Overview of the Belle II experiment

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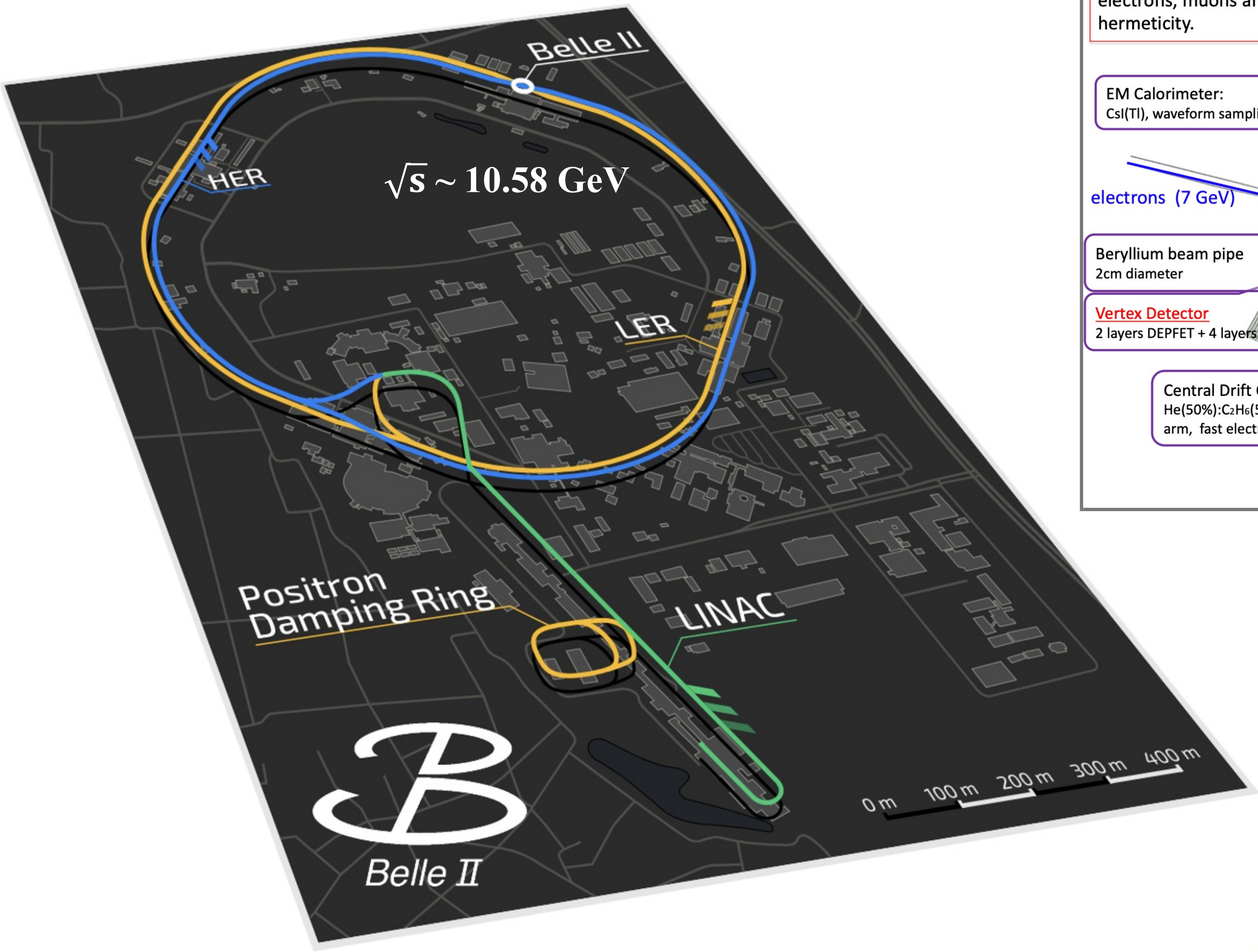
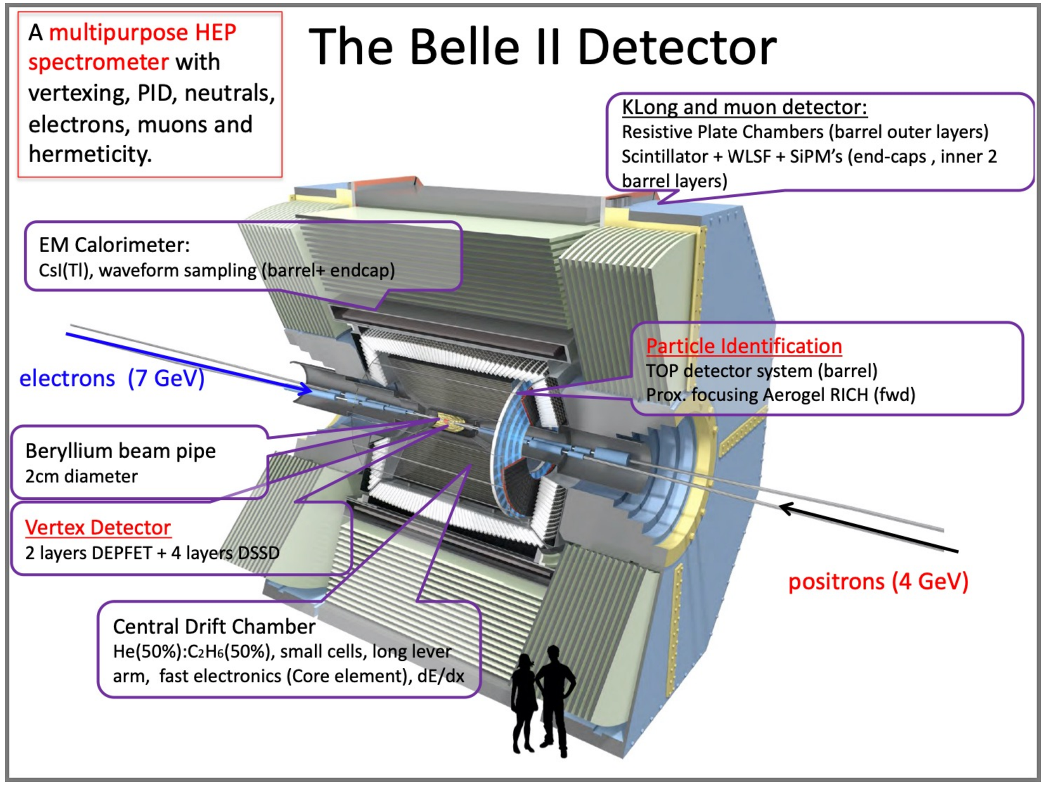
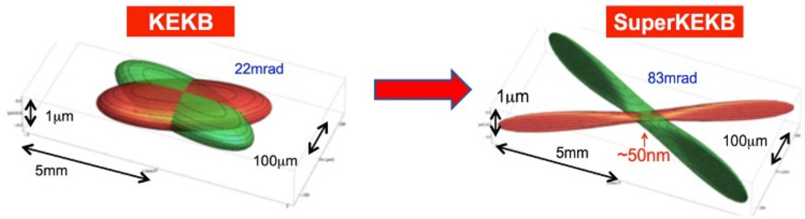
SuperKEKB and Belle II







Nano-beam design:
Beam squeezing: ×20 smaller;
Beam current: ×2 larger
Target peak luminosity: KEKB×30

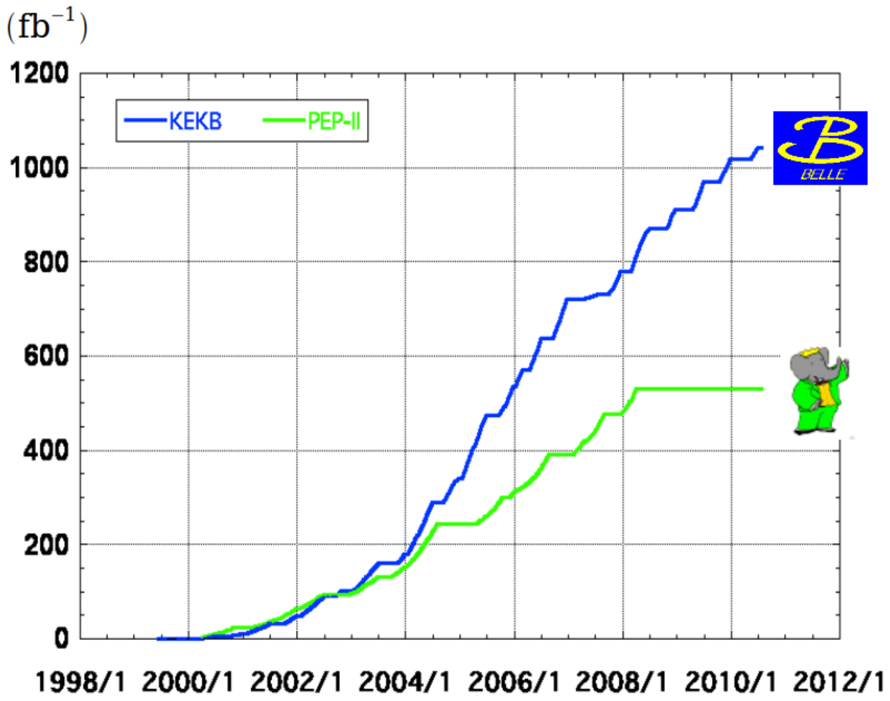
Belle and Belle II Datasets

- **Belle (1999 - 2012)**
- **Belle II RUN-I (2019 - 2023)**
- **Belle II RUN-II (2024 - 2025)**

In December 2024

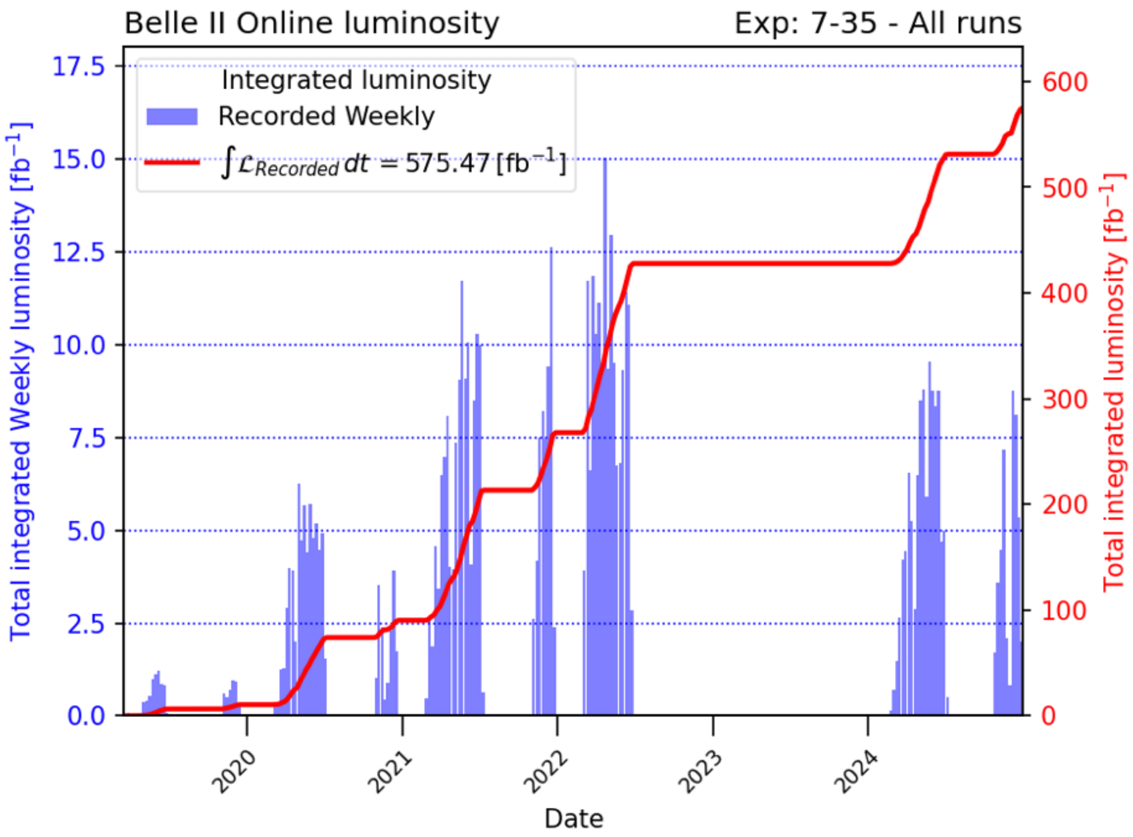
WORLD RECORD: $5.1 \times 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

Integrated luminosity of B factories



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

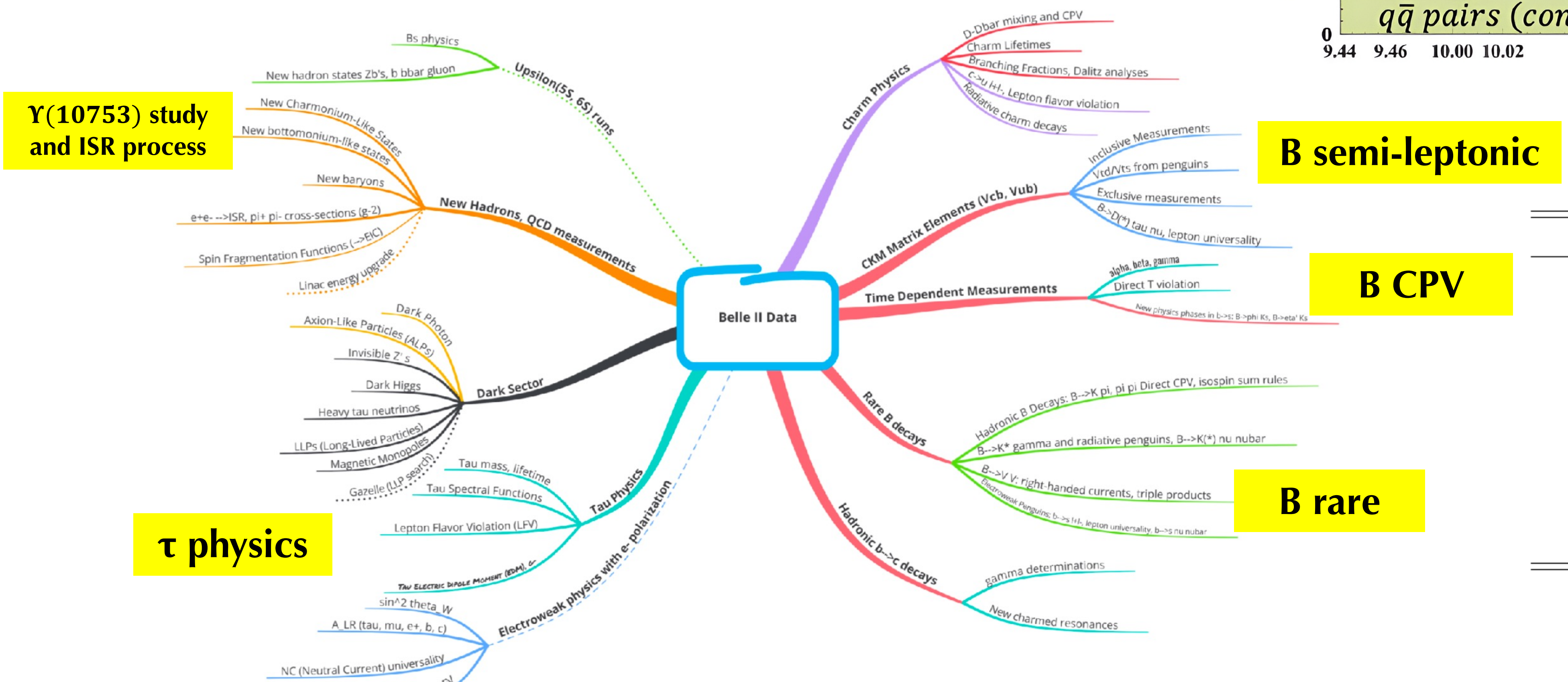
~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

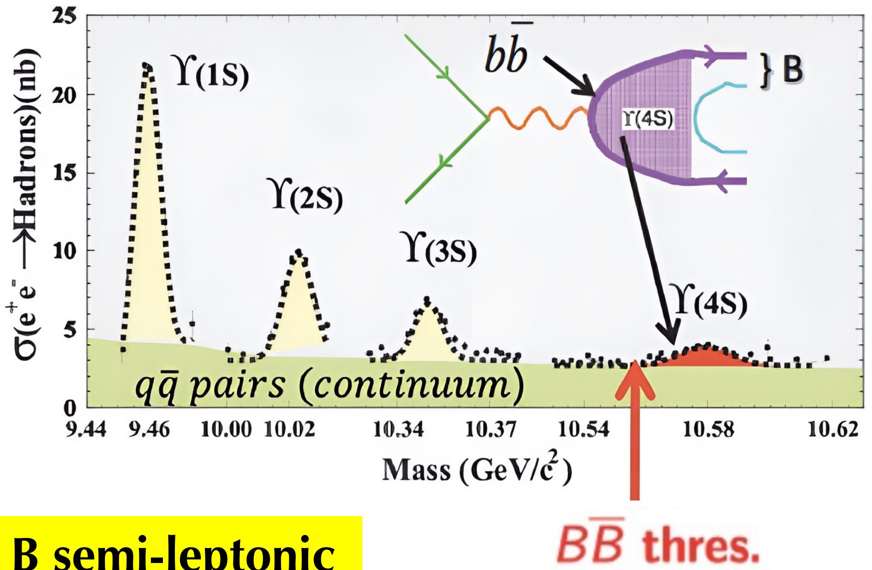


Most data at or near the $\Upsilon(4S)$ resonance, and 19.6 fb^{-1} near $\Upsilon(10753)$

Belle II physics

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



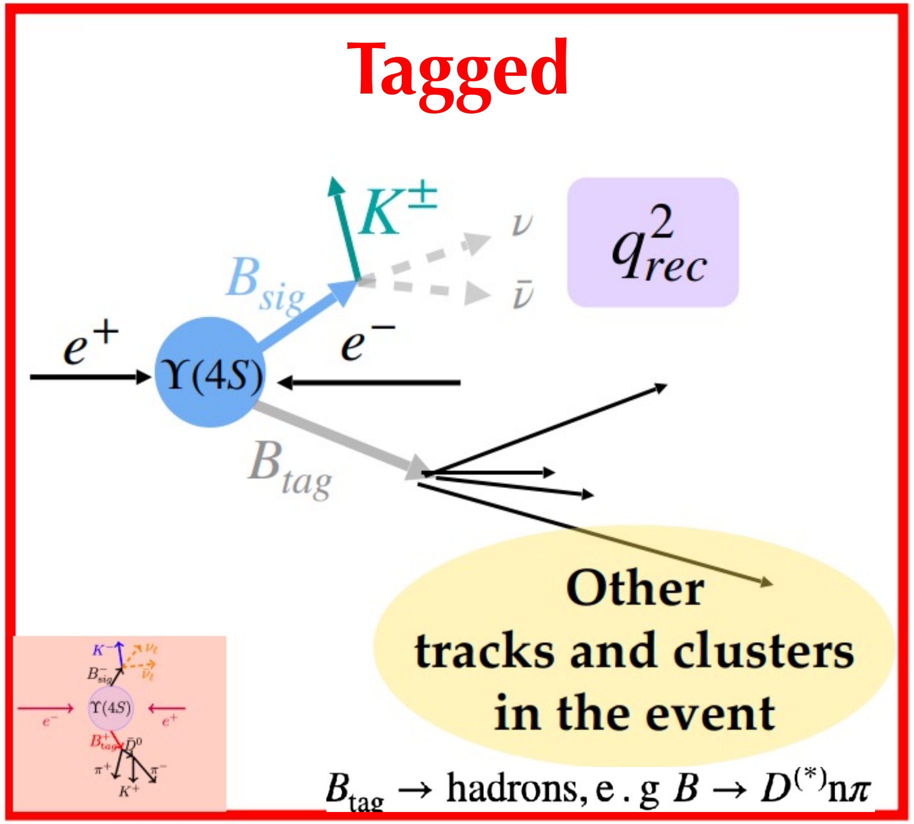


$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3

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.

