Belle II status and perspectives

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Workshop on double charm tetraquark and other exotics

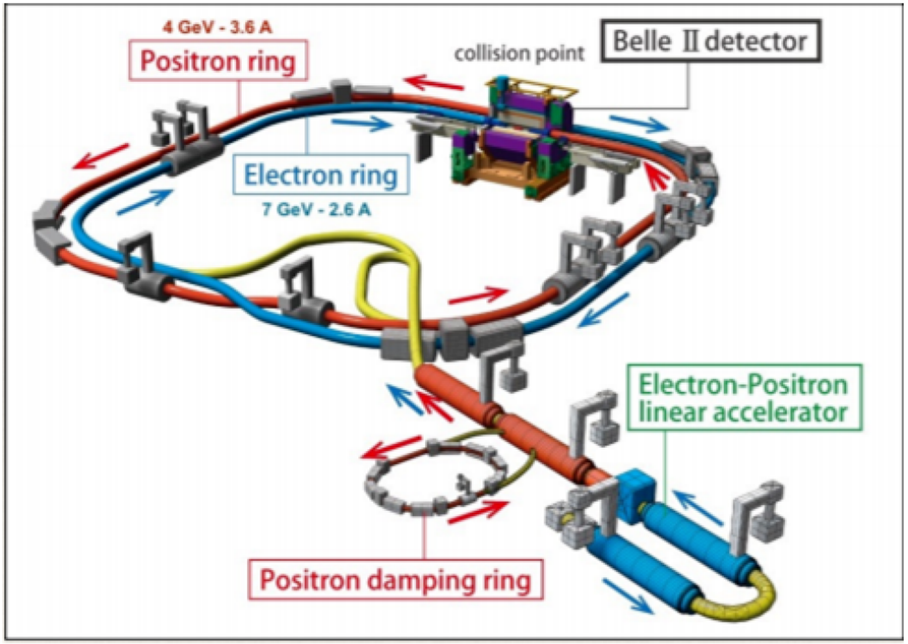
Nov. 22-23, 2021, Lyon

Outline

- Introduction to the Belle II experiment
- Belle II potential in the charmonium region
- Belle II potential in the bottomonium region
- Summary

Introduction to the Belle II experiment

- Belle II operates at SuperKEKB at KEK in Tsukuba, Japan



- Plan to take 50 ab^{-1} ($50 \times$ Belle) data
  $\sigma(e^+e^- \to B\bar{B}/c\bar{c}/\tau\bar{\tau}) \approx 1.05/1.3/0.92$ nb
- Designed $\mathscr{L}$: $6 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Achieved so far:

$3.1 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Belle II at high intensity frontier:

- Search for BSM physics
- Precisely measure SM parameters
- Reveal more properties of the strong interaction

Very rich physics topics:

- Semileptonic & Missing Energy B Decays
- Radiative & Electroweak Penguin B Decays
- Time Dependent CP Violation
- Hadronic B Decays to Charmless
- Hadronic B Decays to Charm
- Bottomonium & Charmonium
- Charm Physics & τ Physics
- Low Multiplicity Physics & Dark Sector Physics

For details, please see PTEP 2019, 123C01
The Belle II Physics Book

Introduction to the Belle II detector

K. R. Nakamura, talk at TIPP2021 (2021);
BELLE2-NOTE-PL-2020-014;
BELLE2-NOTE-PL-2020-027.

Strip and pixel vertex detector
- Inner 2 layers: Pixel detector
- Outer 4 layers: Strip detectors

$\sigma_{\min}^{\mathrm{SVD}} \approx$ 10-25μm

Drift chamber (p, PID)
- Longer lever arm than Belle
- Smaller cell size than Belle

eff. × accept. ≥ 0.8 (for $p_T > 1$ GeV/c)

PID detectors (K/π separation)
- Barrel: Time-Of-Propagation counters
- Endcap: Aerogel RICH
- Wrong PID: x0.5 smaller than Belle

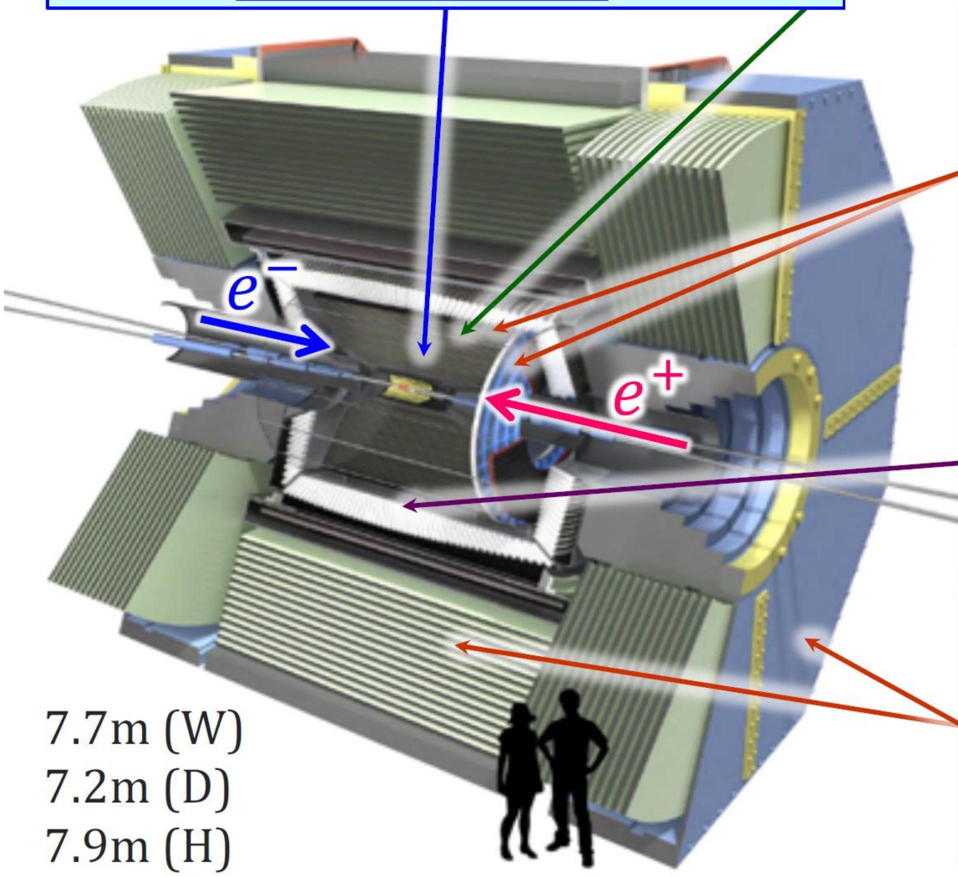
$\epsilon_K^{\mathrm{average}} \gtrsim 0.8$ (for all p region)

EM calorimeter (E_e, E_γ)
- CsI(Tl) + wave-form sampler

$\epsilon_{e^\pm} \approx 94\%$, wrong $h^\pm \to e^\pm$ ID $\approx 2\%$

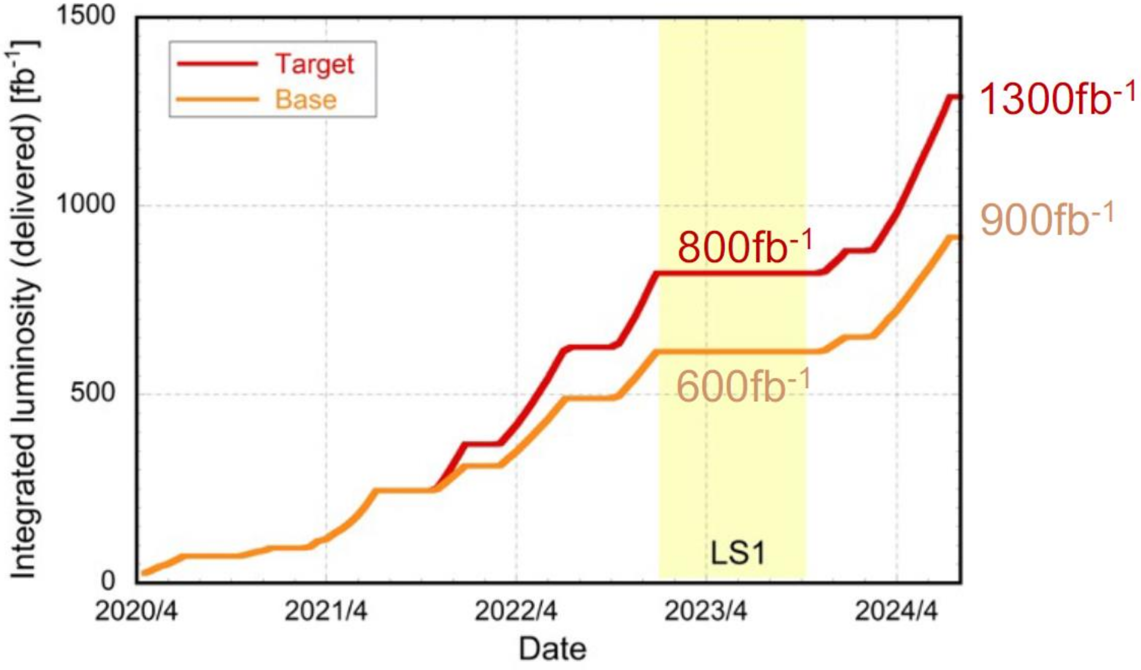
K_L^0/μ detector
- Outer barrel: RPC (streamer mode)
- Endcap, inner barrel: Sci. + WL shifter

$\epsilon_{\mu^\pm} \approx 90\%$, wrong $h^\pm \to \mu^\pm$ ID $\approx 4\%$



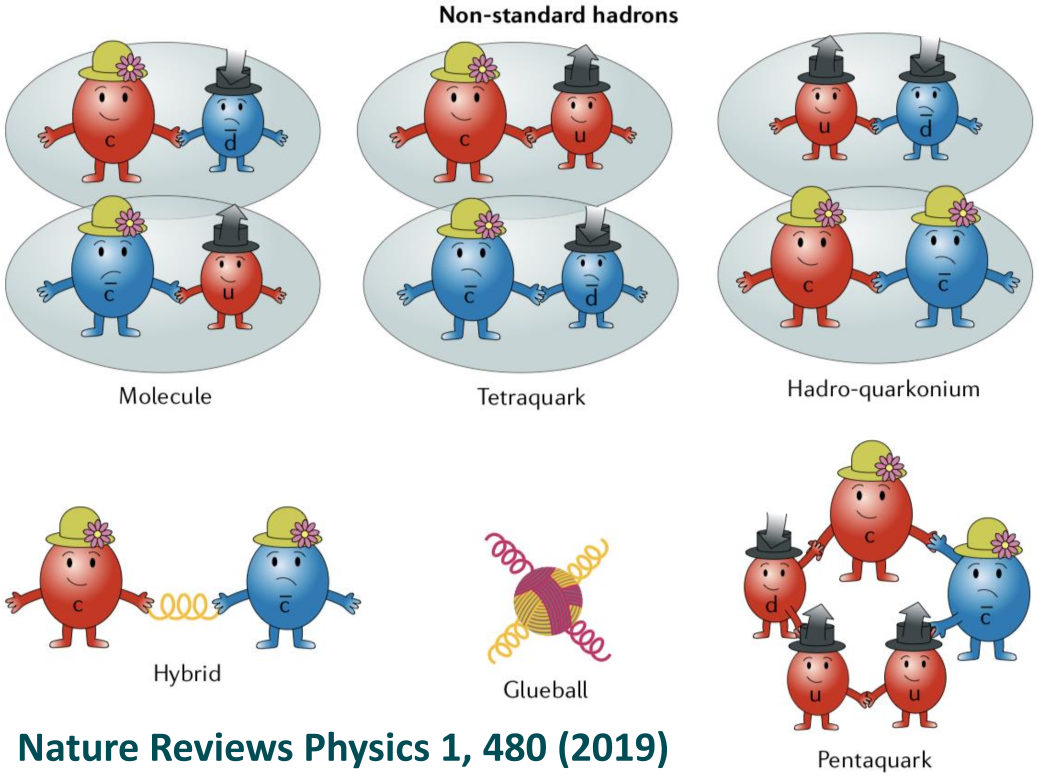
7.7m (W)
7.2m (D)
7.9m (H)

Belle II luminosity plan



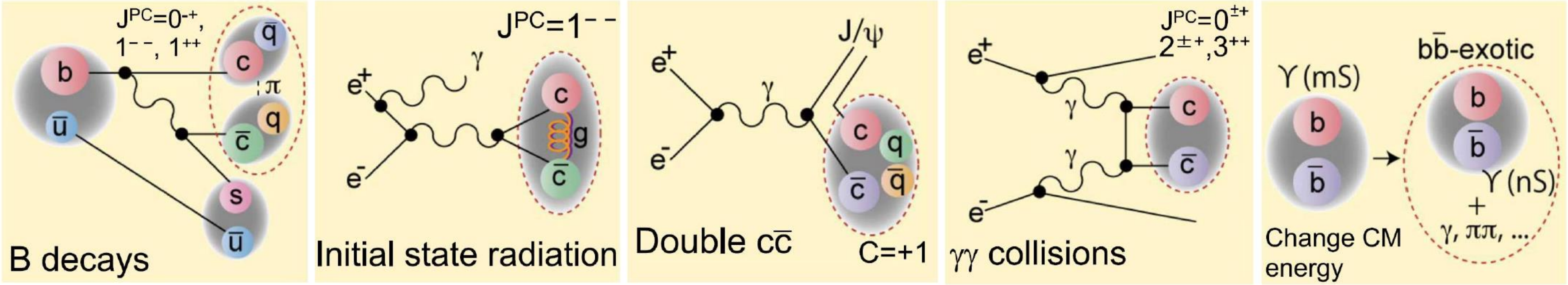
Long Shutdown 1 (LS1) is currently scheduled to start January 2023

Exotic candidates



Nature Reviews Physics 1, 480 (2019)

- Many different processes to study the exotic states
- Full event reconstruction, decays with neutral/soft particles
- Nominal at Υ(4S), potential to reach ~11 GeV



What is X(3872)?

