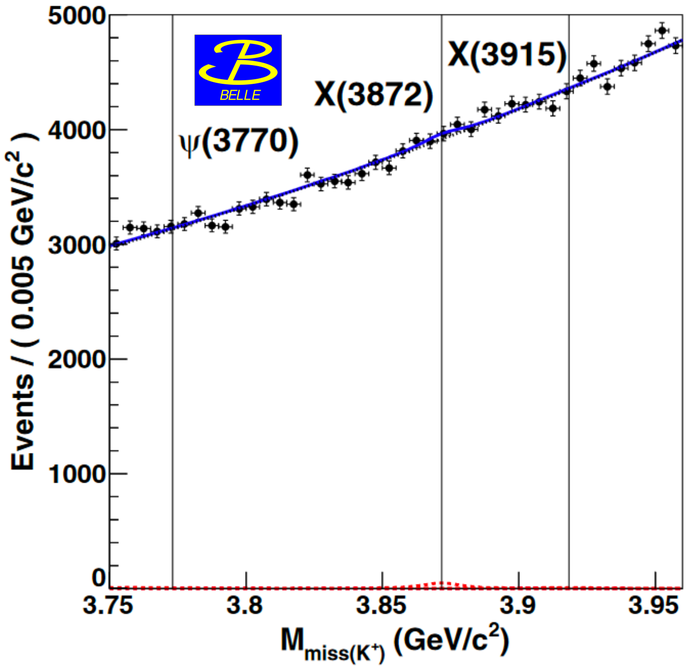
Belle II potential - B decays

- High-statistics continuation from B-factories
- Competition and complementarity with LHCb (advantages for modes with neutrals)
  - Confirm Z_c states and search for neutral partners
  - Absolute branching fractions $B \to X(3872,3915)\ K$
  - Confirmation of $X(3872)$ width measurement with $D^0\bar{D}^0\pi^0$
  - Revamp B → baryons, search for pentaquarks!

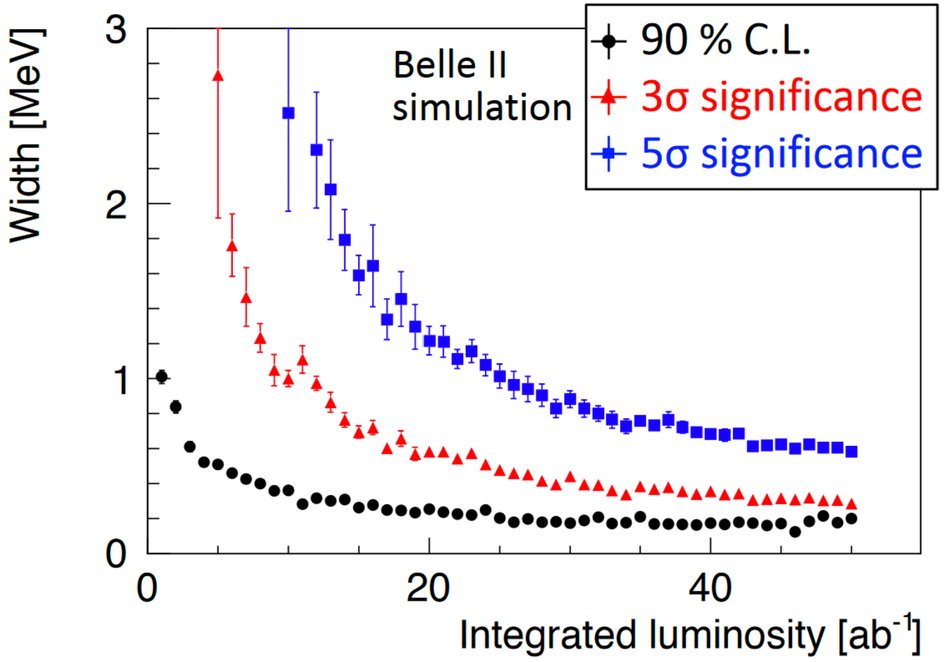




PRD 78, 072004 (2008)

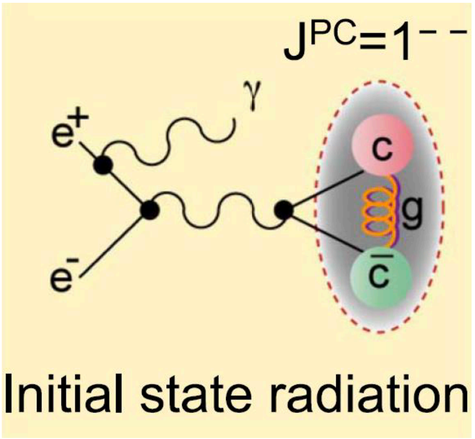


PRD 97, 012005 (2018)



