



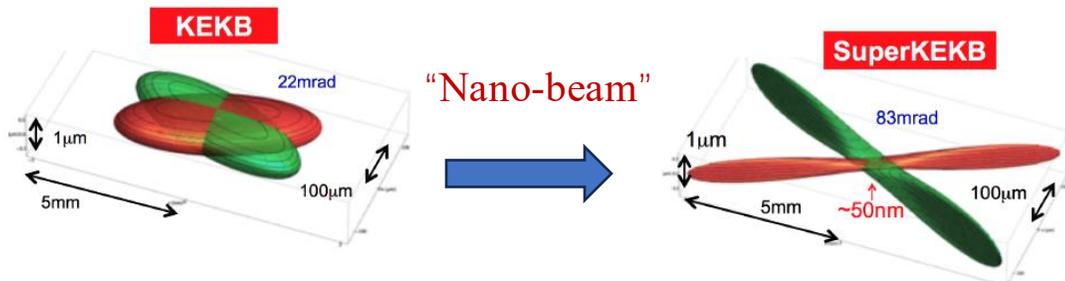
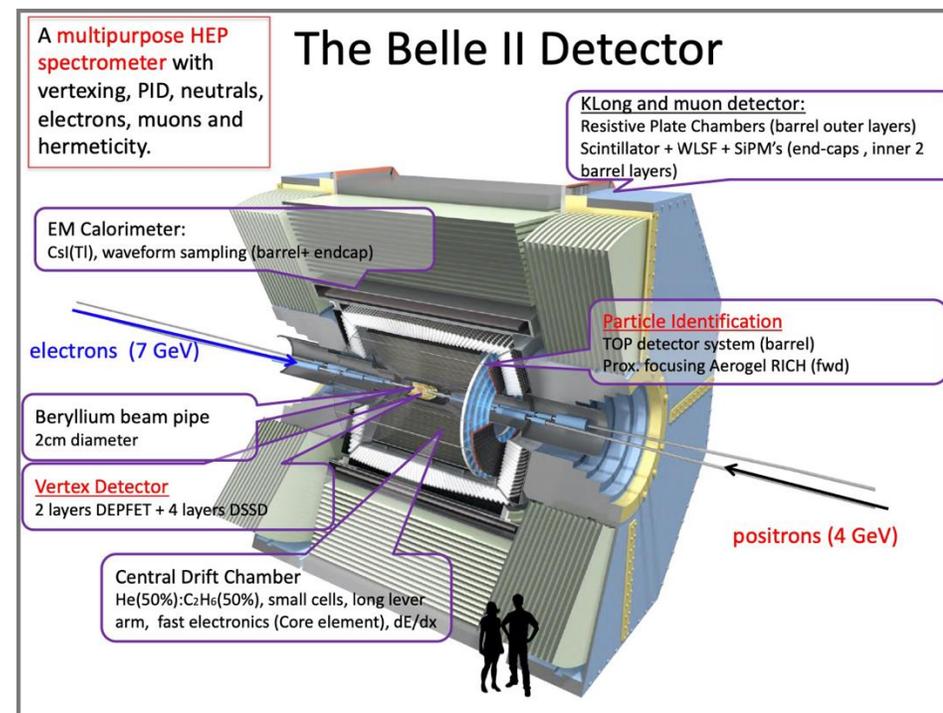
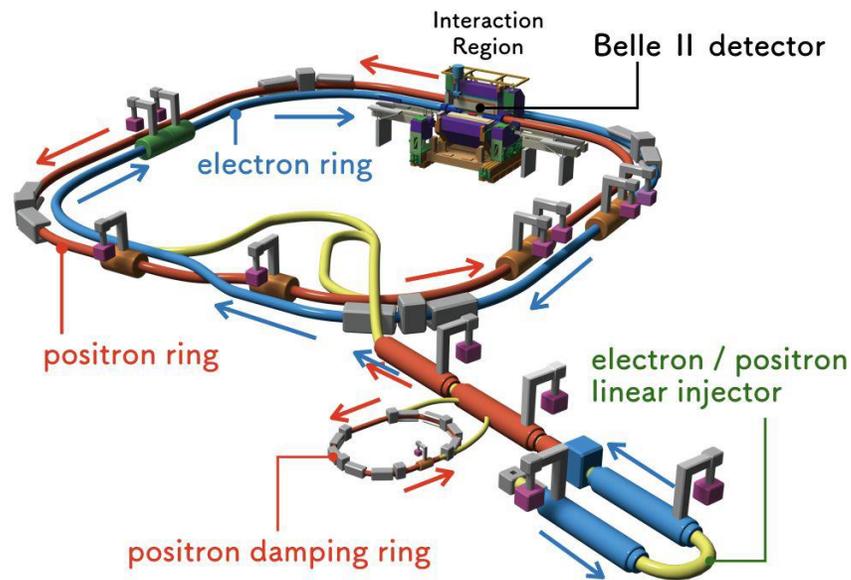
Belle II重味强子物理研究进展

李洋
复旦大学

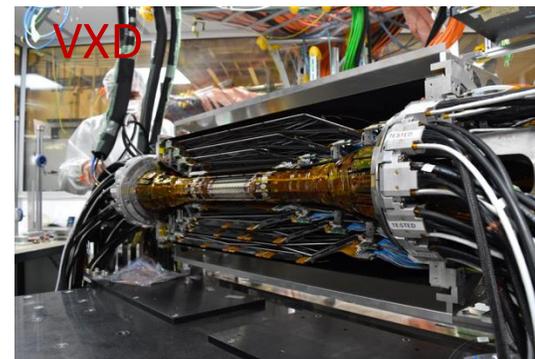
第十届海峡两岸粒子物理和宇宙学研讨会
2026/1/18-1/23 广州

SuperKEKB and Belle II

- SuperKEKB: upgrade of asymmetric e^+e^- collider • Belle II: upgrade of Belle detector at the IP of SuperKEKB.
- KEKB with e^+ (e^-) beam energy at 4.0 (7.0) GeV.



Nano-beam design:
 Beam squeezing: $\times 20$ smaller; Beam current: $\times 2$ larger
 Target peak luminosity: **KEKB $\times 30$**

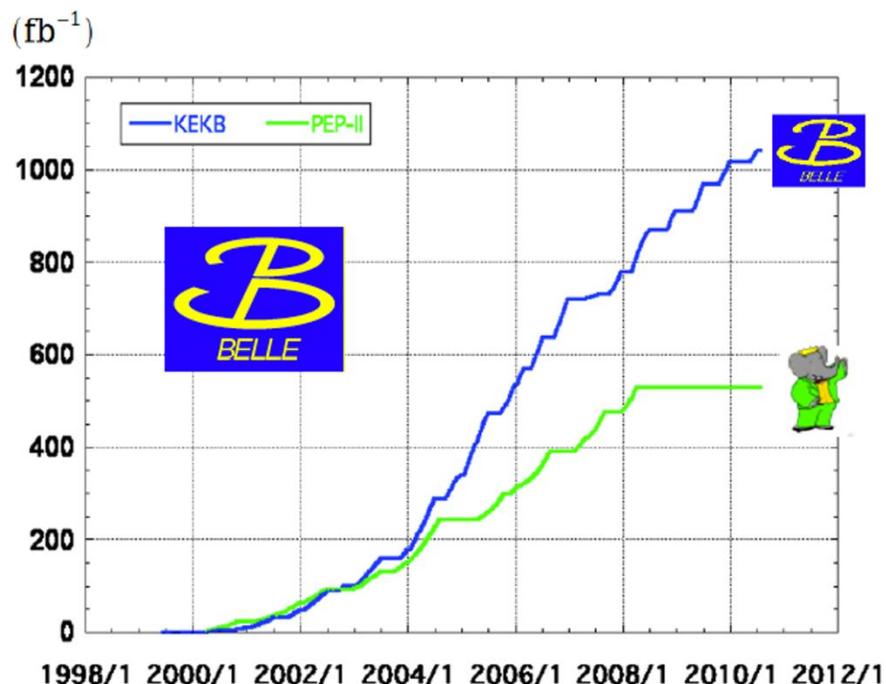


New detectors: vertexing detectors (PXD, SVD), tracking and PID systems (CDC, TOP, ARICH)

Belle (1999 - 2010)

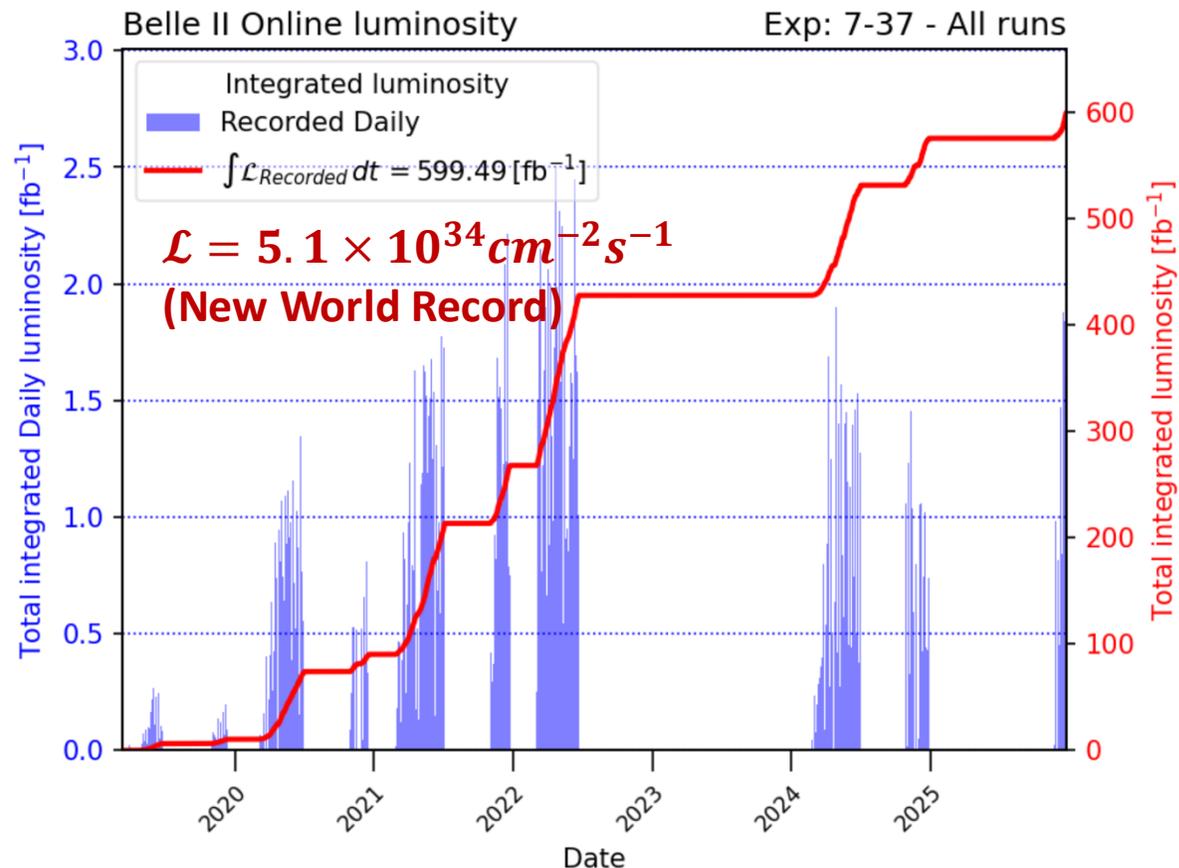
Belle II: RUN-I (2019 - 2022); RUN-II (2024 - now)

Integrated luminosity of B factories



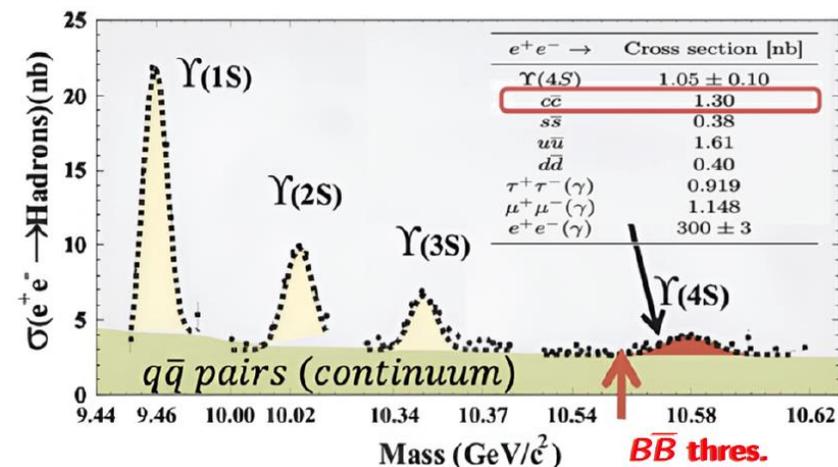
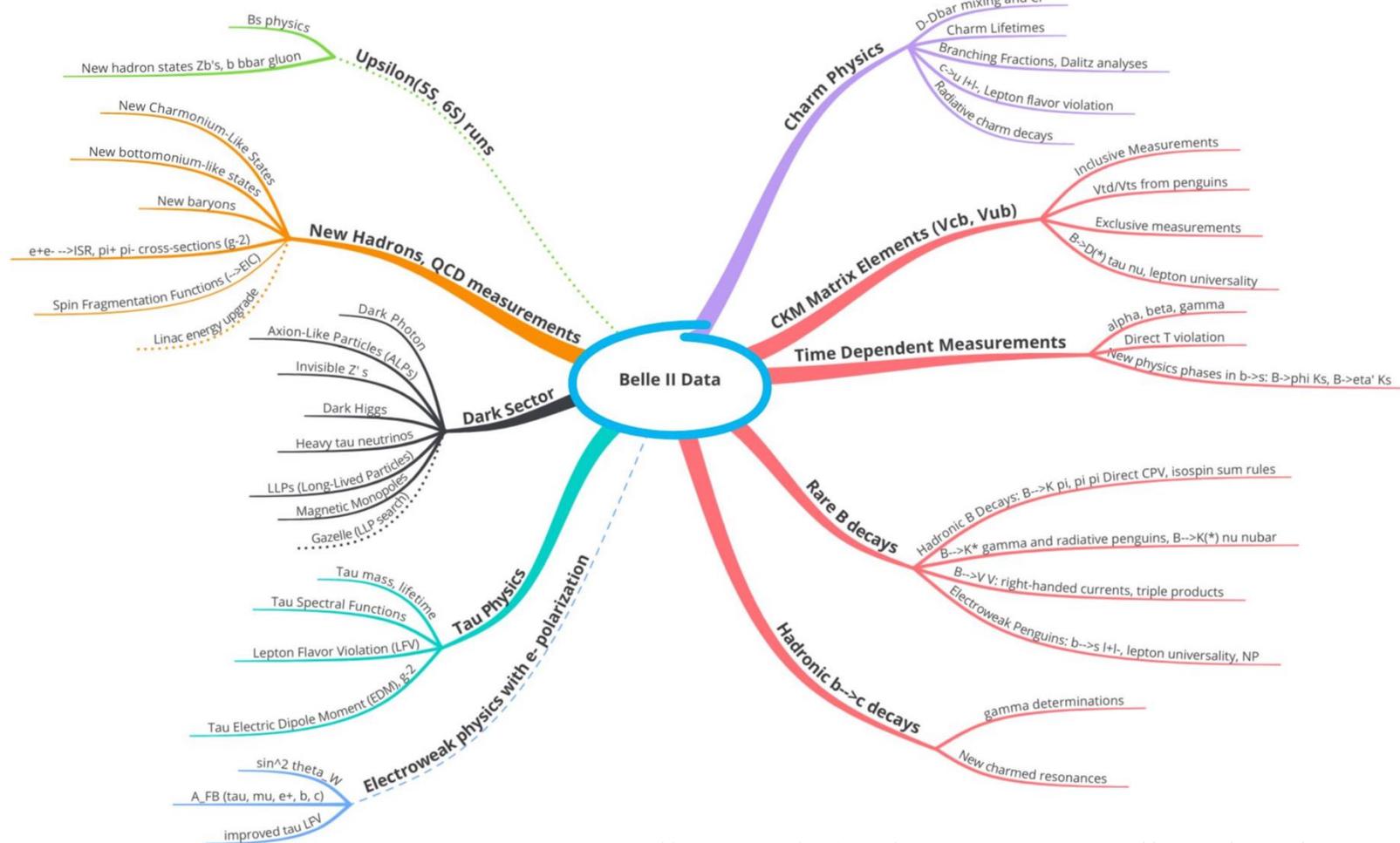
$> 1 \text{ ab}^{-1}$
On resonance:
 $Y(5S): 121 \text{ fb}^{-1}$
 $Y(4S): 711 \text{ fb}^{-1}$
 $Y(3S): 3 \text{ fb}^{-1}$
 $Y(2S): 25 \text{ fb}^{-1}$
 $Y(1S): 6 \text{ fb}^{-1}$
Off reson./scan:
 $\sim 100 \text{ fb}^{-1}$