- **A $D^0\bar{D}^{*0}$ molecular**

Various models predict $Br(X\to J/\psi\pi^+\pi^-) < 10\%$ (PRD 72, 054022 (2005), PRD 69, 054008 (2004), Chin.Phys. C43 12, 124107 (2019))

- **Mixture of $D^0\bar{D}^{*0}$ and $\chi_{c1}(2P)$ bound state**

$Br(X\to J/\psi\pi^+\pi^-) < 20\%$ (PLB 702, 359 (2011))

- **Tetraquark model**

$Br(X\to J/\psi\pi^+\pi^-) \sim 50\%$ (PRD 71, 014028 (2005))

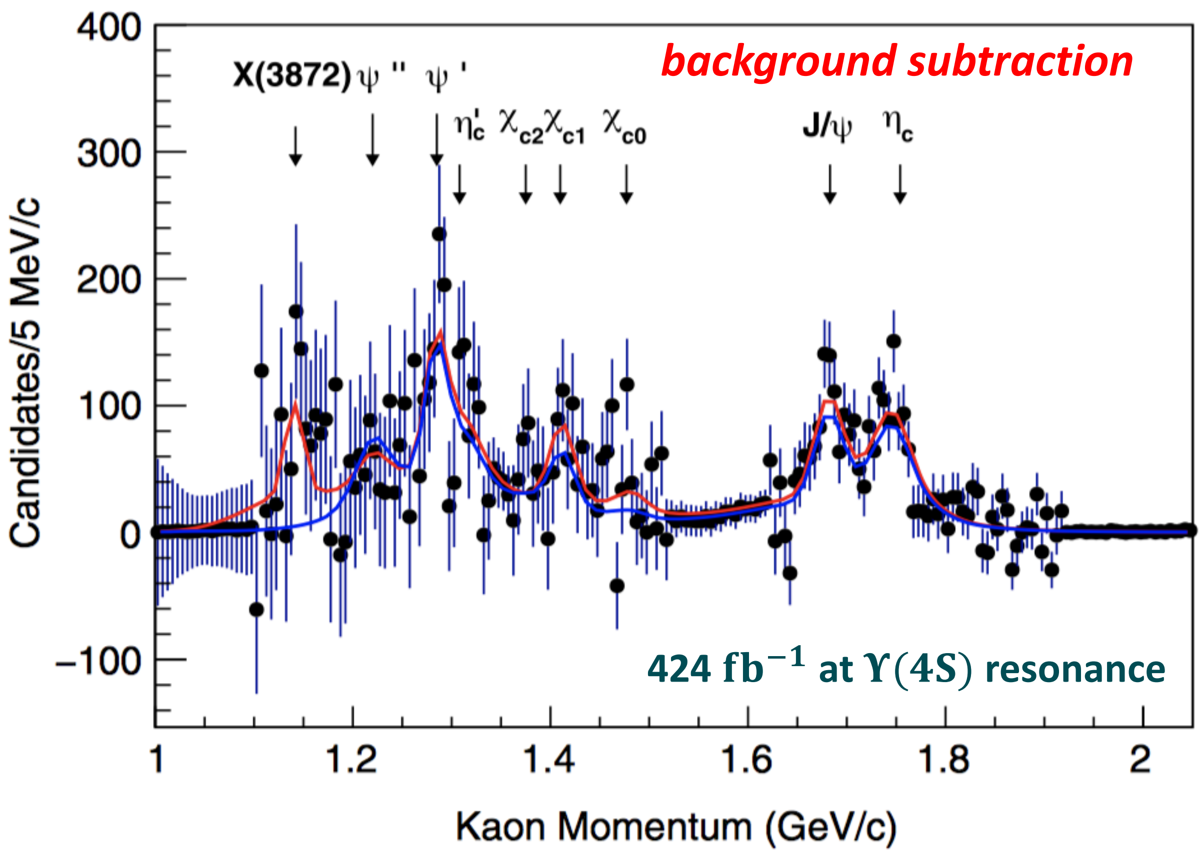
- **$\chi_{c1}(2P)$**

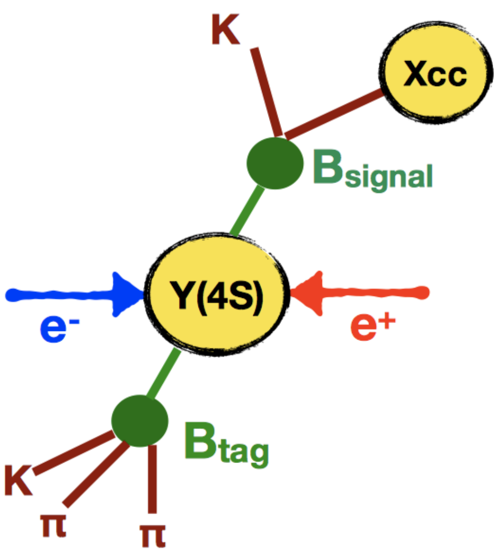
$Br(X\to \gamma J/\psi) \sim 0.6\%$, $Br(X\to \gamma J/\psi) \sim 3.5\%$ (PRD 69, 054008 (2004))

Absolute Brs of X(3872) from BaBar

PRL 124, 152001 (2020)

- If more than one B candidate is found in an event, all candidates are retained to avoid the best one was not the correct one, including those where it belonged to the signal side.
- For the X(3872), the efficiency gains up to a factor of 3.





Absolute Brs of X(3872) from BaBar

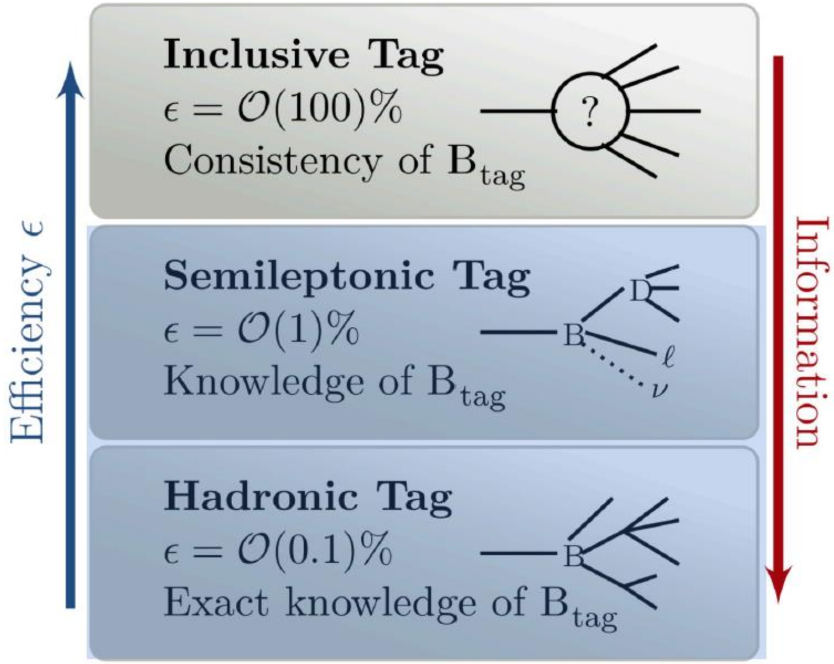
PRL 122, 222001 (2019)

Particle	Yield	$\mathcal{B}(10^{-4})$	N_σ
J/ψ	2364 ± 189	10.1 ± 0.29 (Ref. [21])	10.4
η_c	2259 ± 188	$9.6 \pm 1.2(\text{stat}) \pm 0.6(\text{syst})$	9.3
χ_{c0}	287 ± 181	$2.0 \pm 1.3(\text{stat}) \pm 0.3(\text{syst})$	1.6
χ_{c1}	1035 ± 193	$4.0 \pm 0.8(\text{stat}) \pm 0.6(\text{syst})$	2.2
χ_{c2}	200 ± 164	< 2.0	1.2
$\eta_c(2S)$	527 ± 271	$3.5 \pm 1.7(\text{stat}) \pm 0.5(\text{syst})$	2.3
ψ'	1278 ± 285	$4.6 \pm 1(\text{stat}) \pm 0.7(\text{syst})$	3.1
$\psi(3770)$	497 ± 308	$3.2 \pm 2.0(\text{stat}) \pm 0.5(\text{syst})$	1.2
$X(3872)$	992 ± 285	$2.1 \pm 0.6(\text{stat}) \pm 0.3(\text{syst})$	3.0

- $\mathcal{B}[X(3872) \to J/\psi\pi^+\pi^-] = (4.1 \pm 1.3)\%$
- The measurement therefore suggests that the X(3872) has a significant molecular component.
- At Belle II, we need improve the measurements related to X(3872) decays [reduce the background level; improve B tagging efficiency]

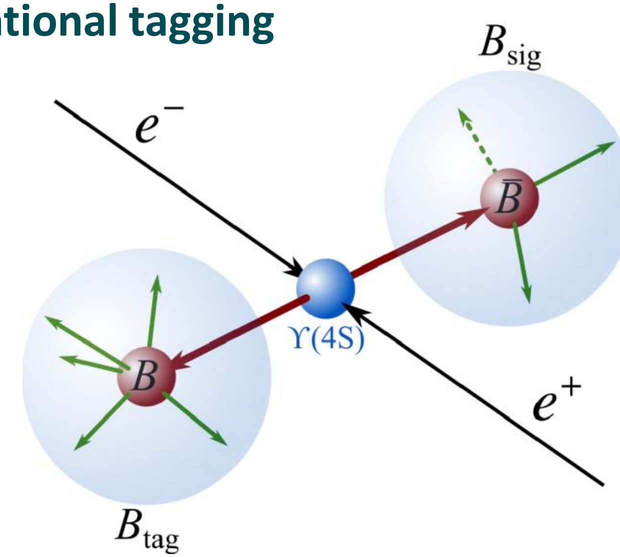
B tagging at Belle II

- **Identify** $B\overline{B}$ by reconstructing one of them
  - **Isolate** B_{tag}
  - B_{tag} **information** constrains B_{sig}
- Always a trade-off between **efficiency** and **information** (incl. **purity**, signal-side kinematic **resolution**, etc.)
- In Belle II, **Full Event Interpretation** (FEI):
  - Hierarchical reconstruction of ~10,000 decay modes
  - Extensive use of machine learning
  - Semileptonic and hadronic tag modes
  - Increase in **efficiency**, comparable **purity**



arXiv: 1807.08680 [hep-ex]
Comput. Softw. Big Sci. 3 (2019) 1, 6

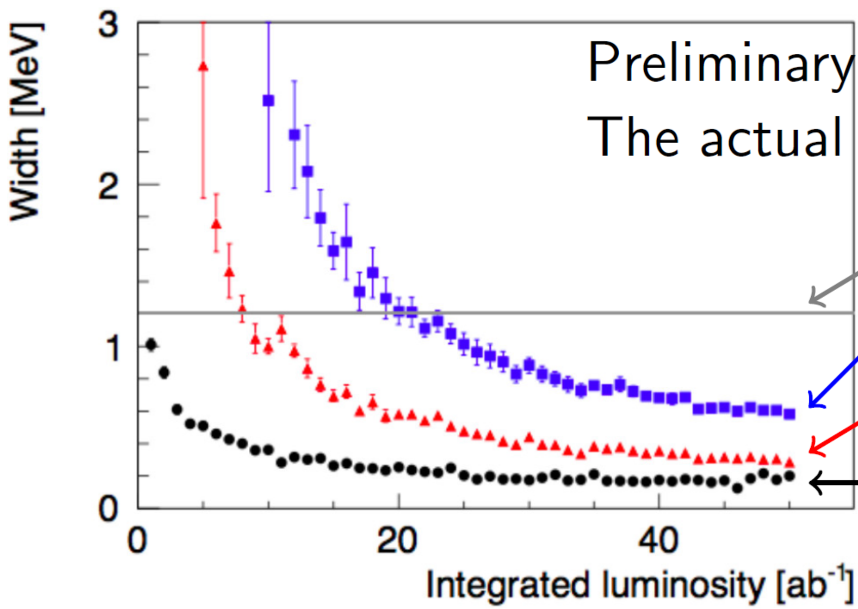
efficiency increases by 30-50% compared with conventional tagging