H. Hirata (KMI/Nagoya), MSc Thesis (2019)

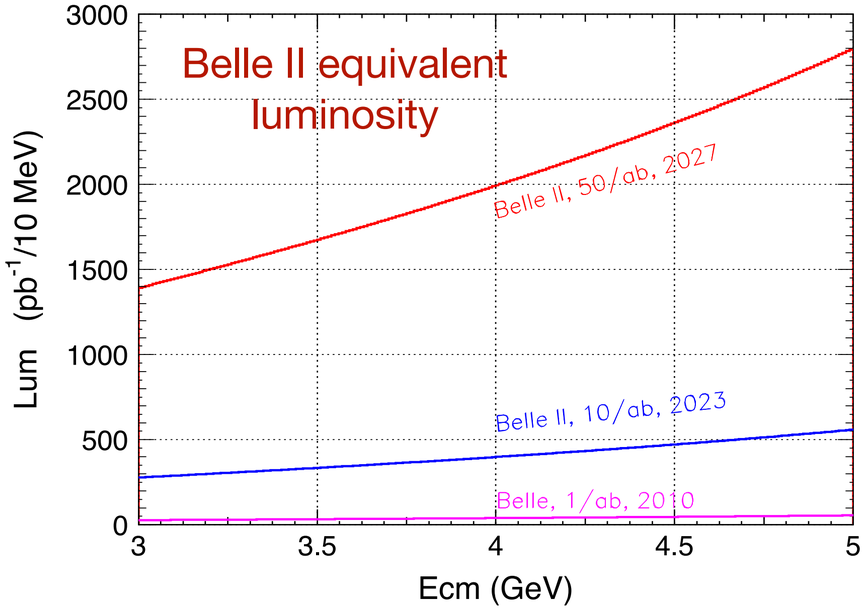
Belle II potential - initial state radiation



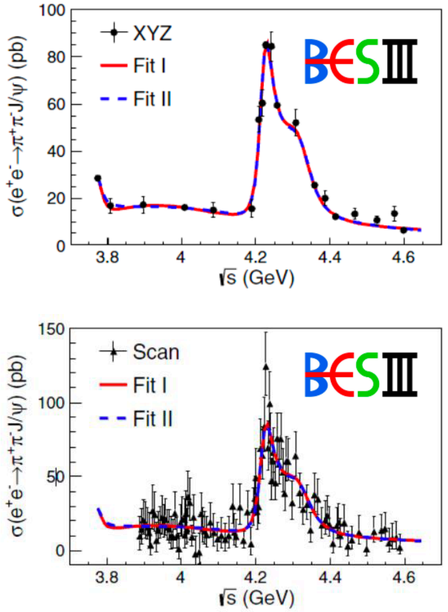
- Study Y states complementary to BESIII direct E_{CM} scans

- Belle II advantages
  - Comparable sample sizes
  - Continuous mass ranges
  - Access E > 4.6 GeV

- Potential contributions
  - Improved $\sigma(e^+e^- \to \gamma_{ISR}(c\bar{c})(x))$
  - Higher masses/channels (e.g. $\gamma_{ISR}\Sigma_c\bar{\Sigma}_c$)
  - Confirm Z_c states (e.g. $e^+e^- \to h_c\pi\pi$)



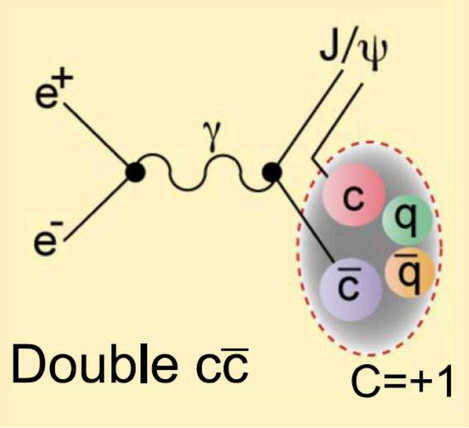
PTEP 2019 123C01 (2019)