B decays

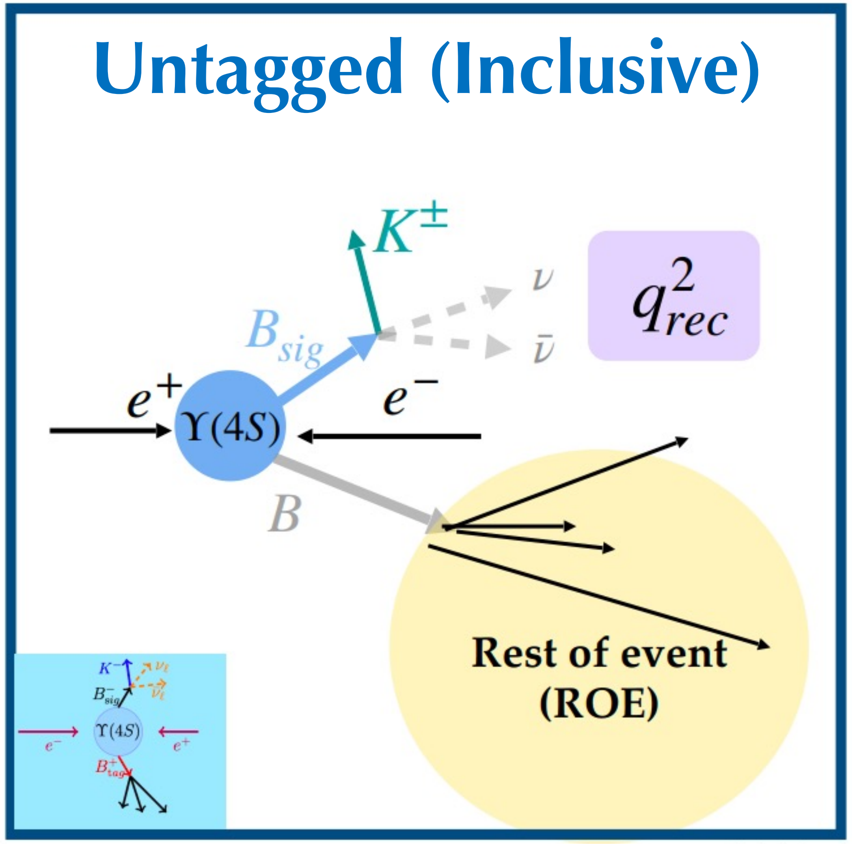
Two ways of tagging



Efficiency

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

Purity, Resolution



- **Tagging: Hadronic + Semileptonic**
- **Inclusive ROE (Rest of Event) (× 10 - 20 efficiency, but large backgrounds); add some ML/AI (boosted decision trees or BDTs) to help suppress the large backgrounds.**

Search for CPV in $B^0 \to \rho^+\rho^-$

[PRD 111, 092001 (2025)]

- **much smaller loop contribution $\Rightarrow$ dominates ϕ_2 precision**
- **two π^0's reconstruction needed $\Rightarrow$ a channel suitable for Belle II**
- **Use hadronic tagging**

Probability distribution

Mixing-induced CPV param.

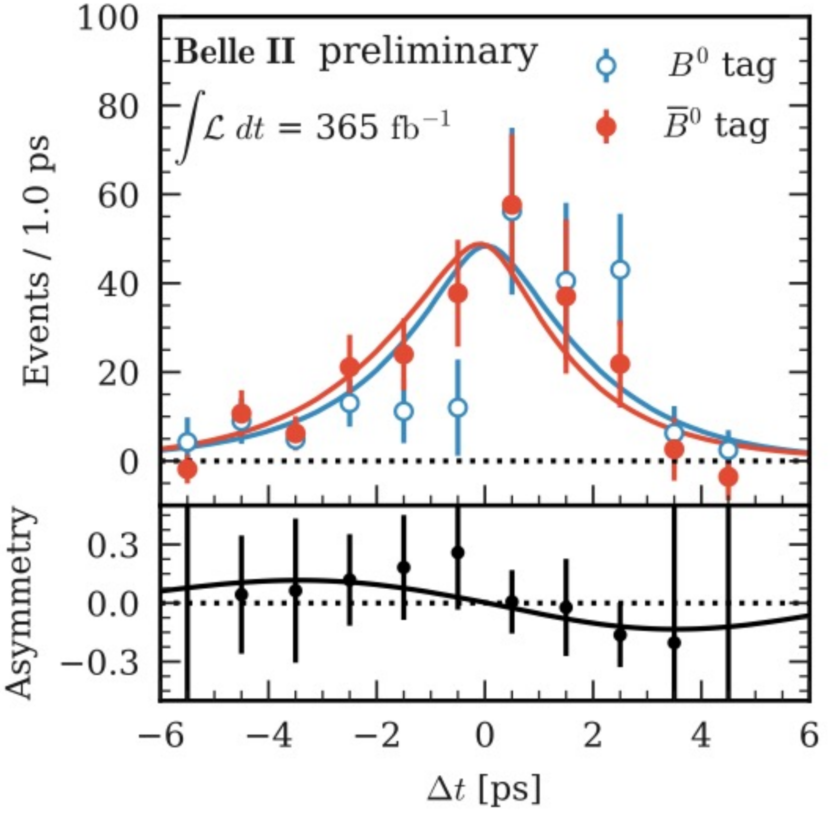
$$P(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}}\Big\{1 + q\big[S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\big]\Big\},$$

Direct CPV param.

Helicity angle distribution

Longitudinal polarisation fraction

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_{\rho^+} d\cos\theta_{\rho^-}} = \frac{9}{4}\Big[\frac{1}{4}(1-f_L)\sin^2\theta_{\rho^+}\sin^2\theta_{\rho^-} + f_L\cos^2\theta_{\rho^+}\cos^2\theta_{\rho^-}\Big],$$



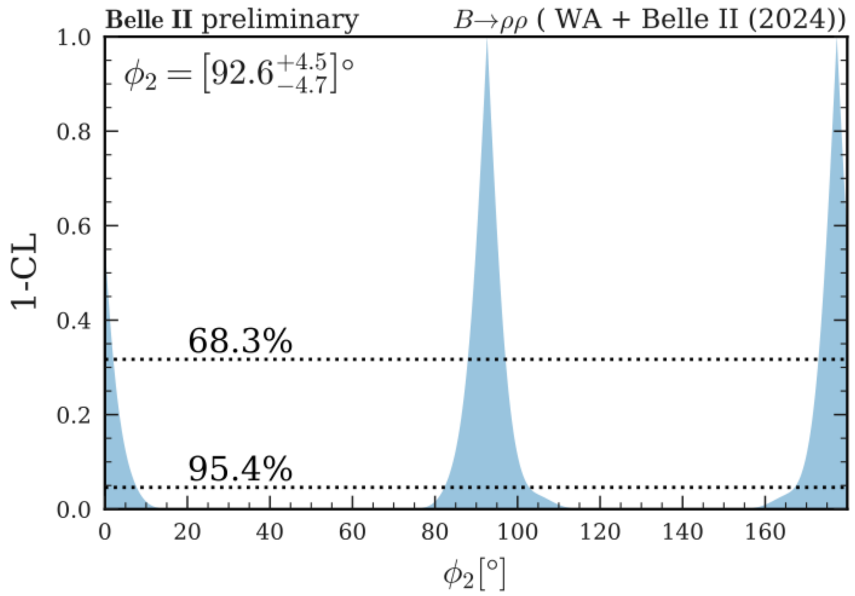
$$\mathcal{B}(B^0 \to \rho^+\rho^-) = (2.89^{+0.37}_{-0.35}) \times 10^{-5}$$

$$f_L = 0.921^{+0.029}_{-0.029}$$

$$S = -0.26 \pm 0.19 \pm 0.08$$

$$C = -0.02 \pm 0.12 \pm 0.05$$

Constraining ϕ_2:



Dominated by systematics from S

$B \to \rho\rho$ world average:
$\phi_2 = (91.5^{+4.5}_{-5.4})^\circ$

$B \to \rho\rho$ world average + Belle II $\rho^+\rho^-$ result
$\Rightarrow \boldsymbol{\phi_2 = (92.6^{+4.5}_{-4.8})^\circ}$

6%

$\mathcal{R}$(D) and $\mathcal{R}$(D*)

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

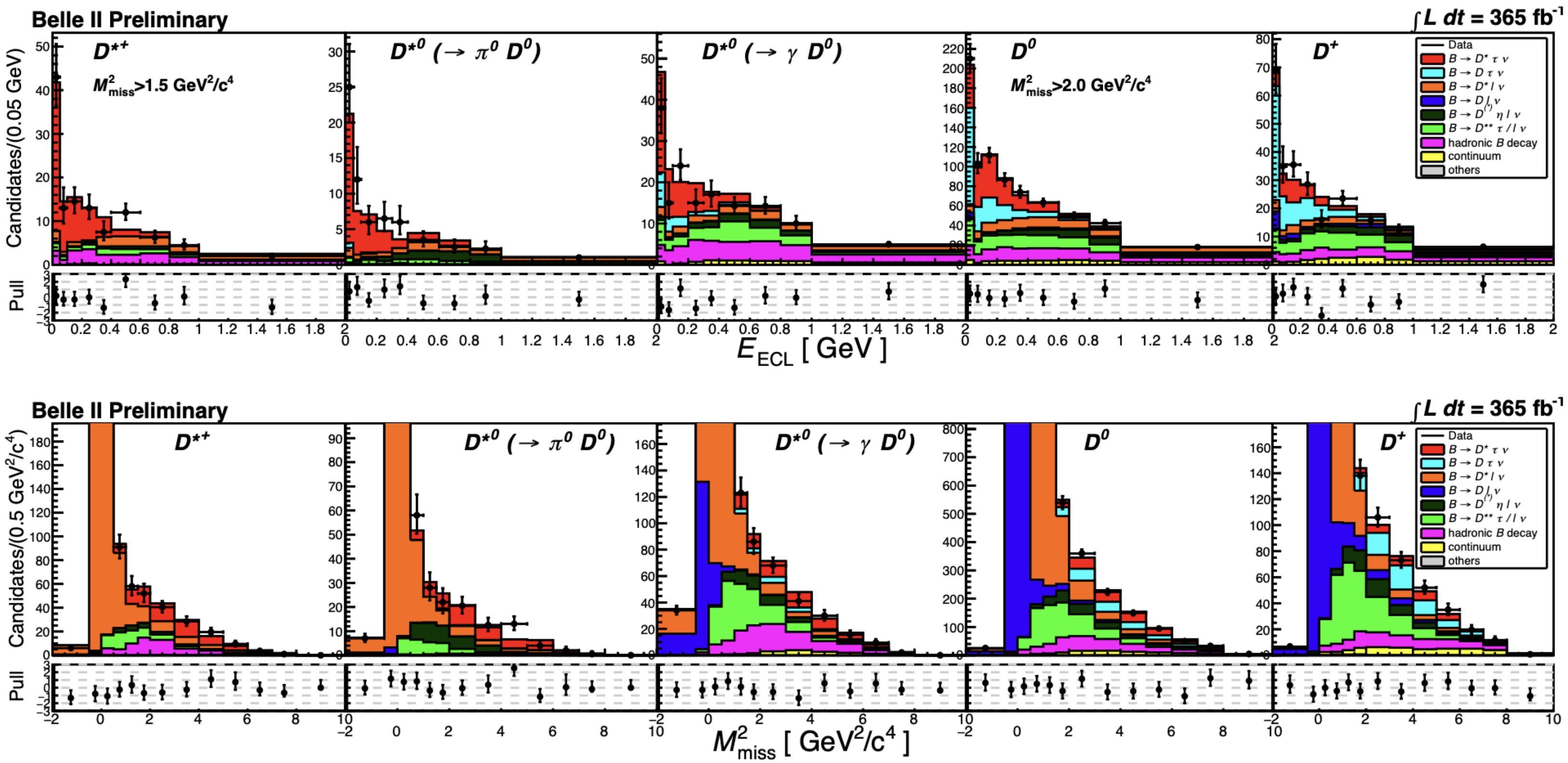
- **Test Lepton-Flavor Universality**
- **Use hadronic tagging, efficiency: 0.30%, purity: 29%**

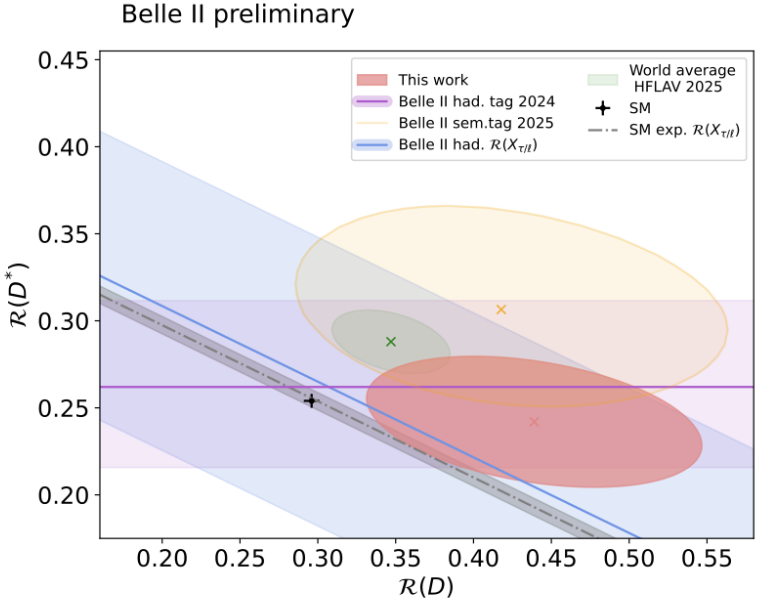
[Belle II Preliminary]

Signal extraction

- 2D log-likelihood fit to E_{ECL} and M^2_{miss}

$$R(D^*) = 0.242 \pm 0.019(\text{stat}) \pm 0.016(\text{syst})$$
$$R(D) = 0.439 \pm 0.055(\text{stat}) \pm 0.045(\text{syst})$$





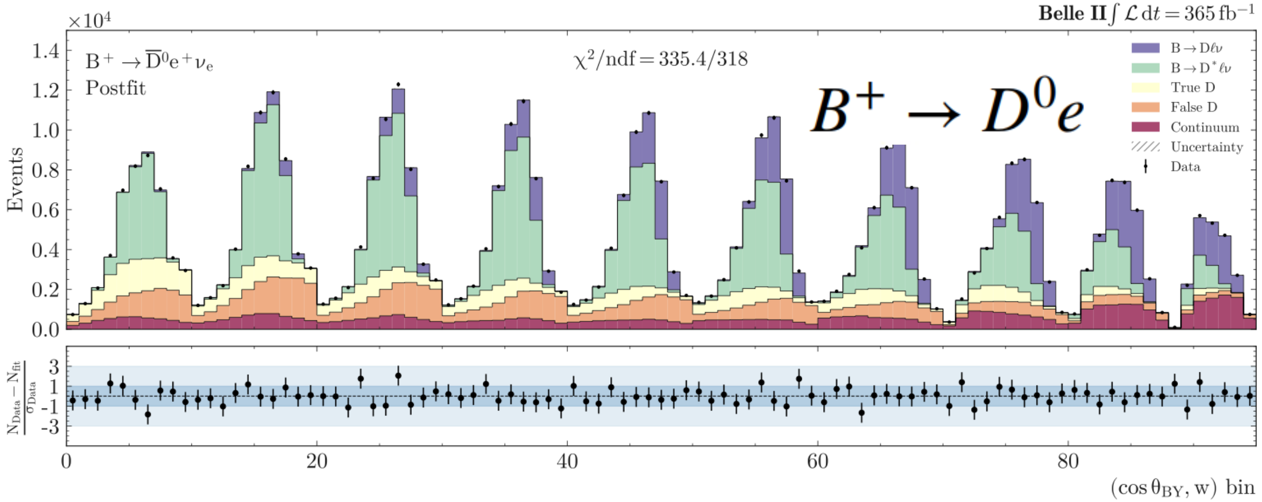
Most precise determination of $\mathcal{R}(D^{(*)})$ with hadronic tagging

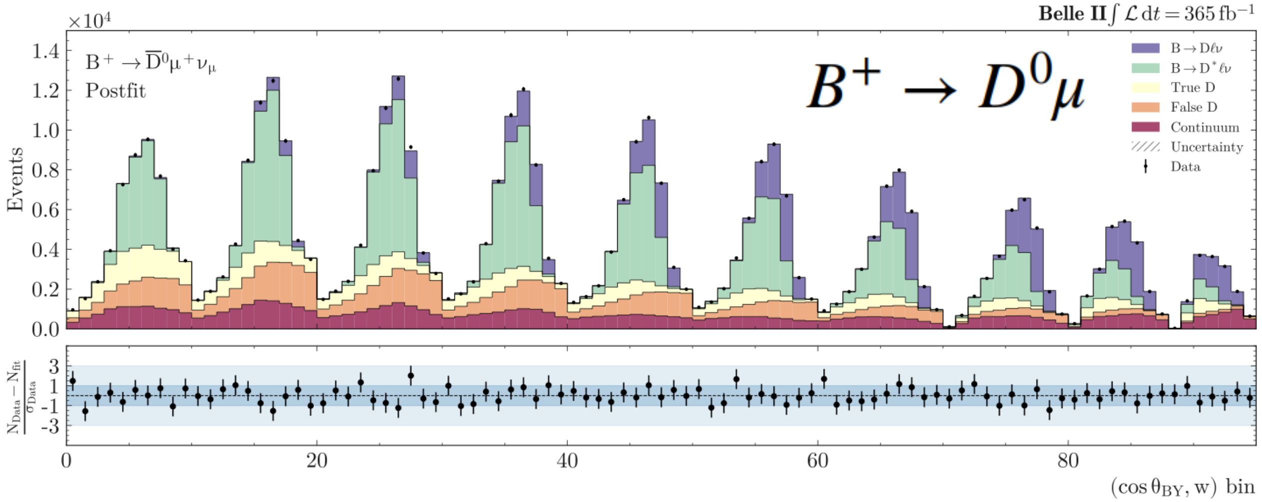
$|V_{cb}|$ from untagged exclusive $B \to D\ell\nu_\ell$

Signal yields are extacted in 10 bins of w by fitting the simultaneously in the electron and muon channels and in the charged and neutral modes

The recoil variable $w = v_B \cdot v_D$

$\cos\vartheta_{BY}$: the angle between the signal B and $D\ell$ system





[Belle II Preliminary]

$$\mathcal{B}(B^0 \to D^-\ell^+\nu_\ell) = (2.06 \pm 0.05(\text{stat.}) \pm 0.10(\text{syst.}))\ \%$$

$$\mathcal{B}(B^+ \to \bar{D}^0\ell^+\nu_\ell) = (2.31 \pm 0.04(\text{stat.}) \pm 0.09(\text{syst.}))\ \%$$

Extract by fitting values of $\Delta\mathcal{T}/\Delta w$ using BCL (Phys. Rev. D 82, 099902 (2010)) form factor parametrisation.