$\sim 550 \text{ fb}^{-1}$
On resonance:
 $Y(4S): 433 \text{ fb}^{-1}$
 $Y(3S): 30 \text{ fb}^{-1}$
 $Y(2S): 14 \text{ fb}^{-1}$
Off resonance:
 $\sim 54 \text{ fb}^{-1}$



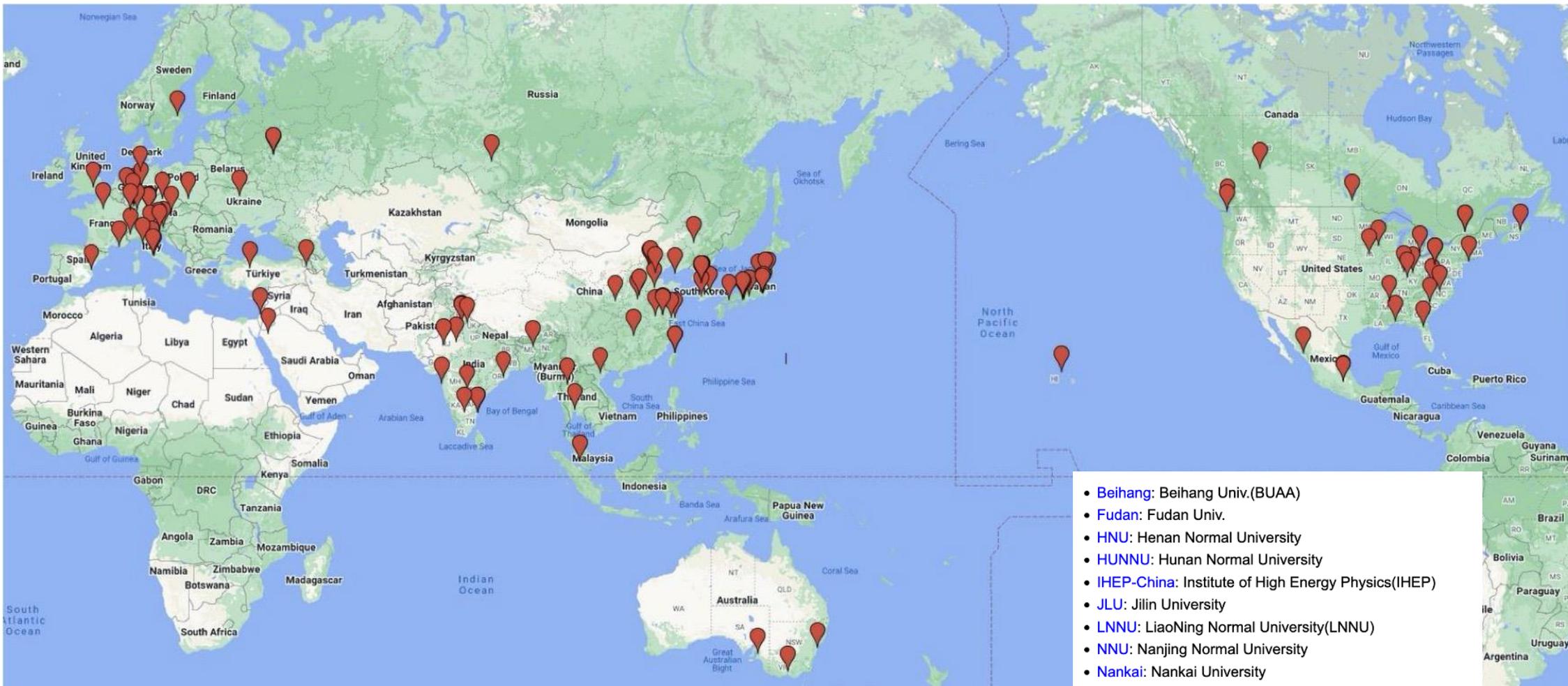
Most data at or near the $Y(4S)$ resonance, and 19.6 fb^{-1} near $Y(10753)$

The Belle II Physics Book [PTEP 2019 (2019) 12, 123C01]



$e^+e^- \rightarrow$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

From [Belle II website homepage](#): Belle II has been designed to make precise measurements of **weak interaction parameters**, study **exotic hadrons**, and search for **new phenomena beyond the Standard Model** of particle physics.



- **Beihang**: Beihang Univ.(BUAA)
- **Fudan**: Fudan Univ.
- **HNU**: Henan Normal University
- **HUNNU**: Hunan Normal University
- **IHEP-China**: Institute of High Energy Physics(IHEP)
- **JLU**: Jilin University
- **LNNU**: LiaoNing Normal University(LNNU)
- **NNU**: Nanjing Normal University
- **Nankai**: Nankai University
- **SEU**: Southeast University
- **Shandong**: Shandong University
- **Soochow**: Soochow University
- **USTC**: Univ. of Science and Technology of China(USTC)
- **XJTU**: Xi'an Jiaotong University
- **ZZU**: Zhengzhou University

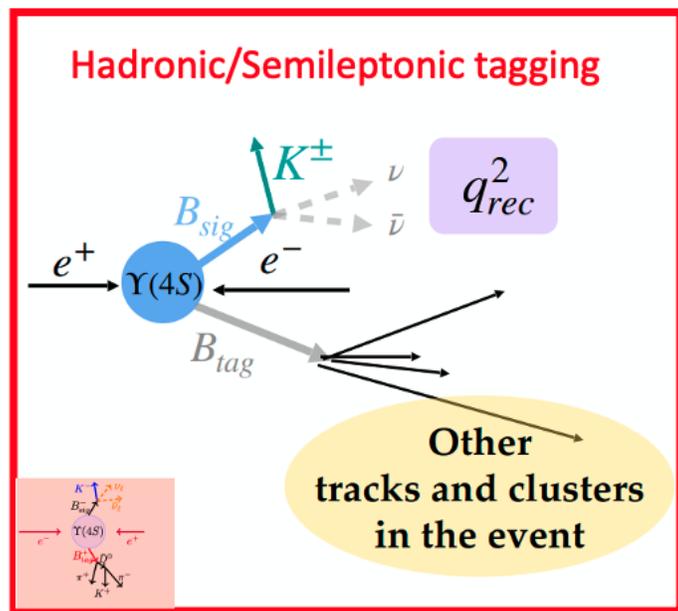
Belle II has now grown to 700+ members from 28 countries/regions.

Chinese Mainland: 15 institutions, 151 members.

Taiwan: 2 institutions (NTU, Fu-Jen), 33 members.

B decays

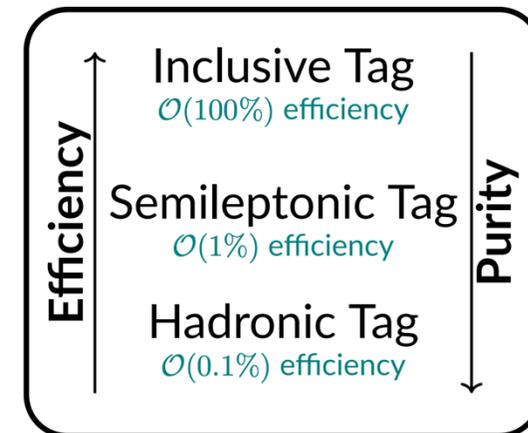
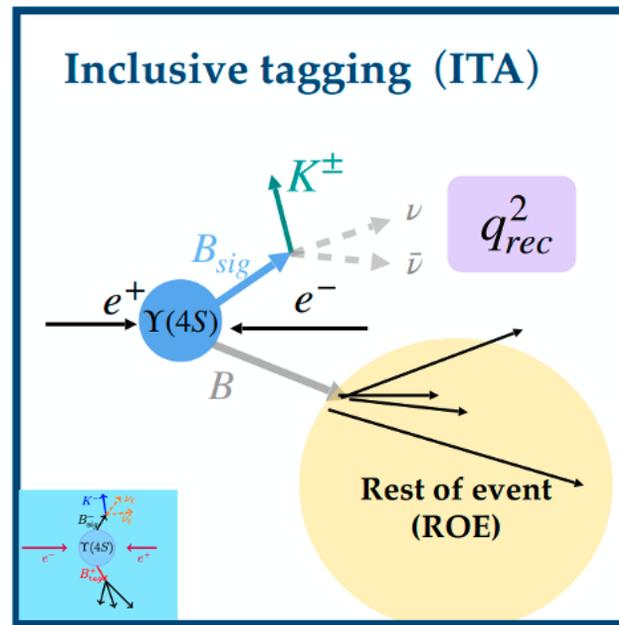
- B decays with missing energy (ν , τ) final states can be reconstructed by tagging the accompanying B meson.



Efficiency

q_{rec}^2 : mass squared of the neutrino pair

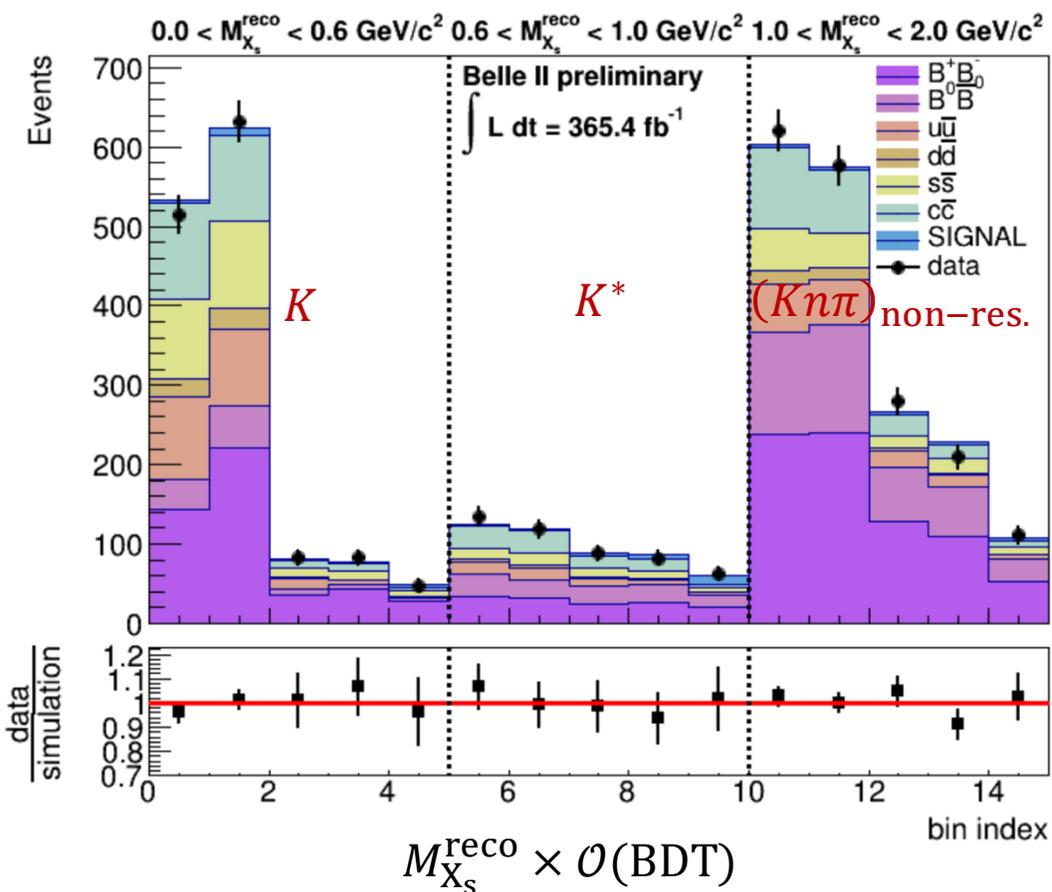
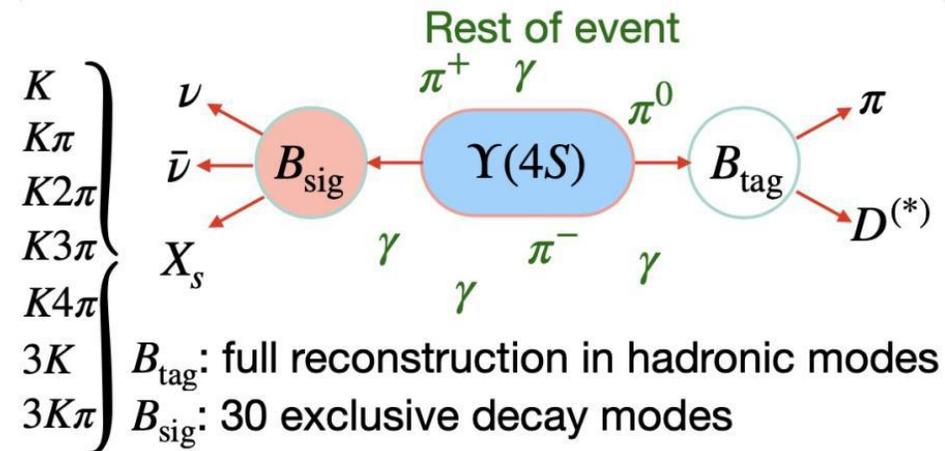
Purity, Resolution



- ✓ **Hadronic/semileptonic tagging:** Reconstruct B_{tag} in low multiplicity, high branching fraction decay modes using Full Event Interpretation (FEI). [Comp. Softw. for Big Science 3 (2019) 6]
- FEI consists of >200 BDTs reconstructing O(10k) decay chains.
- ✓ **Inclusive tagging:** Reconstruct B_{sig} and assign everything else to the rest-of-event (ROE).
- 100% efficiency tagging efficiency, but large backgrounds; add some ML/AI (boosted decision trees or BDTs) to help suppress the large backgrounds.

Search for $B \rightarrow X_s \nu \bar{\nu}$ with hadronic tagging

- Probe flavor changing neutral currents (FCNC) in $b \rightarrow s \nu \bar{\nu}$.
- Complimentary measurement to the exclusive $B \rightarrow K^{(*)} \nu \bar{\nu}$ searches.
- The branching fraction for $B \rightarrow X_s \nu \bar{\nu}$ is cleanly predicted to be $(2.9 \pm 0.3) \times 10^{-5}$ in the SM [JHEP 02, 184 (2015)].



[arXiv: 2511.10980]

[Belle II: $365 \text{ fb}^{-1} \Upsilon(4S)$ data]

M_{X_s} [GeV/ c^2]	ϵ	N_{sig}	\mathcal{B} [10^{-5}]		
			Central value	UL_{obs}	UL_{exp}
* [0, 0.6]	0.26%	10^{+18+18}_{-17-16}	$0.5^{+0.9+0.9}_{-0.8-0.8}$	2.5	2.4
[0.6, 1.0]	0.12%	37^{+27+31}_{-25-26}	$3.8^{+2.8+3.2}_{-2.6-2.7}$	10.1	7.3
[1.0, m_B]	0.06%	33^{+44+63}_{-42-53}	$7.3^{+9.6+13.7}_{-9.3-11.5}$	34.4	27.4

*Compatible with the hadronically-tagged Belle II $B^+ \rightarrow K^+ \nu \bar{\nu}$ result

Full range:

$$\mathcal{B}(B \rightarrow X_s \nu \bar{\nu}) = [8.8^{+8.5}_{-8.2}(\text{stat.})^{+12.6}_{-10.8}(\text{syst.})] \times 10^{-5}$$

$$\mathcal{B}(B \rightarrow X_s \nu \bar{\nu}) < 3.2 \times 10^{-4} \text{ (90\% C.L.)}$$

- In the SM, the $\mathcal{B}(B^+ \rightarrow \mu^+ \nu_\mu)$ is given by

$$\mathcal{B}(B^+ \rightarrow \mu^+ \nu_\mu) = \frac{G_F^2 m_B m_\mu^2}{8\pi} \left[1 - \frac{m_\mu^2}{m_B^2} \right]^2 f_B^2 |V_{ub}|^2 \tau_B$$