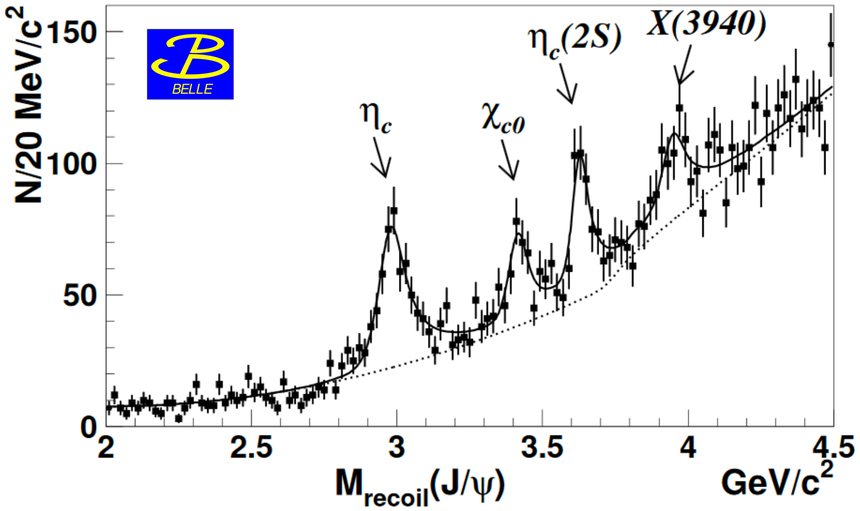
PRL 118, 092001 (2017)

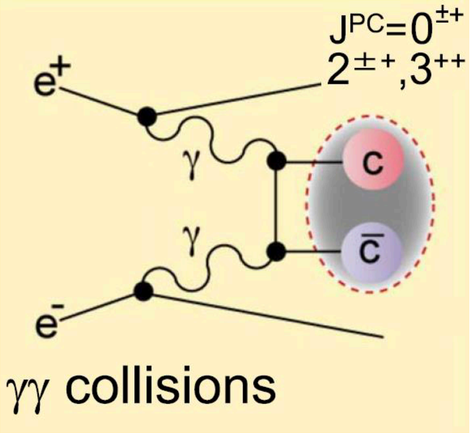
Belle II potential - double charmonium and two-photon processes

- Unique production modes at Belle II



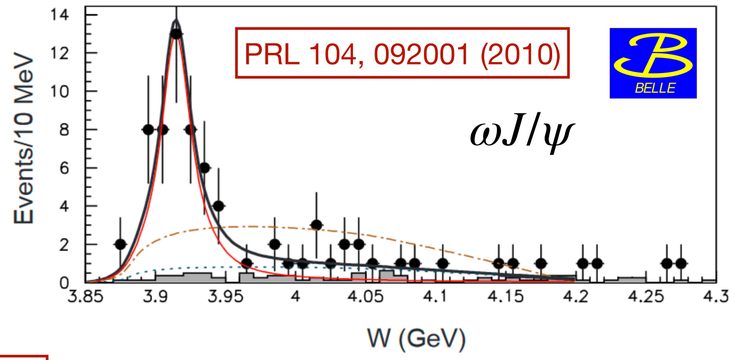
- Double-$c\bar{c}$
  - $e^+e^- \to (c\bar{c})_{J=1}(c\bar{c})_{J=0}$ production rule
  - Discovery of X(3940, 4160)
  - Expand to other $c\bar{c}$, search for new states

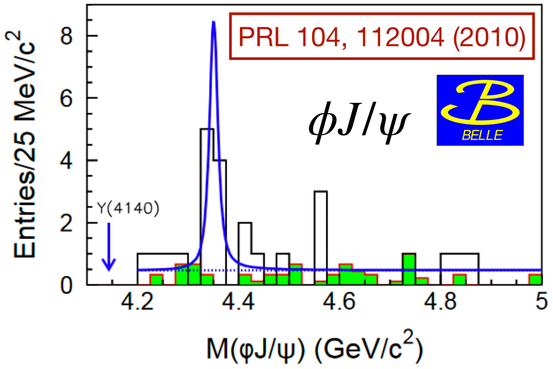




- Two-photon
  - J^{PC} of X(3915)
  - Confirm $\phi J/\psi$ state?
  - $D^{(*)}\bar{D}^{(*)}$ final states
  - Search for $T_{cc\bar{c}\bar{c}}$