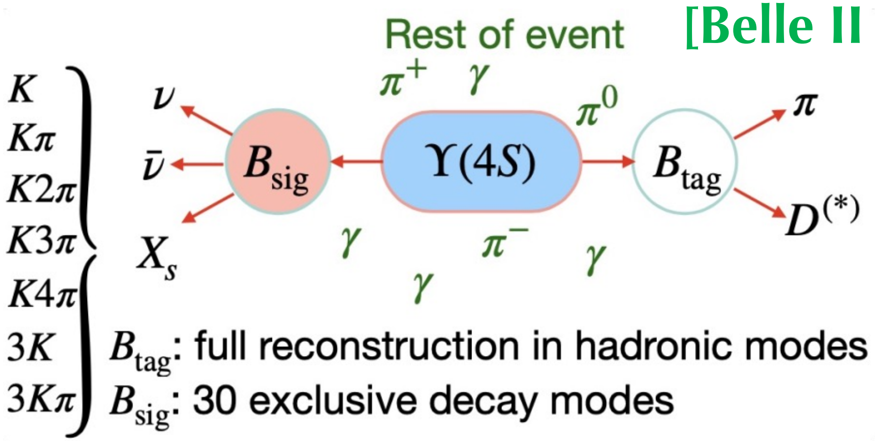
$$|V_{cb}| = (39.2 \pm 0.4(\text{stat.}) \pm 0.6(\text{syst.}) \pm 0.5(\text{th.})) \times 10^{-3}$$

- **Result in agreement with exclusive HFLAV average**
- **Most precise measurement using $B \to D\ell\nu_\ell$ decays**

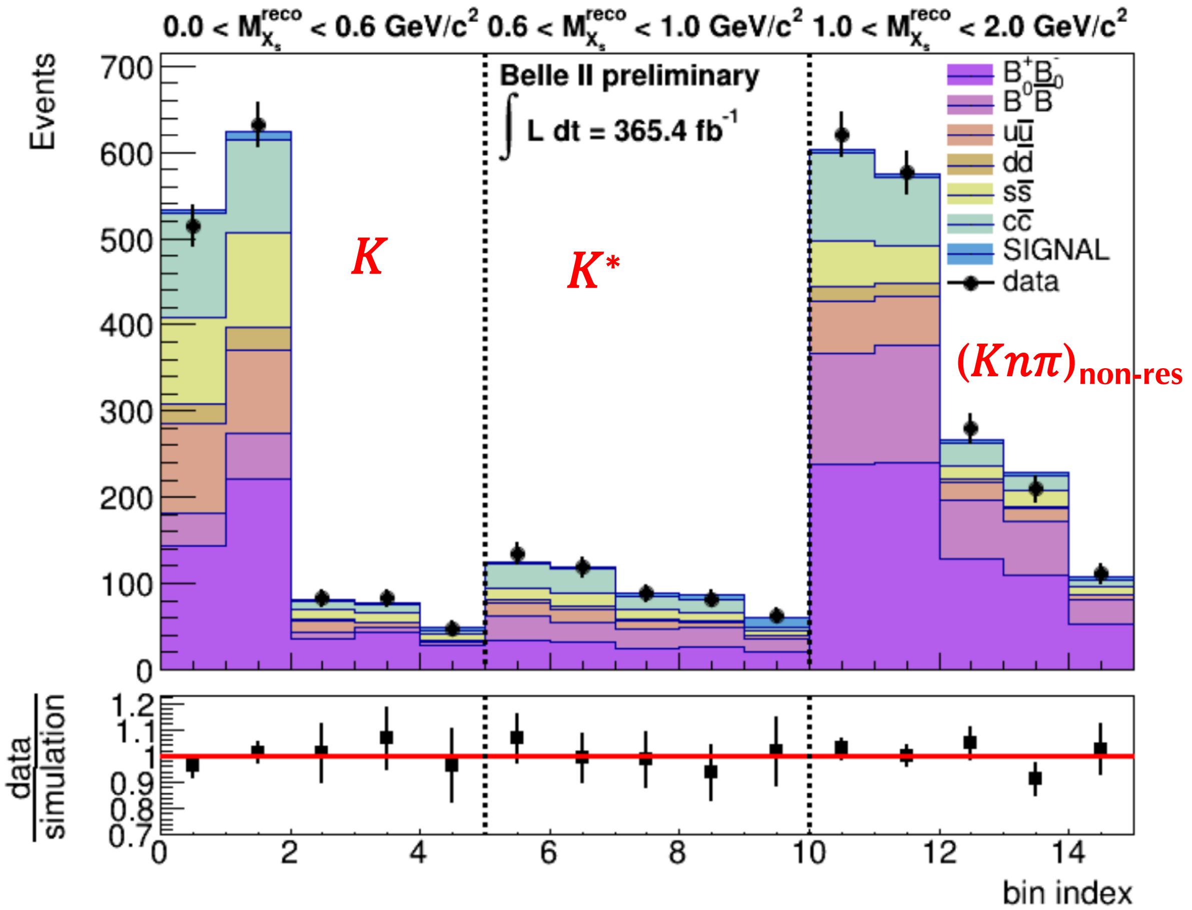
Inclusive $B \to X_s \nu\nu$ with hadronic tagging

[Belle II Preliminary]

- Probe flavor changing neutral currents (FCNC) in $b \to s\nu\nu$.
- The branching fraction for $B \to X_s\nu\nu$ is cleanly predicted to be $(2.9\pm0.3)\times10^{-5}$ in the SM [JHEP 02, 184 (2015)].



Maximum likelihood fit in $M_{X_s} \times \mathcal{O}_{BDT}$ with 3 × 5 bins:



			$\mathcal{B}$ $[10^{-5}]$		
M_{X_s} [GeV/c^2]	ϵ	N_{sig}	Central value	UL$_{obs}$	UL$_{exp}$
[0, 0.6]	0.29%	6^{+18+19}_{-17-16}	$0.3^{+0.8+0.9}_{-0.8-0.7}$	2.2	2.0
[0.6, 1.0]	0.12%	36^{+27+31}_{-26-26}	$3.5^{+2.6+3.1}_{-2.5-2.6}$	9.5	6.6
[1.0, $M_{X_s}^{max}$]	0.07%	24^{+44+62}_{-43-53}	$5.1^{+9.2+12.9}_{-8.8-11.0}$	31.2	26.7
Full range	0.10%	66^{+64+95}_{-62-81}	$8.8^{+8.5+12.6}_{-8.2-10.8}$	32.2	24.4

Full range:

$$\mathcal{B}(B \to X_s\nu\bar{\nu}) < 3.6 \times 10^{-4}\ (90\,\%\ \text{CL})$$

Most stringent upper limit on the inclusive rate

B rare decays

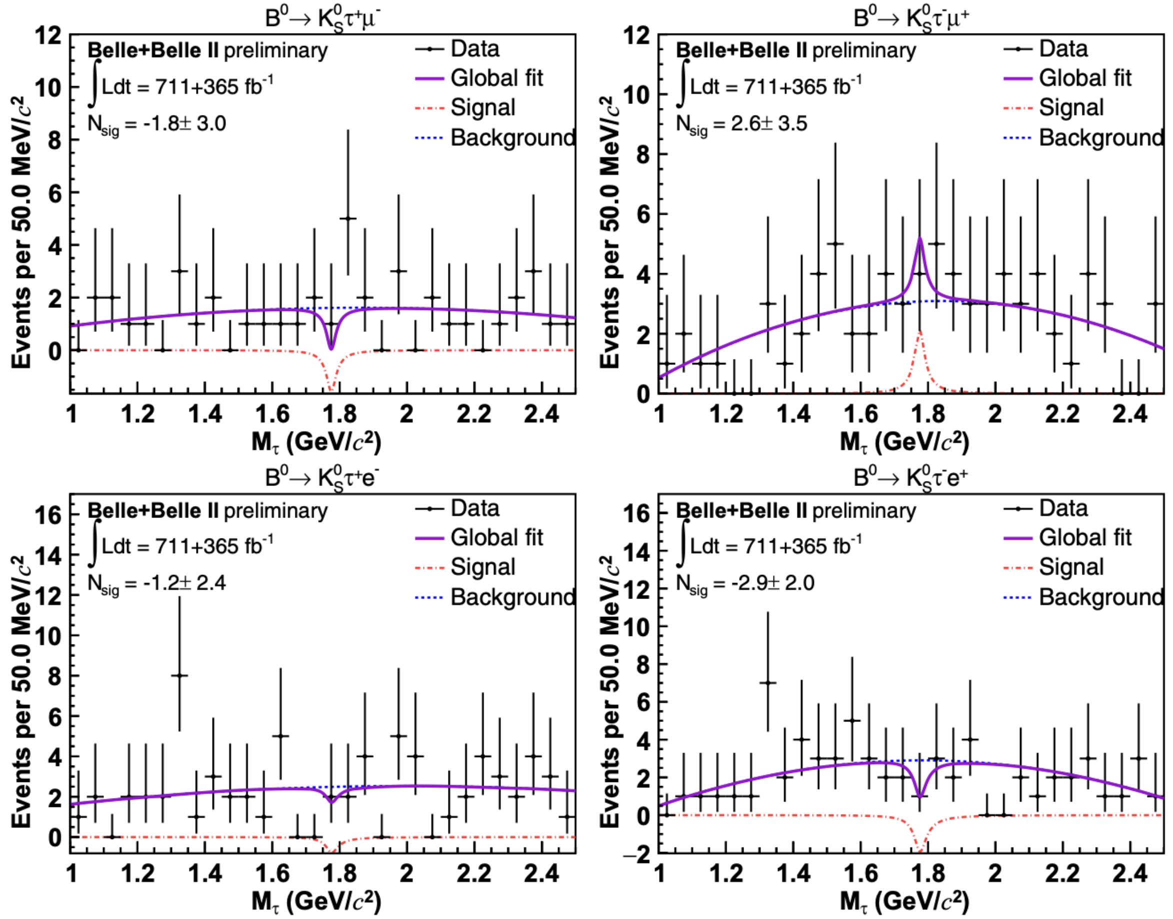
- Flavor changing neutral current processes are forbidden at tree level in SM.
- Lepton flavor-violating decays are forbidden in SM.
- The decay rates can be enhanced by physics beyond the SM.

➢ Use hadronic tagging

➢ No significant signals, and upper limits were set.

Channel	UL at 90% C.L.	Comments	References
$B^0 \to K_S^0 \tau^\pm \ell^\mp$	3.6×10^{-5}	Best limits	PRL 135, 041801 (2025)
$B^0 \to K^{*0} \tau^\pm \ell^\mp$	6.4×10^{-5}	LHCb: 5.9×10^{-6} (e mode) 1.0×10^{-5} (μ mode)	JHEP 08 (2025) 184
$B^0 \to K^{*0} \tau^+ \tau^-$	1.8×10^{-3}	Best limits	arXiv:2504.10042, PRL accepted
$B^+ \to K^+ \tau^+ \tau^-$	0.9×10^{-3}	Best limits	Belle II preliminary

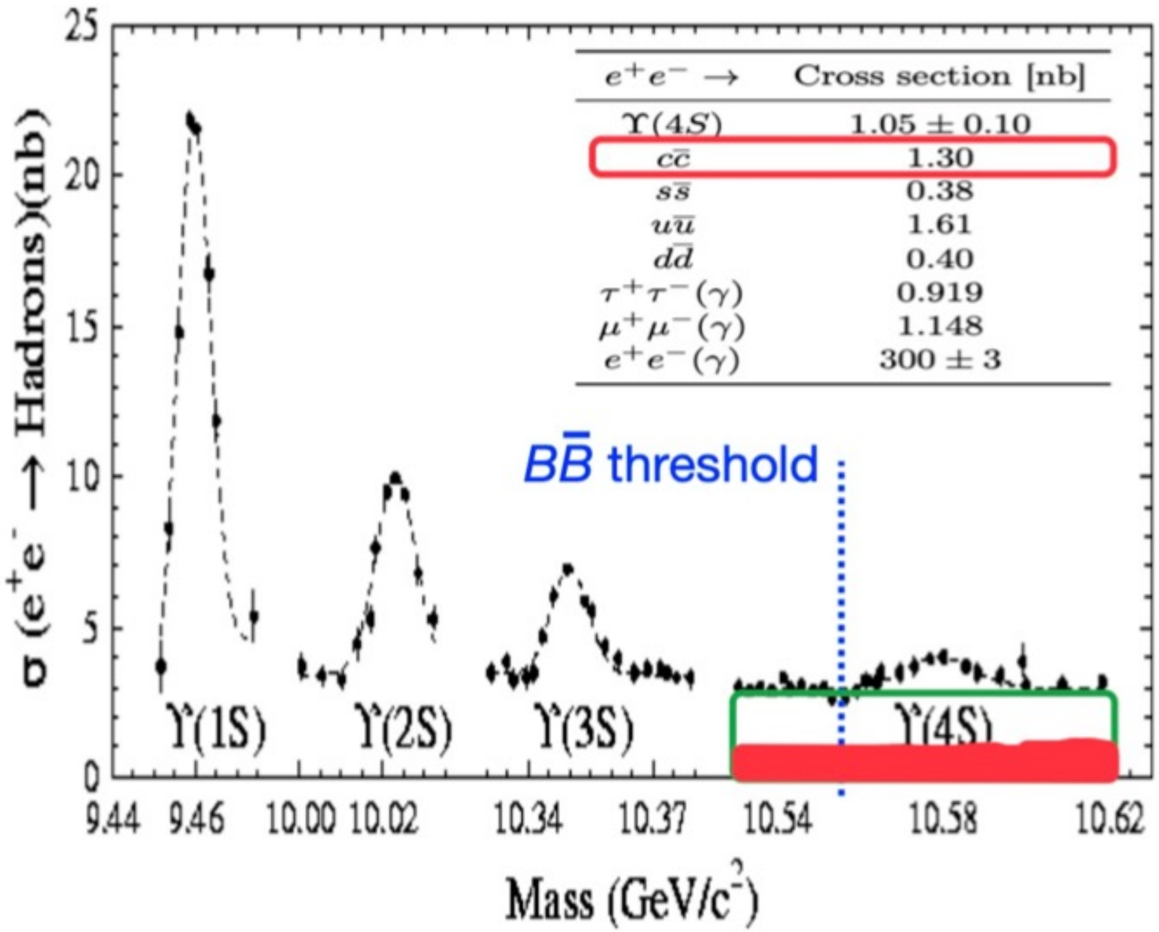
$B^0 \to K_s^0 \tau^\pm \ell^\mp$



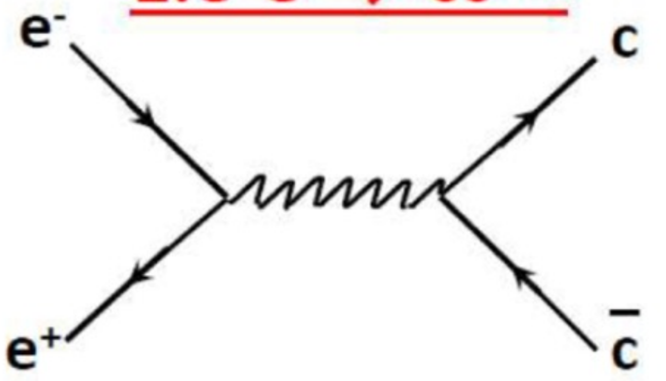
Charm

Charm production at Belle II

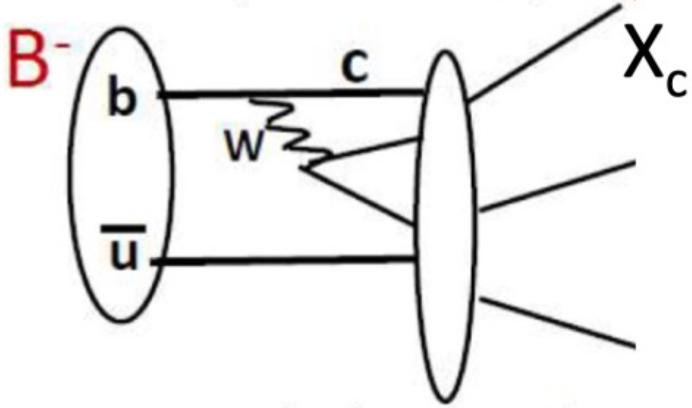
- At Belle II, e^+e^- mainly collide at 10.58 GeV to make $\Upsilon(4S)$ resonance mainly decaying into $B\bar{B}$.
- Meanwhile, **continuum processes $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) have large cross sections**.
- Two ways to produce charm samples: **1) $e^+e^- \to c\bar{c}$, and 2) $B \to$ charm decays**.



1.$e^+e^- \to cc^{bar}$

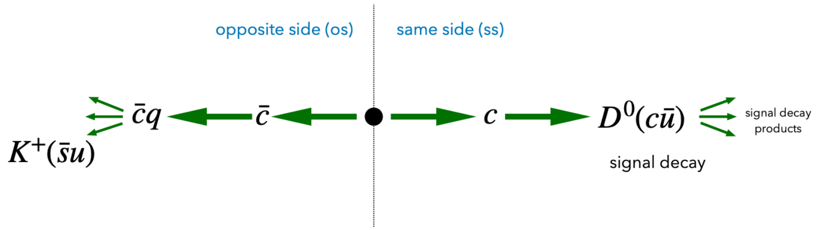


2.B-decay



Charm CPV

New Charm-flavor-tag (CFT) D^0:



- The D → ππ decays help to determine the source of CPV:

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

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

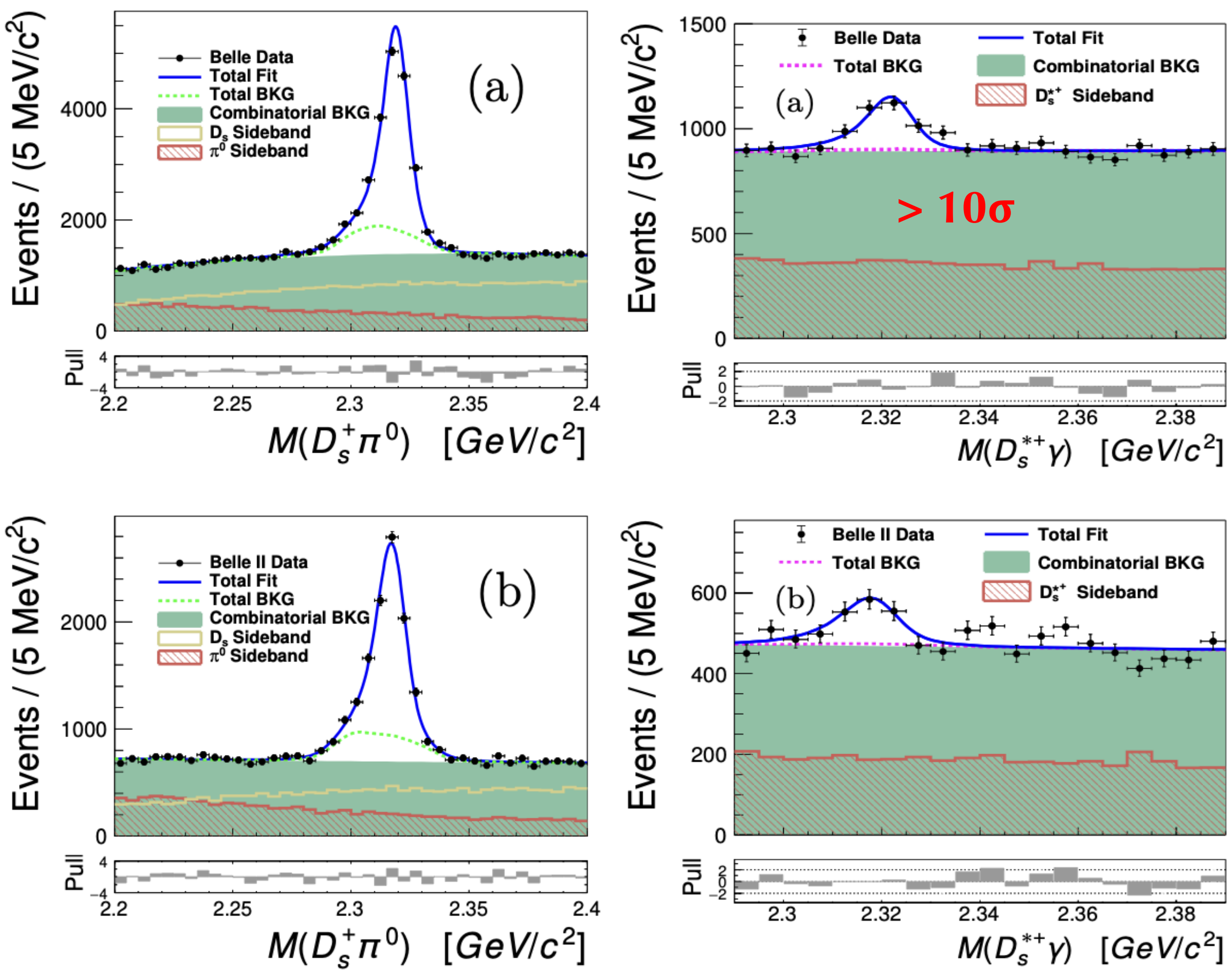
Search for Charm CPV in following channels:

Channel	A_{CP}	References
$D^0 \to \pi^0\pi^0$	$(+0.3\pm0.7\pm0.2)\%$	PRD 112, 012006 (2025)
$D^+ \to \pi^+\pi^0$	$(-1.8\pm0.9\pm0.1)\%$	PRD 112, L031101 (2025)
$D^0 \to \pi^+\pi^-\pi^0$	$(0.3\pm0.3\pm0.1)\%$	Preliminary result
$D^0 \to K_S^0K_S^0$	$(-0.6\pm1.1\pm0.1)\%$	PRD 111, 012015 (2025), PRD 112, 012017 (2025)
$D^+, D_s^+ \to K_S^0K^-\pi^+\pi^+$	$(+3.9\pm4.5\pm1.1)\%$, $(-0.2\pm2.5\pm1.1)\%$	JHEP 04 (2025) 036
$\Lambda_c^+ \to \Lambda K^+$, Σ^0K^+	$(+2.1\pm2.6\pm0.1)\%$, $(+2.5\pm5.4\pm0.4)\%$	Sci. Bull. 68 (2023) 583
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	$(+3.9\pm1.7\pm0.7)\%$, $(+0.3\pm1.0\pm0.2)\%$	Preliminary result
$\Xi_c^+ \to \Sigma^+K^+K^-$, $\Sigma^+\pi^+\pi^-$	$(+3.7\pm6.6\pm0.6)\%$, $(+9.5\pm6.8\pm0.5)\%$	Preliminary result

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

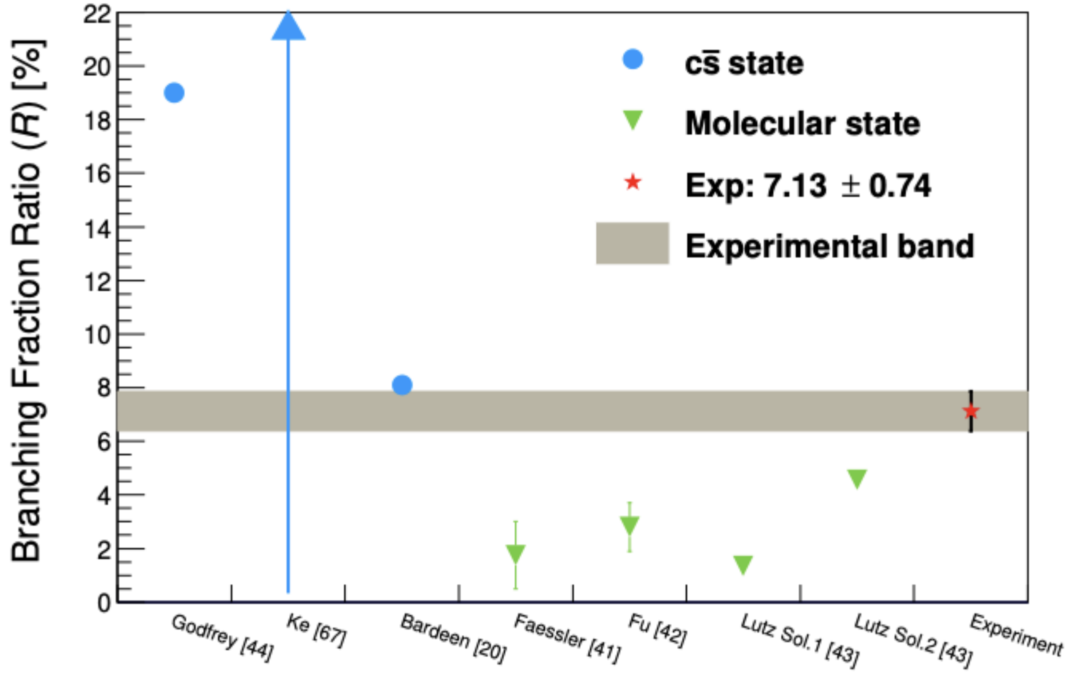
- Target: $D_{s0}^{*}(2317)^{+} \to D_s^{*+}\gamma$
- Control channel: $D_{s0}^{*}(2317)^{+} \to D_s^{+}\pi^{0}$ ($Br = (100^{+0}_{-20})\%$)

Partial decay widths:
unique in discriminating between various models



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

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



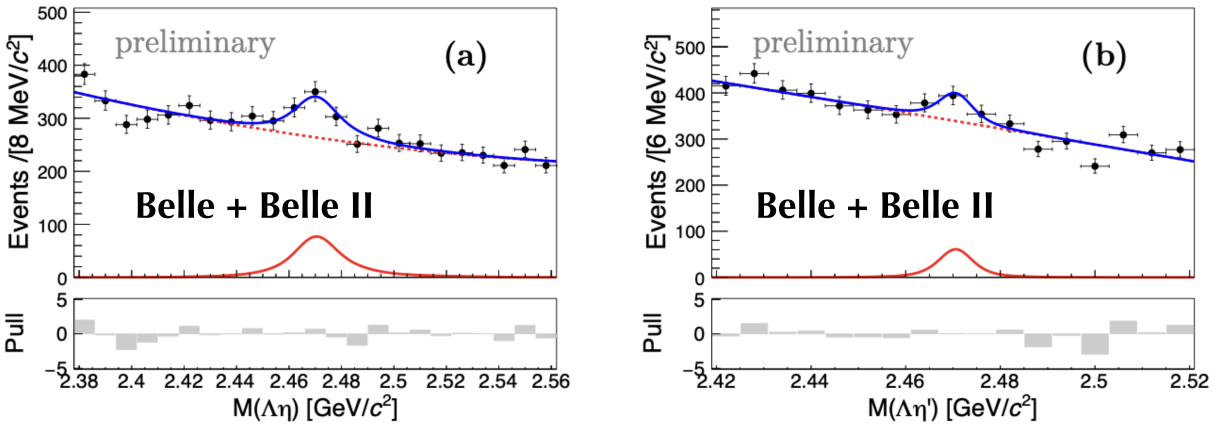
$D_{s0}(2317)^{+}$ could be the mixture state of pure $c\bar{s}$ state and molecular state.

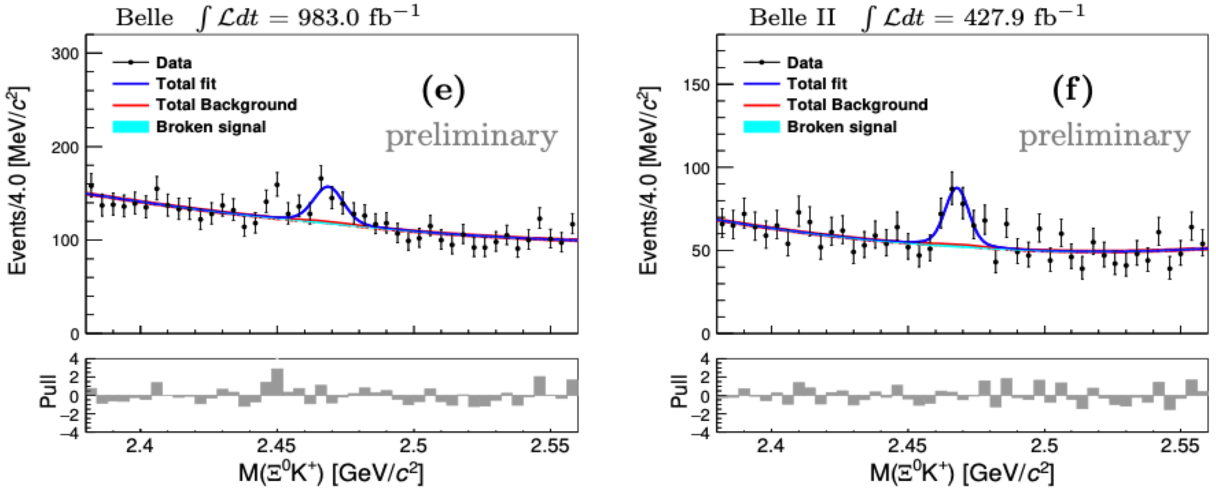
Ξ_c^+ and Ξ_c^0 decays

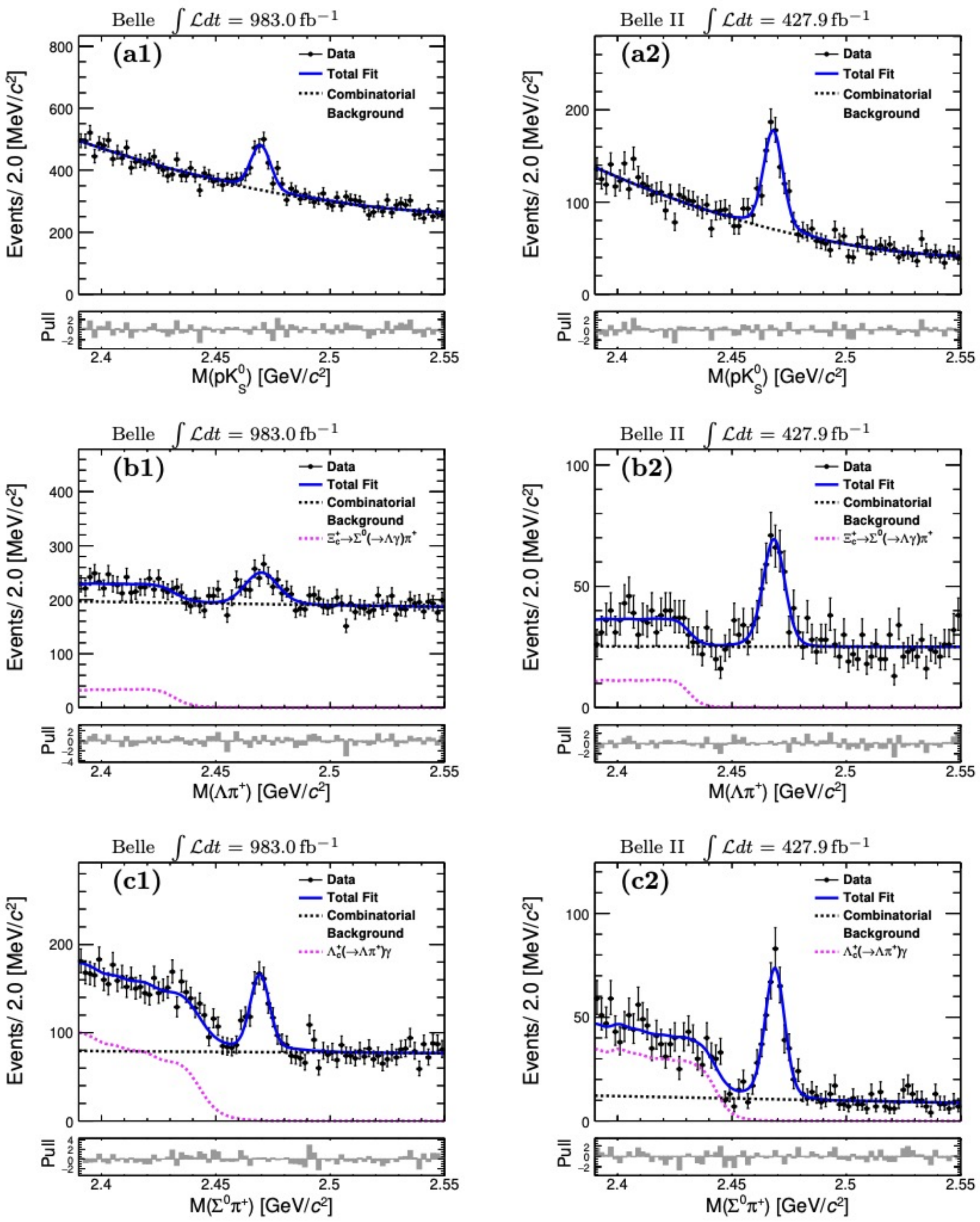
$e^+e^- \to \Xi_c^+/\Xi_c^0$ + anything

Reconstruct:

- $\Xi_c^0 \to \Lambda\eta$, $\Xi_c^0 \to \Lambda\eta'$ (singly Cabibbo-suppressed (SCS))
- $\Xi_c^+ \to \Xi^0 K^+$, $\Xi_c^+ \to pK_s^0$, $\Xi_c^+ \to \Lambda\pi^+$, $\Xi_c^+ \to \Sigma^0\pi^+$ (SCS)





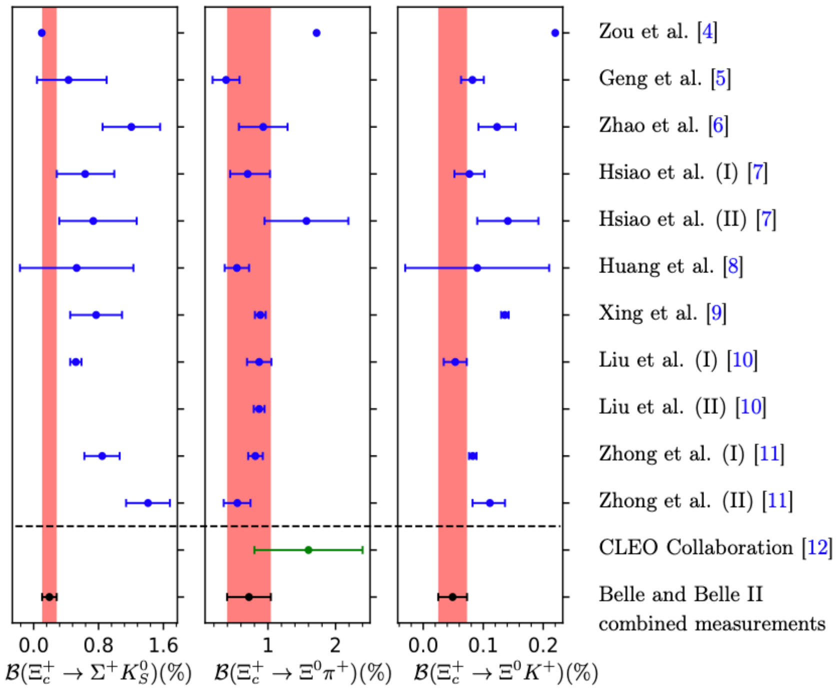


Branching fractions

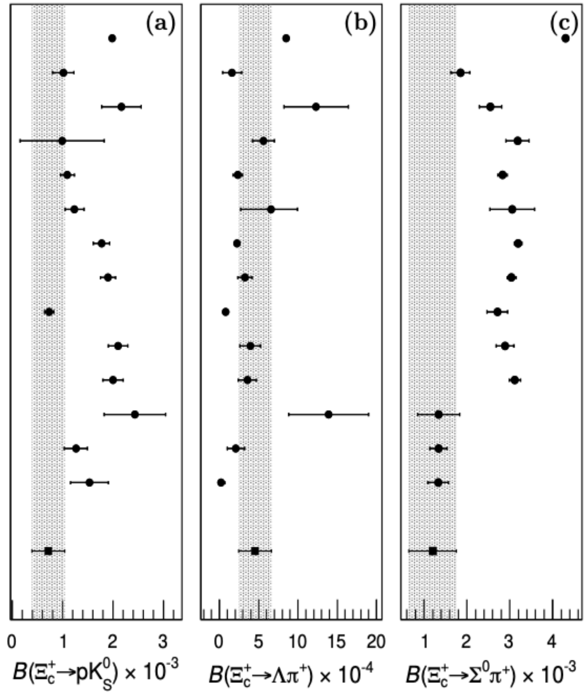
First or most precise measurements!

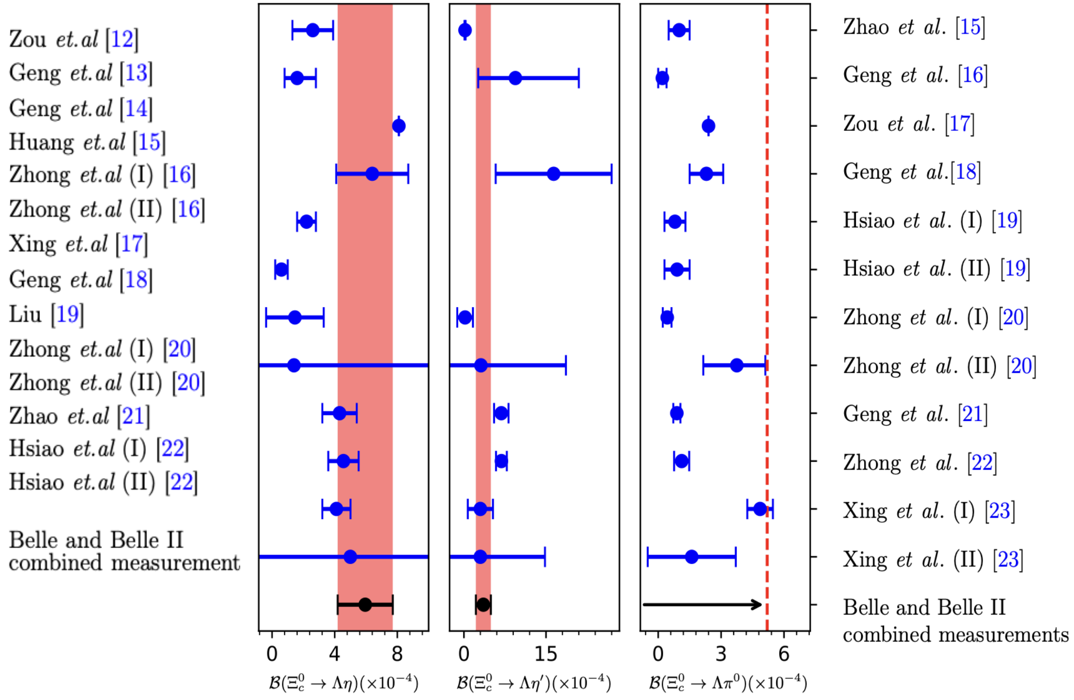
- In hadronic weak decays of charmed baryons, nonfactorizable contributions play an essential role and cannot be neglected.
- Various approaches describe the nonfactorizable effects: the covariant confined quark model, the pole model (Pole), current algebra (CA), and, $SU(3)_F$ flavor symmetry.

[JHEP 08 (2025) 195]



[JHEP 03 (2025) 061]





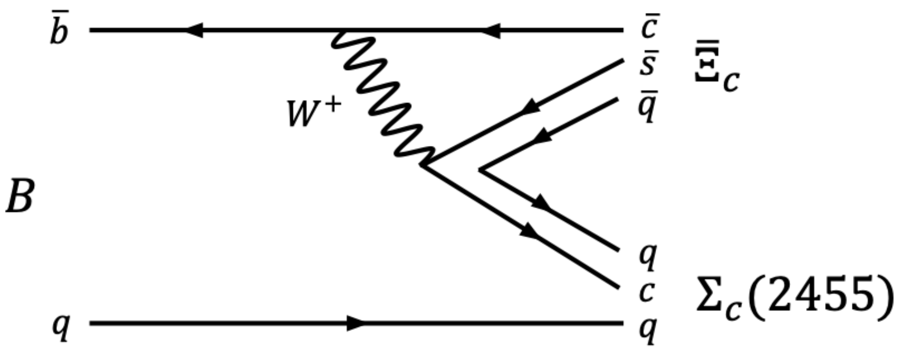
[Belle II Preliminary]

Next steps: 1. Explore three-body decays; 2. Amplitude analyses to search for new intemediate states and identify J^P.