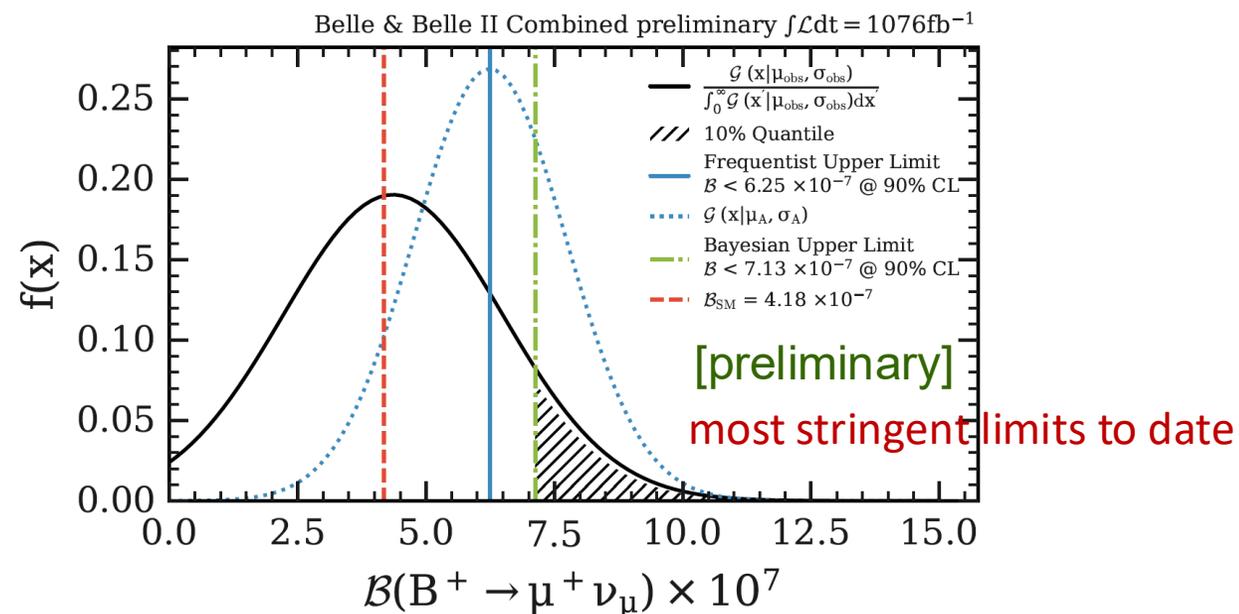
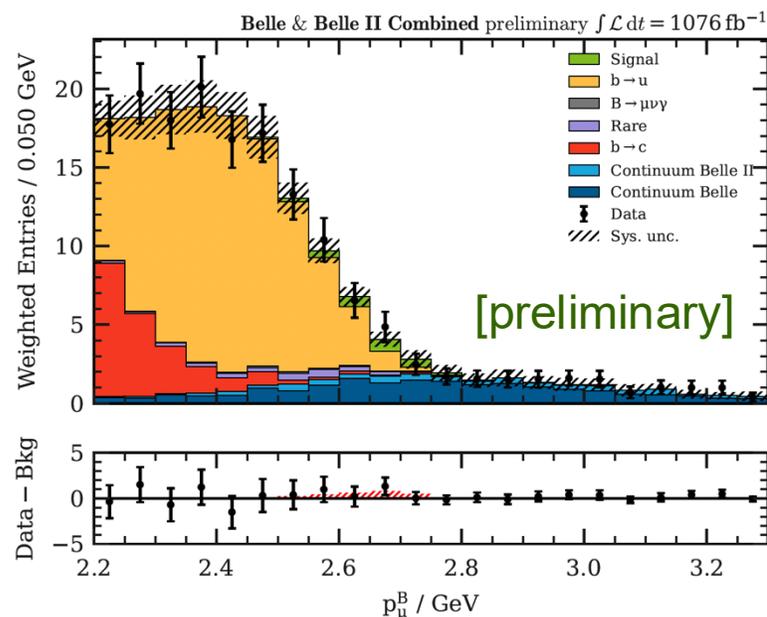
SM predicted: $\mathcal{B}(B^+ \rightarrow \mu^+ \nu_\mu) = (4.18 \pm 0.44) \times 10^{-7}$

Belle: $\mathcal{B}(B^+ \rightarrow \mu^+ \nu_\mu) = (5.3 \pm 2.0 \pm 0.9) \times 10^{-7} (2.8\sigma)$

- The existence of a charged Higgs boson could significantly modify the branching fraction.

- Using combined Belle and Belle II data ($1.1 \text{ ab}^{-1} \Upsilon(4S)$ data) + inclusive B tagging.

[To be submitted to PRD]



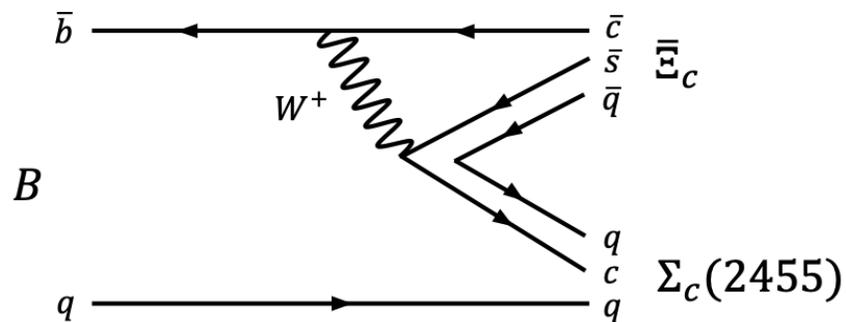
$$\mathcal{B}(B^+ \rightarrow \mu^+ \nu_\mu) = (4.36 \pm 1.89 \pm 1.01) \times 10^{-7} (2.35\sigma)$$

$$|V_{ub}| = (3.90_{-0.96-0.49}^{+0.77+0.43} \pm 0.03) \times 10^{-3}$$

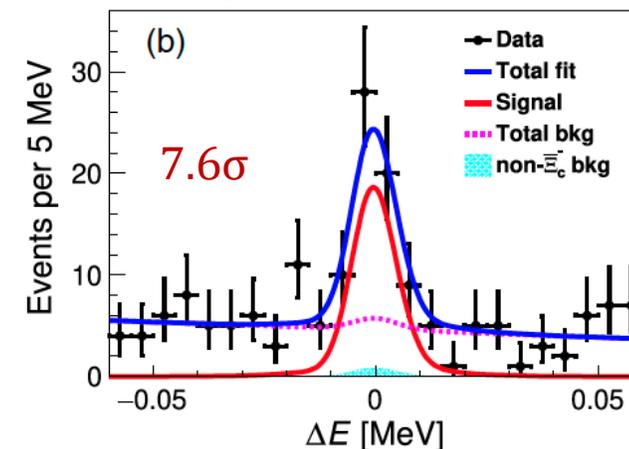
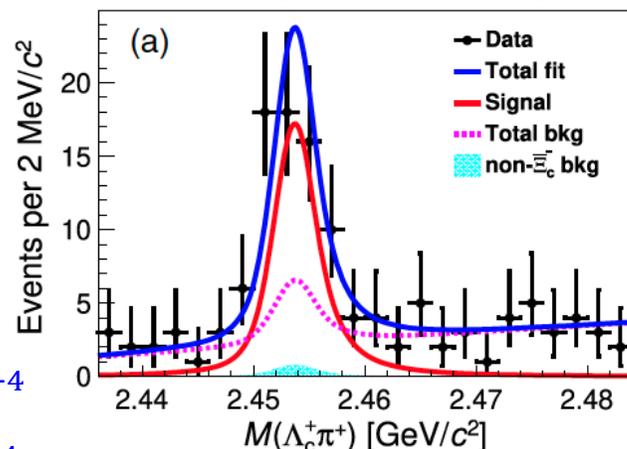
Consistent with recent excl. and incl. measurements

[PRD 112 L051101 (2025)]

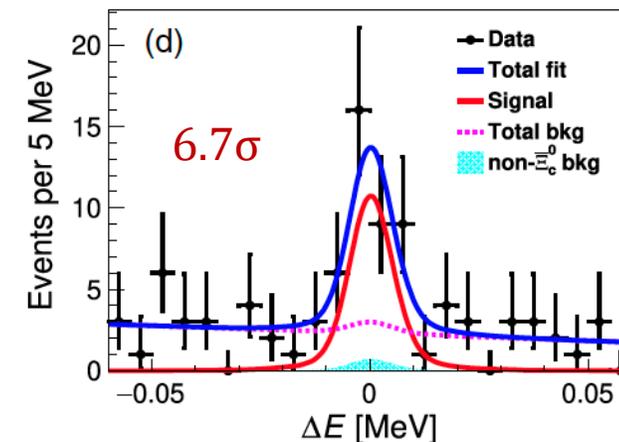
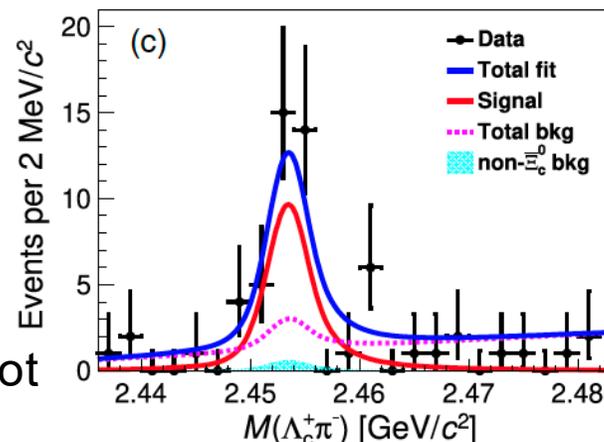
- The decays $B \rightarrow \Sigma_c(2455)\bar{\Xi}_c$ proceed through a purely internal W -emission.
- We report the first observation of $B^+ \rightarrow \Sigma_c(2455)^{++}\bar{\Xi}_c^-$ and $B^0 \rightarrow \Sigma_c(2455)^0\bar{\Xi}_c^0$ decays.



$B^+ \rightarrow \Sigma_c(2455)^{++}\bar{\Xi}_c^-$ @ Belle + Belle II [1.1 ab^{-1} $\Upsilon(4S)$ data]



$B^0 \rightarrow \Sigma_c(2455)^0\bar{\Xi}_c^0$ @ Belle + Belle II [1.1 ab^{-1} $\Upsilon(4S)$ data]



$$\mathcal{B}(B^+ \rightarrow \Sigma_c(2455)^{++}\bar{\Xi}_c^-) = (5.81 \pm 1.01 \pm 0.37_{-1.55}^{+2.50}) \times 10^{-4}$$

$$\mathcal{B}(B^0 \rightarrow \Sigma_c(2455)^0\bar{\Xi}_c^0) = (5.20 \pm 1.08 \pm 0.38_{-0.67}^{+0.79}) \times 10^{-4}$$

- $\mathcal{B}(B \rightarrow \Sigma_c(2455)\bar{\Xi}_c)$ are larger than those of $B \rightarrow \bar{\Sigma}_c p$:

◆ Similar size of CKM matrix elements:

$$V_{bc} * V_{cs} \sim V_{bc} * V_{ud}$$

◆ Smaller phase-space

- One possible mechanism is that hard gluons are not necessarily required for double charm decays.

[Int. J. Mod. Phys. A 21(2006) 4209]

Charm

- Charm CPV effect is very small (10^{-3} level or smaller); a sensitive probe for New Physics.
- 2019, charm CPV observation by LHCb: $A_{CP}(D^0 \rightarrow K^+K^-) - A_{CP}(D^0 \rightarrow \pi^+\pi^-) = (-1.54 \pm 0.29) \times 10^{-3}$ (5.3σ). [PRL 122, 211803 (2019)]
- 2023, a 3.8σ CPV in D meson observed by LHCb: $A_{CP}^{dir}(D^0 \rightarrow \pi^+\pi^-) = (2.32 \pm 0.61) \times 10^{-3}$. [PRL 131, 091802 (2023)]
- The following sum-rule for CPV in $D \rightarrow \pi\pi$ decays; it helps to determine the source of CPV :

$$R = \frac{A_{CP}^{dir}(D^0 \rightarrow \pi^+\pi^-)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{+-}} \left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} - \frac{2}{3} \frac{\mathcal{B}_{+0}}{\tau_{D^+}} \right)} + \frac{A_{CP}^{dir}(D^0 \rightarrow \pi^0\pi^0)}{1 + \frac{\tau_{D^0}}{\mathcal{B}_{00}} \left(\frac{\mathcal{B}_{+-}}{\tau_{D^0}} - \frac{2}{3} \frac{\mathcal{B}_{+0}}{\tau_{D^+}} \right)} + \frac{A_{CP}^{dir}(D^+ \rightarrow \pi^+\pi^0)}{1 - \frac{3}{2} \frac{\tau_{D^+}}{\mathcal{B}_{+0}} \left(\frac{\mathcal{B}_{00}}{\tau_{D^0}} + \frac{\mathcal{B}_{+-}}{\tau_{D^0}} \right)}$$

if $R \neq 0$, CPV from $\Delta I = 1/2$ amplitude; if $R = 0$ and at least one $A_{CP}^{dir} \neq 0$, CPV from a beyond-SM $\Delta I = 3/2$ amplitude.

[EPJC 83, 279 (2023); PRD 107, 052008 (2023)]

- In SM, no direct CPV is expected in the decay $D^+ \rightarrow \pi^+\pi^0$. The $\pi^+\pi^0$ final state has isospin $I = 2$ and cannot be reached from the $I = 1/2$ initial state via a $\Delta I = 1/2$ transition.
- The R value is measured to be $R = (0.9 \pm 3.1) \times 10^{-3}$, where the uncertainty is dominated by the asymmetry of the $\pi^0\pi^0$ final state.

- The D^0 decays are required to originate from the flavor-conserving $D^{*+} \rightarrow D^0 \pi^+$ decay.

- Raw asymmetry of the tagged $D^0 \rightarrow \pi^0 \pi^0$ sample:

$$A_{raw}^{\pi^0 \pi^0} = A_{CP}(D^0 \rightarrow \pi^0 \pi^0) + A_{prod}^{D^{*+}} + A_{\epsilon}^{\pi_s}$$

- $A_{prod}^{D^{*+}}$: being an odd function of $\cos\theta^*$, i.e. the cosine of the charmed-meson polar angle in e^+e^- c.m.s
- $A_{\epsilon}^{\pi_s}$: using tagged and untagged $D^0 \rightarrow K^- \pi^+$ samples

- Result at Belle II (428 fb^{-1}): [PRD 112, 012006 (2025)]

$$A_{CP}(D^0 \rightarrow \pi^0 \pi^0) = (0.30 \pm 0.72 \pm 0.20)\%$$

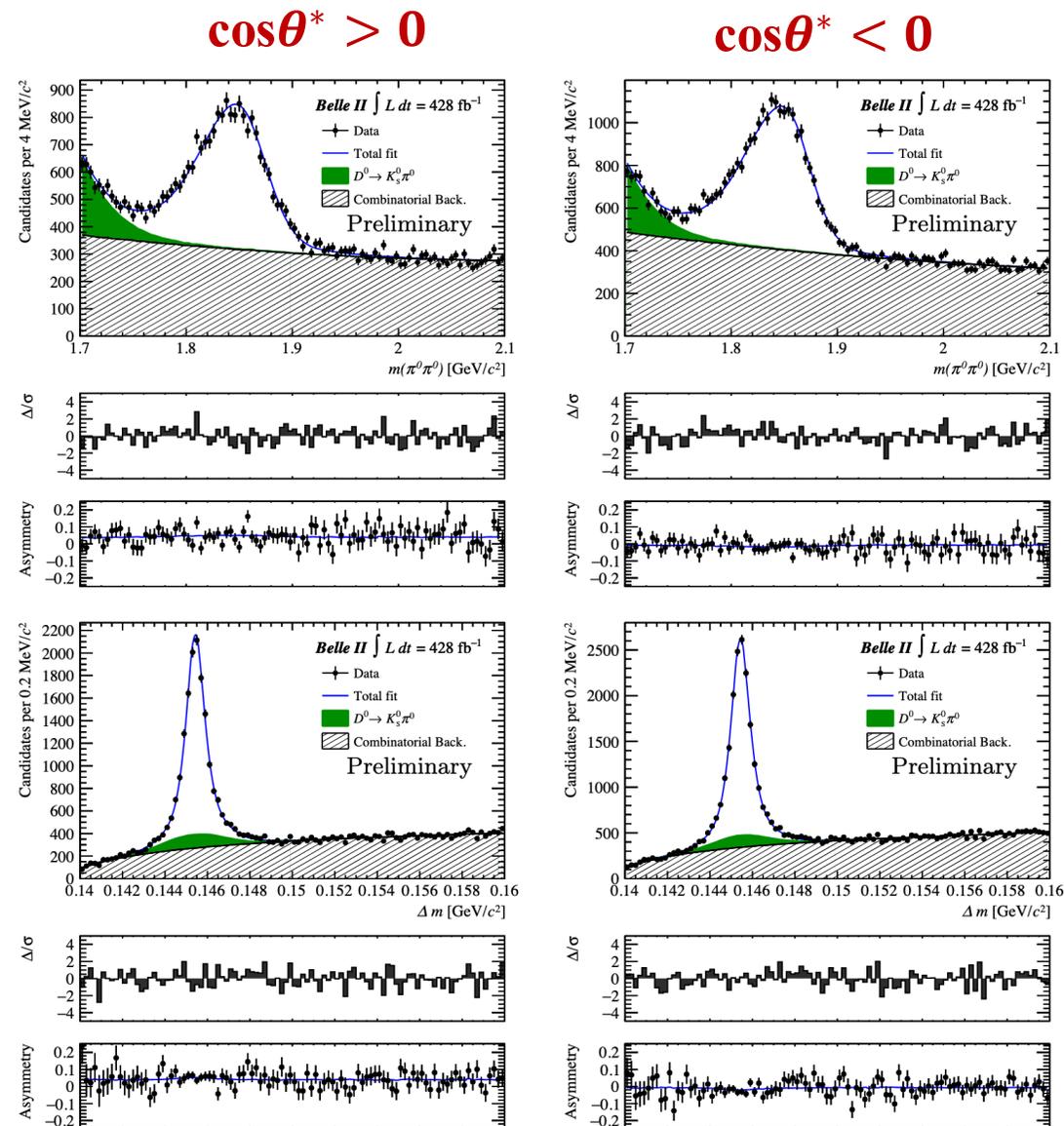
- Consistent with CP symmetry and with Belle (980 fb^{-1}): $(-0.03 \pm 0.64 \pm 0.10)\%$. [PRL 112, 211601 (2014)]

- 15% less precise than Belle, but with < 50% datasets.