The $X(3872)$ width: sensitivity

- X(3872) width has been measured by LHCb [PRD 102, 092005 (2020); JHEP 08, 123 (2020)]. PDG average value: 1.19 ± 0.21 MeV

- Using the $B \to (D^0\bar{D}^0\pi^0)K$ data can significantly improve the mass resolution (near-threshold decay), and, consequently, the total-width sensitivity.
- The sensitivity has been estimated on MC



Preliminary and the error is statistical only.
The actual limit should be larger.

Current limit: 1.2 MeV at 90% C. L.

Measureable width (5σ)

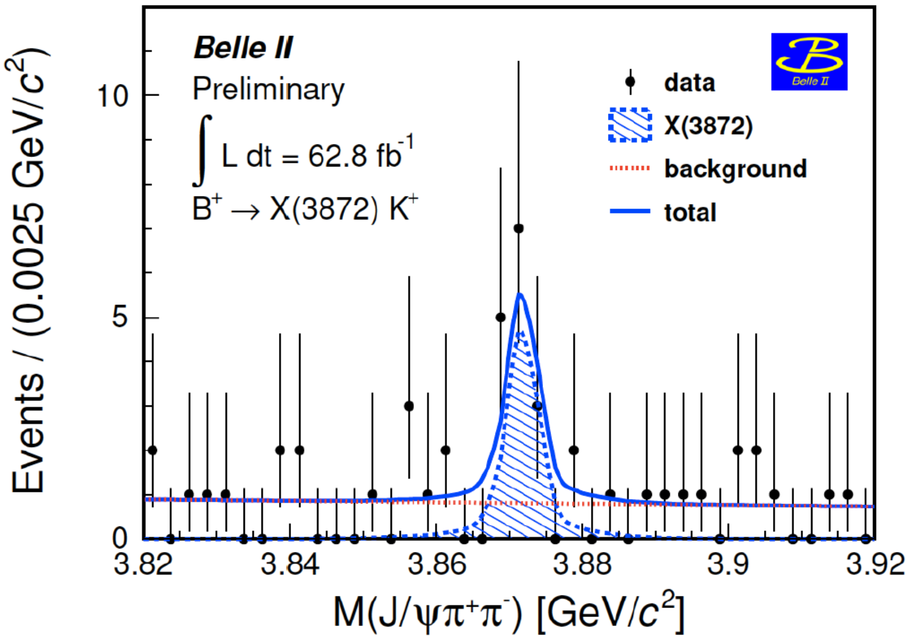
Measureable width (3σ)

Limit (90%C.L.) if $\Gamma = 0$ MeV
About 180 keV for full data sample

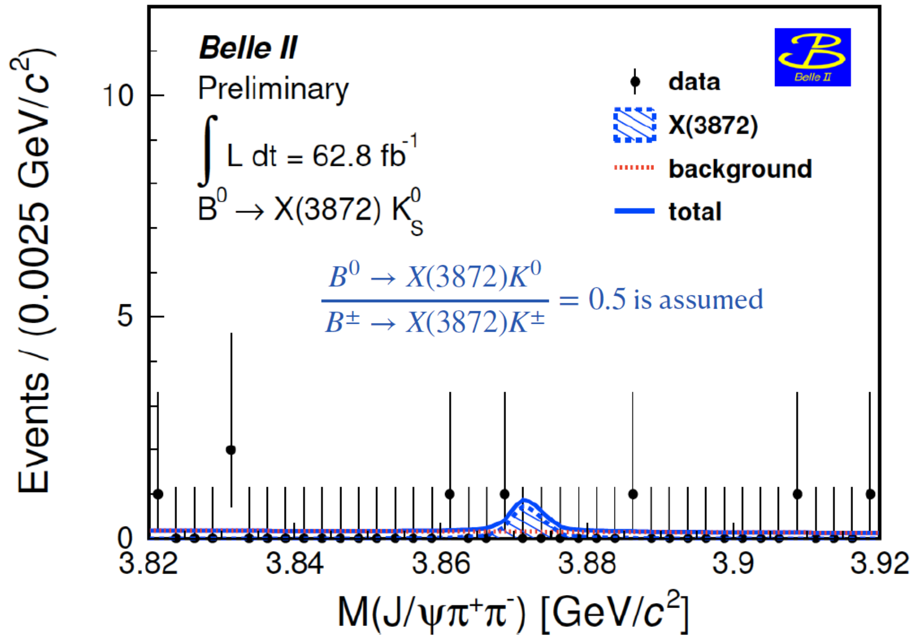
Reconstruction of B→ KX(3872), X(3872)→ $\pi^+\pi^-$J/ψ

- A new resonance $X(3872)$ was first reported by Belle in 2003 by reconstructing $B^+ \to J/\psi\,\pi^+\pi^- K^+$ decay.
- We reconfirmed evidence for $X(3872)$ in Belle II data with 4.6σ significance.

BELLE2-NOTE-PL-2021-002

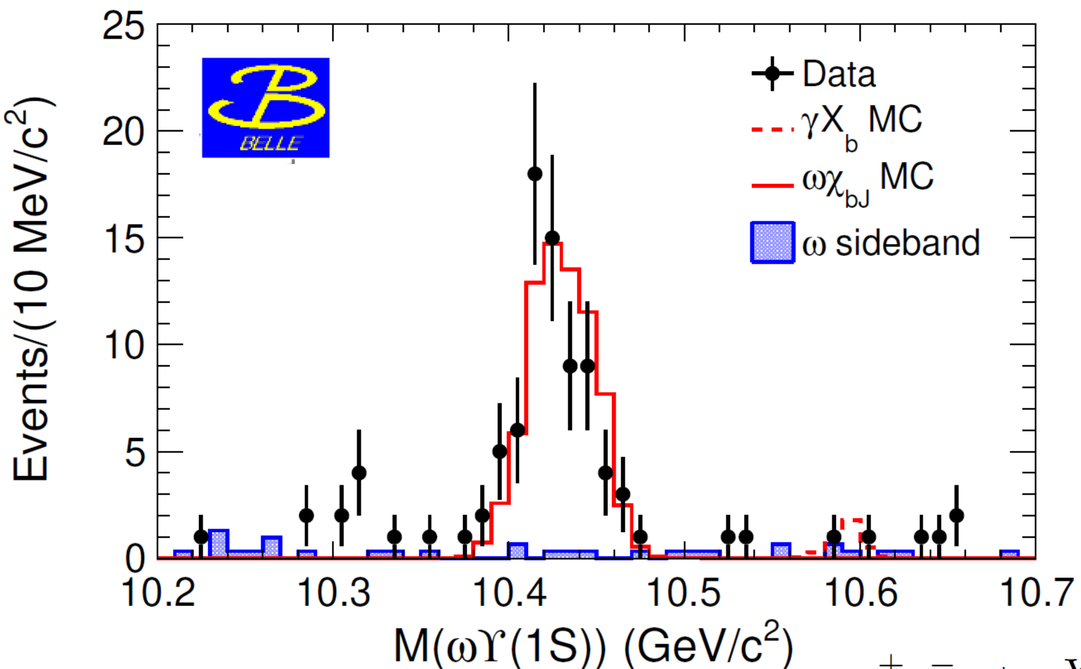


$B^+ \to X(3872)(J/\psi\,\pi^+\pi^-)K^+$



$B^0 \to X(3872)(J/\psi\,\pi^+\pi^-)K_S^0$

Search for X(3872) partner in bottomonium X_b



$e^+e^- \to \gamma X_b,\ X_b \to \omega\Upsilon(1S)$

The peak in $M(\omega\Upsilon(1S))$ comes from $e^+e^- \to \omega\chi_{bJ},\ \chi_{bJ} \to \gamma\Upsilon(1S)$

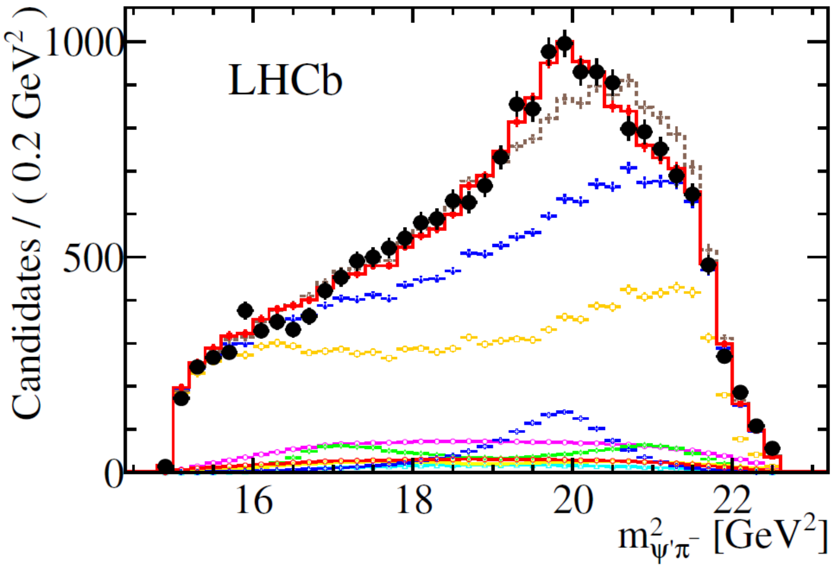
$\mathcal{B}(\Upsilon(10860) \to \gamma X_b)\mathcal{B}(X_b \to \omega\Upsilon(1S)) < (2.6 - 3.8) \cdot 10^{-5}$ btw. 10.55 and 10.65 GeV

X.H. He et al., Phys. Rev. Lett. 113, 142001 (2014)

- At Belle II, with larger data samples at Y(5S) and higher resonance, we will continue such search.