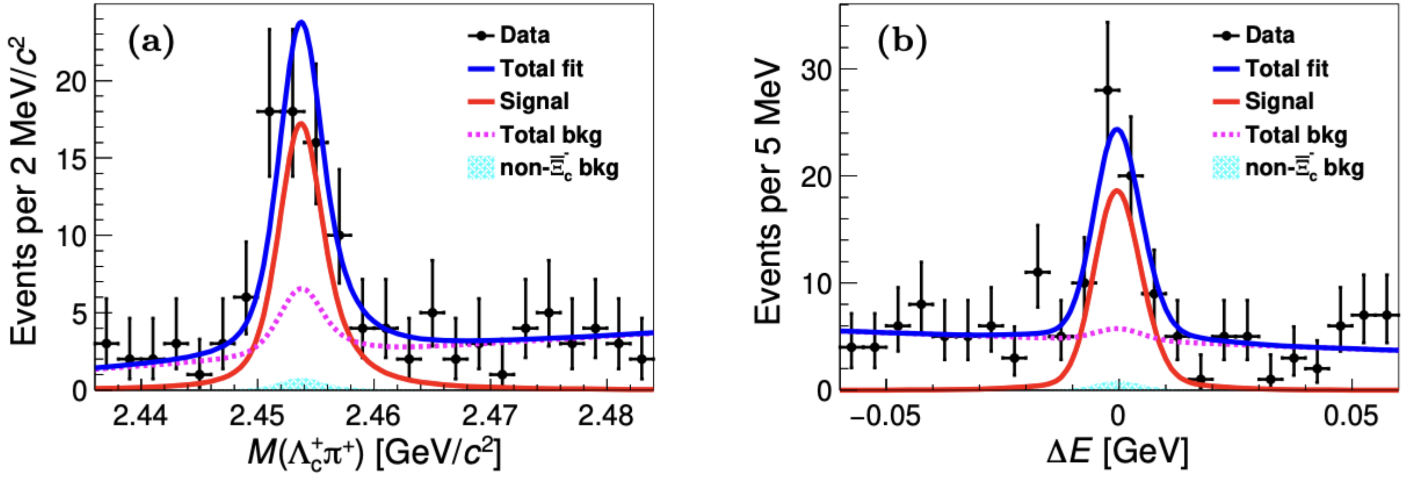
$\mathbf{B^{+,0} \to \Sigma_c(2455)^{++,0}\bar{\Xi}_c^{-,0}}$

[PRD 112 (2025) L051101]

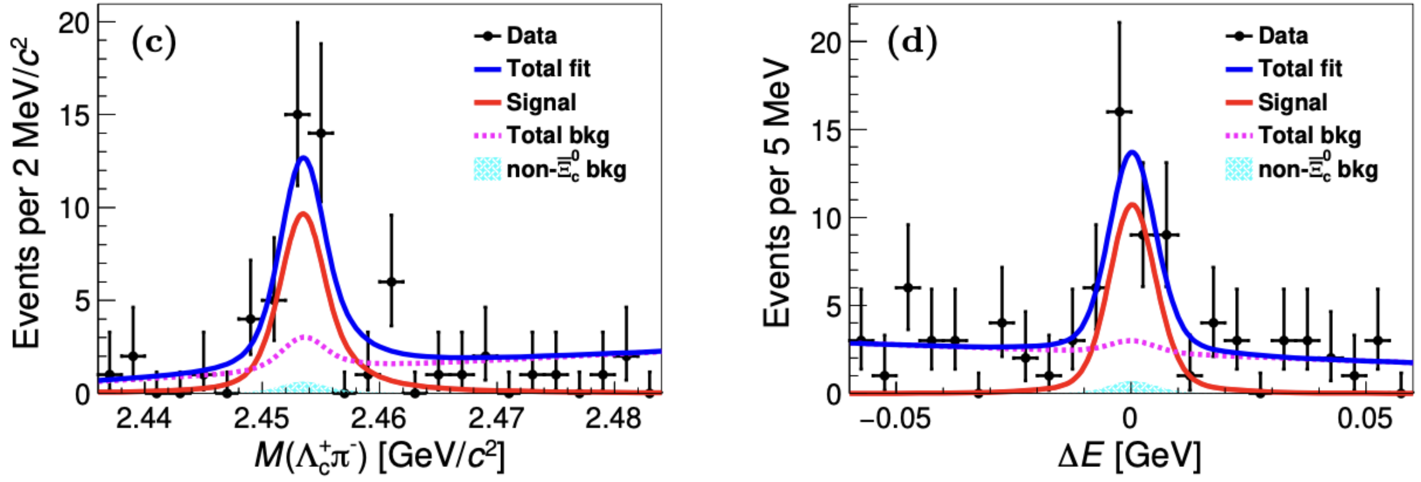
These two decays proceed through a purely internal W-emission:



$B^+ \to \Sigma_c^{++}\bar{\Xi}_c^-$



$B^0 \to \Sigma_c^0\bar{\Xi}_c^0$



To date, no B decays into charmed baryon pairs containing both a sextet and an antitriplet have been observed.

$$\mathcal{B}(B^+ \to \Sigma_c^{++}\bar{\Xi}_c^-) = (5.74 \pm 1.11 \pm 0.42^{+2.47}_{-1.53}) \times 10^{-4}$$

$$\mathcal{B}(B^0 \to \Sigma_c^{0}\bar{\Xi}_c^0) = (4.83 \pm 1.12 \pm 0.37^{+0.72}_{-0.60}) \times 10^{-4}$$

First observations!

quarkoium

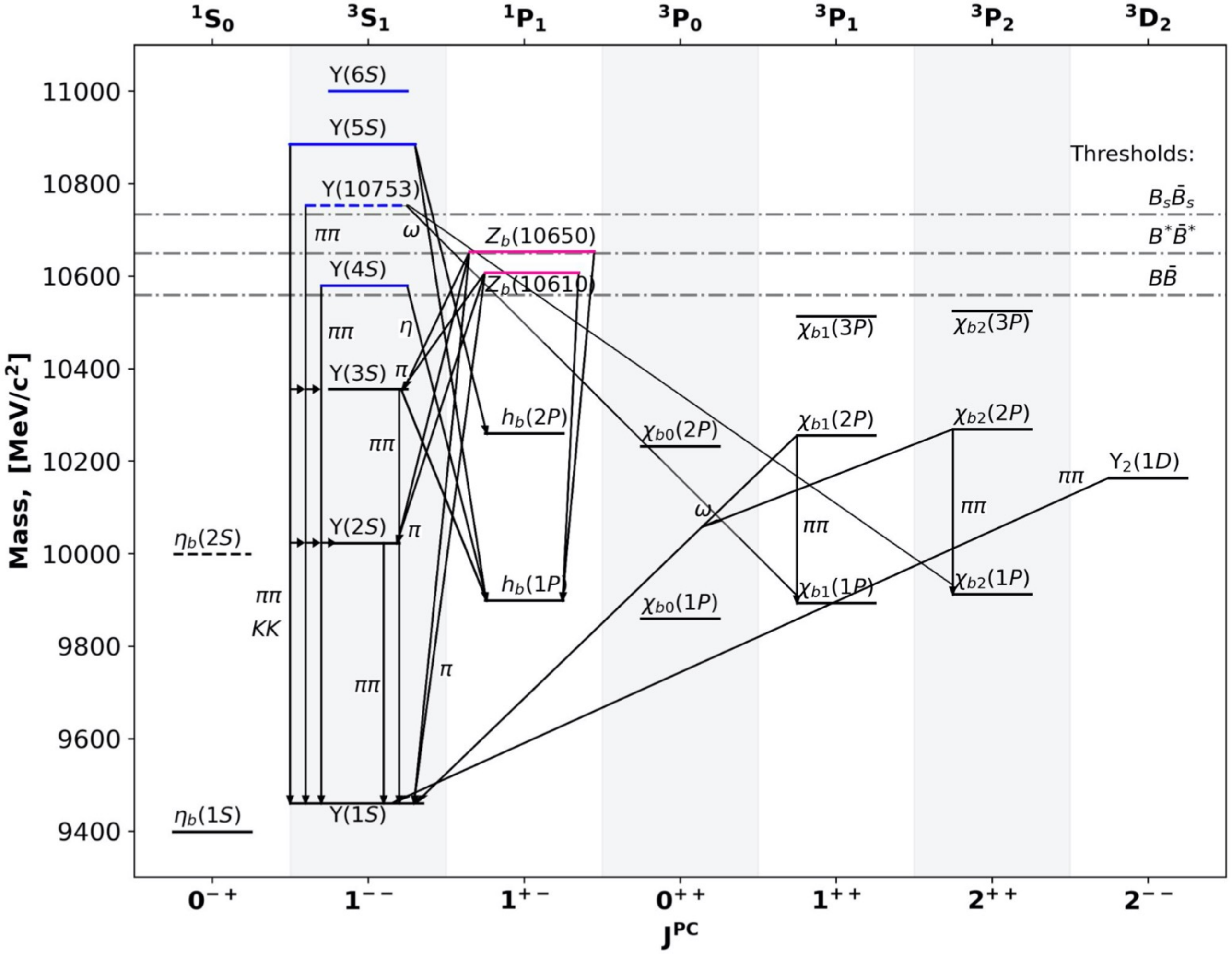
Bottomonium

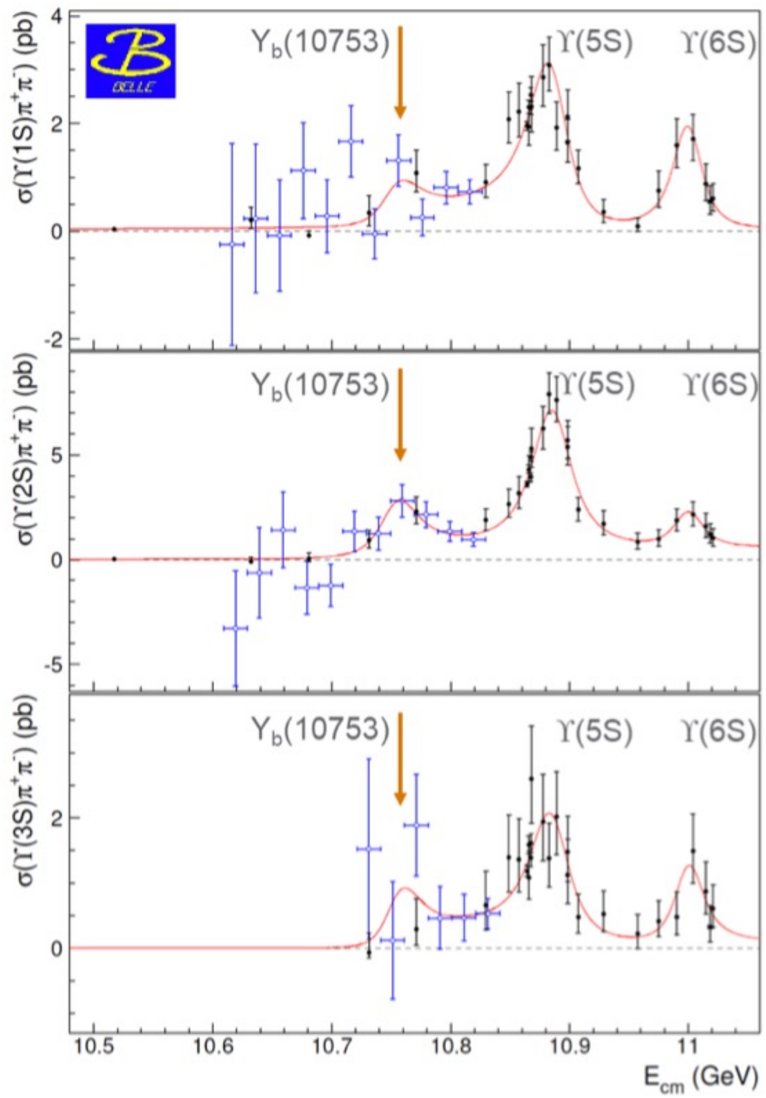
The $\Upsilon(10753)$ was first discovered in $\pi^+\pi^-\Upsilon(nS)$ final states using scan data by Belle [JHEP 10, 220 (2019)].

Conventional bottomonium (pure $b\bar{b}$ states)

Bottomonium-like states (mix of $b\bar{b}$ and $B\bar{B}$)

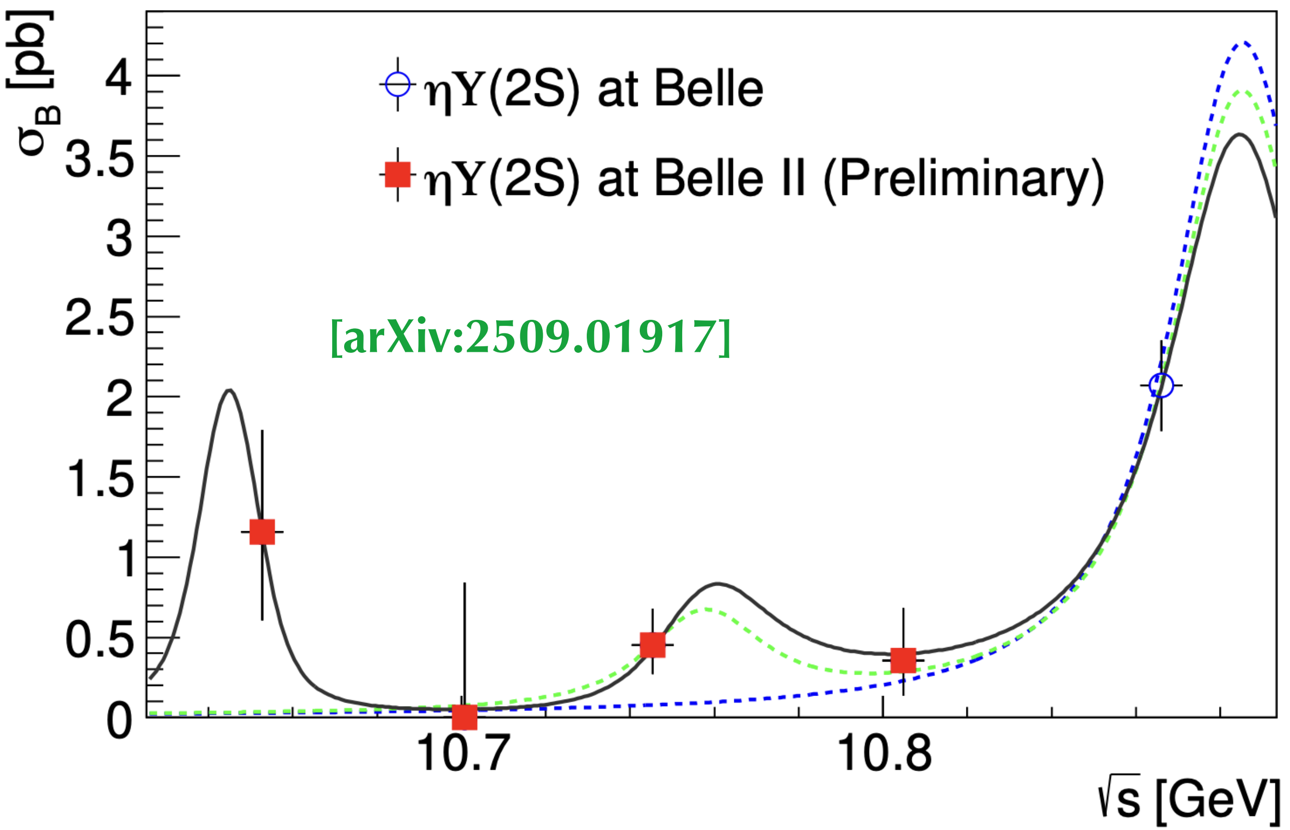
Exotic charged states (Z_b^+)



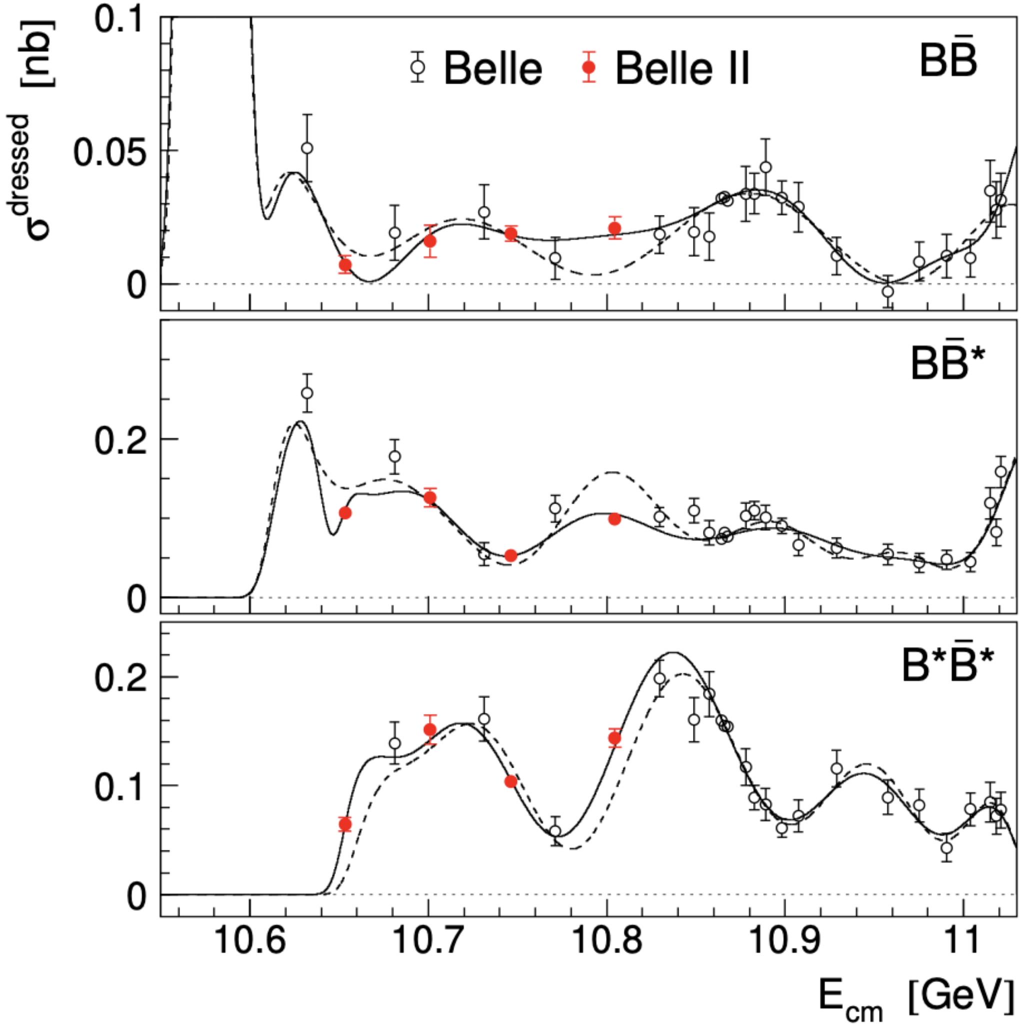


Belle II collected **19 fb⁻¹ of unique data around $\sqrt{s} \sim$ 10.75 GeV** to study the nature of the $\Upsilon(10753)$.

$e^+e^- \to \eta\Upsilon(2S)$ and $e^+e^- \to B^{(*)}\bar{B}^{(*)}$



[JHEP 10 (2024) 114]

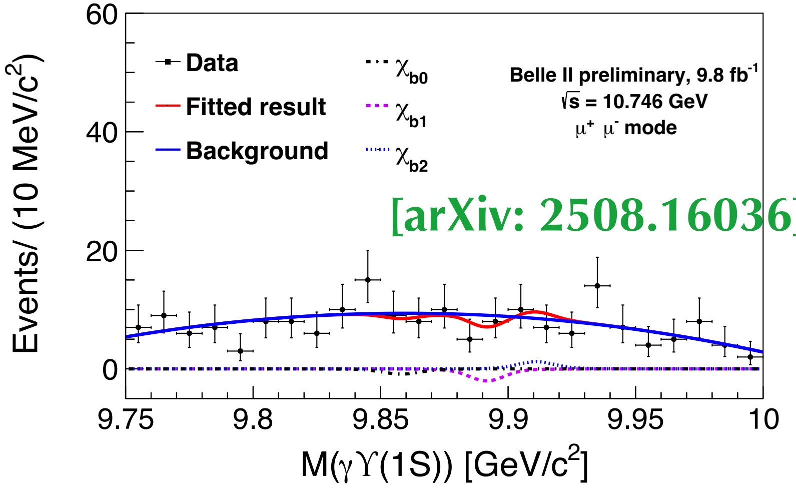


- The Born cross section of $e^+e^- \to \eta\Upsilon(2S)$ around $B^*\bar{B}^*$ mass is relatively large.
- The significance of $B^*\bar{B}^*$ bound state is larger than 3.2σ.