- Using our result, $A_{CP}^{\pi^+ \pi^-}$ (LHCb), W.A. $A_{CP}^{\pi^+ \pi^0}$, ΔY (LHCb), W.A. B and D lifetimes,

$$R = (1.5 \pm 2.5) \times 10^{-3}$$

20% improved precision



$A_{CP}(D^+ \rightarrow \pi^+ \pi^0)$

[PRD 97, L031101 (2025)]

- In SM, the no CPV is expected in $D^+ \rightarrow \pi^+ \pi^0$ decay.
- Utilizing split sample: D^+ from $D^{*+} \rightarrow D^+ \pi^0$ decay or not.
- $D^+ \rightarrow K_S^0 \pi^+$ to eliminate common asymmetry sources: A_{prod}^D and A_{ϵ}^{π} .

$$A_{CP}^{\pi^+ \pi^0} = A_{\text{raw}}^{\pi^+ \pi^0} - A_{\text{raw}}^{K_S^0 \pi^+} + A_{\bar{K}^0}$$

- We obtain:

$$A_{CP} = (-3.9 \pm 1.8 \pm 0.2)\%$$

For D^{*+} – tagged sample

$$A_{CP} = (-1.1 \pm 1.0 \pm 0.1)\%$$

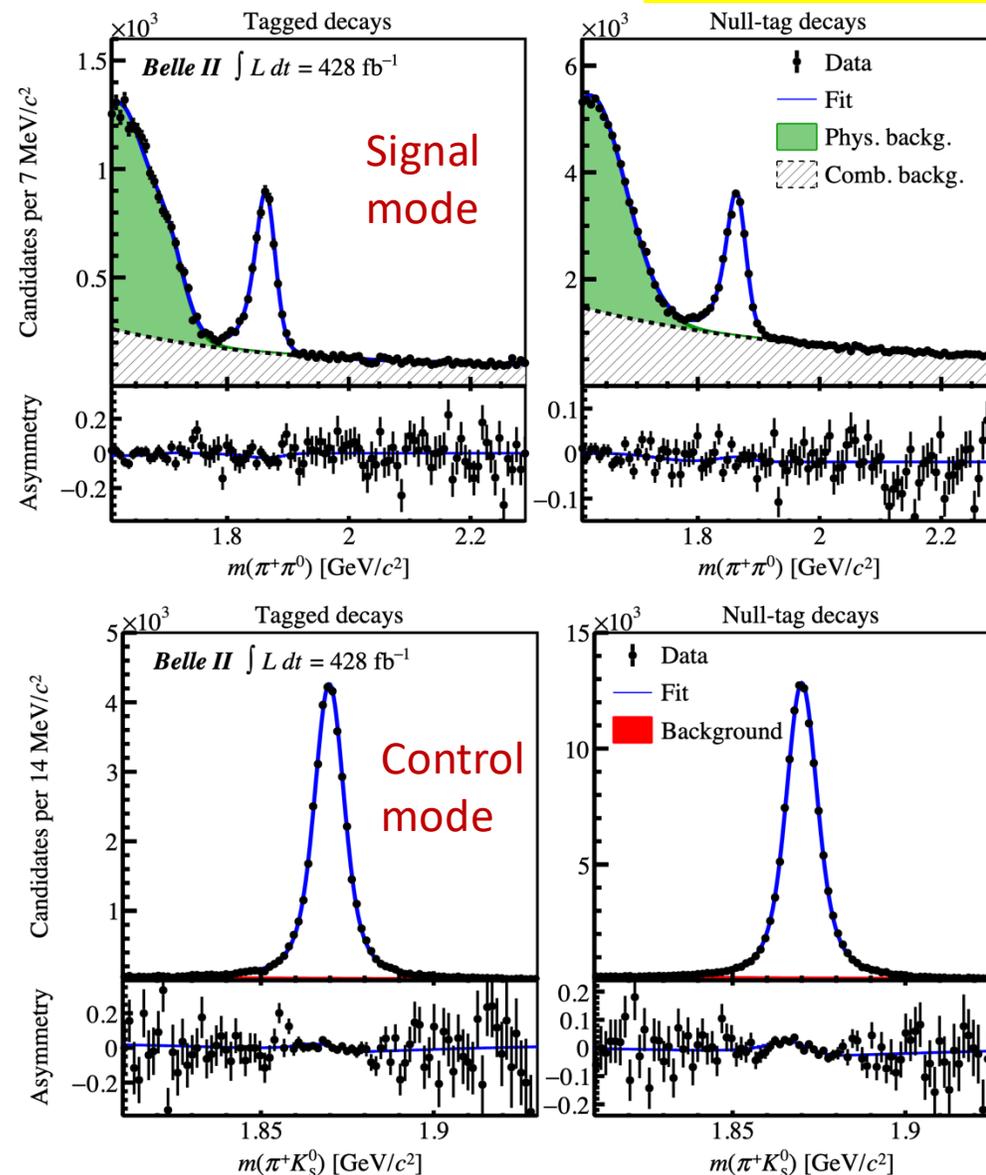
For null–tag sample

- Combined result:

$$A_{CP} = (-1.8 \pm 0.9 \pm 0.1)\%$$

30% improved precision compared to Belle (921 fb^{-1}):
 $(+2.31 \pm 1.24 \pm 0.23)\%$

[PRD 97, 011101 (2018)]



[arXiv: 2509.25765]

- First measurement of A_{CP} in SCS three-body charged baryon decays.

$$A_{CP}(X_c^+ \rightarrow f^+) \equiv \frac{\Gamma(X_c^+ \rightarrow f^+) - \Gamma(\bar{X}_c^- \rightarrow \bar{f}^-)}{\Gamma(X_c^+ \rightarrow f^+) + \Gamma(\bar{X}_c^- \rightarrow \bar{f}^-)}$$

$$A_{raw}(X_c^+ \rightarrow f^+) = A_{CP}(X_c^+ \rightarrow f^+) + A_p^{X_c^+} + A_\varepsilon^{f^+}$$

Control sample:

$$\Xi_c^+ \rightarrow \Sigma^+ h^+ h^-: \Lambda_c^+ \rightarrow p h^+ h^-$$

$$\Lambda_c^+ \rightarrow p h^+ h^-: \Lambda_c^+ \rightarrow p \pi^+ K^-, D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$$

- Measured A_{CP} :

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ K^+ K^-) = (3.7 \pm 6.6 \pm 0.6)\%$$

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-) = (9.5 \pm 6.8 \pm 0.5)\%$$

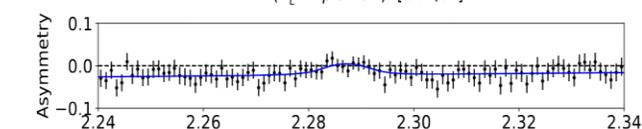
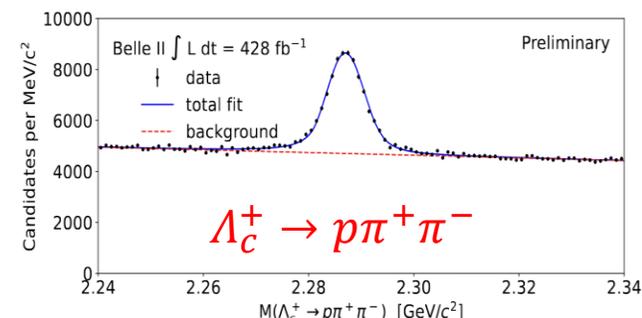
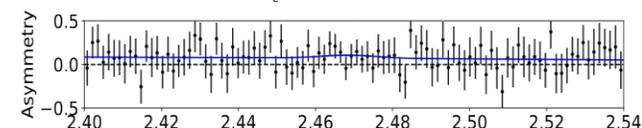
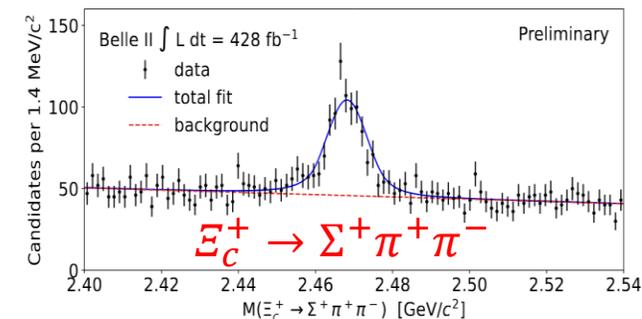
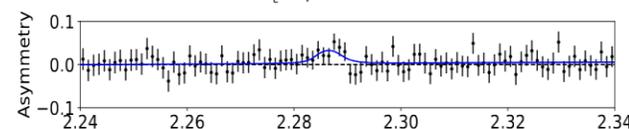
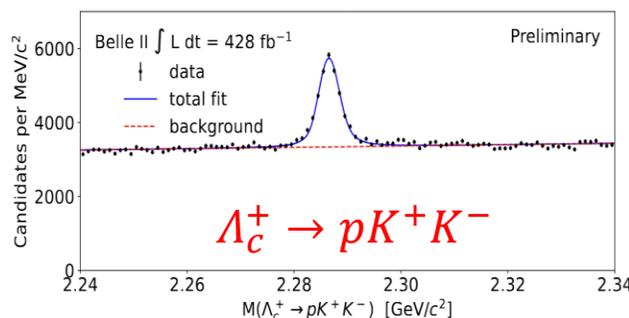
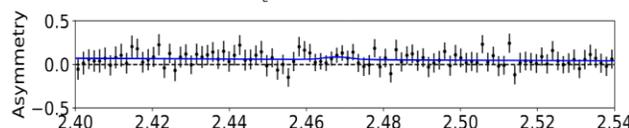
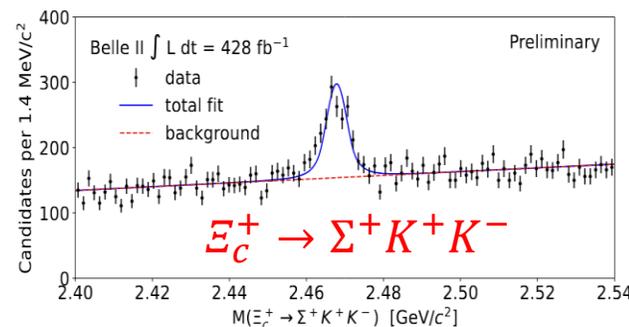
$$A_{CP}(\Lambda_c^+ \rightarrow p K^+ K^-) = (3.9 \pm 1.7 \pm 0.7)\%$$

$$A_{CP}(\Lambda_c^+ \rightarrow p \pi^+ \pi^-) = (0.3 \pm 1.0 \pm 0.2)\%$$

- Test U-spin sum rules:

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ \pi^+ \pi^-) + A_{CP}(\Lambda_c^+ \rightarrow p K^+ K^-) = (13.4 \pm 7.0 \pm 0.9)\%$$

$$A_{CP}(\Xi_c^+ \rightarrow \Sigma^+ K^+ K^-) + A_{CP}(\Lambda_c^+ \rightarrow p \pi^+ \pi^-) = (4.0 \pm 6.6 \pm 0.7)\%$$

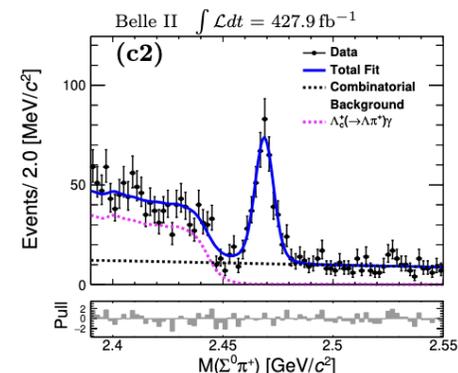
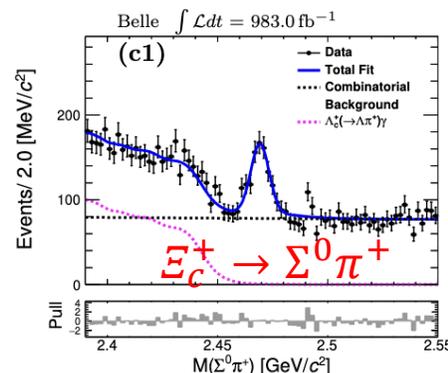
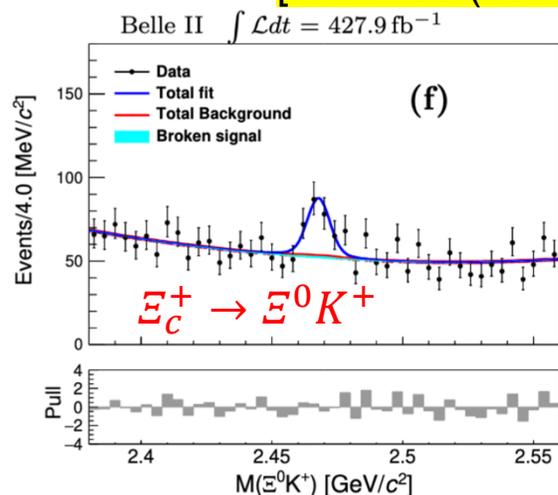
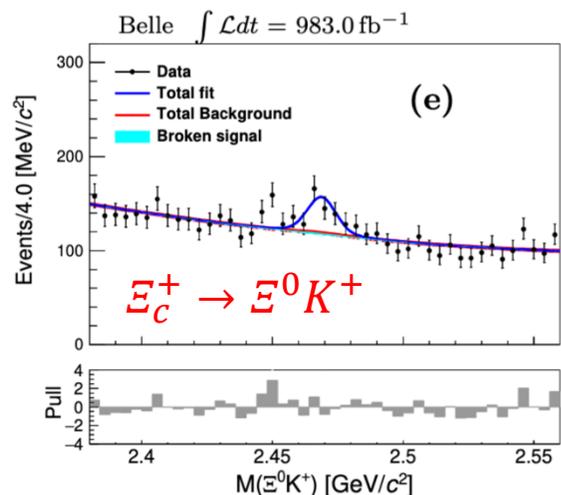
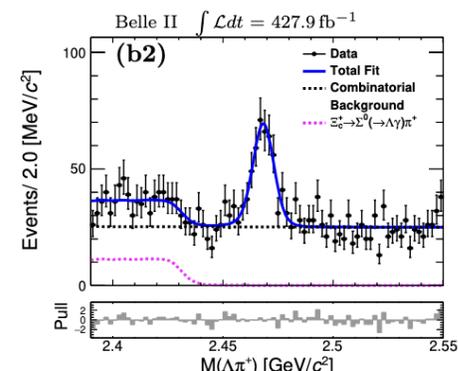
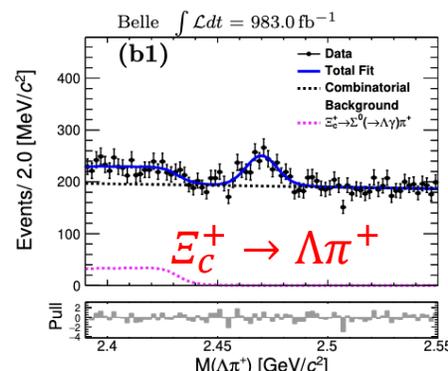
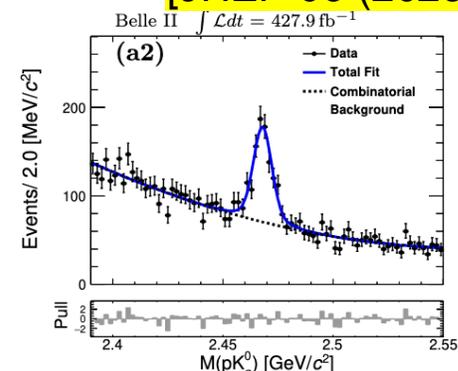
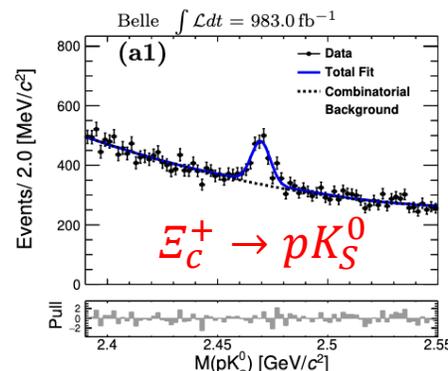
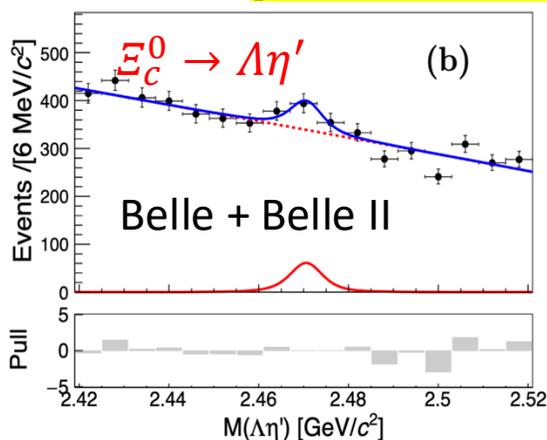
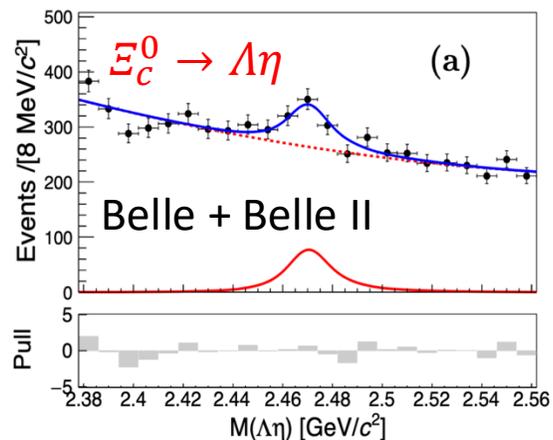


[JHEP 03 (2025) 061]

[arXiv: 2510. 20882]

[JHEP 08 (2025) 195]

- Using combined Belle and Belle II data (1.4 ab^{-1}), many two-body hadronic decays of Ξ_c^0 and Ξ_c^+ are measured.