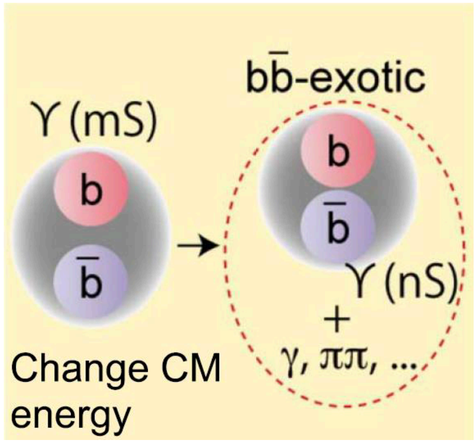
https://arxiv.org/pdf/2109.10359.pdf

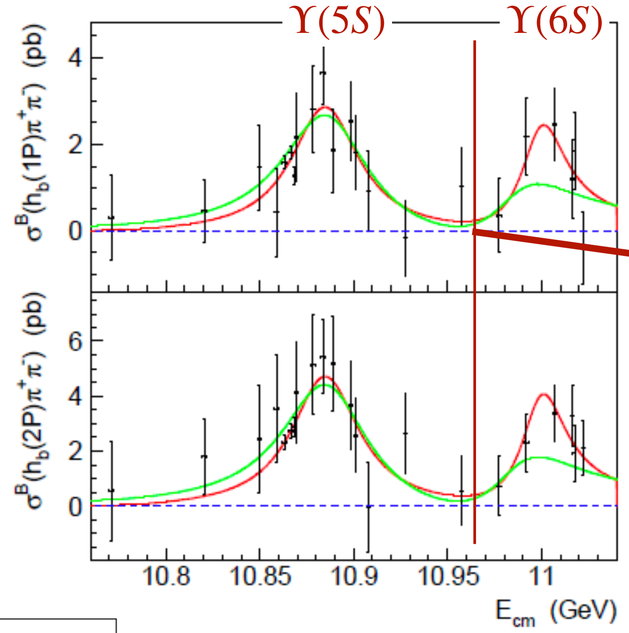


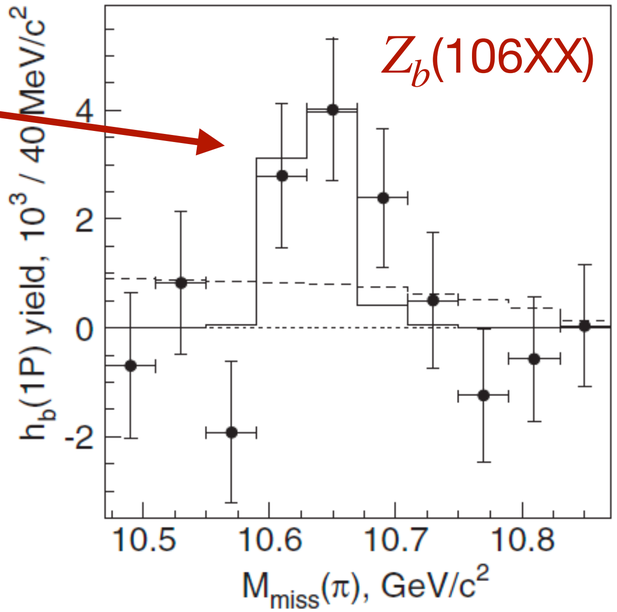


Belle II potential - above $\Upsilon(4S)$

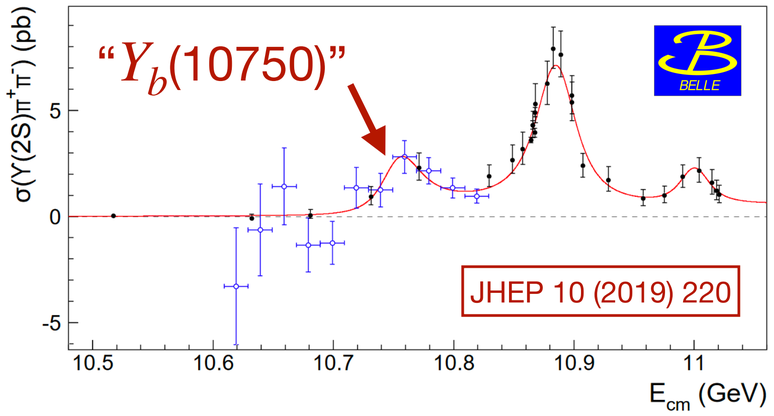
- Aside from $\Upsilon(5S)$, B-factories collected limited data above $\Upsilon(4S)$
- $\Upsilon(6S)$ = 11 GeV, L_{eff} = ~3 fb^{-1}
  - Study nature of Z_b and $\Upsilon(6S)$
  - Higher energy: pathway to other states?
- "Y_b(10750)", L = ~1 fb^{-1}
  - Far from threshold, no direct conventional match
  - Further study needed - dedicated Belle II data