Charged charmoniumlike states: current status

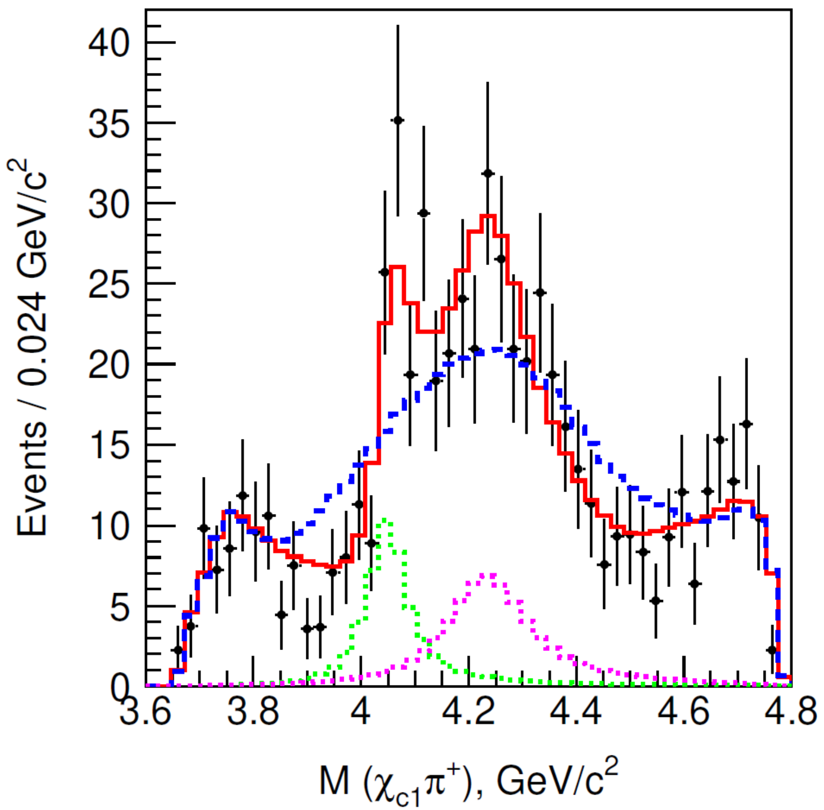
$Z_c(4430)^+$ $(B^0 \to \psi(2S)\pi^- K^+)$
LHCb PRL **112**, 222002 (2014)



Belle (first J^P): PRD **88**, 074026 (2013)

(These analyses are the latest ones; observed by Belle in PRL **100**, 142001 (2008).)

$Z_c(4050)^+$, $Z_c(4250)^+$
$(B^0 \to \chi_{c1}\pi^- K^+)$
Belle PRD **78**, 072004 (2008)



Only the $Z_c(4430)^+$ is confirmed (seen by Belle and LHCb), it is studied relatively well now. Other charged charmoniumlike states observed in B decays are not confirmed; the analyses were performed either only at Belle or only at LHCb.

Potential for charged states from B decays

1. Updated amplitude analysis of $\bar{B}^0 \to \psi(2S)\pi^+K^-$: confirmation of the LHCb observation of the resonant character of the $Z_c(4430)^+$, confirmation of the $Z_c(4240)^+$ / $R_{c0}(4240)^+$.
2. Confirmation of the $W_{c0}(4100)^+$ in $\bar{B}^0 \to \eta_c\pi^+K^-$
3. Amplitude analysis of $\bar{B}^0 \to \chi_{c1}\pi^+K^-$, measurement of the $Z_c(4050)^+$ and $Z_c(4250)^+$ quantum numbers.
4. Search for the neutral partners of all charged charmoniumlike states observed in B decays.
5. Amplitude analyses of unexplored channels, for example $\bar{B}^0 \to X(3872)\pi^+K^-$.
6. Search for the $Z_c(3900)^+$ in $\bar{B}^0 \to J/\psi\pi^+\pi^-K^+$.
7. Search for decays of charged charmoniumlike states to $D^{(*)}\bar{D}^{(*)}$ in $B \to D^{(*)}\bar{D}^{(*)}K$.

Can be done at Belle II and LHCb.

Belle II has a good sensitivity for neutral partners.

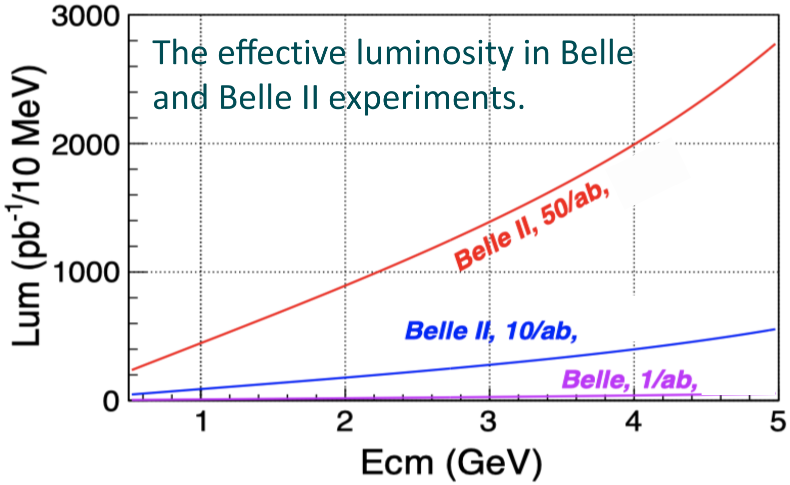
Potential for neutral states from B decays

1. Amplitude analysis of $B \to J/\psi\phi K$, confirmation of 4 states observed by LHCb.
2. Amplitude analysis of $B \to J/\psi\omega K$, measurement of the $X(3915)$ quantum numbers in B decays.
3. Updated search for $B \to Y(4260)(\to J/\psi\pi^+\pi^-)K$ and other $J^{PC} = 1^{--}$ charmoniumlike states.
4. Amplitude analyses of unexplored channels with a J/ψ such as $B \to J/\psi\eta K$ or $B \to J/\psi\eta' K$.
5. Analyses of the above channels with K_S^0.
6. Search for decays of known charmoniumlike states to other final states, for example, $X(3915) \to \eta_c\eta$ ($X(3915)$ should decay to this channel if it is a $c\bar{c}s\bar{s}$ state).
7. Absolute branching fractions for $B \to X(3872)K$, $B \to X(3915)K$.

Can be done at Belle II and LHCb.

Absolute branching fractions are unique for Belle II!

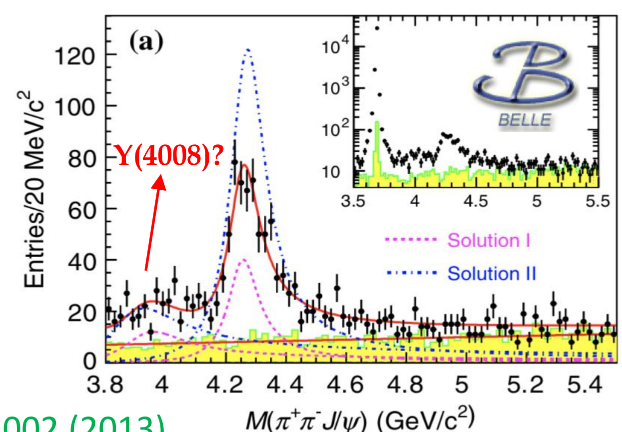
$e^+e^- \to \pi^+\pi^-J/\psi$ via initial-state radiation at Belle II



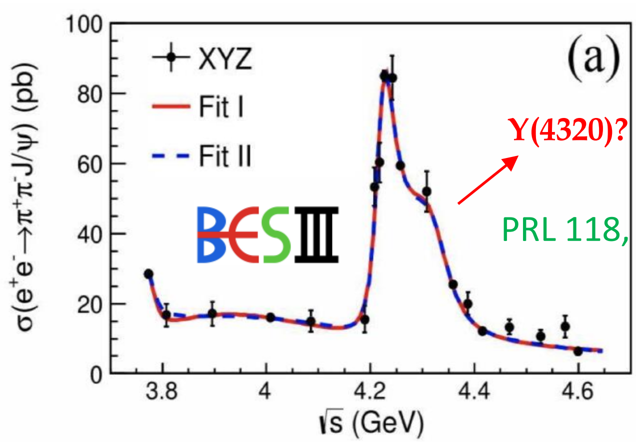
- ISR technique can explore $J^{PC} = 1^{--}$ states far away from e^+e^- collision energy.
- The whole hadron spectrum is visible.
- The effective luminosity and detection efficiency are relatively low.

For $e^+e^- \to \pi^+\pi^-J/\psi(\to \mu^+\mu^-)$ via ISR at Belle II

- Rediscover the first Y state at Belle II
- Identify existences of the Y(4008) and Y(4320) in $M(\pi^+\pi^-J/\psi)$
- Minimize the statistical errors.
- Study the properties of charged charmonium-like state $Z_c(3900)$.



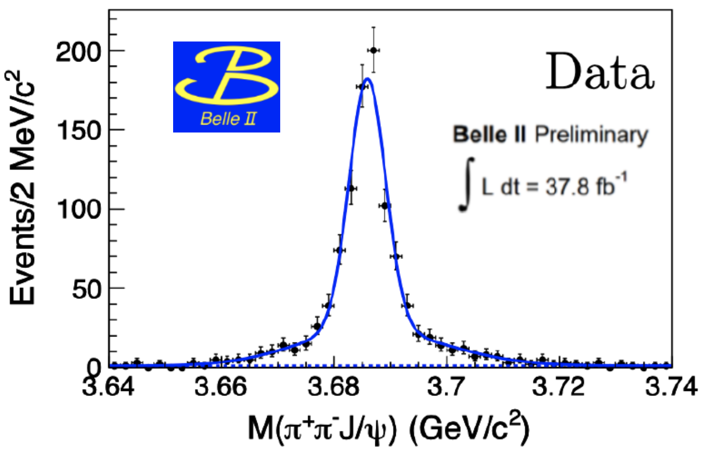
PRL 110, 252002 (2013)



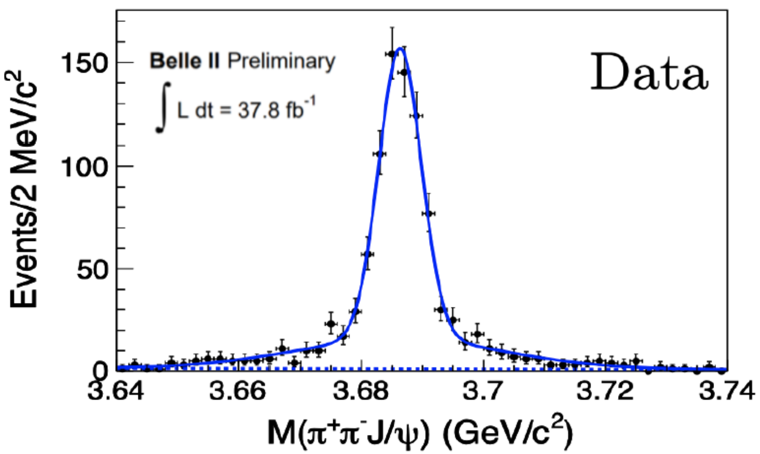
PRL 118, 092001 (2017)

Control samples of $\psi(2S) \to \pi^+\pi^- J/\psi$ via ISR

$J/\psi \to \mu^+\mu^-$



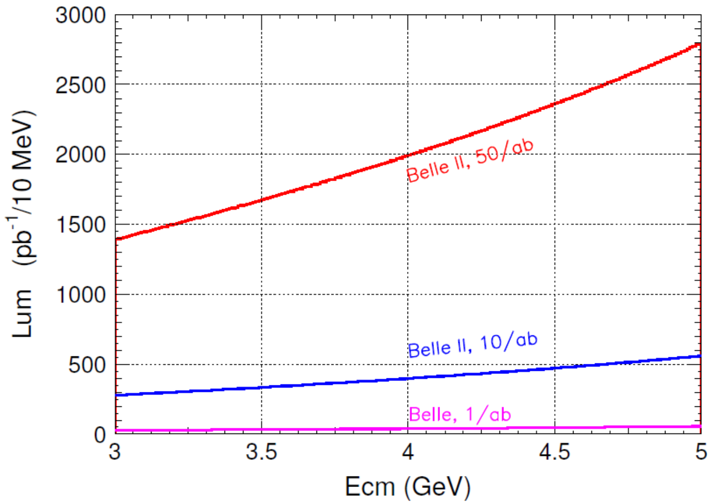
$J/\psi \to e^+e^-$



Mode	Our measurements	Theoretical calculation [Yad. Fiz. 41, 733 (1985)]
$J/\psi \to \mu^+\mu^-$	(12.0 ± 1.2) pb	(14.1 ± 0.3) pb
$J/\psi \to e^+e^-$	(13.0 ± 1.2) pb	

- Further PID and tracking corrections at Belle II are needed.
- The numbers of the expected Y(4260) signal events in data are (12.5 ± 2.3) and (10.6 ± 1.8) for $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$.
- Next step is Y(4260) rediscovery. Expecting ~60 total events per 100 fb^{-1}

Charmonium in ISR: can be done



- Comparable samples for e.g. $e^+e^- \to J/\psi\pi^+\pi^-$.
- Access to high energy region
- Data are accumulated at the same time for all energies - simplifies lineshape analysis.