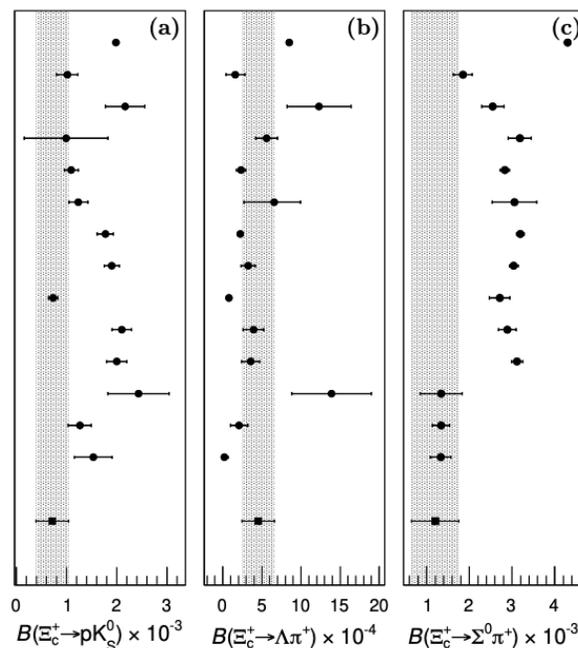
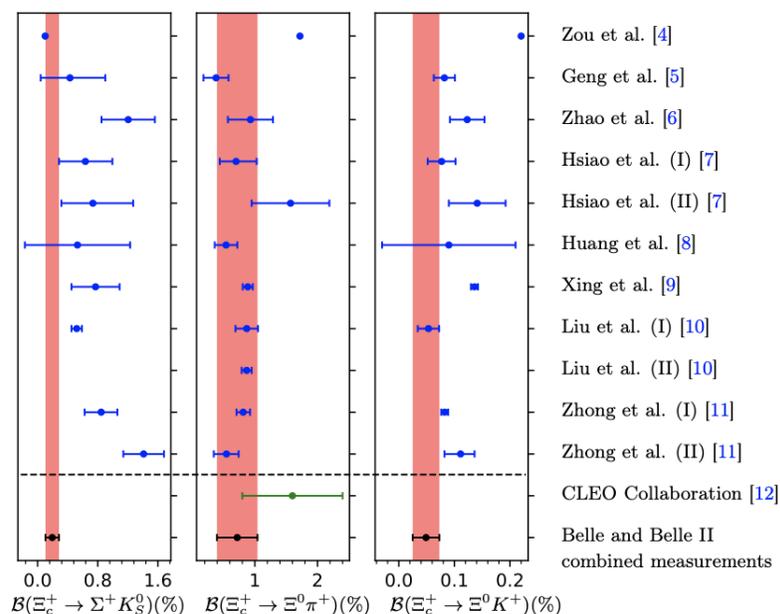
First or most precise measurements of branching fractions!

- These measurements serve as experimental inputs to constrain and test the quark model, the pole model (Pole), current algebra (CA), and SU(3) flavor symmetry.

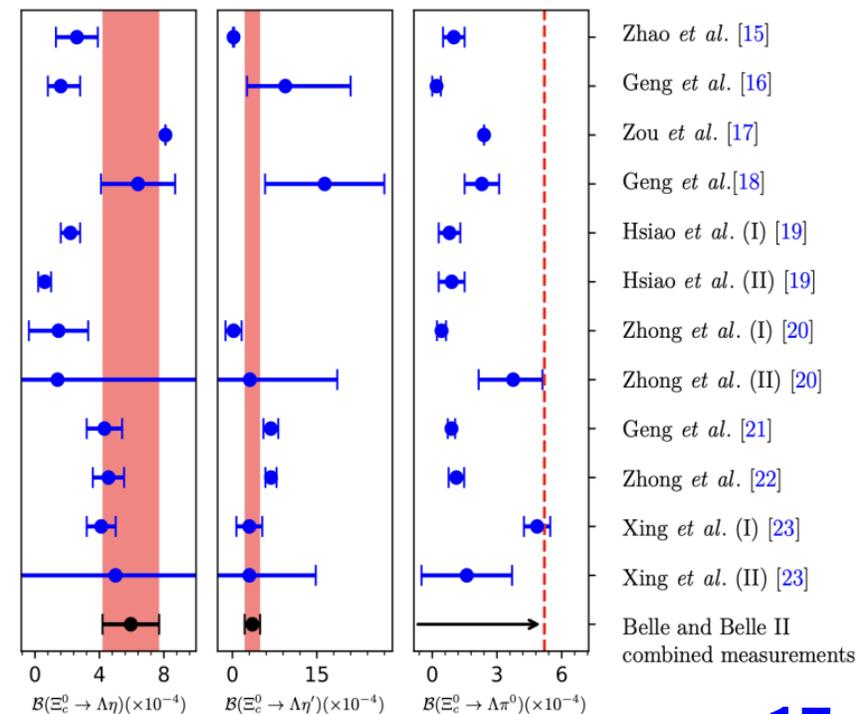
JHEP 08 (2025) 195

JHEP 03 (2025) 061

arXiv: 2510.20882



- Zou et al. [12]
 Geng et al. [13]
 Geng et al. [14]
 Huang et al. [15]
 Zhong et al. (I) [16]
 Zhong et al. (II) [16]
 Xing et al. [17]
 Geng et al. [18]
 Liu [19]
 Zhong et al. (I) [20]
 Zhong et al. (II) [20]
 Zhao et al. [21]
 Hsiao et al. (I) [22]
 Hsiao et al. (II) [22]
 Belle and Belle II combined measurement



Next steps:

- Explore three-body decays;
- Amplitude analyses to search for new intermediate states and identify J^P .

Exotic states

First observation of $D_{S0}^*(2317)^+ \rightarrow D_S^{*+} \gamma$

- The $D_{S0}^*(2317)^+ \rightarrow D_S^+ \pi^0$ was first observed by Babar in 2003. [PRL 90, 242001 (2003)].

$D_{S0}^*(2317)^\pm$ DECAY MODES

$D_{S0}^*(2317)^\pm$ modes are charge conjugates of modes below.

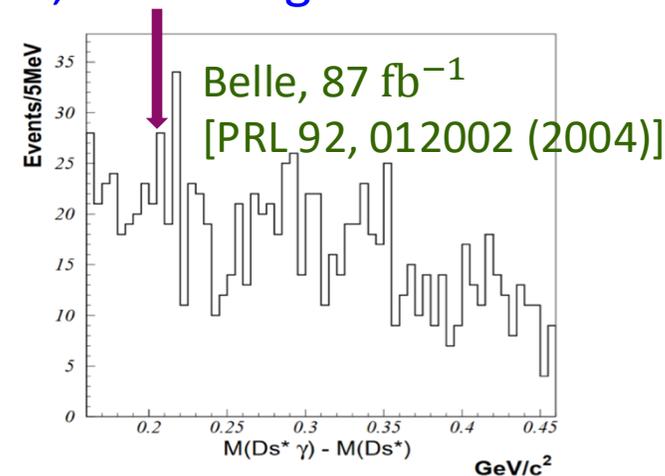
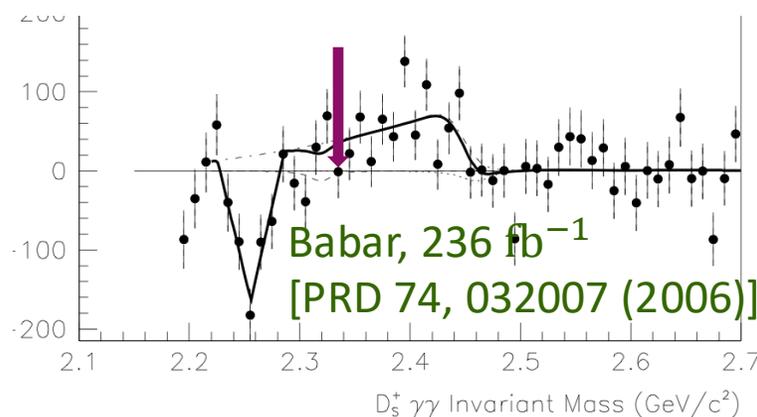
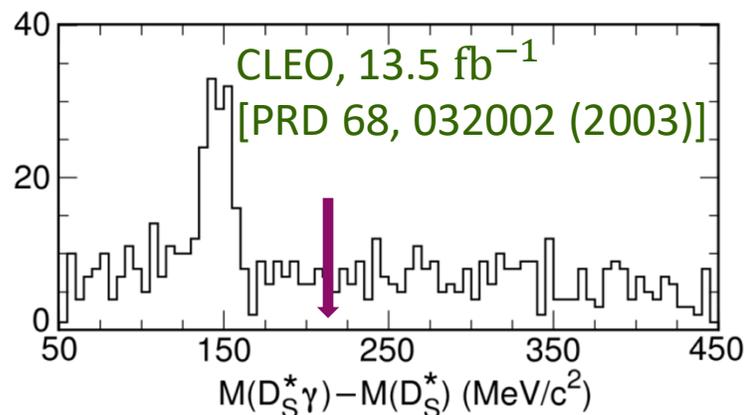
Mode	Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	$P(\text{MeV}/c)$
Γ_1 $D_S^+ \pi^0$	$(100^{+0}_{-20})\%$		298
Γ_2 $D_S^+ \gamma$	<5 %	CL=90%	323
Γ_3 $D_S^*(2112)^+ \gamma$	<6 %	CL=90%	
Γ_4 $D_S^+ \gamma \gamma$	<18 %	CL=95%	323
Γ_5 $D_S^*(2112)^+ \pi^0$	<11 %	CL=90%	
Γ_6 $D_S^+ \pi^+ \pi^-$	< 4×10^{-3}	CL=90%	194
Γ_7 $D_S^+ \pi^0 \pi^0$	not seen		205

Mass of $D_{S0}^*(2317)^+$ is much lower than the quark model predictions of the lowest $c\bar{s}$ mesons with $J^P = 0^+$

- Modifying the $c\bar{s}$ quark model
- D^*K hadronic molecule
- Compact tetraquarks
- Chiral partners of the ground states D_S^*

Partial decay widths:
unique in discriminating between various models

- The $D_{S0}^*(2317)^+ \rightarrow D_S^{*+} \gamma$ was searched for by CLEO, Belle, and Babar, but no signals were found.



First observation of $D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma$

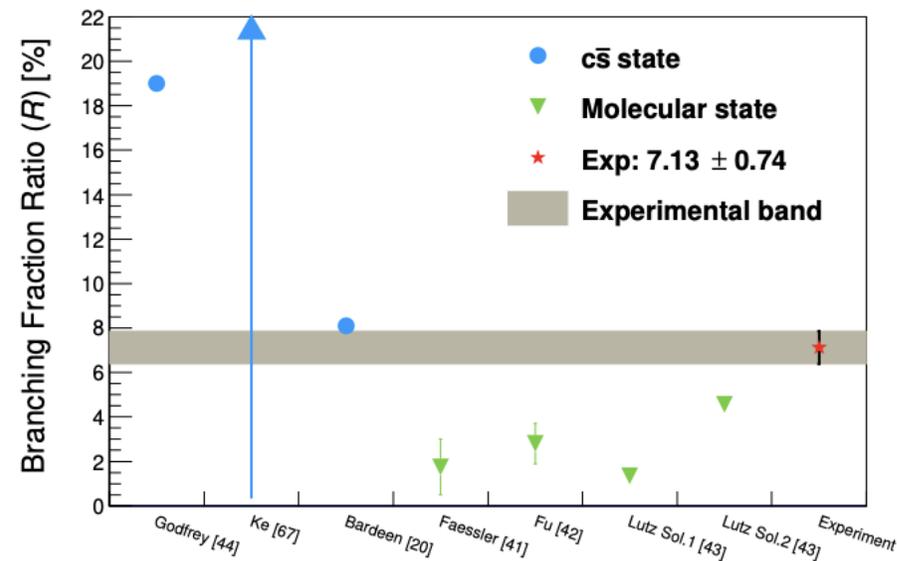
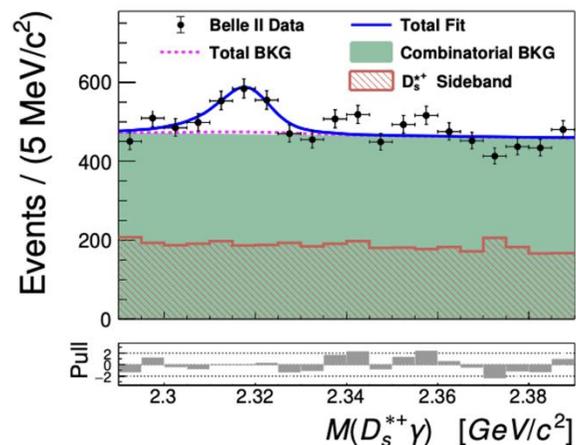
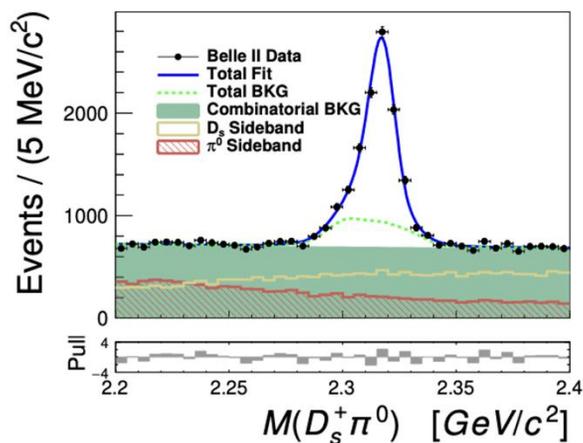
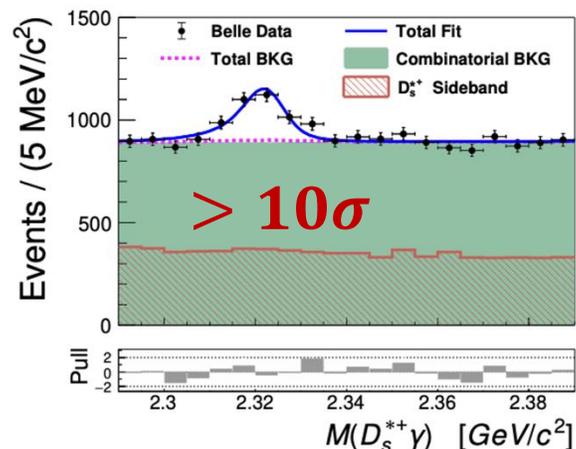
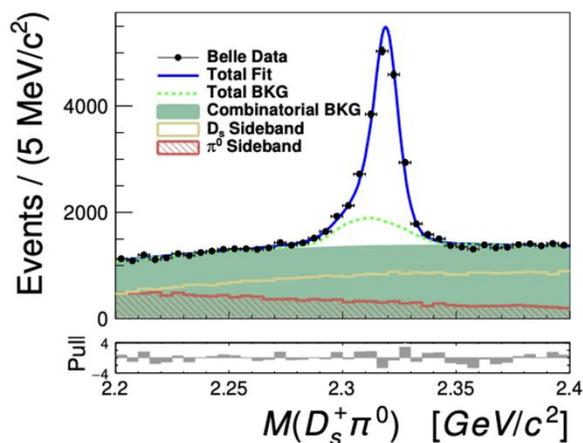
[arXiv: 2510.27174]

Using all Belle data (983 fb^{-1}) and Belle II data (427 fb^{-1})

- Target: $D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma$
- Control channel: $D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0$ [$B = (100_{-20}^{+0})\%$]

$$\mathcal{R} = \frac{\mathcal{B}(D_{s0}^*(2317)^+ \rightarrow D_s^{*+} \gamma)}{\mathcal{B}(D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0)}$$

$$= [7.14 \pm 0.70(\text{stat.}) \pm 0.23(\text{syst.})]\%$$



$D_{s0}^*(2317)^+$ could be the mixture state of pure $c\bar{s}$ state and molecular state.