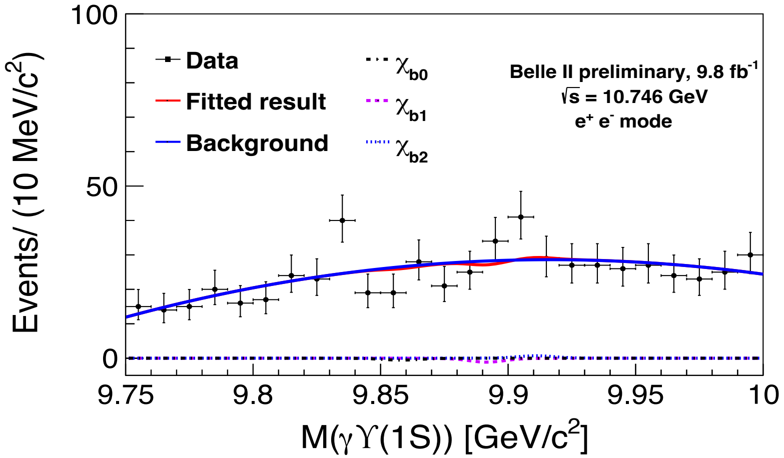
Rapid increase of $\sigma_{B^*\bar{B}^*}$ just above the threshold.

A new bottomonium-like state around $B^*\bar{B}^*$ threshold?
The $Y_b(10650)$ is predicted in Refs. [arXiv:2505.02742, arXiv:2508.11127, arXiv:2505.03647].

$e^+e^- \to \gamma\chi_{bJ}$ and $e^+e^- \to \pi^+\pi^-\Upsilon_J(1D)$

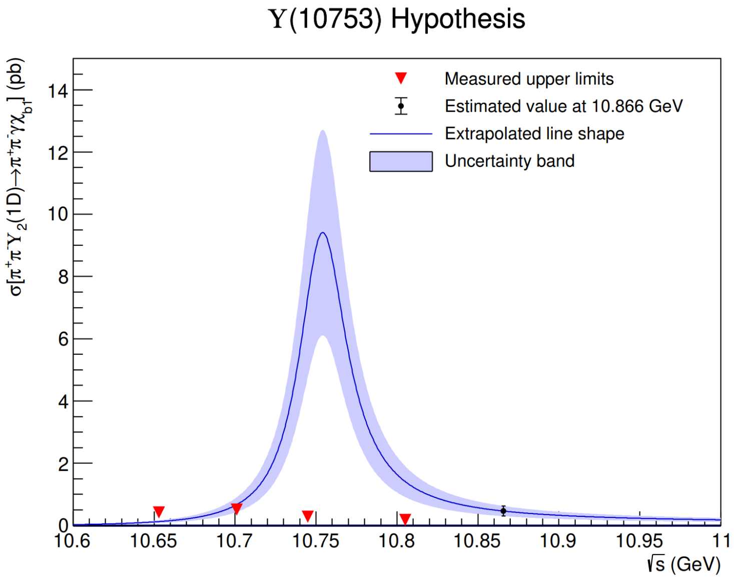


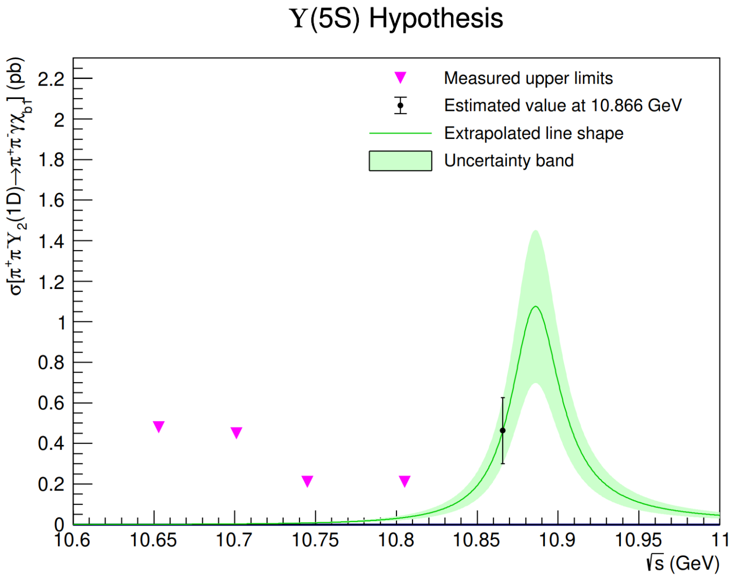
[arXiv: 2508.16036]



[Belle II Preliminary]

Inverted triangles: the 90% C.L. upper limits on the product $\sigma(e^+e^- \to \pi^+\pi^-\Upsilon_2(1D))\mathcal{B}(\Upsilon_2(1D) \to \gamma\chi_{b1})$ as a function of C.M. energy.

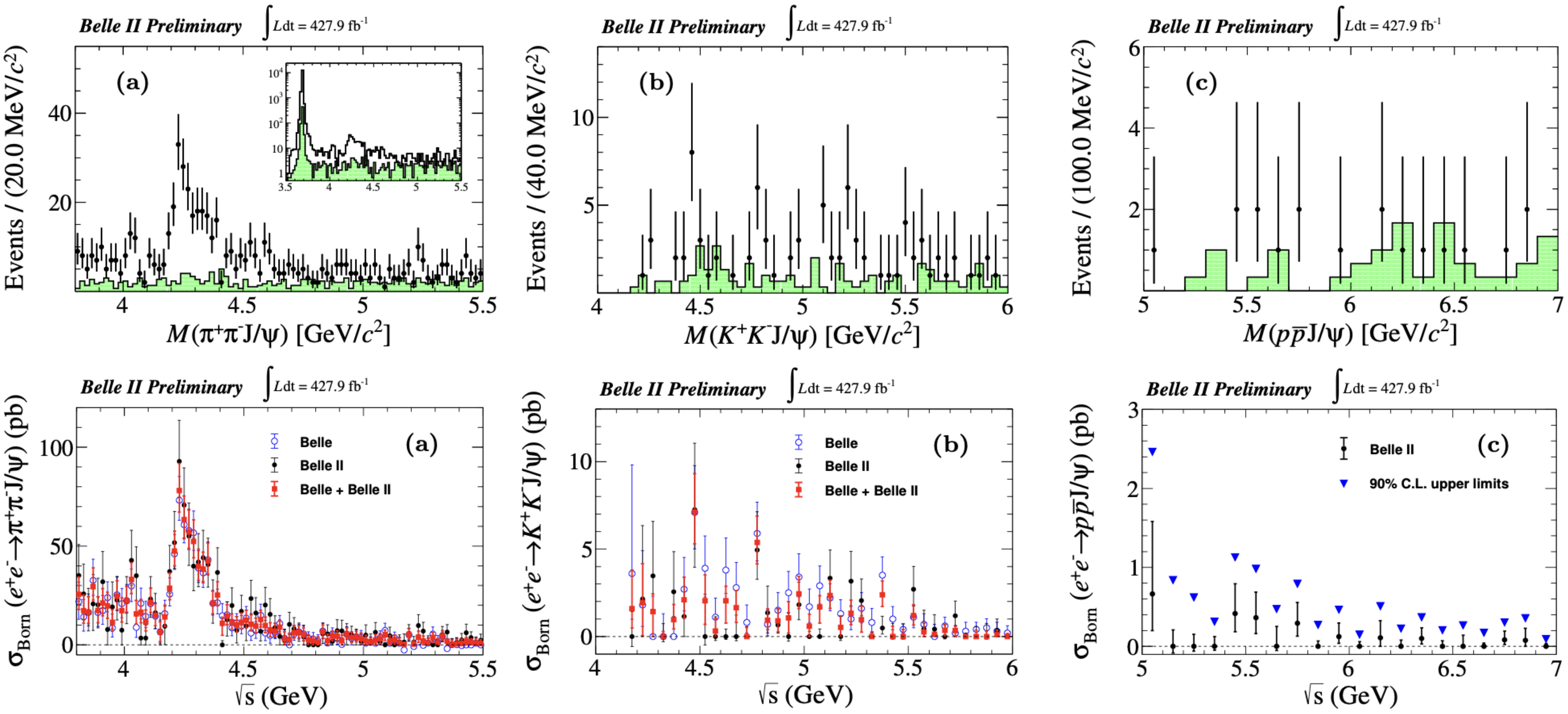




- **A pronounced suppression in the coupling of the $\Upsilon(10753)$ resonance to $\Upsilon_J(1D)$ states via dipion transitions.**
- **The upper limits do not conflict with the $\Upsilon(10860)$ line shape.**

- **No clear signal of $e^+e^- \to \gamma\chi_{bJ}$ can be seen.**
- **$\sigma^{UL}_{Born}(e^+e^- \to \gamma\chi_{b1})$ at 90% C.L. at $\sqrt{s}$ = 10.746 GeV is 0.25 pb**
- **This measurement indicates that the $\Upsilon_b(10753)$ maybe not a $\Upsilon_2(2D)$ state**

$e^+e^- \rightarrow h^+h^-J/\psi$ (h = π, K, p) via initial-state radiation at Belle II



- We can see Y(4008) and Y(4260) signals.
- No clear signals were found in K^+K^-J/ψ and $p\bar{p}J/\psi$ systems.

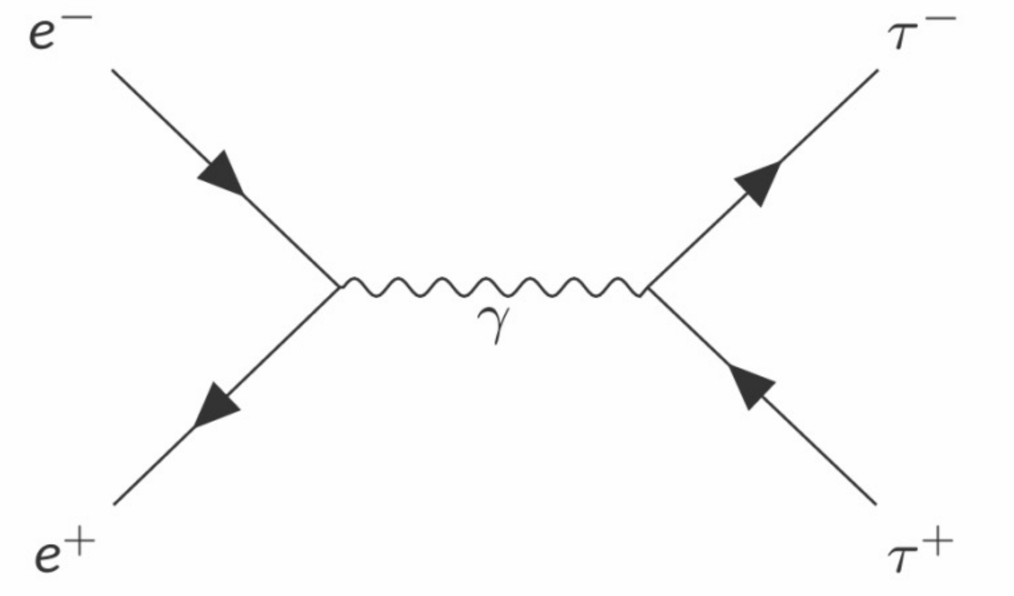
Tau

τ physics

SuperKEKB as a ***τ factory***

≫ τ mass and lifetime, lepton flavor violation, CKM unitarity, CP violation, ...

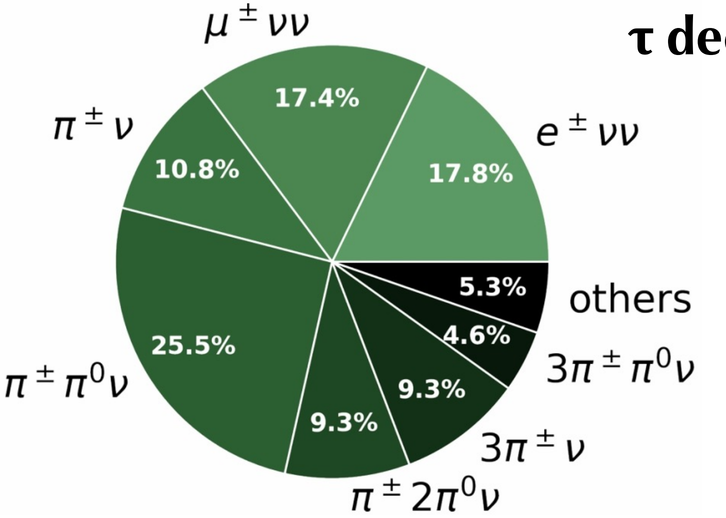
- e^+e^- collider produce τ lepton pairs at high rate



$$\sigma(e^+e^- \to \tau^+\tau^-) = 0.92\ nb$$

$$\sigma(e^+e^- \to B\bar{B}) = 1.05\ nb$$

τ decay modes



Advantages at Belle II:
- ✓ High luminosity
- ✓ Good vertexing and tracking capabilities
- ✓ Good trigger system and particle ID

Lepton-flavor violation in τ physics

[JHEP 08 (2025) 092]

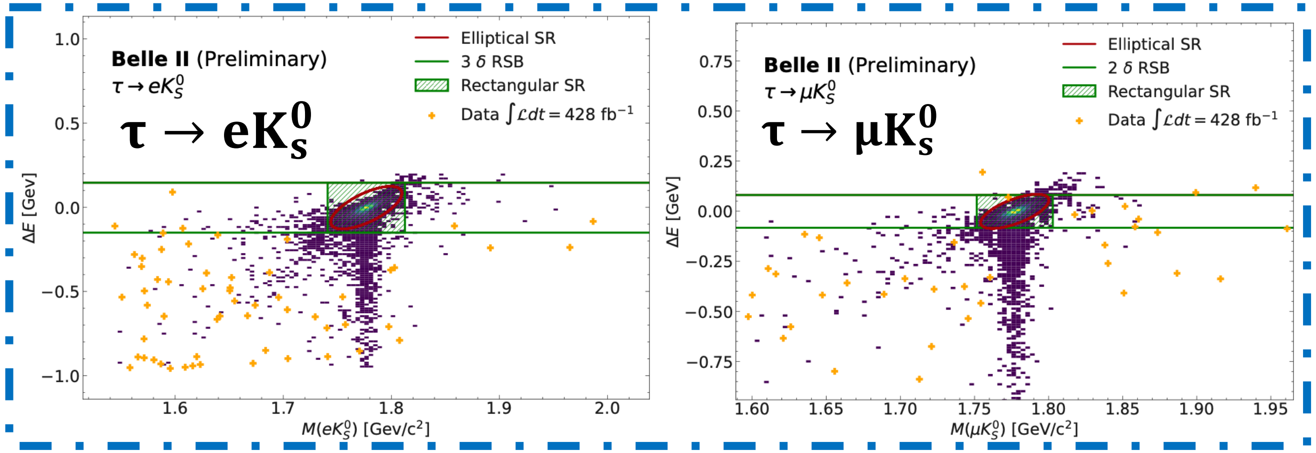
Lepton flavour violation is only allowed by:

- **Neutrino oscillations** $\mathcal{O}(10^{-55})$

far beyond current experimental sensitivities

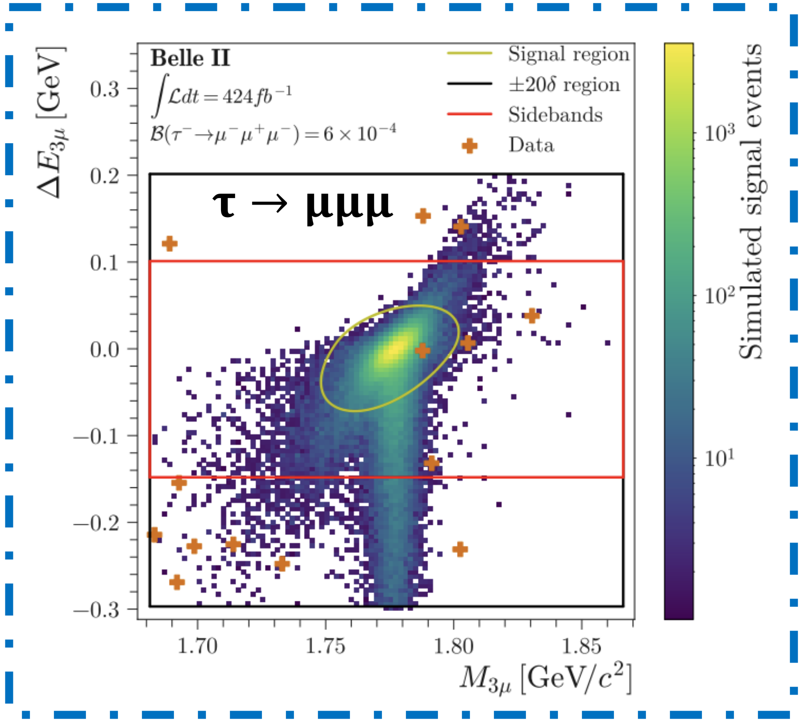
- **New Physics models** $\mathcal{O}(10^{-8})$

e.g. Leptoquarks for $\tau^- \to \ell^- V^0$ deals with $R(K^{*0})$ anomalies

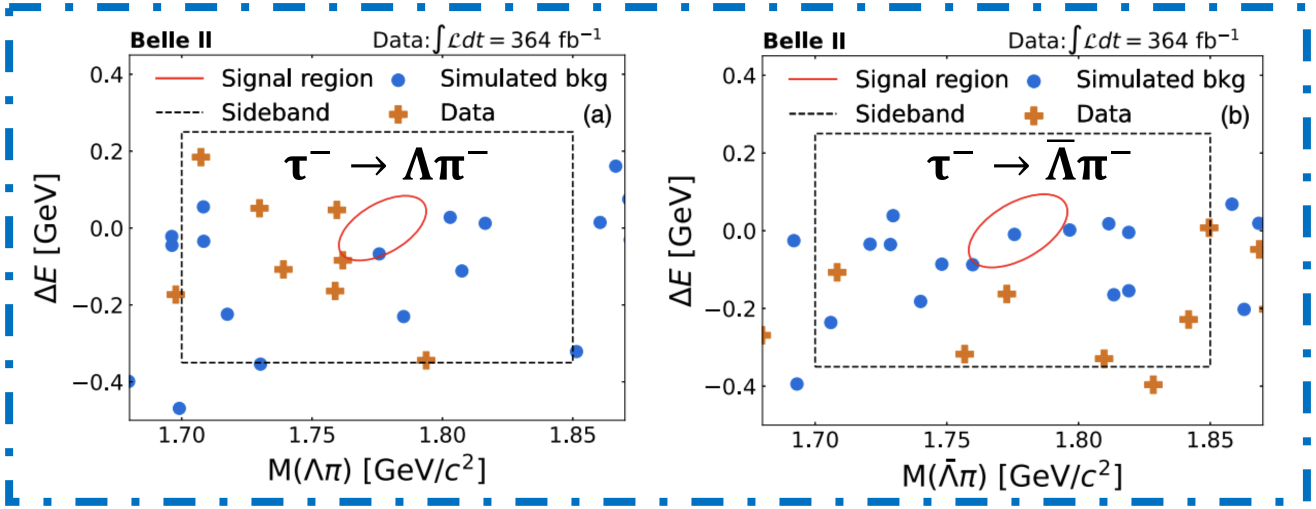


[JHEP 09 (2024) 062]

[PRD 110, 112003 (2024)]



$$\Delta E_{3\mu} = E_\tau^* - \sqrt{s}/2$$



$\mathcal{B}^{UL}(\tau \to e(\mu)K_S^0) < 0.8(1.2)\times 10^{-8}$	The most stringent constraints
$\mathcal{B}^{UL}(\tau \to \mu\mu\mu) < 1.9\times 10^{-8}$	Less data, more restrictive than Belle
$\mathcal{B}^{UL}(\tau^- \to \Lambda\pi^-(\bar{\Lambda}\pi^-)) < 4.7(4.3)\times 10^{-8}$	The most stringent constraints