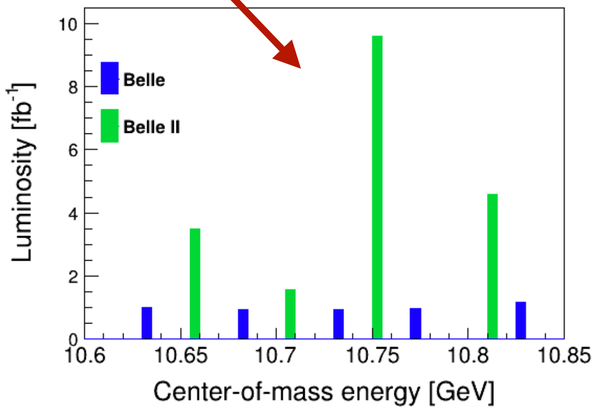




PRL 117, 142001 (2016)



JHEP 10 (2019) 220

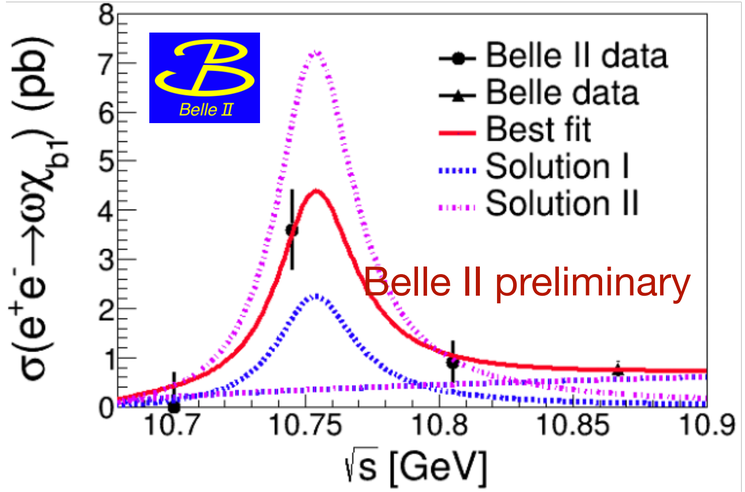


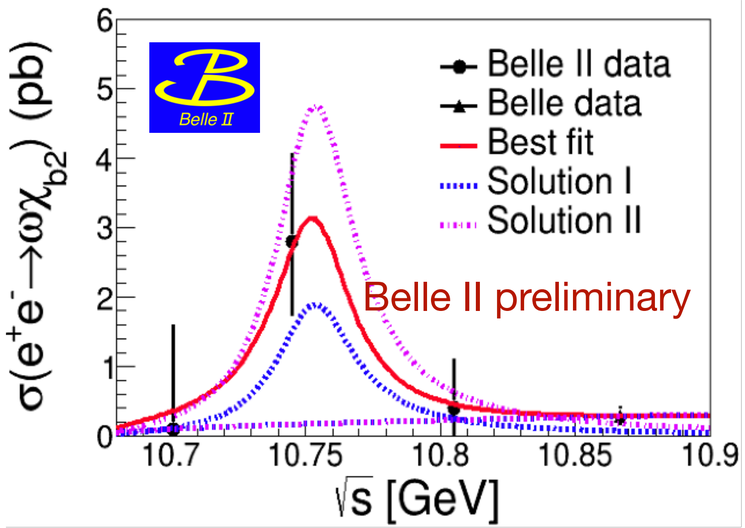
Unique potential for SuperKEKB/Belle II

MPLA 32, 1750025 (2017)

Unique Belle II dataset - dedicated run at 10.750 GeV

- Scan data near $\sqrt{s}$ = 10.75 GeV at Belle II - unique opportunity
  - First results quickly after data taking in Fall 2021!
- NEW! Y(10753) $\rightarrow \omega\chi_{bJ}$ observed for the first time
  - $\sigma^B(e^+e^-[@10.745] \rightarrow \omega\chi_{b1}) = 3.6^{+0.7}_{-0.7} \pm 0.4$ pb
  - $\sigma^B(e^+e^-[@10.745] \rightarrow \omega\chi_{b2}) = 1.8^{+1.2}_{-1.0} \pm 0.5$ pb
- No significant X_b signal around 10.6 GeV
  - Upper limits are set
- Additional searches ongoing
  - Precise measurements of mass and width
  - Search for additional decay modes
  - Study hadronic transitions (test NRQCD)





Many recent results in charm baryon spectroscopy!