Advantages of initial-state radiation (ISR):

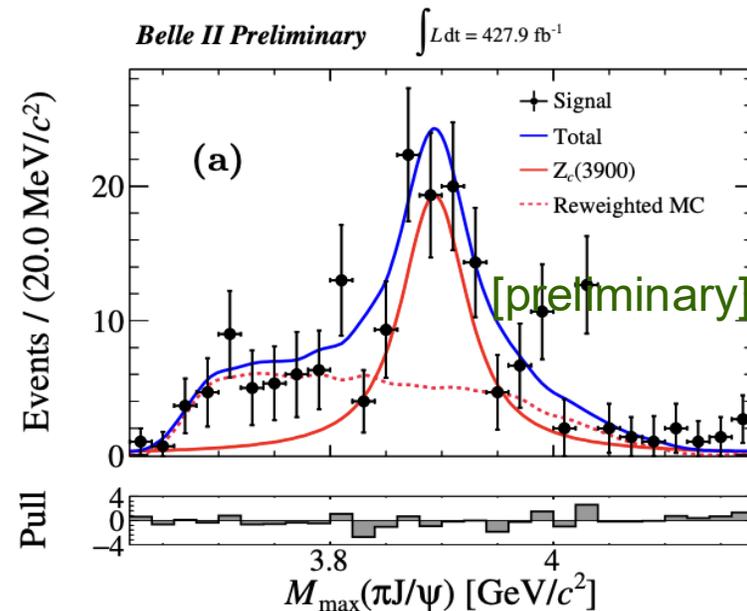
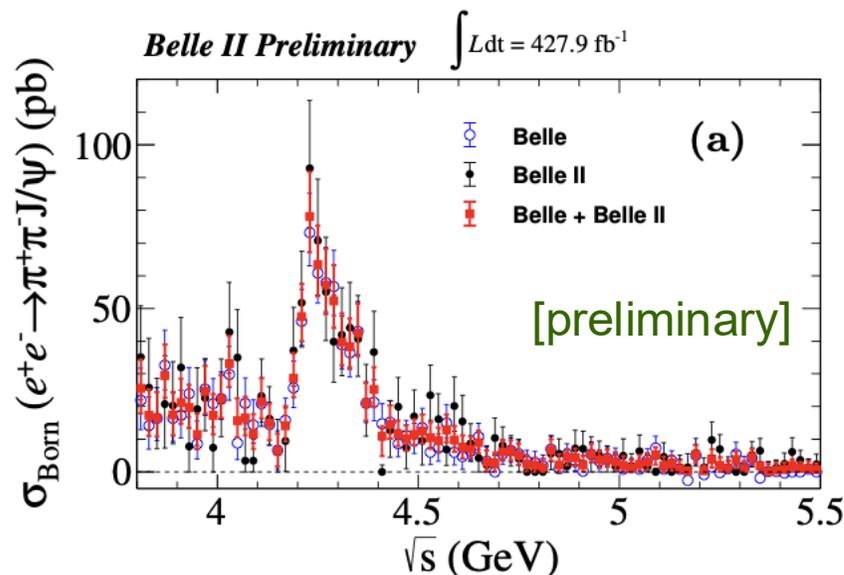
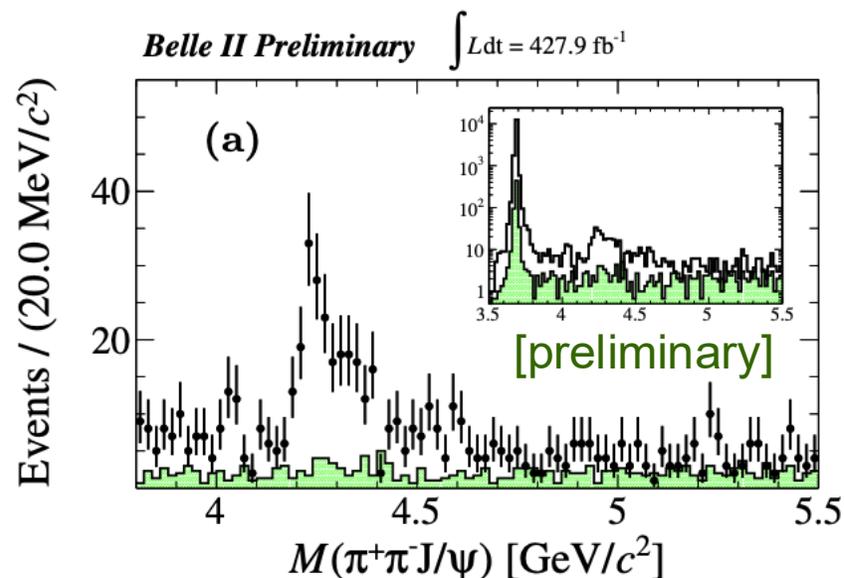
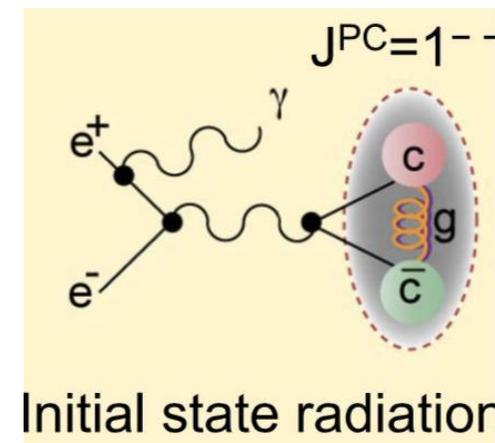
- Allows to study energies below $E_{c.m.}$
- Wide energy range available
- Measure more precisely the line shapes

$$e^+e^- \rightarrow \pi^+\pi^-J/\psi \text{ via ISR}$$

Disadvantages of ISR:

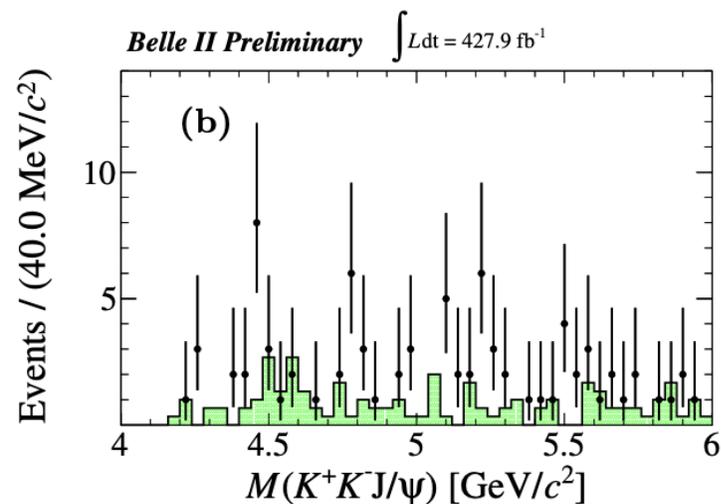
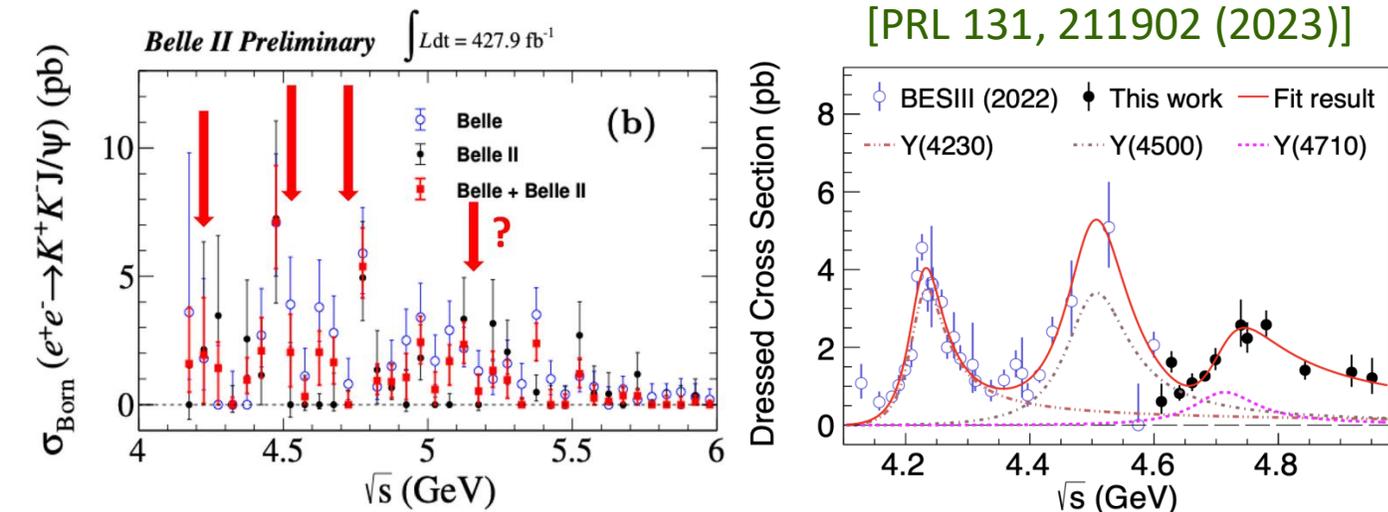
- The effective integrated luminosity decreases as the c.m. energy decreases
- The detection efficiency is also smaller

[To be submitted to PRD]



- We can see the $Y(4008)$ evidence and $Y(4230/4320)$ signals.
- The significance of $Z_c(3900)$ is 5.3σ .

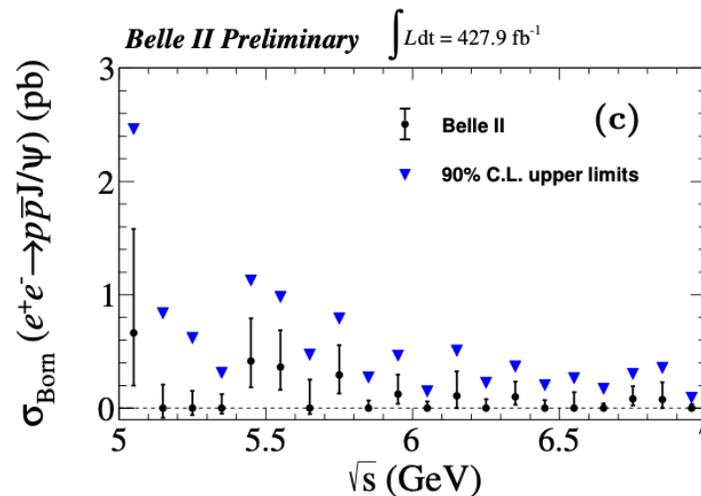
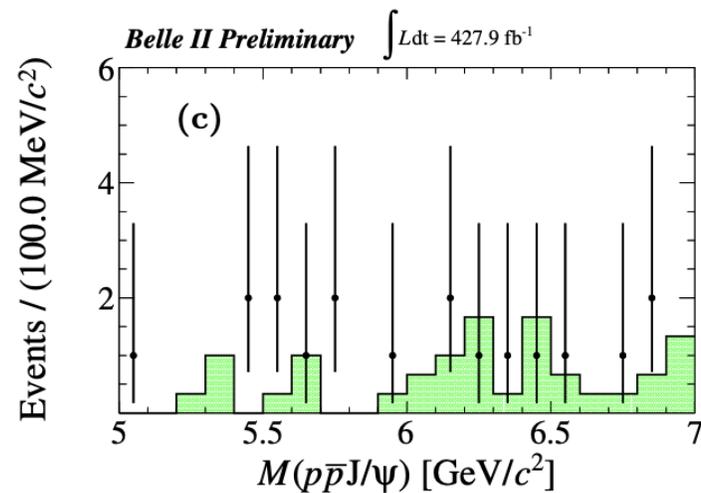
$e^+e^- \rightarrow K^+K^-J/\psi$ via ISR



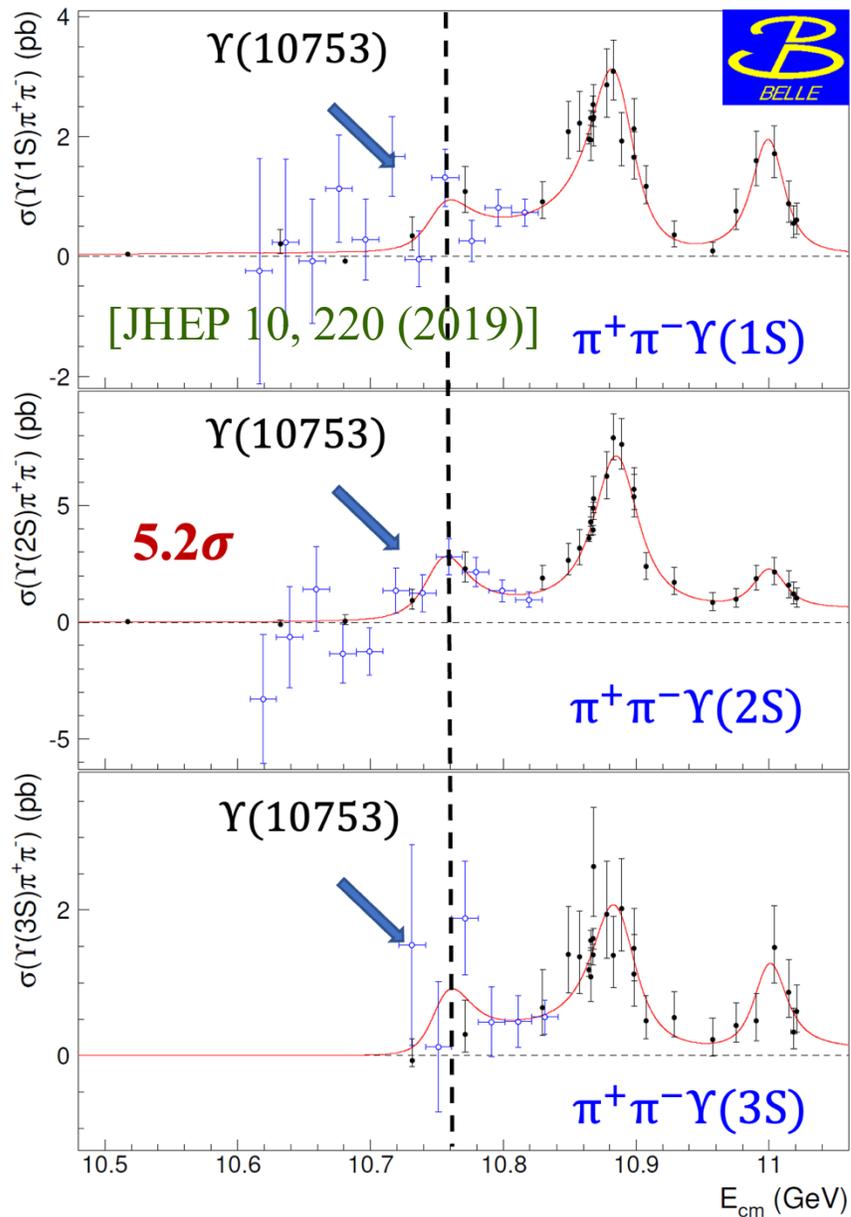
- No clear signals were observed at Belle II.
- More data are needed.

$e^+e^- \rightarrow p\bar{p}J/\psi$ via ISR

The cross section for $e^+e^- \rightarrow P_c\bar{p}$ is estimated to be $\lesssim \mathcal{O}(0.1 \text{ pb})$ [arXiv: 2508.08694].