1. Improved measurements and fits of $e^+e^- \to \gamma_{\text{ISR}}(c\bar{c})(X)$ cross sections.
2. Improved measurements and fits of the open-charm cross-sections, for example $e^+e^- \to \gamma_{\text{ISR}} D^{(*)}\bar{D}^{(*)}(X)$
3. Measurements of higher mass open-charm channels, for example $e^+e^- \to \gamma_{\text{ISR}}\Sigma_c^+\overline{\Sigma}_c^-$.
4. Analyses of the channels that are currently studied at BESIII only, for example $e^+e^- \to h_c\pi^+\pi^-$ with confirmation of the $Z_c(4020)^+$.

Can be done at Belle II and BESIII with direct production.

Other productions for charmonium-like states

Two photon processes

Study of $\chi_{c2}(3930)$ using $\gamma\gamma \to Z(3930) \to D\bar{D}$

Mass and width precision study.

X(3915) (thought to be $\chi_{c0}(2P)$)was discovered in two photon process.

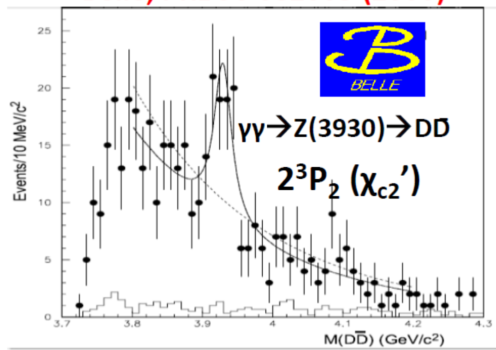
Currently, $\chi_{c0}(2P)$ has been suggested to be recently found X(3860) in $J/\psi D\bar{D}$.

Belle observed X(4350) in $\gamma\gamma \to J/\psi\phi$.

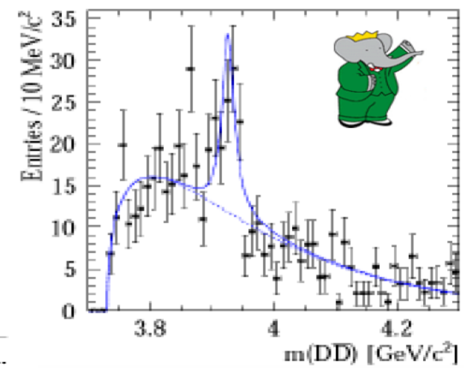
Recently, LHCb did amplitude analysis of $B \to J/\psi\phi K$, found several structures Y(4140), Y(4274), X(4500), X(4700) but not X(4350) (?)

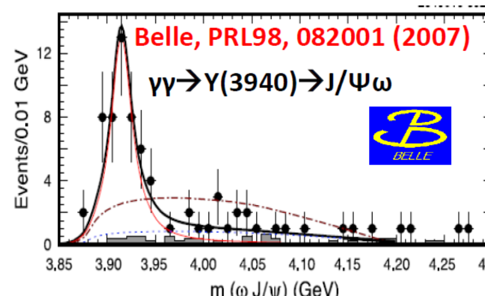
Belle II should revisit with more data.

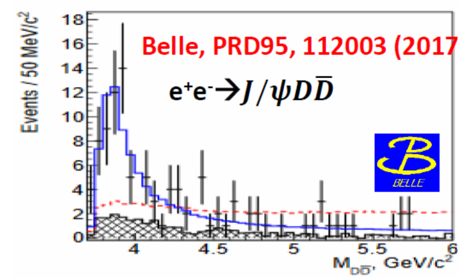
Belle, PRL 96 082003 (2006)



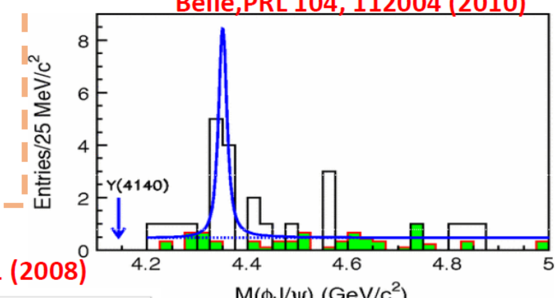
BaBar, PRD81 092003 (2010)



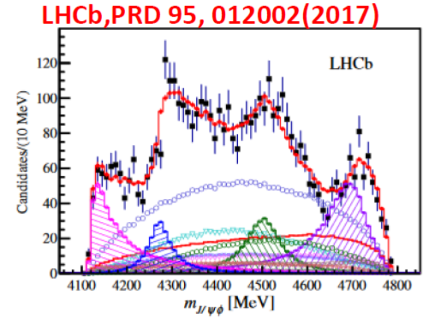




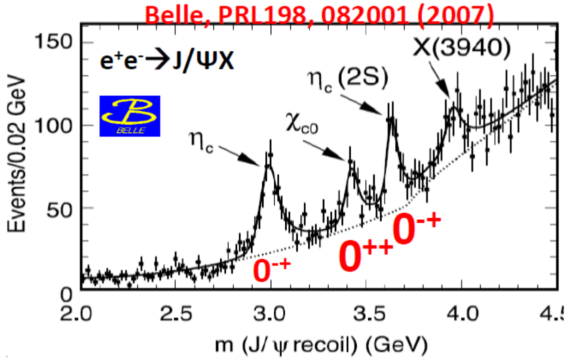
Belle,PRL 104, 112004 (2010)



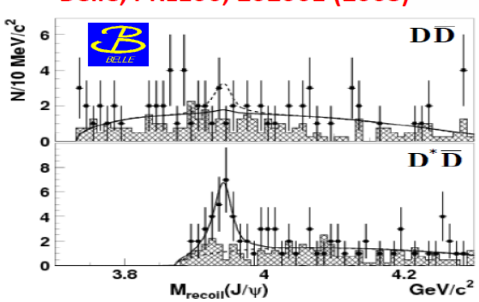
LHCb,PRD 95, 012002(2017)



Belle, PRL198, 082001 (2007)



Belle, PRL100, 202001 (2008)



$e^+e^- \to J/\Psi X(3940)$

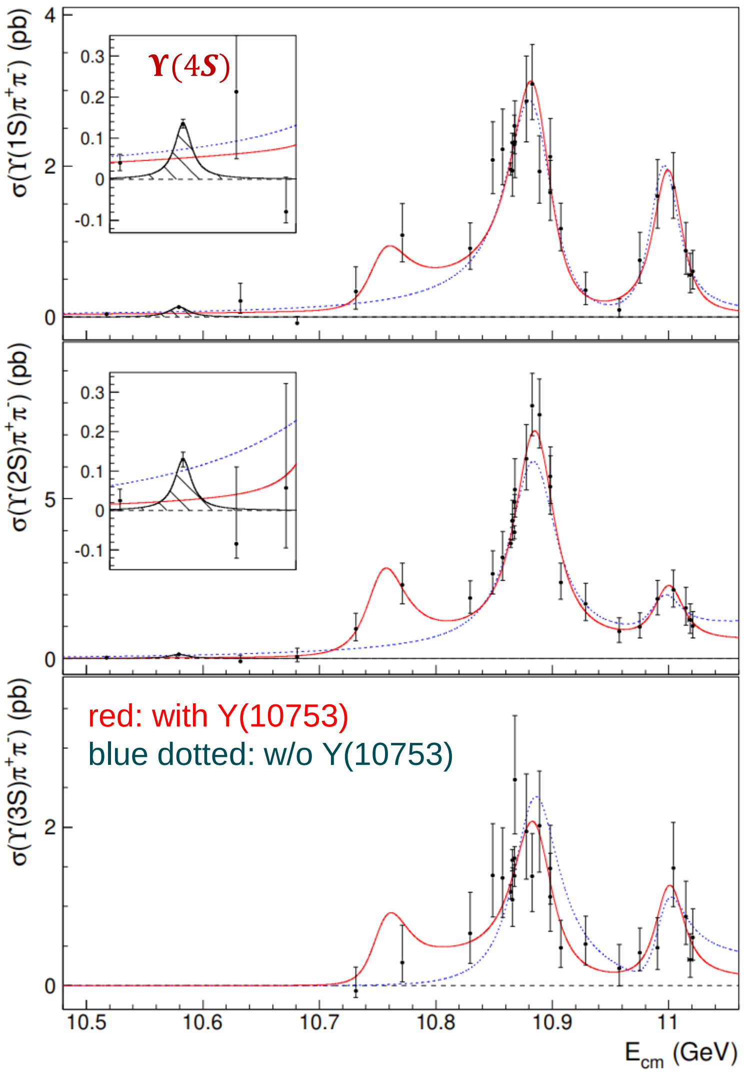
Double charmonium production, another interesting process through which Belle II can access C=+ even states.

$e^+e^- \to \Upsilon(nS)\pi^+\pi^-$ cross sections and Y(10750)

Scan data: 22 points, each point 1fb^{-1}

$\Upsilon(10860)$ on-resonance data: 121 fb^{-1}, between 10.864 and 10.868 GeV

Continuum data at 10.52 GeV, 60 fb^{-1}



global significance: 6.7σ

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

$\Gamma_{ee} \times \mathcal{B}$ (in eV) a range due to multi-solutions

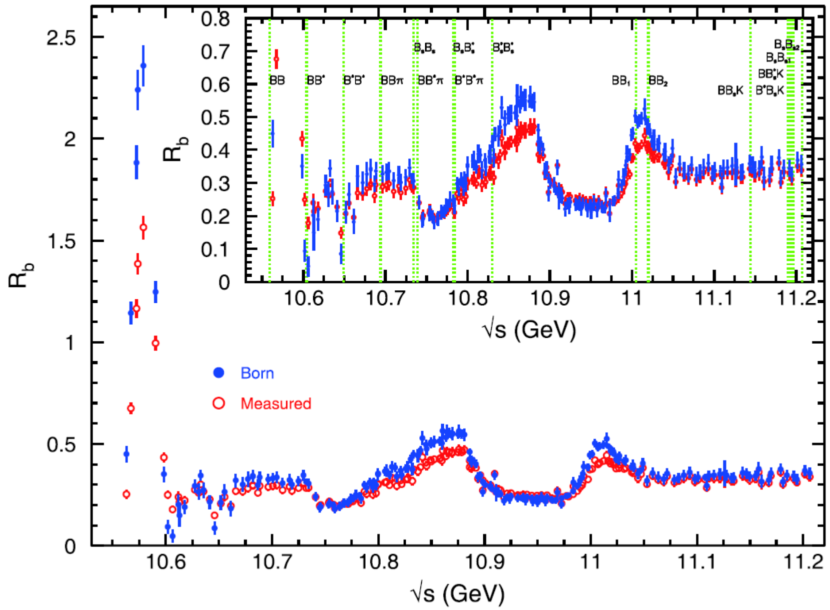
	$\Upsilon(10860)$	$\Upsilon(11020)$	new
$\Upsilon(1S)\pi^+\pi^-$	0.75 – 1.43	0.38 – 0.54	0.12 – 0.47
$\Upsilon(2S)\pi^+\pi^-$	1.35 – 3.80	0.13 – 1.16	0.53 – 1.22
$\Upsilon(3S)\pi^+\pi^-$	0.43 – 1.03	0.17 – 0.49	0.21 – 0.26

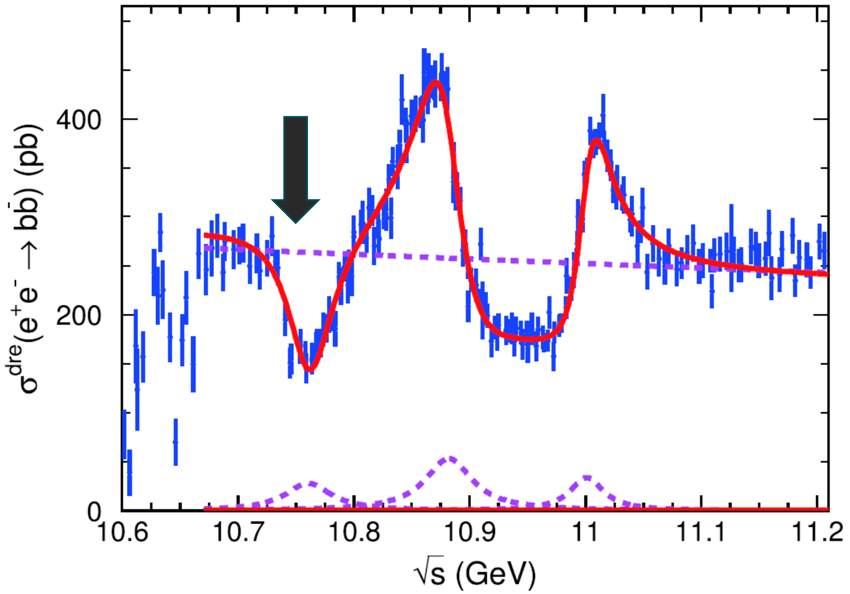
- Could there be a Z_b enhancement?
- Could it be Υ(3D) bottomonium or a tetraquark?
- Near $B^{(*)}B^*\pi$ threshold regions

Belle II is taking data at 10.75 GeV !