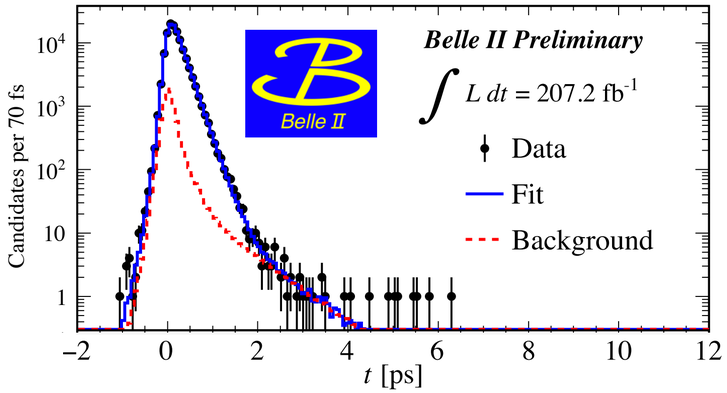
- Production via quark fragmentation, B decays
- Search for new states, measure properties

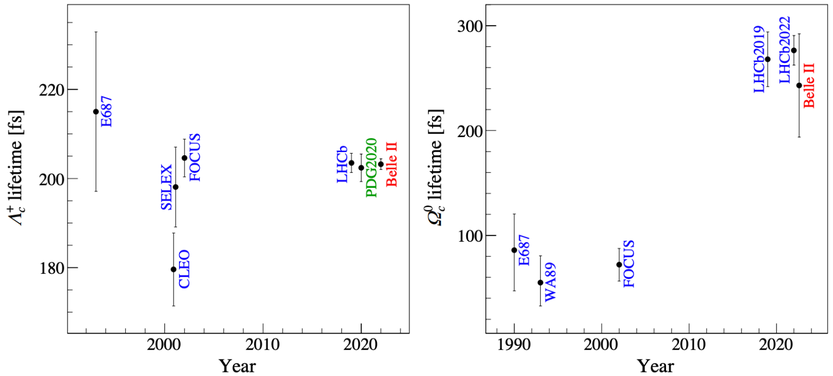
- Recent Belle results
  - $\Lambda_c^+ \to p\omega$, PRD 104, 072008 (2021)
  - $\Lambda_c^+ \to p\eta,\ p\pi^0$ PRD 103, 072004 (2021)
  - $\Lambda_c^+ \to \eta\Lambda\pi^+, \eta\Sigma^0\pi^+, \Lambda(1670)\pi^+, \eta\Sigma(1385)^+$ PRD 103, 052005 (2021)
  - $\Xi_c^0 \to \Lambda K_S^0,\ \Sigma^0 K_S^0,\ \Sigma^+ K^-$ arXiv:2111.08981
  - $\Xi_c^0 \to \Xi^0 K^+ K^-$ PRD 103, 112002 (2021)
  - $\Xi_c^0 \to \Lambda \bar{K}^{*0}, \Xi_c^0 \to \Sigma^0 \bar{K}^{*0}, \Xi_c^0 \to \Sigma^+ K^{*-}$ JHEP06 160 (2021)
  - $\Xi_c^0 \to \Xi^- \ell^+ \nu_\ell$, asymmetry par. of $\Xi_c^0 \to \Xi^- \pi^+$ PRL 127, 121803 (2021)
  - Spin and parity of $\Xi_c(2970)^+$ PRD 103, L111101 (2021)
  - Masses and Widths of $\Sigma_c(2455)^+, \Sigma_c(2520)^+$ PRD 104, 052003 (2021)
  - Evidence for $\Omega_c^0 \to \pi^+\Omega(2012)^- \to \pi^+(\bar{K}\Xi)^-$ PRD 104, 052005 (2021)

Belle II is already in the game!

World's most precise measurement of the Λ_c^+ lifetime

arXiv:2206.15227





Confirmation that the Ω_c is not the shortest-lived charm baryon

ICHEP presentation

Summary

- Belle II: next generation B-factory building upon success of Belle
- Wide-ranging physics program including study of new XYZ states
- Many opportunities in unique production and decay modes