Discovery of $\Upsilon(10753)$



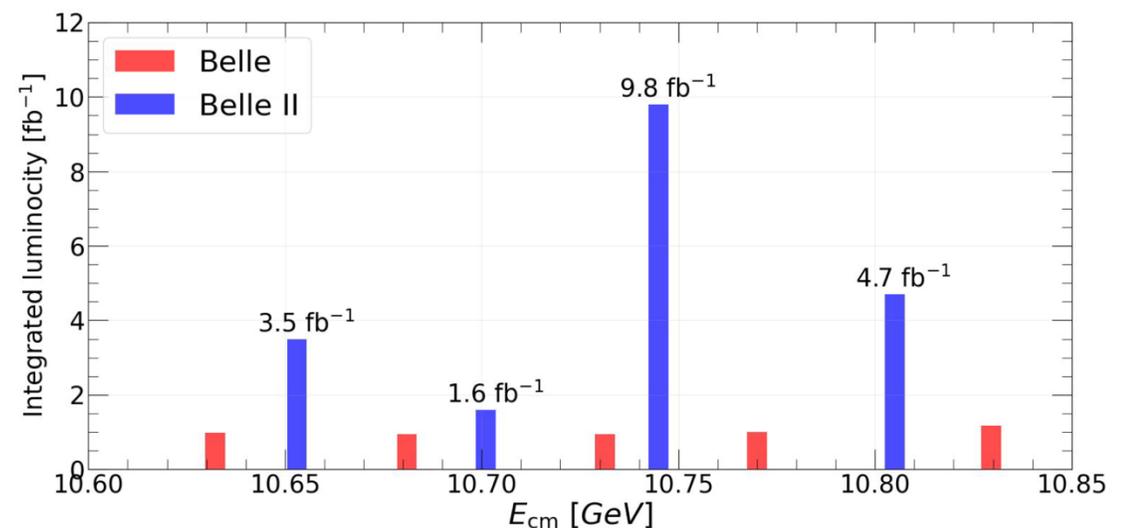
- Belle: several $\sim 1 \text{ fb}^{-1}$ scan points below $\Upsilon(5S)$
- New structure observed in $\pi^+ \pi^- \Upsilon(nS)$ ($n = 1, 2, 3$)

	$\Upsilon(10860)$	$\Upsilon(11020)$	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)	$36.6^{+4.5}_{-3.9} +^{0.5}_{-1.1}$	$23.8^{+8.0}_{-6.8} +^{0.7}_{-1.8}$	$35.5^{+17.6}_{-11.3} +^{3.9}_{-3.3}$

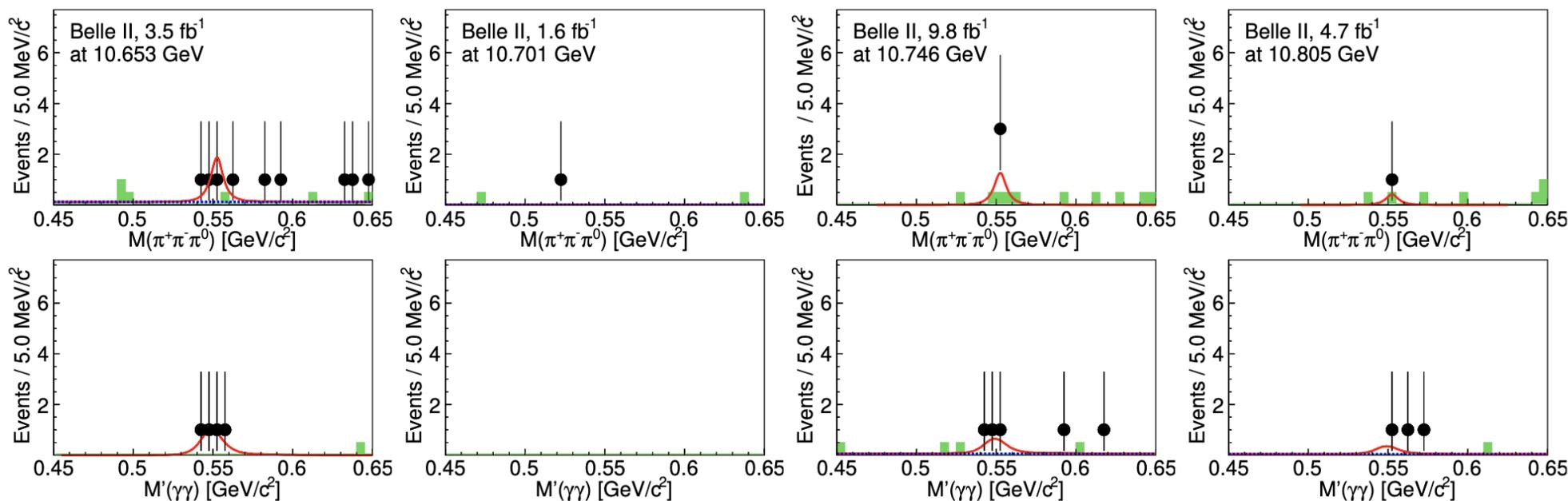
Possible interpretations:

Conventional bottomonium? Hybrid state? Tetraquark state? ...

In November 2021, Belle II collected 19.6 fb^{-1} of scan data at four energy points near 10.75 GeV.



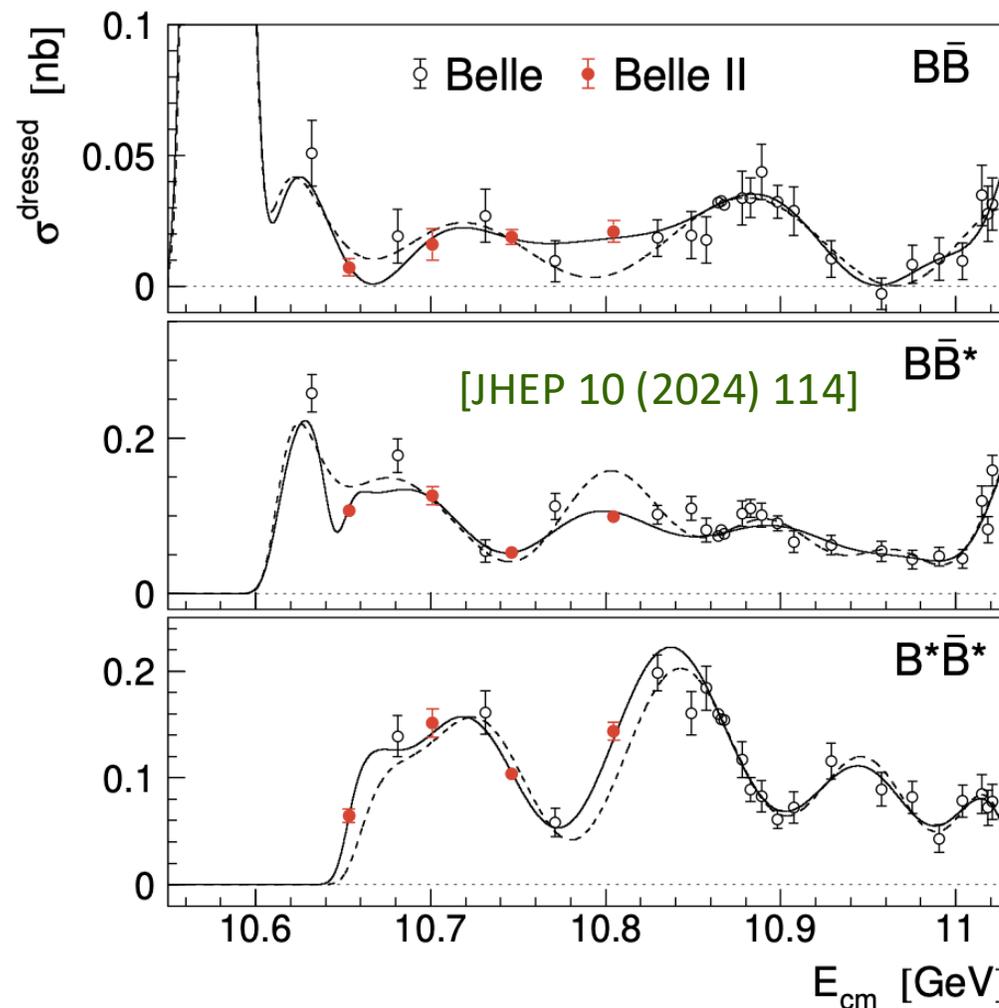
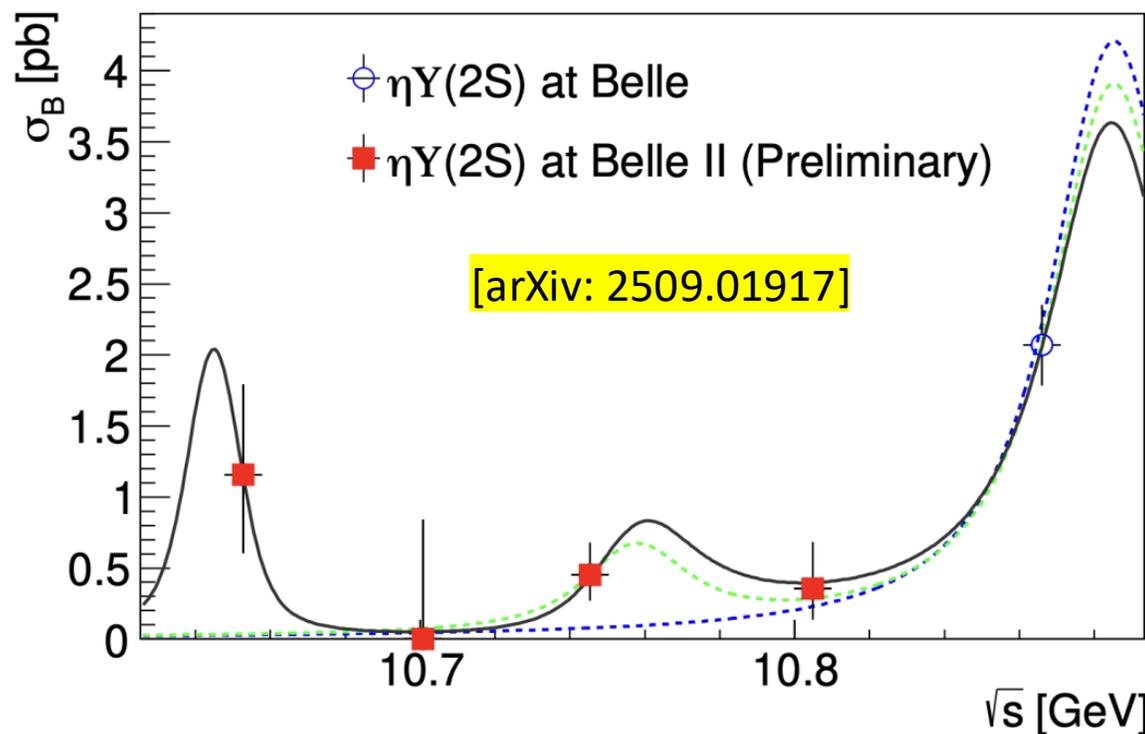
- A relatively large branching fraction of $\Upsilon(10753) \rightarrow \eta\Upsilon(nS)$ would support a 4S–3D interpretation of $\Upsilon(10753)$. [PRD 104 034036 (2021)]
- An enhancement near $B^*\bar{B}^*$ can decay into $\eta\Upsilon(1S, 2S)$ similarly to how $\psi(4040)$ observed at $D^*\bar{D}^*$ threshold decays into $\eta J/\psi$. [JHEP 10 (2024) 114]



[arXiv: 2509.01917]

$\eta \rightarrow \gamma\gamma, \Upsilon(2S) \rightarrow \pi^+\pi^-\Upsilon(1S),$
 $\Upsilon(1S) \rightarrow \ell^+\ell^-$
 $\eta \rightarrow \pi^+\pi^-\pi^0, \Upsilon(2S) \rightarrow \ell^+\ell^-$

- After requiring $\Upsilon(2S)$ signal region, simultaneous fit to $M(\gamma\gamma)$ and $M(\pi^+\pi^-\pi^0)$ for each energy point.
- ✓ The signal yields for $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ are $6.0_{-1.5}^{+1.7}$ and $11.5_{-2.8}^{+3.3}$
- ✓ The signal significance is 6.0σ for $e^+e^- \rightarrow \eta\Upsilon(2S)$ at near 10.75 GeV.
- ✓ No clear signals were observed for $e^+e^- \rightarrow \eta\Upsilon(1S)$ at near 10.75 GeV.



Rapid increase of $\sigma_{\text{B}^*\bar{\text{B}}^*}$ just above the threshold.

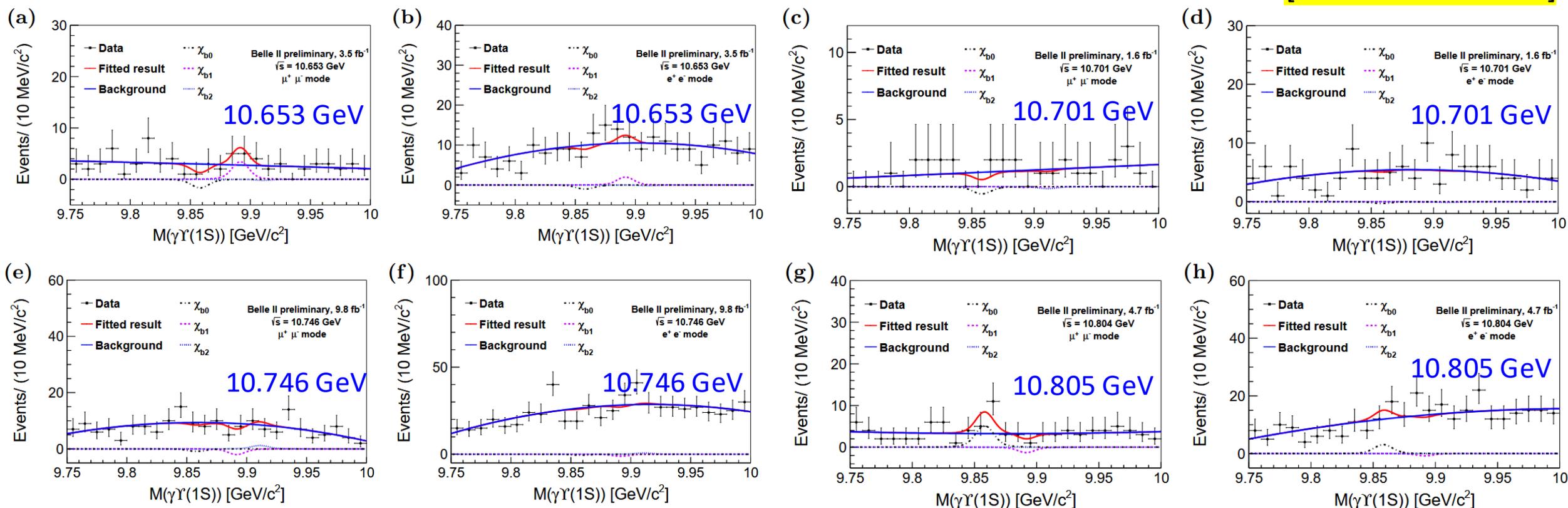
- ✓ The Born cross section of $e^+e^- \rightarrow \eta\Upsilon(1S, 2S)$ around $\text{B}^*\bar{\text{B}}^*$ mass is relatively large.
- ✓ The hypothesis that these events are associated solely with the production of the $\Upsilon(5S)$ or $\Upsilon(10753)$ resonances is rejected at the level of 3.6σ .

A new bottomonium-like state around $\text{B}^*\bar{\text{B}}^*$ threshold?

The $\Upsilon_b(10650)$ is predicted in Refs. [arXiv:2505.02742, arXiv:2508.11127, arXiv:2505.03647].

- If the $\Upsilon(10753)$ is a pure $\Upsilon(2D)$ state, the \mathcal{B} for $\Upsilon(10753) \rightarrow \gamma\chi_{b1}$ can reach 12%. [EPJC 78, 915 (2018)]
- We search for $e^+e^- \rightarrow \gamma\chi_{bJ} (J = 0,1,2)$ using 19.6 fb^{-1} scan data collected near 10.75 GeV.

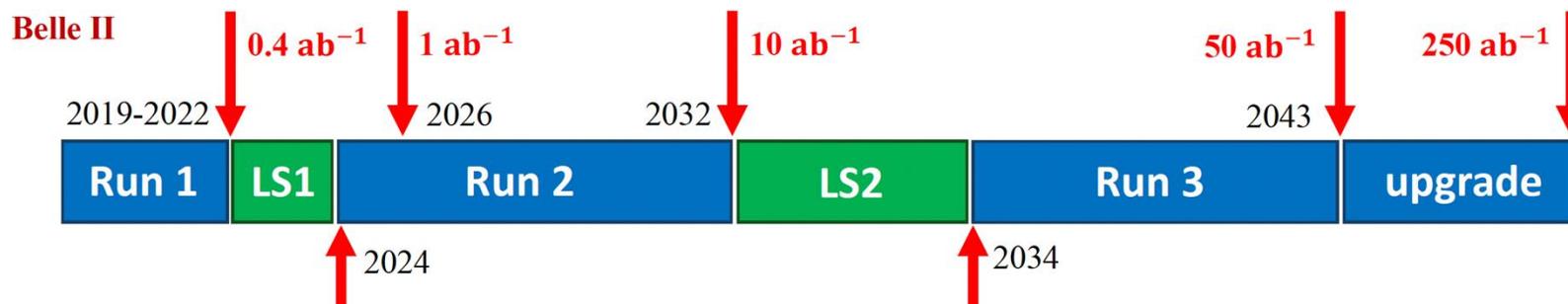
[arXiv : 2508.16036]



✓ No clear signal of $e^+e^- \rightarrow \gamma\chi_{bJ}$ can be seen.