$e^+e^- \to b\bar{b}$ cross sections and Y(10750)

X. K. Dong, X. H. Mo, P. Wang, C. Z. Yuan, Chin. Phys. C 44, (2020) 083001





Solution	Parameter	$Y(10750)$	$\Upsilon(5S)$	$\Upsilon(6S)$
1–8	Mass/(MeV/c^2)	10761 ± 2	10882 ± 1	11001 ± 1
	Width/MeV	48.5 ± 3.0	49.5 ± 1.5	35.1 ± 1.2

A dip at 10.75 GeV in $e^+e^- \to b\bar{b}$ cross sections. Similar to Y(4260).

Interpretation of the Y(10750)

- D-wave bottomonium
  - B. Chen, A.L. Zhang, J. He, arXiv:1910.06065, Bottomonium spectrum in the relativistic flux tube model (3D)
  - Q. Li, M.S. Liu, Q.F. Lü, L.C. Gui, X.H. Zhong, arXiv:1905.10344, Canonical interpretation of Y(10750) and Y(10860) in the Y family (4D)
- $\bar{B}^{(*)}B^{(*)}$ dynamically generated pole
  - P. Bicudo, M. Cardoso, N. Cardoso, M. Wagner, arXiv:1910.04827, Bottomonium resonances with I=0 from lattice QCD correlation functions with static and light quarks
- Hybrid
  - J. T. Castellà, arXiv:1908.05179, Spin Structure of heavy-quark hybrids
- Tetraquark state
  - A. Ali, L. Maiani, A. Y. Parkhomenko, W. Wang, arXiv:1910.07671, Interpretation of Yb (10753) as a tetraquark and its production mechanism
  - Z.G. Wang, arXiv:1905.06610, Vector hidden-bottom tetraquark candidate: Y(10750)

Belle II potential in the Bottomonium region

- Run at Υ(6S) and Υ(5S) and high energy scan:
  - Search for new, predicted, resonances such missing bottomonia, exotic states,
  - Improve precision of already known process and states: e.g. Zb's,
  - Measure the effect of the coupled channel contribution,
  - Study $B^{(*)}\overline{B}^{(**)}$ and $Bs^{(*)}\overline{Bs}^{(**)}$ threshold regions (challenging for Super-KEKb).

- Run at Υ(3S) and Υ(2S):
  - Search for missing $\pi\pi/\eta$ transitions to constrain further theoretical models,
  - Search for new physics: LFV, LFU, new scalars...

Future plan at Bottomonium region

- Main focus to collect Υ(4S) on-peak data.
- Upcoming non-Υ(4S) plans (Nov 2021):
  - 10.751 GeV (10 fb^{-1}): to study Υ_b(10753) on-peak,
  - 10.657, 10.706, 10.810 (1+2+3 fb^{-1}): additional points for $B\overline{B}$ decomposition.

- 9 month upgrade, then data taking till 2026, expected O(10 ab^{-1}).
- After upgrade: 11 GeV (30 fb^{-1}): to study Υ(6S) on-peak.
- Future proposals: options for larger Υ(6S), Υ(3S), Υ(5S) datasets.

the energy scan is happening now, and by the time of the talk, is almost complete.

Summary

- The expected Belle II data sample of 50 ab^{-1} will provide a lot of new opportunities for physics analyses in the area of exotic states
- Some of them, such as double charmonium production, two-photon processes, bottomonium physics, absolute branching fractions, have advantages for Belle II.
- Several quarkonium(-like) states and exclusive B decays to charmonium and other particles were "rediscovered" using the currently available data.
- More exciting results are expected with larger data sample in the near future.

Thanks a lot!

FUDAN UNIVERSITY

Thanks for your attention

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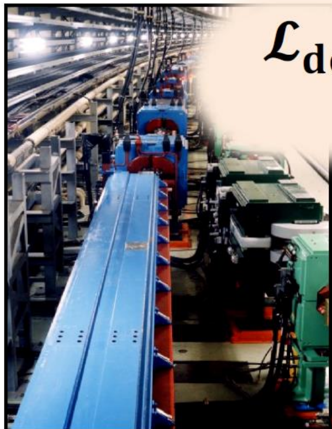
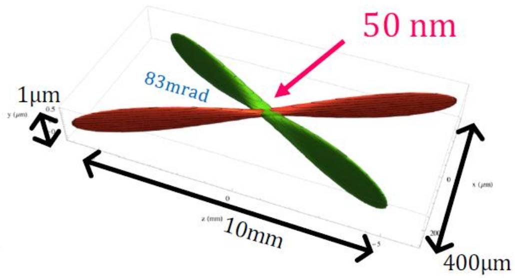
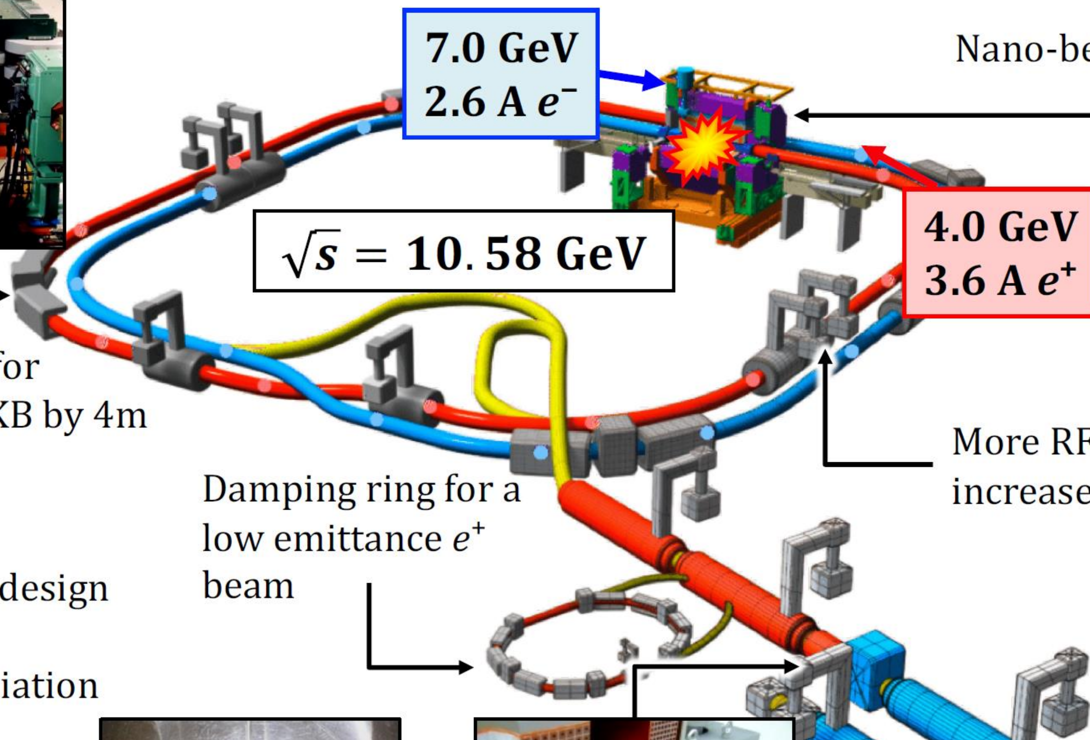
SuperKEKB Accelerator

$$\mathcal{L}_{\mathbf{design}} = 6.5 \times 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\int \mathcal{L}dt = 50\ \mathrm{ab}^{-1}$$





Nano-beam scheme



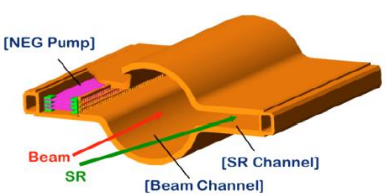
New final focusing magnets

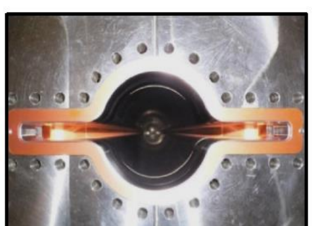
Longer magnets for the LER than KEKB by 4m

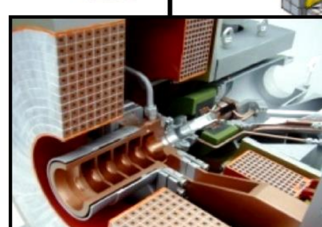
More RF cavities to increase the beam currents

Damping ring for a low emittance e^+ beam

New beam pipe design to reduce the synchrotron radiation







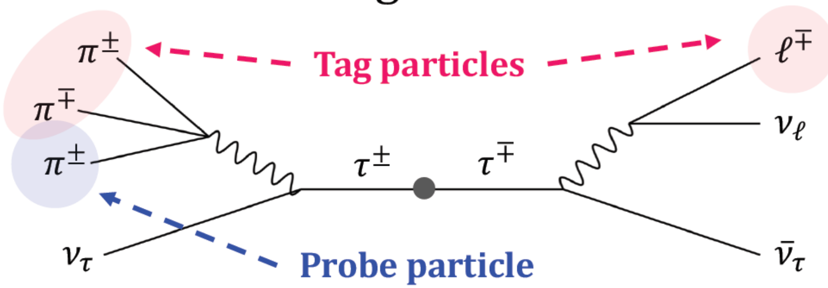
Positron source

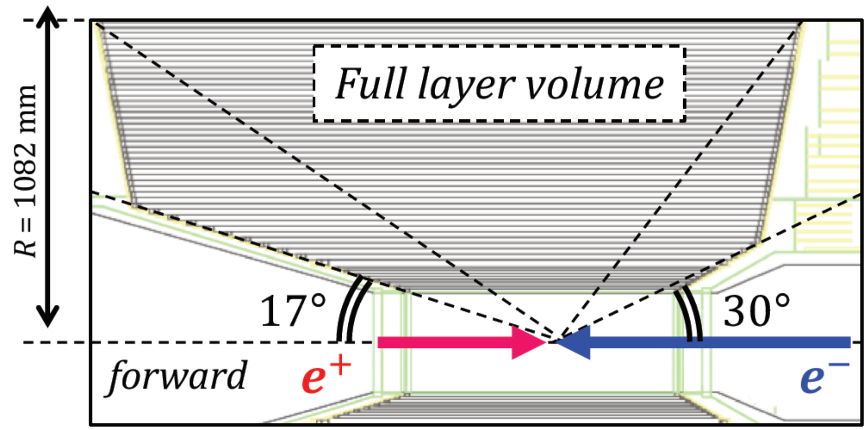
Tracking Detector Performance

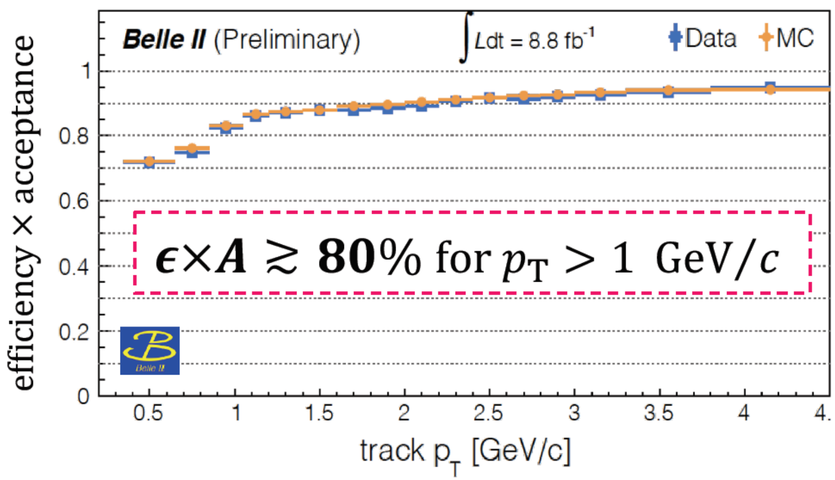
BELLE2-NOTE-PL-2020-014

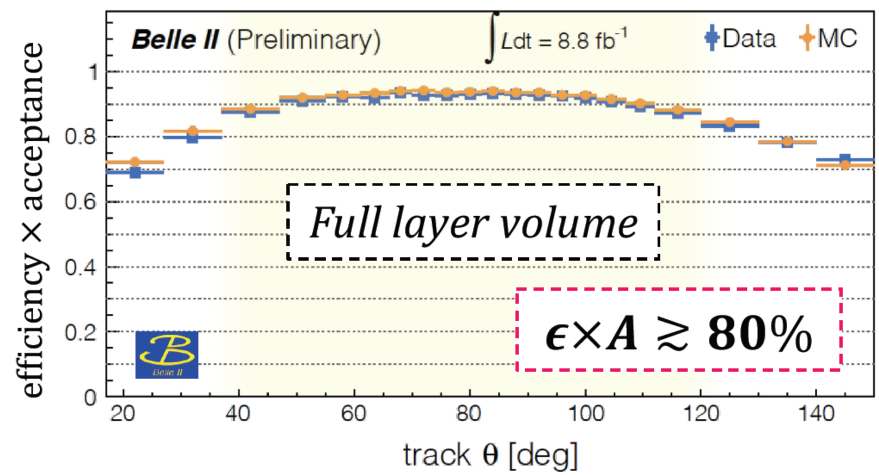
Track finding efficiency ϵ

Estimated using $e^+e^- \to \tau^+\tau^-$.









Momentum resolution δ_{p_T}

Estimated using cosmic rays.

(preliminary)

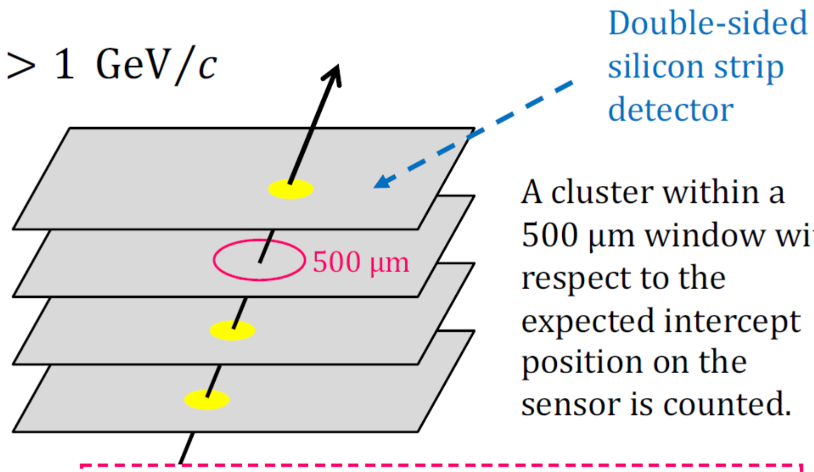
$$\delta_{p_T} = \left(0.127 p_T (\mathrm{GeV}/c^2) \oplus 0.321\right)\%$$

Vertex Detector Performance

VXD hit efficiency ϵ for tracks with $p_T > 1$ GeV/c

4-layers of the silicon strip detector

Layer	ϵ [%] (P-side)	ϵ [%] (N-side)
6	99.31 ± 0.08	99.58 ± 0.06
5	99.66 ± 0.03	99.77 ± 0.04
4	99.69 ± 0.03	99.68 ± 0.03
3	99.83 ± 0.01	99.48 ± 0.03

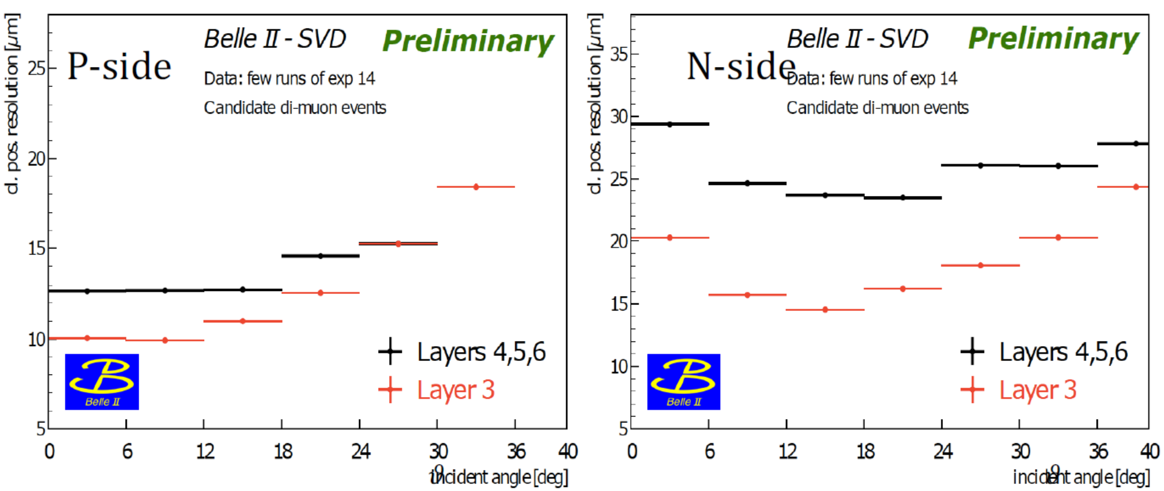


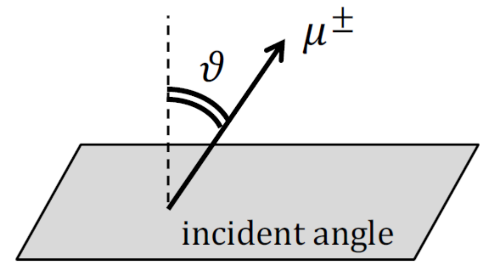
A cluster within a 500 μm window with respect to the expected intercept position on the sensor is counted.

Excellent efficiency $\epsilon > 99\%$ for both sides for all layers

Cluster position resolution σ

The σ is estimated $e^+e^- \to \mu^+\mu^-$ events.



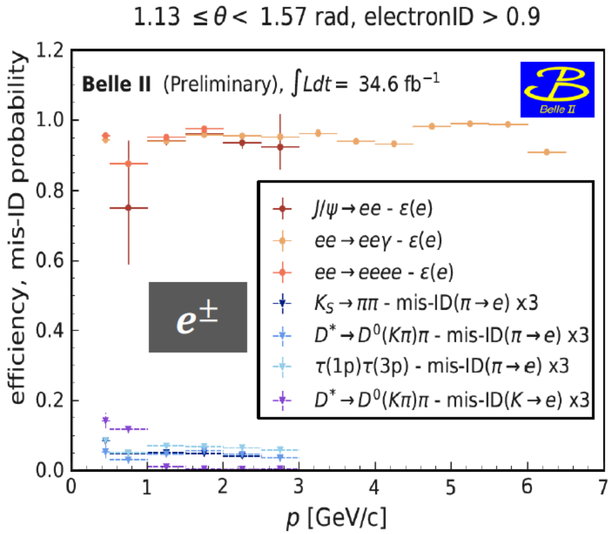


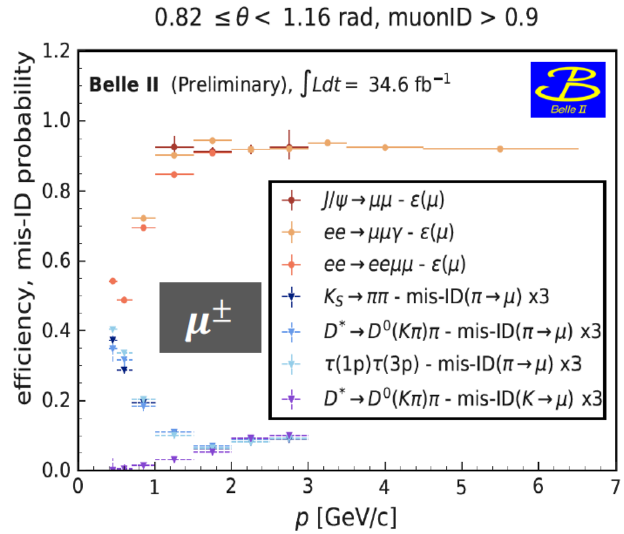
Excellent resolution σ_P^{L3} = 10-20 μm and σ_N^{L3} = 15-25 μm for $\vartheta < 40°$ in L3 ladders

Lepton Identification

BELLE2-NOTE-PL-2020-027

$e^{\pm}$-ID and $\mu^{\pm}$-ID efficiencies ϵ_ℓ and mis-ID rate $w_{h\to\ell}$





$\epsilon_e \approx 94\%, \epsilon_\mu \approx 90\%$

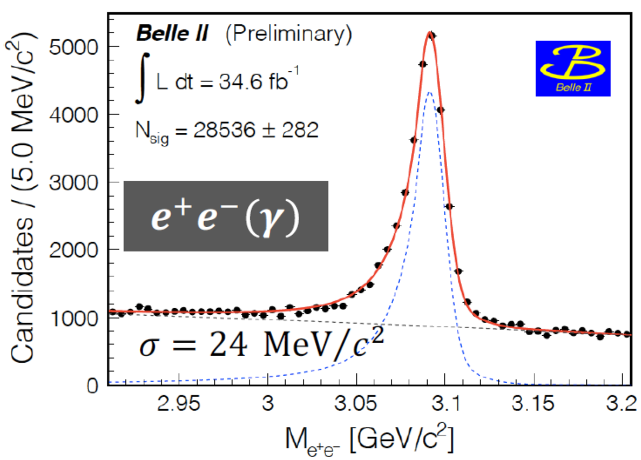
with analyses of $J/\psi \to \ell^+\ell^-$, $e^+e^- \to \ell^+\ell^-(\gamma)$, and $e^+e^- \to e^+e^-\ell^+\ell^-(\gamma)$

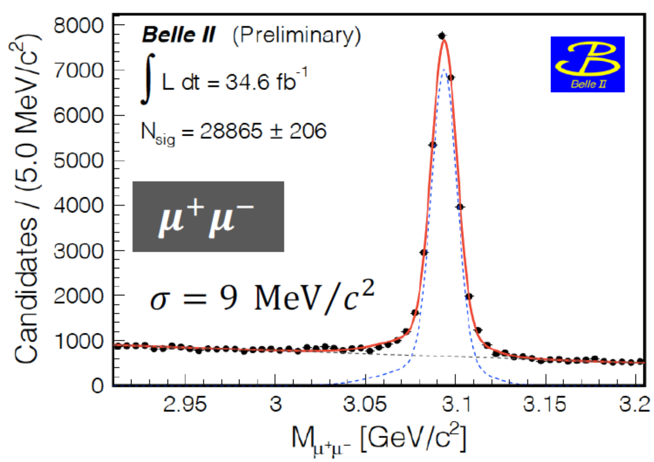
$w_{h\to e} \approx 2\%, w_{h\to\mu} \approx 4\%$

with analyses of $K_S^0 \to \pi^+\pi^-$, $\tau \to 3\pi(nh^0)\nu_\tau$, and $D^{*+} \to D^0(K^-\pi^+)\pi^+$

The mis-ID rates are inflated by ×3 for the illustration purpose.

Demonstration: $J/\psi \to e^+e^-(\gamma), \mu^+\mu^-$ reconstruction





A clear peak is observed at the $m_{J/\psi}$ position.