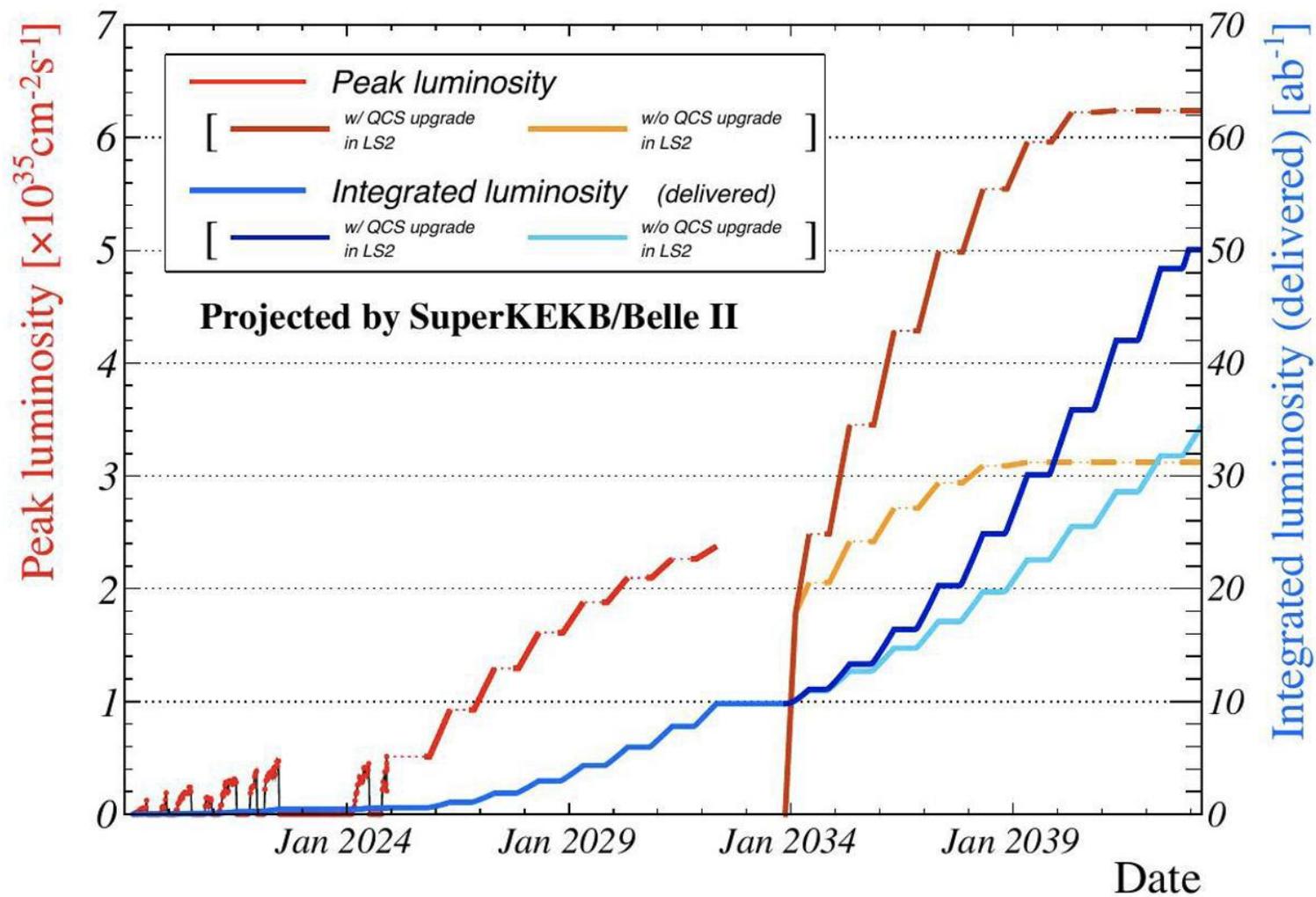
✓ $\sigma_{\text{Born}}^{\text{UL}}(e^+e^- \rightarrow \gamma\chi_{bJ})$ at 90% C.L. at 10.746 GeV is 0.25pb

- The $e^+e^- B$ factory provides various opportunities to conduct a wide range of studies in the flavor physics field.
 - Belle and Belle II are actively producing and analyzing data jointly.
- The SuperKEKB accelerator continues to break world records for instantaneous luminosity. At the end of 2024 during Run 2, it achieved a peak luminosity of $5.1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$.
- Belle II: new data + new vertex detectors + new software tools.
- Only 2% of target luminosity collected so far. Stay tuned for more exciting results from Belle II.

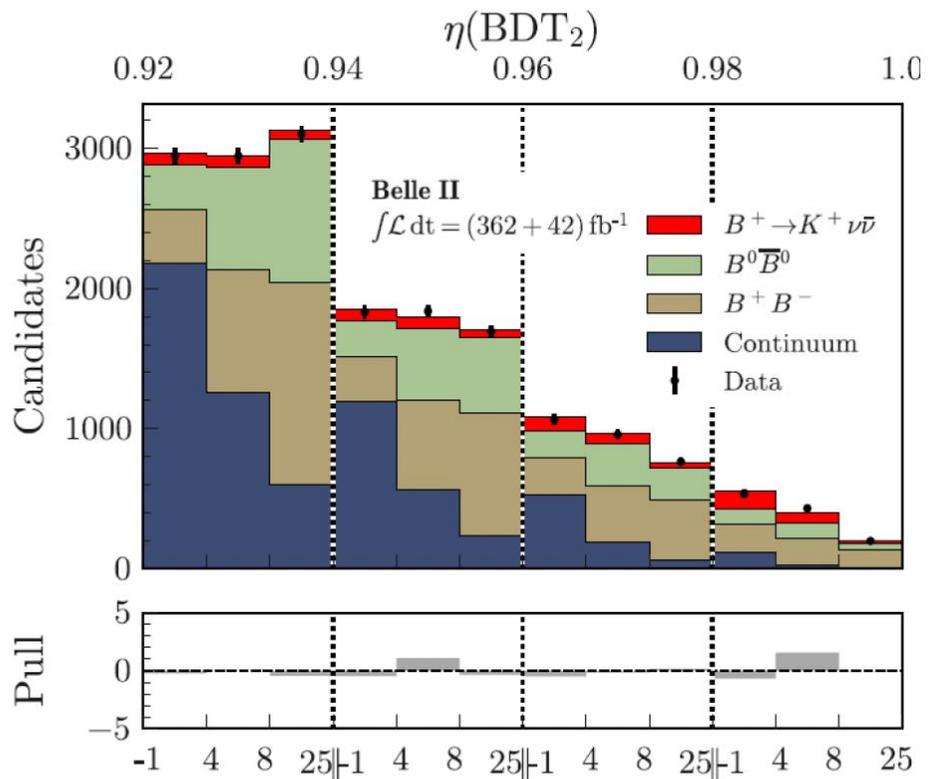


Thanks for your attention!

Backup

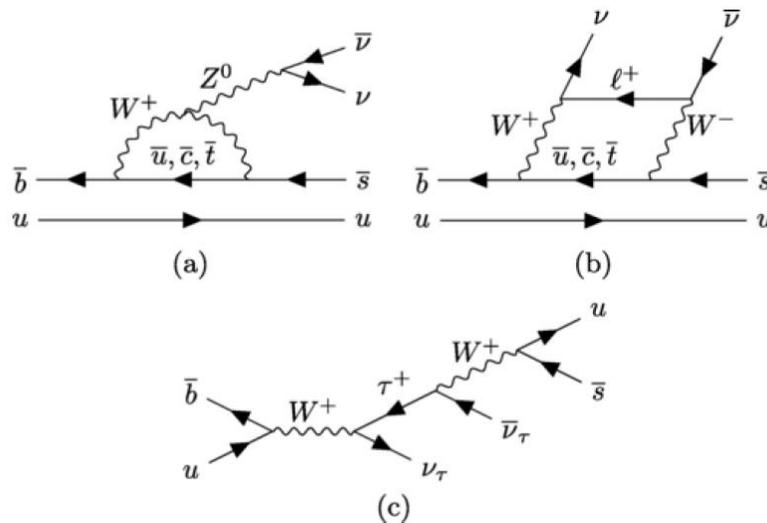


Evidence for $B^+ \rightarrow K^+ \nu \bar{\nu}$ Decays



In bins of $q_{rec}^2 = \frac{s}{4} + m_K^2 - \sqrt{s} E_K^* \simeq (p_\nu + p_{\bar{\nu}})^2$

- Belle II saw the evidence for this B meson decaying to two invisible neutrino + hadron.
- [Phys Rev D.109.112006 \(2024\)](#)
- $B^+ \rightarrow K^+ \nu \bar{\nu}$ as $[2.3 \pm 0.7] \times 10^{-5}$

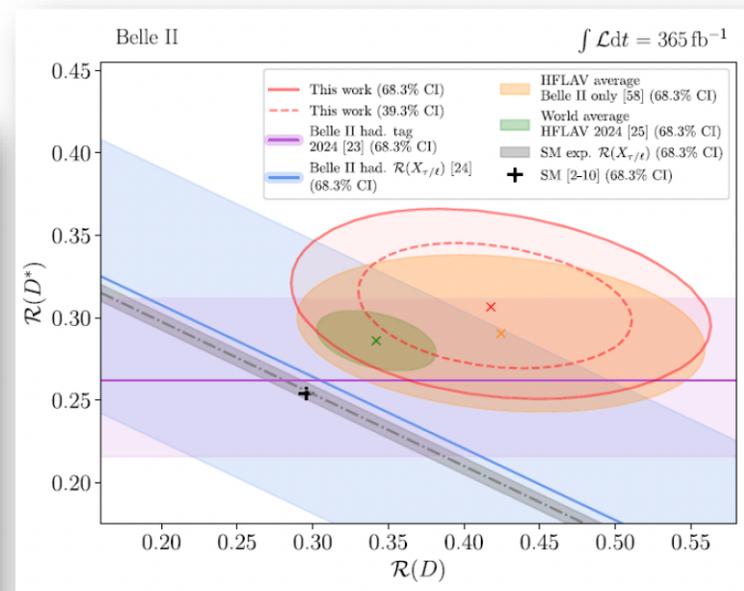
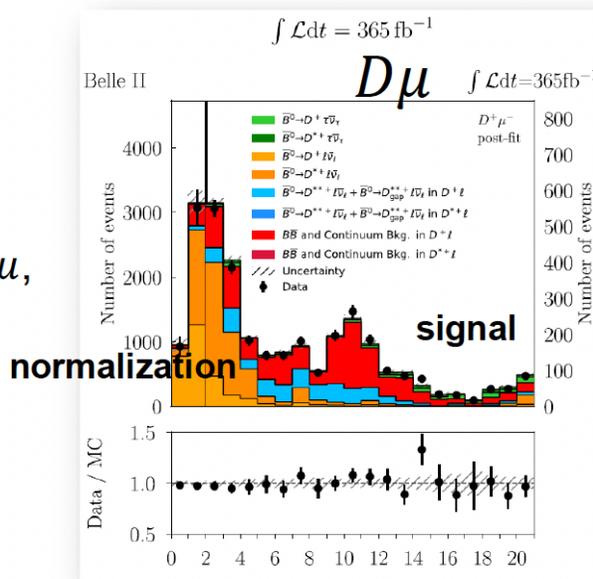


LFU Test in $R(D^{(*)})$: Semi-Leptonic Tag

Method 1: Use semi-leptonic decays of tag B.

- For signal B, use leptonic decays of τ .
- [PRD 112 \(2025\), 032010](#) by Belle II
- Classify signal B to De , $D\mu$, D^*e , and $D^*\mu$ by a multi-class algorithm.
- The signal event and the normalization event have the same lepton.
- Belle II results are consistent with the SM within 1.7σ

$$\mathcal{R}(D^{(*)+}) = \frac{\mathcal{B}r(\bar{B}^0 \rightarrow D^{(*)+} \tau^- \bar{\nu}_\tau)}{\mathcal{B}r(\bar{B}^0 \rightarrow D^{(*)+} \ell^- \bar{\nu}_\ell)}$$



$$\mathcal{R}(D^+) = 0.418_{-0.073}^{+0.075} (\text{stat})_{-0.056}^{+0.049} (\text{syst}),$$

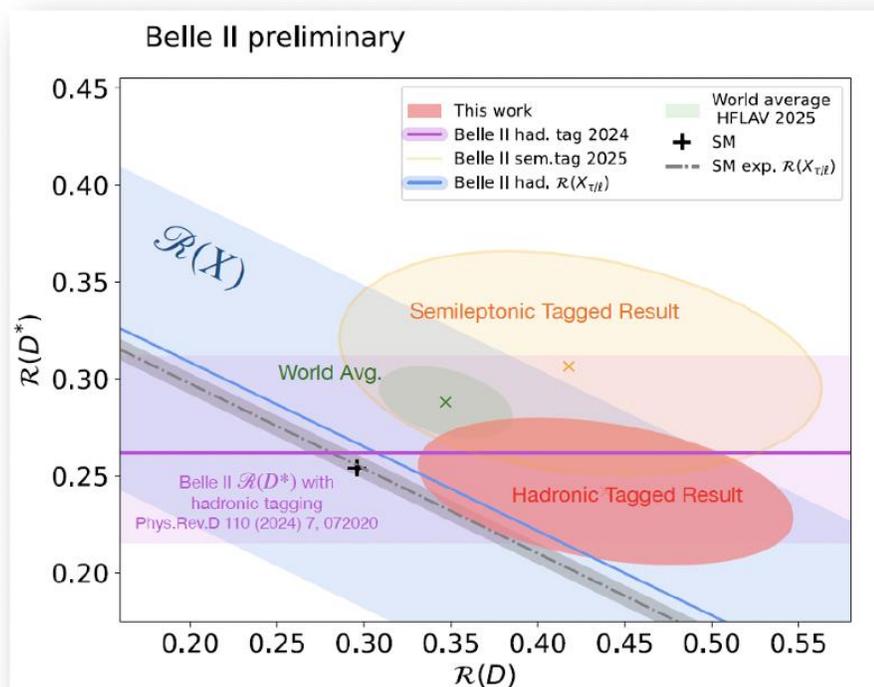
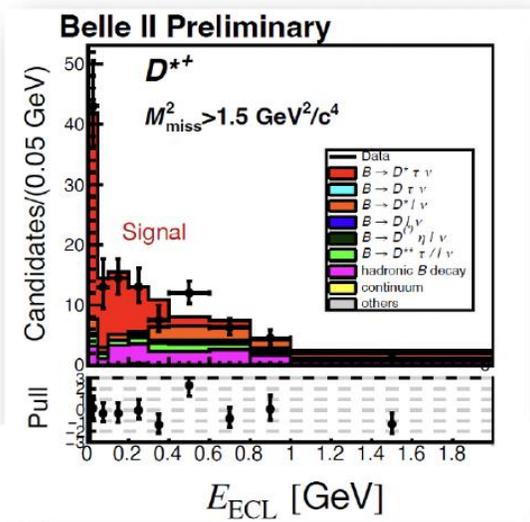
$$\mathcal{R}(D^{*+}) = 0.306_{-0.033}^{+0.035} (\text{stat})_{-0.018}^{+0.016} (\text{syst}),$$

LFU Test in $R(D^{(*)})$: Hadronic Tag

Method 2: Use hadronic decays of tag B.

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}r(\bar{B} \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau)}{\mathcal{B}r(\bar{B} \rightarrow D^{(*)} \ell^- \bar{\nu}_\ell)}$$

- In this study, signal B is categorized to D^{*+} , $D^{*0}(D^0\pi^0)$, $D^{*0}(D^0\gamma)$, D^+ , and D^0
- 2D fit of E_{ECL} (residual) and $M_{miss}^2 = (p_{e^+e^-} - p_{B\text{tag}} - P_{D^{(*)}} - P_\ell)^2 \sim m_{3\nu}^2$



$$R(D^{*}) = 0.242 \pm 0.019(\text{stat}) \pm 0.016(\text{syst}),$$

$$R(D) = 0.439 \pm 0.055(\text{stat}) \pm 0.045(\text{syst}) \leftarrow 1.5 \sigma \text{ above SM}$$

- Unlike in Beauty sector, Charm sector has rather small CPV in standard model:
 1. GIM mechanism
 2. small size of $|V_{cb}|$
 3. dominance of tree-level (lack of **interference**)

→ **CP violation** $\sim 10^{-3}$
- Dominance of matter in the Universe indicates Charge-Parity (CP) Violation. KM is not sufficient. There should be additional source of CPV.
- Observation of “sizable” CPV in charm could be a hint to physics beyond standard model.