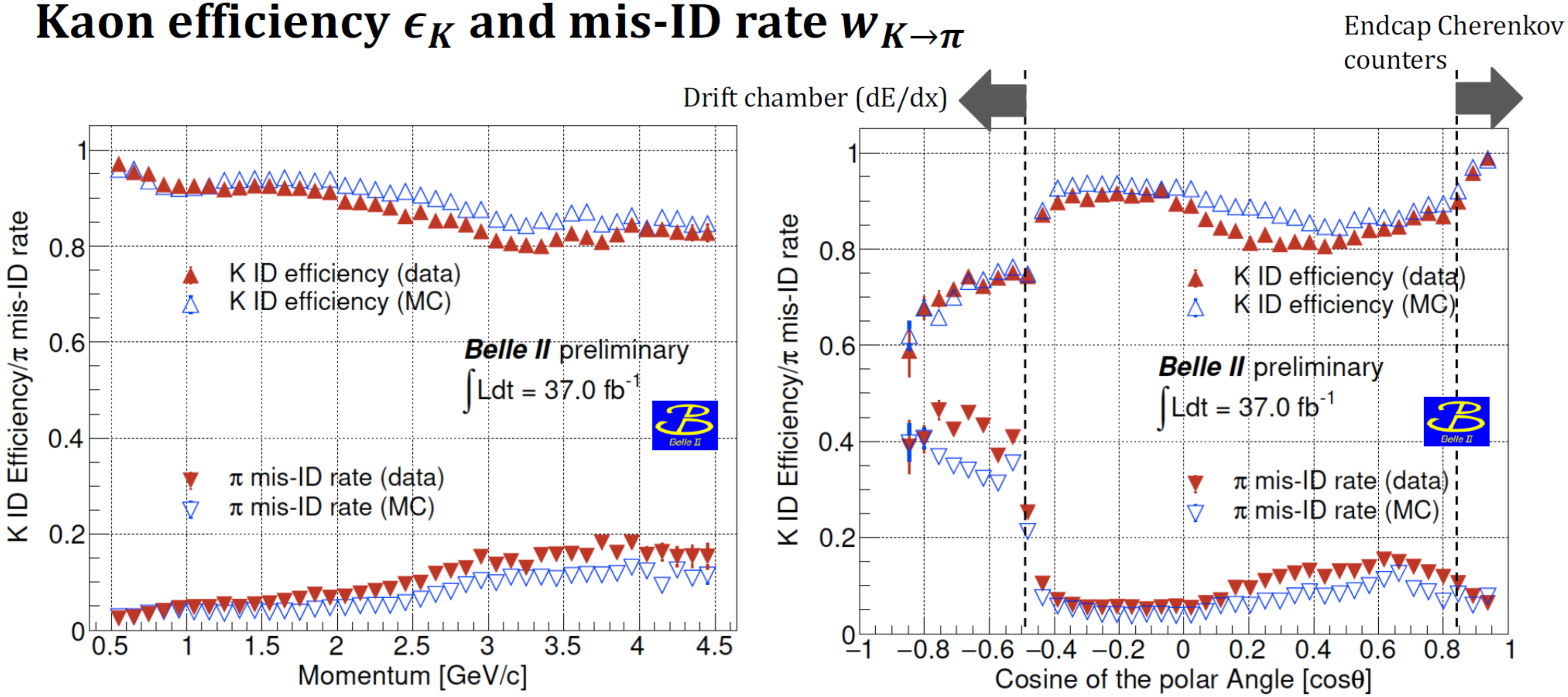
K/π Separation

Quasi K/π tagging

BELLE2-NOTE-PL-2020-024

1. Reconstruct $\pi_{\text{slow}} + (h_1^+ + h_2^-)$
2. When $\pi_{\text{slow}} = \pi_{\text{slow}}^+$, $[\pi_{\text{slow}} + (h_1^+ + h_2^-)] = D^{*+}$, $[h_1^+ + h_2^-] = D^0$, and $h_1^+ = \pi^+$ and $h_2^- = K^-$.
3. When $\pi_{\text{slow}} = \pi_{\text{slow}}^-$, $h_1^+ = K^+$ and $h_2^- = \pi^-$.

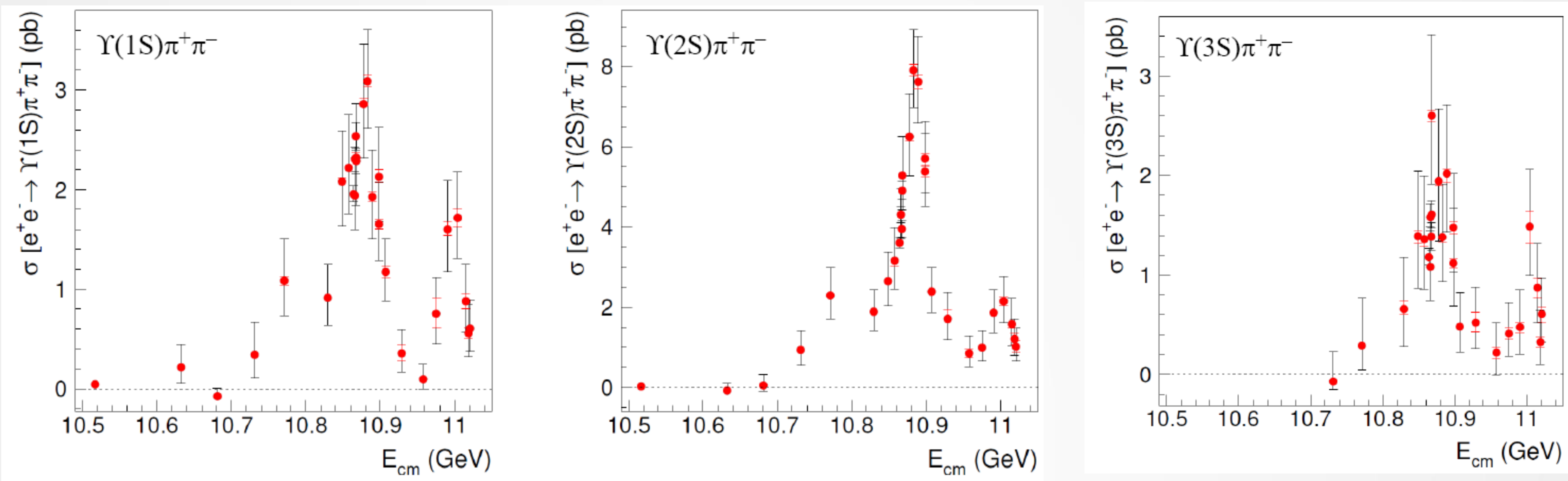
Kaon efficiency ϵ_K and mis-ID rate $w_{K\to\pi}$



Good kaon efficiency and K/π separation power are confirmed.

Update cross sections of $e^+e^- \to \pi^+\pi^-\Upsilon(nS)$

Belle, JHEP 1910, 220 (2019)



Black error bars: statistical

Red error bars: uncorrelated systematic errors

Structure at 10.75 GeV is more significant

Fits to energy dependent cross sections

$$|\mathrm{BW}^{(n)}_{\Upsilon(5S)} + e^{i\alpha_n}\,\mathrm{BW}^{(n)}_{\Upsilon(6S)} + e^{i\beta_n}\,\mathrm{BW}^{(n)}_{\mathrm{new}} + e^{i\gamma_n}\,\mathrm{BW}^{(n)}_{\Upsilon((n+1)S)}|^2 \otimes \mathrm{Gaussian}$$

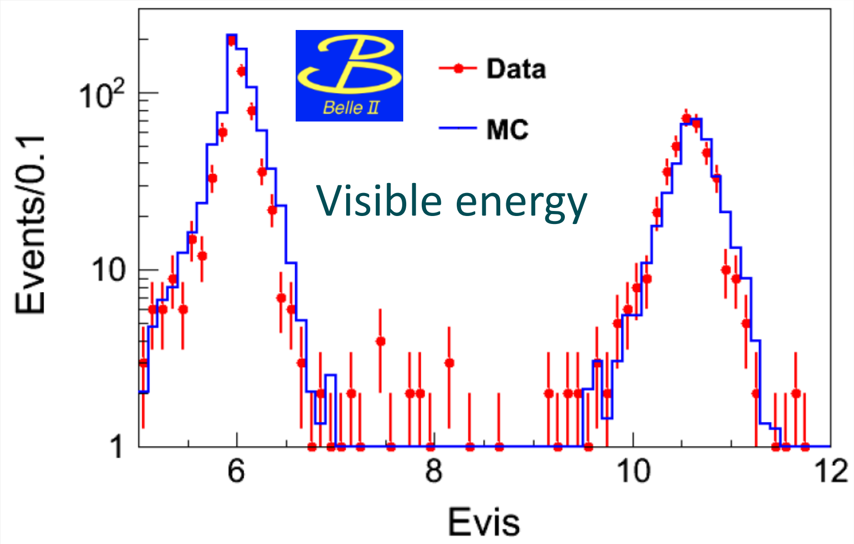
$$F_{BW}(s, M, \Gamma, \Gamma^0_{ee}\times\mathcal{B}_f) = \frac{\sqrt{12\pi\,\Gamma\,\Gamma^0_{ee}\times\mathcal{B}_f}}{s - M^2 + iM\Gamma}\sqrt{\frac{\Gamma_f(s)}{\Gamma_f(M^2)}},$$

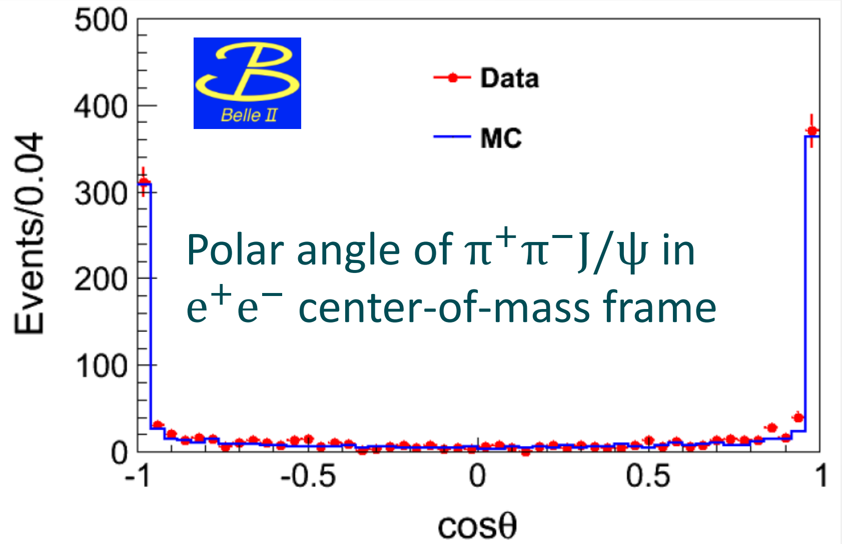
Simultaneous fit to three channels with some common parameters.

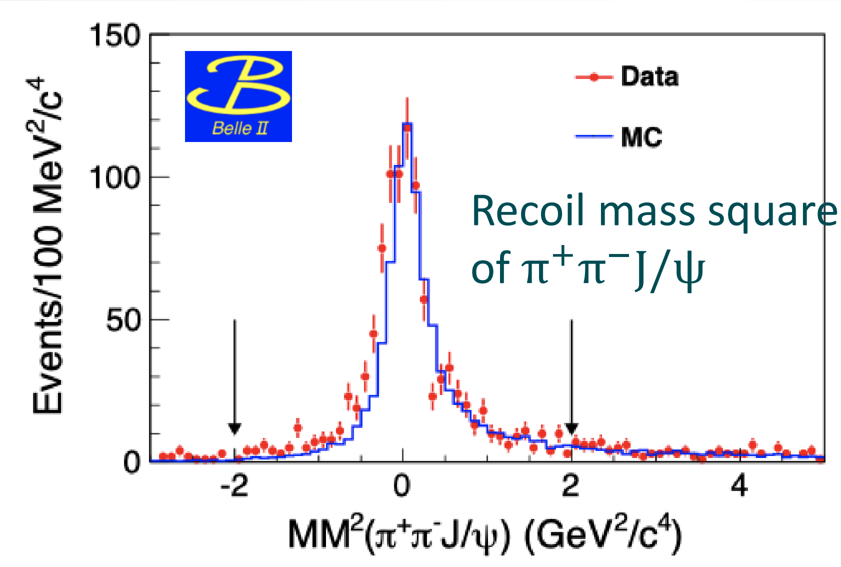
Free parameters: Mass M, width Γ, product of partial width and branching fraction $\Gamma_{ee}B(\pi\pi\Upsilon)$, relative phase ϕ.

ISR characteristics

The distributions from data and signal MC are compatible, which are all consistent with ISR characteristics.







Data sample:
37.8 fb^{-1} in e^+e^- collisions at $\sqrt{s}$ = 10.58 GeV

MC samples:
MC signal samples are generated with Phokhara generator with NLO corrections.