Summary

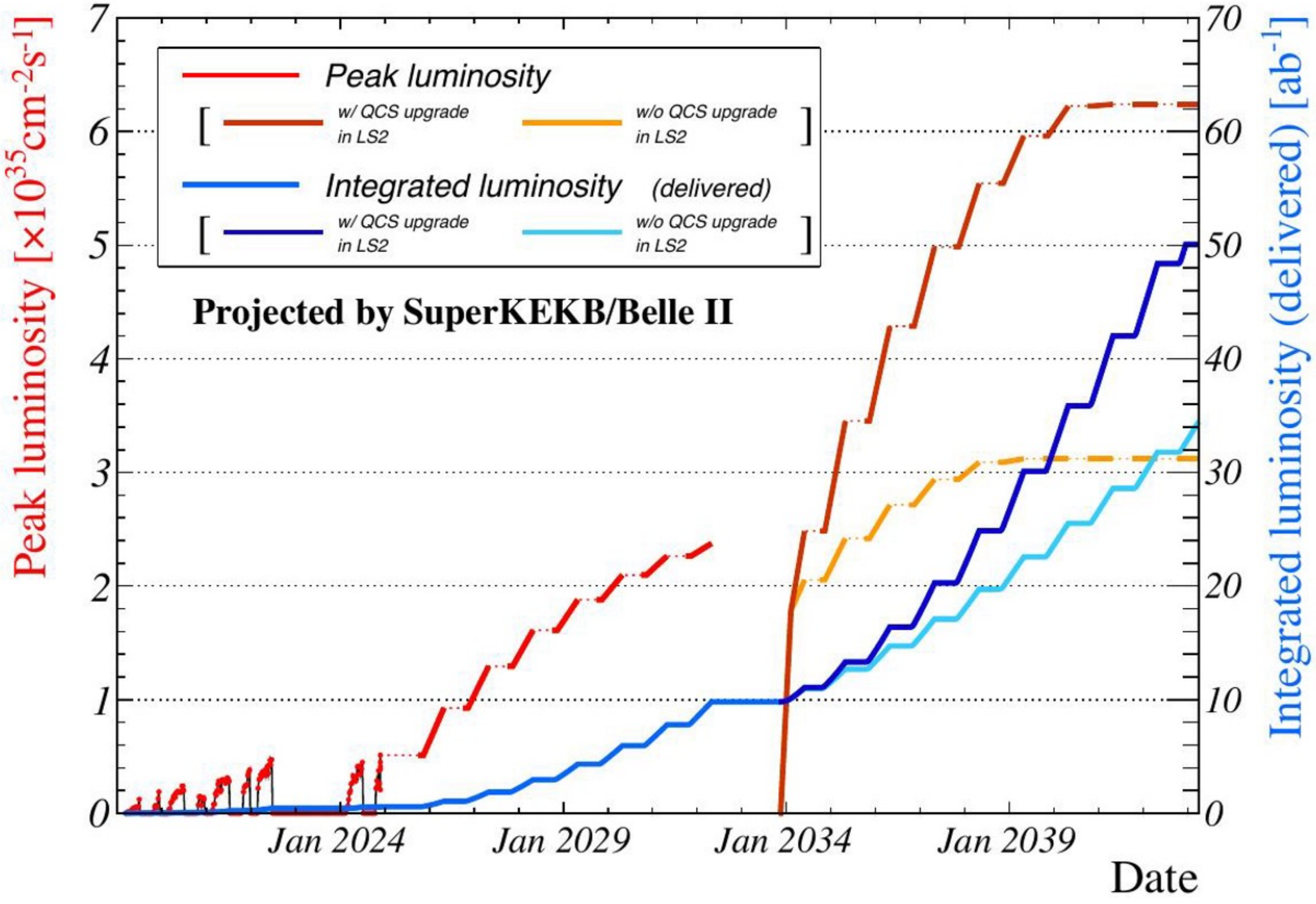
- Belle II: new data + new vertex detectors + new software tools
  - B CPV/semi-leptonic/rare, charm CPV/BF/α/spectrum $\Longleftarrow$ recoiling/γ/π^0/K_s^0/ν etc.
  - Exotic states, τ physics, dark sectors $\Longleftarrow$ special data at e^+e^- collider

- Only 1% of target luminosity collected so far. Until 2026, about 1 ab^{-1} data at Belle II. Stay tuned for more exciting results from Belle II.

Thanks for your attention!

Backup slides

Data-taking plan at Belle II



- **Until 2026, about 1 ab^{-1} data, comparable to Belle**
- **Until 2029, about 4 ab^{-1} data.**

Search for CPV in $B^0 \to \rho^+\rho^-$

Table VI. Systematic uncertainties for $\mathcal{B}$ and f_L. Relative uncertainties are shown for $\mathcal{B}$.

Source	$\mathcal{B}$ [%]	$f_L[10^{-2}]$
Tracking	±0.54	—
π^0 efficiency	±7.67	—
PID	±0.08	—
$\mathcal{T}_C$	±2.87	—
MC sample size	±0.24	±0.2
Single candidate selection	±0.55	±0.3
SCF ratio	$^{+2.97}_{-2.45}$	$^{+0.2}_{-0.3}$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.94}_{-0.98}$	±0.1
$\tau^+\tau^-$ background yield	$^{+0.65}_{-0.69}$	±0.0
Signal model	$^{+1.14}_{-2.02}$	±0.2
$q\bar{q}$ model	$^{+0.49}_{-0.51}$	$^{+0.1}_{-0.2}$
$B\bar{B}$ model	$^{+1.00}_{-0.40}$	$^{+0.3}_{-0.1}$
$\tau^+\tau^-$ model	$^{+0.17}_{-0.26}$	$^{+0.0}_{-0.1}$
Peaking model	$^{+1.37}_{-1.01}$	$^{+0.3}_{-0.5}$
Interference	±1.20	±0.5
Data-MC mis-modeling	$^{+3.51}_{-1.70}$	$^{+0.8}_{-0.3}$
Fit bias	±1.03	±1.2
f_{00}	$^{+1.67}_{-1.50}$	—
$N_{\Upsilon(4S)}$	±1.45	—
Total systematic uncertainty	$^{+10.10}_{-9.51}$	$^{+1.7}_{-1.5}$
Statistical uncertainty	$^{+7.95}_{-7.61}$	$^{+2.4}_{-2.5}$

Table VII. Systematic uncertainties for S and C.

Source	$S[10^{-2}]$	$C[10^{-2}]$
$\mathcal{B}$'s of peaking backgrounds	$^{+0.6}_{-0.5}$	±0.1
$\tau\tau$ background yield	±0.9	$^{+0.0}_{-0.1}$
Data-MC mis-modeling	$^{+0.6}_{-1.1}$	$^{+1.5}_{-0.6}$
Single candidate selection	±1.3	±1.9
SCF ratio	$^{+0.5}_{-0.4}$	$^{+0.7}_{-0.0}$
Signal model	$^{+1.1}_{-1.4}$	$^{+0.3}_{-0.4}$
$q\bar{q}$ model	$^{+2.2}_{-1.0}$	±0.2
$B\bar{B}$ model	±0.9	$^{+0.7}_{-0.5}$
$\tau^+\tau^-$ model	±0.1	±0.0
Peaking model	$^{+0.8}_{-0.4}$	$^{+0.2}_{-0.4}$
Fit bias	±2.0	±0.6
Interference	±2.8	±1.7
Resolution	$^{+3.4}_{-4.4}$	$^{+1.9}_{-1.4}$
Δt PDF for $q\bar{q}$ and $B\bar{B}$	$^{+3.8}_{-1.8}$	$^{+0.7}_{-0.1}$
Tag side interference	±0.5	±2.1
Wrong tag fraction	$^{+0.2}_{-0.3}$	±0.5
Background CP violation	$^{+3.8}_{-3.6}$	$^{+4.2}_{-3.7}$
CP violation in TP signal	$^{+0.8}_{-0.2}$	$^{+0.2}_{-0.4}$
Tracking detector misalignment	±1.4	±0.5
τ_{B^0} and Δm_d	$^{+1.4}_{-1.6}$	±0.3
Total systematic uncertainty	$^{+8.2}_{-7.8}$	$^{+6.1}_{-5.3}$
Statistical uncertainty	±18.8	±12.1

Table II. Summary of the systematic uncertainties on $R(D^{(*)})$ and their correlation. The description of each source is provided in the text.

Source	$R(D^*)$	$R(D)$	ρ
Simulation sample size	4.8%	8.4%	−0.44
gap-mode branching fraction	2.6%	2.6%	0.00
$\bar{B} \to D^{**}\tau^-/(\ell^-)\bar{\nu}_\ell$ branching fractions	0.3%	1.3%	0.25
Hadronic B decay branching fractions	1.6%	1.5%	−0.26
Form factors	0.5%	0.9%	−0.70
Fraction of misreconstructed $D^{(*)}$	0.5%	1.2%	0.00
Continuum background	2.4%	2.1%	0.93
Fit biases	0.3%	1.2%	0.00
Low-momentum π^0, γ efficiency	2.2%	2.4%	0.99
Other efficiency corrections	0.7%	1.4%	0.92
B-tagging efficiency of data	0.9%	1.8%	−1.00
B-tagging efficiency of $B \to D\tau\nu$	0.1%	1.8%	1.00
M^2_{miss} resolution	0.5%	0.8%	0.48
Total systematic uncertainty	6.7%	10.2%	−0.20
Statistical uncertainty	8.3%	16.3%	−0.40

Table V. Fractional contributions to the total uncertainty the extracted value of $|V_{cb}|$. The sizes of the contributions a given relative to the central value.

Source		Uncertainty [%]
Statistical		0.9
Systematic		1.5
	$B^{0/+}$ lifetime	0.1
	Signal form factor	0.1
	$B \to D^*\ell\nu$ form factor	0.1
	$\mathcal{B}(B \to X_c\ell\nu)$	0.3
	$\mathcal{B}(D \to K\pi(\pi))$	0.5
	Tracking efficiency	0.5
	$N_{\Upsilon(4S)}$	0.7
	f_{00}/f_{+-}	0.1
	$f_{\not{B}}$	0.4
	Background w modelling	0.3
	(E^*_Y, m_Y) reweighting	0.3
	Lepton identification	0.3
	Kaon identification	0.6
	Vertex fit χ^2 correction	0.3
	Simulation sample size	0.5
Theoretical		1.3
	Lattice QCD inputs	1.2
	Long-distance QED	0.5
Total		2.1

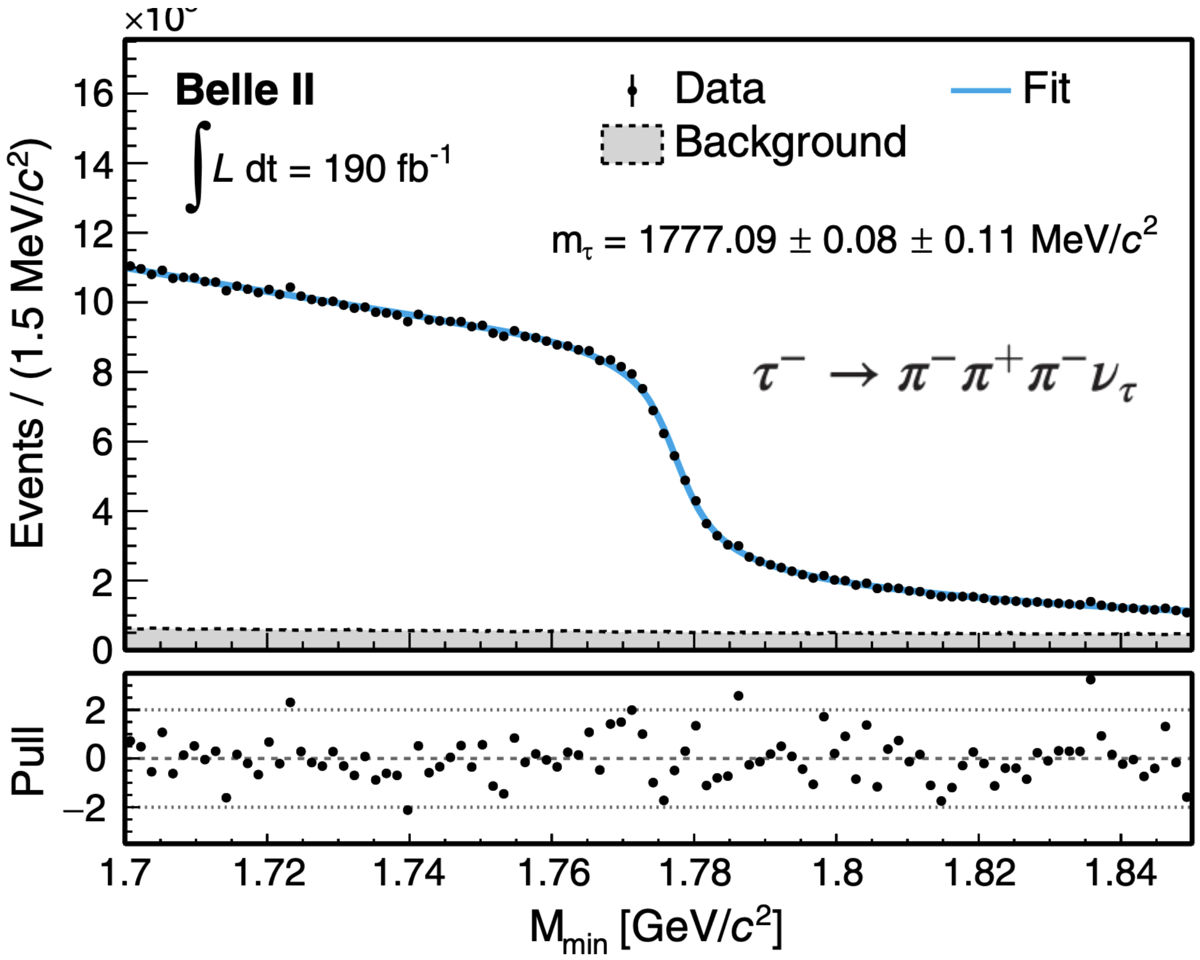
$B \to X_s \nu\nu$

Source	Impact on $\sigma_{\mathcal{B}}$ [10^{-5}]
Simulated-sample size	6.0
Background normalization	5.7
Branching ratio of major B meson decay	2.3
Non-resonant $X_s\nu\bar{\nu}$ generation point	2.1
$\mathcal{O}_{\mathrm{BDT}}$ selection efficiency	2.0
Photon multiplicity correction	1.8
$q\bar{q}$ background efficiency	1.8
Other subdominant contributions	3.0
Total systematic sources	11.7

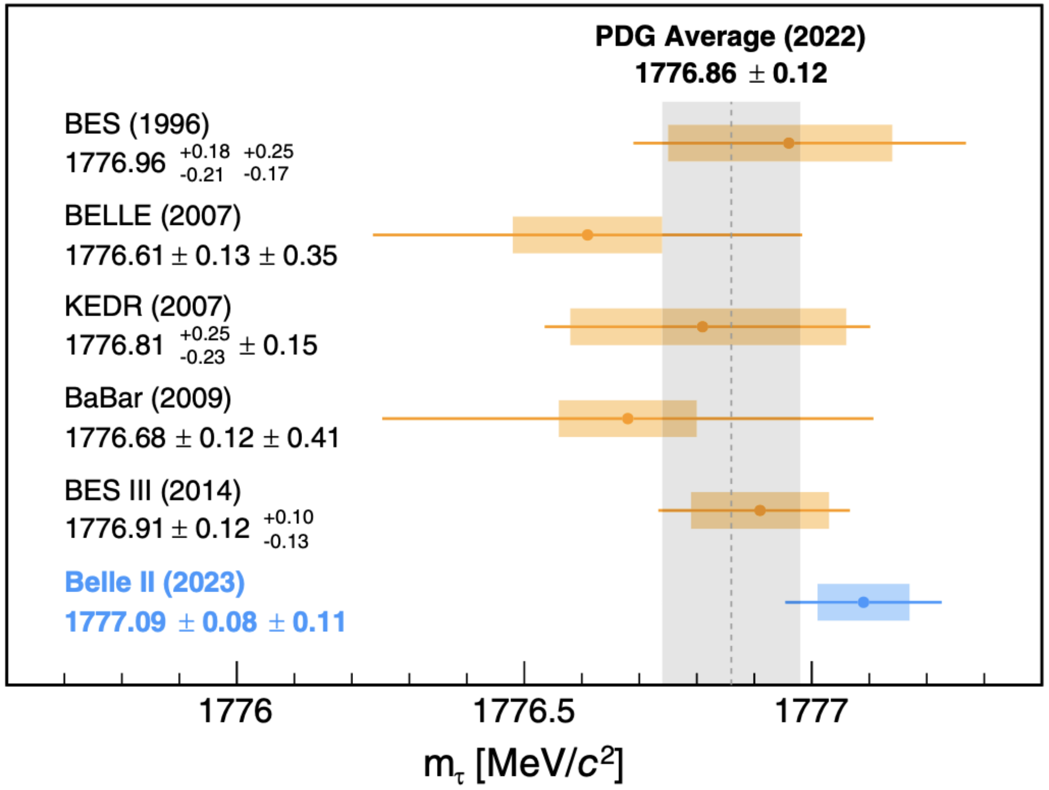
τ mass

M(τ) = (1777.09±0.08±0.11) MeV/c²
Most precise to date.

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - p_{3\pi}^*)} \leq m_\tau$$



Systematic uncertainty (0.11), dominant by beam-energy correction and charged-particle momentum correction. [PRD 108, 032006 (2023)]



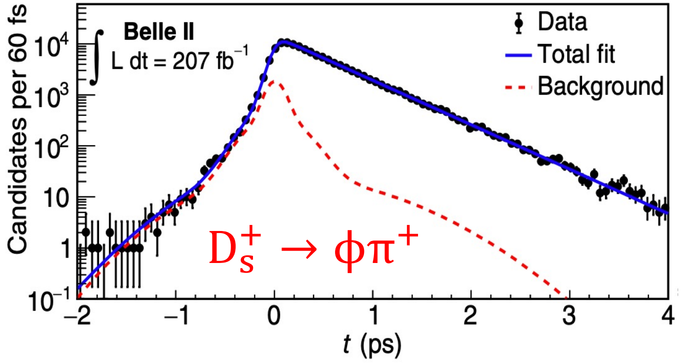
Fit the distribution with a Heaviside step function:

$$F(M_{\min}) = 1 - P_3 \arctan\left(\frac{M_{\min} - \boxed{P_1}}{P_2}\right) + P_4(M_{\min} - P_1) + P_5(M_{\min} - P_1)^2$$

τ mass

Charm Meson and Charmed Baryon Lifetimes

[PRL 131, 171803 (2023)]

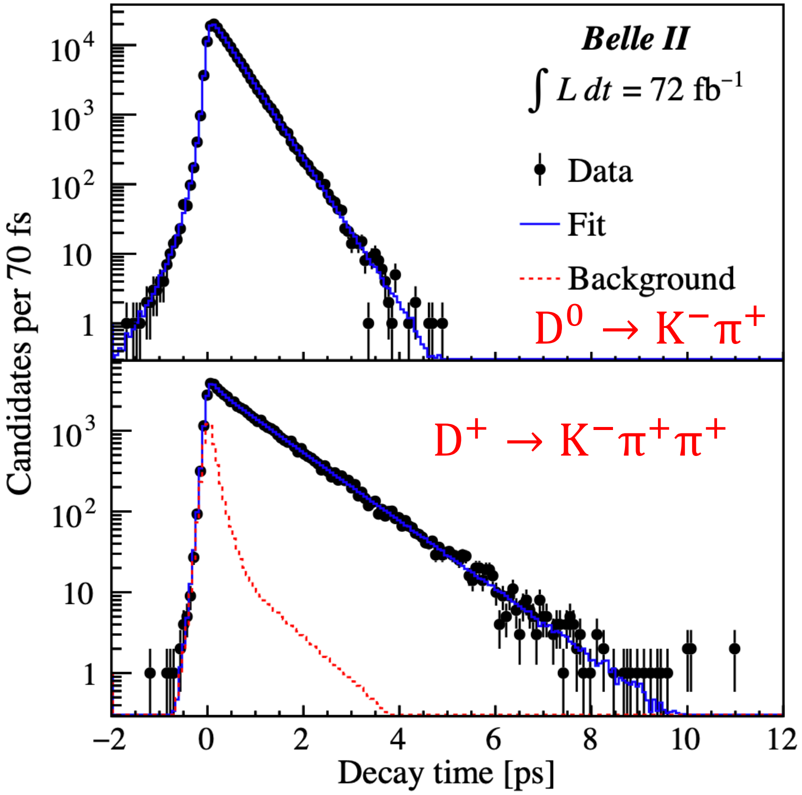


- PDF Model:

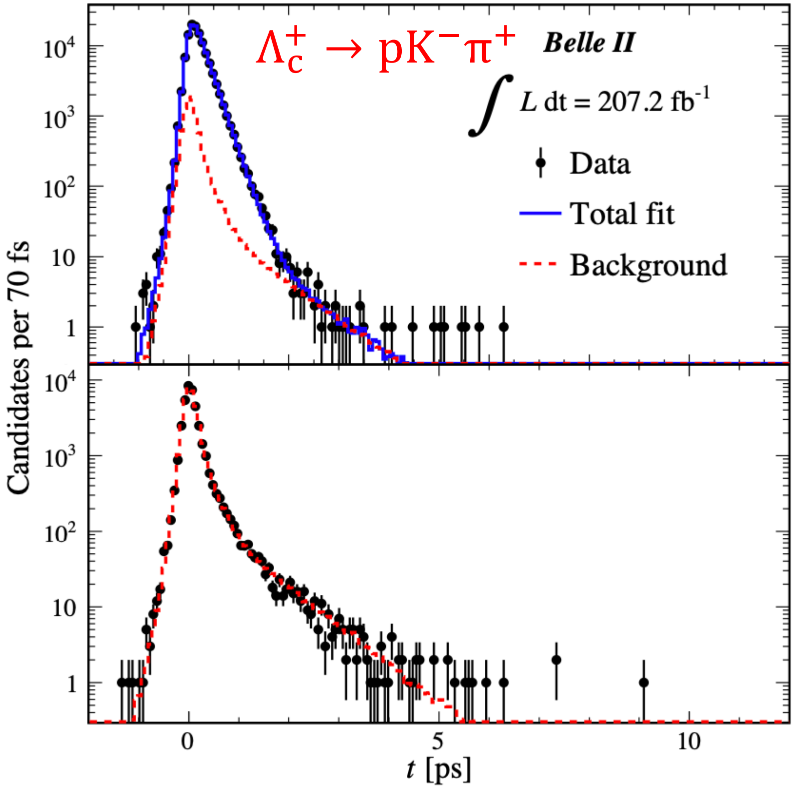
$$\mathrm{PDF}(t,\sigma_t) = (1-\mathrm{f_b})\int_0^{\infty} e^{-t_{\mathrm{true}}/\tau} R(t - t_{\mathrm{true}}\,|\,b, s\sigma_t)\,dt_{\mathrm{true}}\,\mathrm{PDF_{sig}}(\sigma_t) + \mathrm{f_b}\mathrm{PDF_{bkg}}(t,\sigma_t)$$

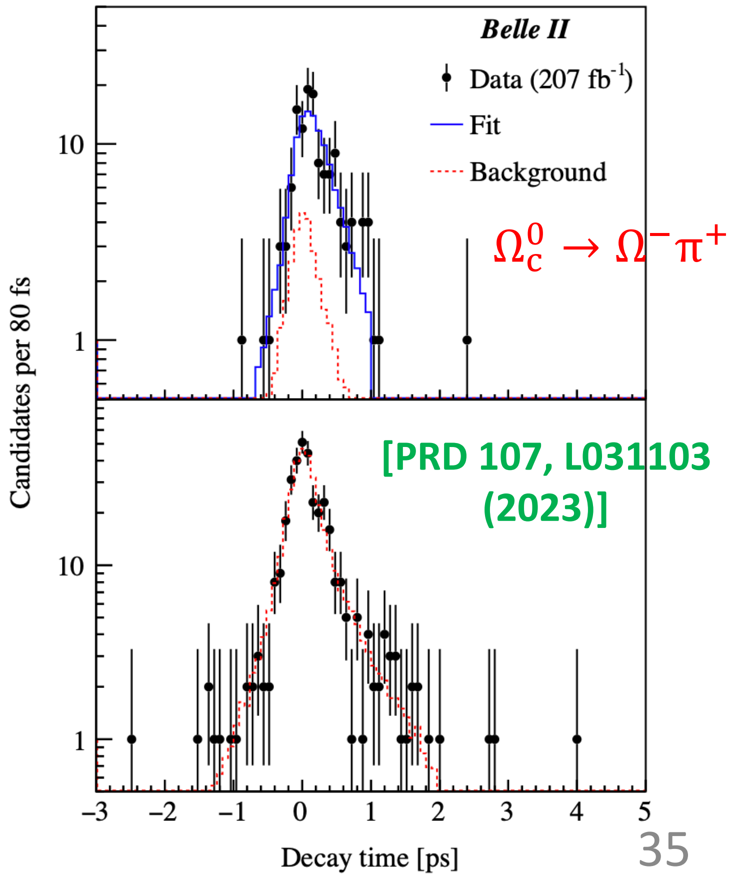
t: decay-time; σ_t: decay-time uncertainty

[PRL 127, 211801 (2021)]



[PRL 130, 071802 (2023)]



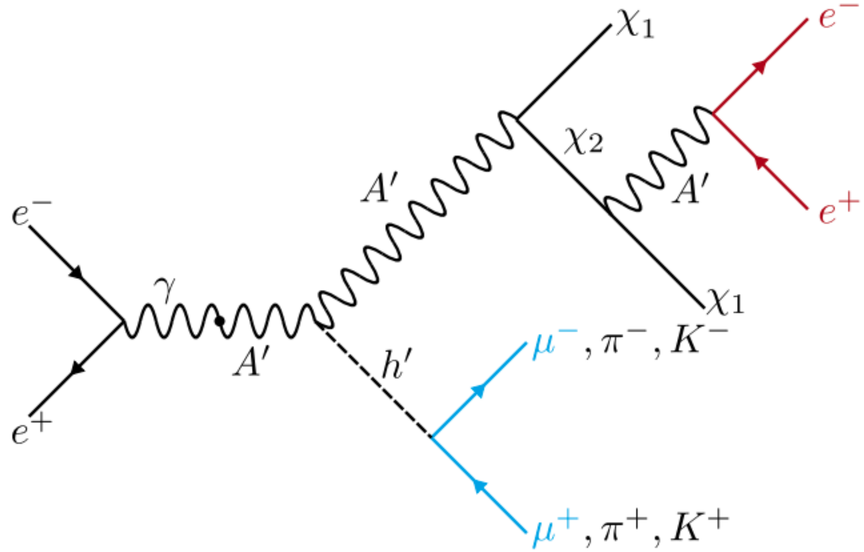


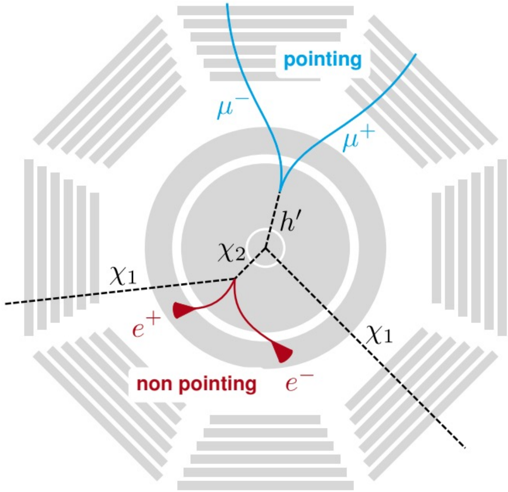
[PRD 107, L031103 (2023)]

A dark Higgs boson in association with inelastic dark matter

[Preliminary results]

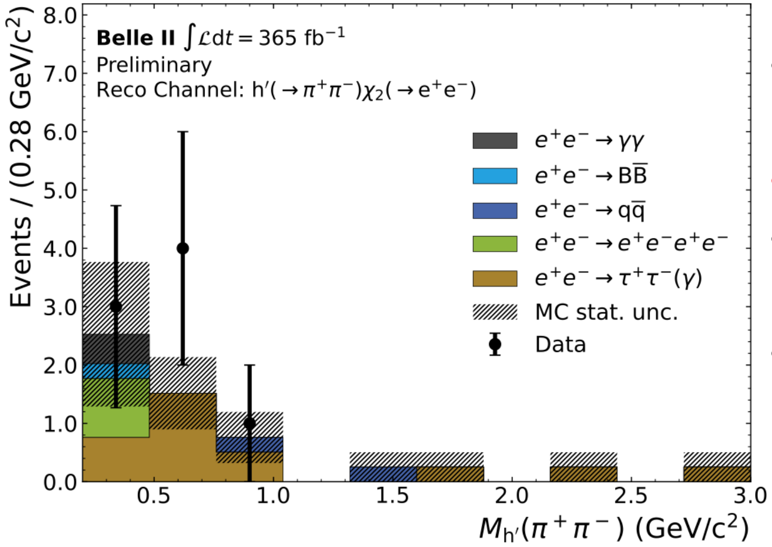
Dark photon A′, dark Higgs h′, and two dark matter states χ_1, χ_2



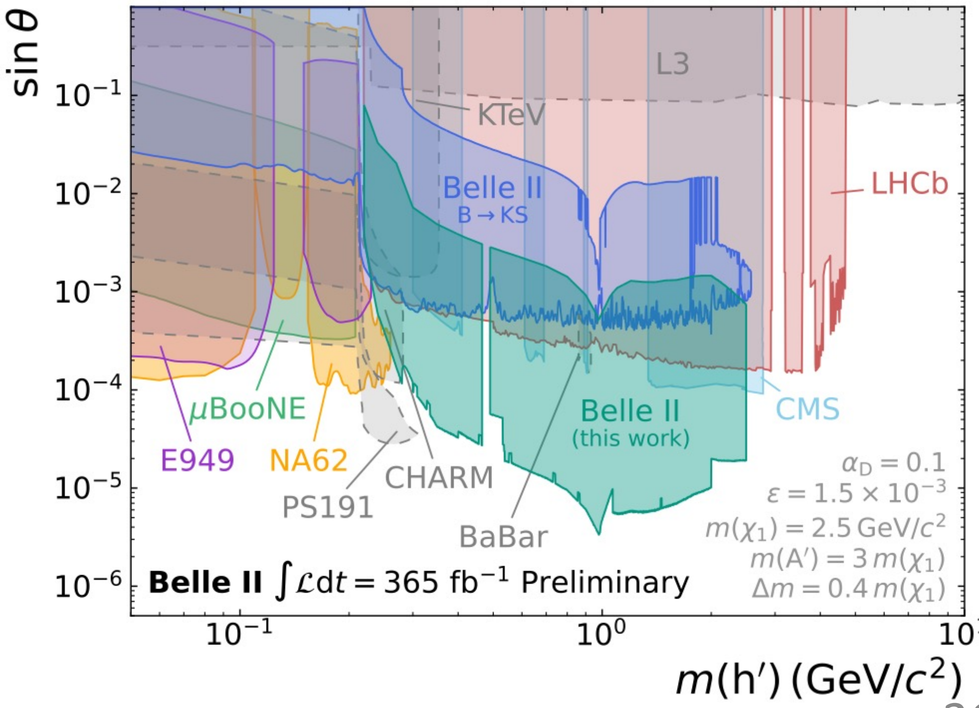


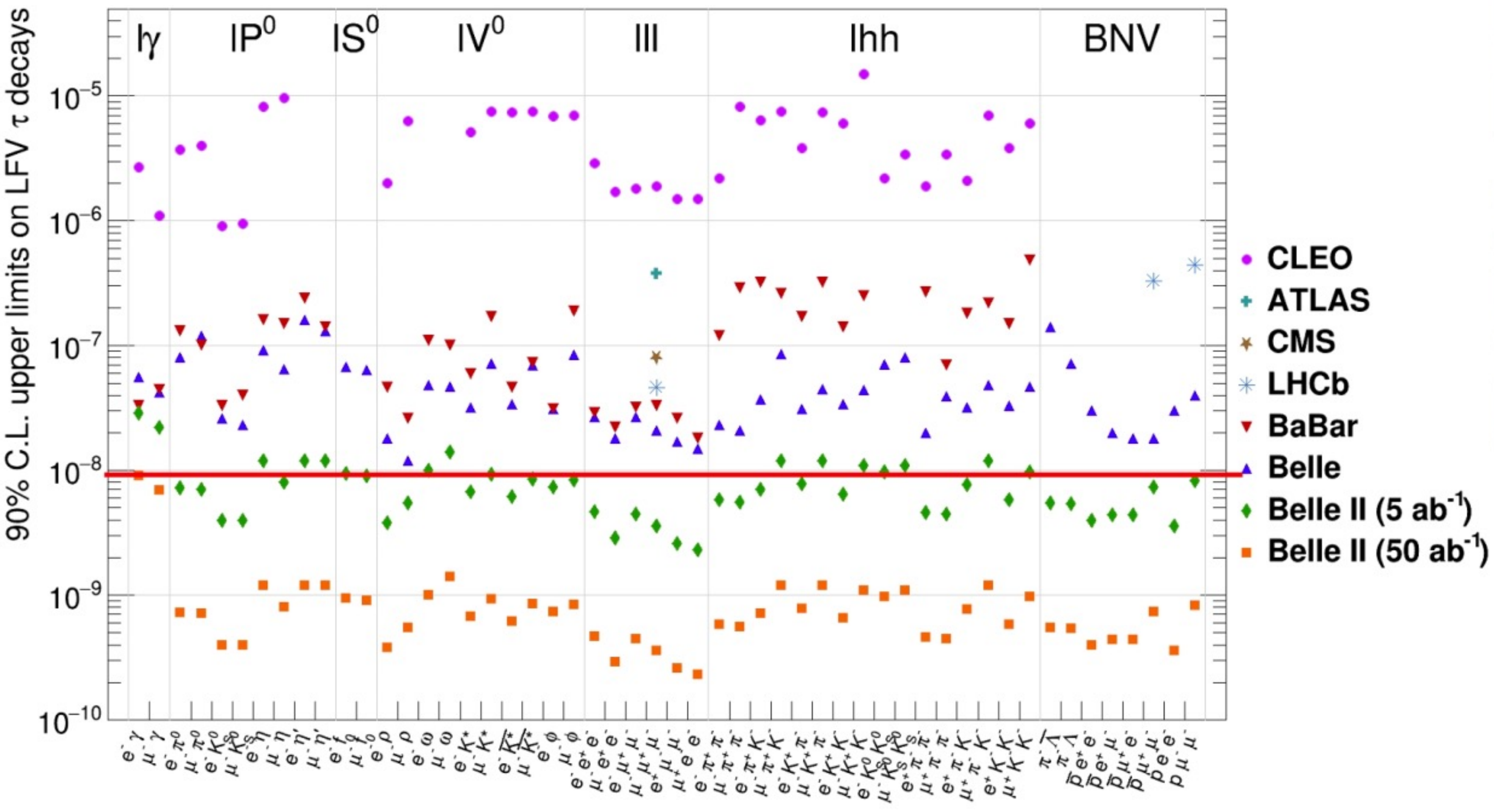
Looking for simultaneous production of A′ and h′

- 4 tracks in the final state
- 2 forming a pointing dispaced vertex
- mising energy



- cut-and-count strategy in $M_{h'}(x^+x^-)$ distributions
- No signicant excess found
- 8 events observed consistent with expected background
- Convert UL at 90% C.L. of $\sigma(e^+e^- \rightarrow \chi_1\chi_2 h') \times \mathcal{B}(\chi_2 \rightarrow \chi_1 e^+e^-) \times \mathcal{B}(h' \rightarrow x^+x^-)$ to mixing angle θ





90% C.L. upper limits on LFV τ decays
lγ
lP^0
lS^0
lV^0
lll
lhh
BNV
CLEO
ATLAS
CMS
LHCb
BaBar
Belle
Belle II (5 ab^{-1})
Belle II (50 ab^{-1})

CKM matrix element

Exclusive: $B \to \pi l\nu, B \to \rho l\nu, B \to D^{(*)}l\nu, etc$

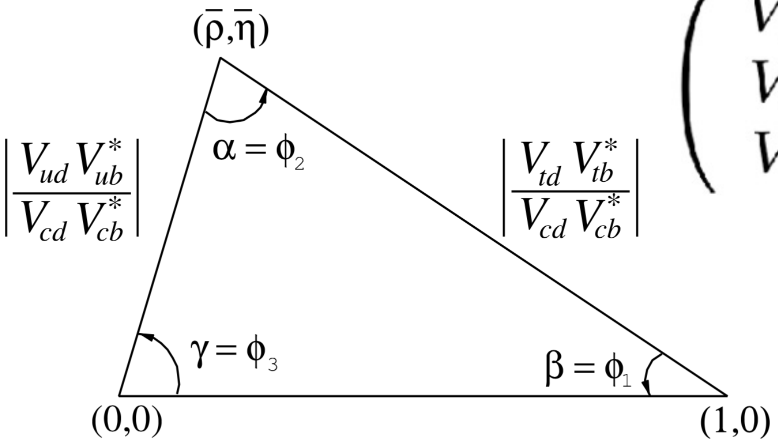
$\frac{dB}{dq^2} \propto |V_{xb}|^2 \times |FF(q^2)|^2$ Form factor from LCSR, LQCD

Inclusive: $B \to X_u l\nu, B \to X_c l\nu$

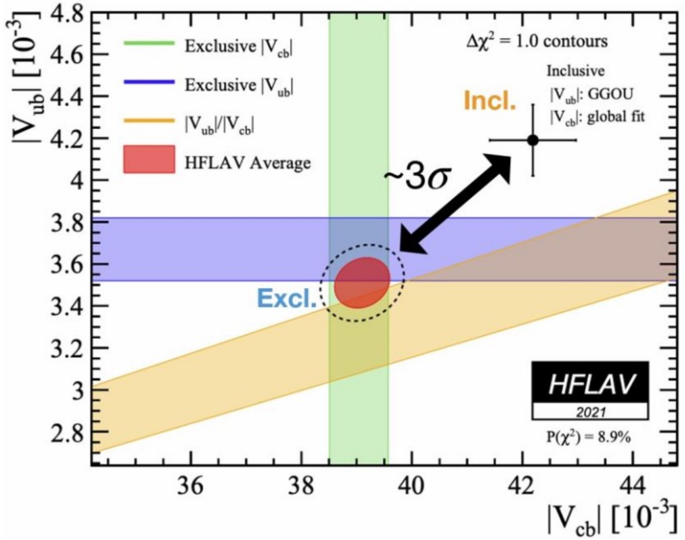
$\mathcal{B} \propto |V_{xb}|^2 \times \left[\Gamma(b \to q l \bar{\nu}_l) + \frac{1}{m_b} + \alpha_s + \cdots\right]$ From OPE

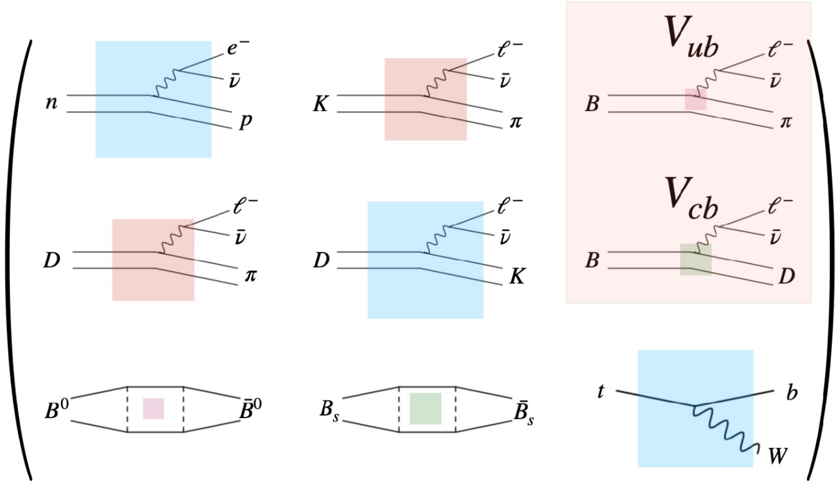
Belle II important task:

Constrain CKM unitarity triangle & test SM



$$\begin{pmatrix} V_{ud} & V_{us} & \boxed{V_{ub}} \\ V_{cd} & V_{cs} & \boxed{V_{cb}} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$





Several measurements carried out by Belle and Belle II:

$\vert V_{cb}\vert$	- Angular coefficients of $B \to D^* l\nu$	**Belle: PRL 133, 131801 (2024)**
$\vert V_{ub}\vert$	- $\vert V_{ub}\vert$ from $B \to (\pi, \rho) l\nu$ simultaneous analysis	New from Belle II
	- Simultaneous inclusive and exclusive $\vert V_{ub}\vert$	**Belle: PRL 131, 211801 (2023)**
$\frac{\vert V_{ub}\vert}{\vert V_{cb}\vert}$	- Ratio of inclusive $b \to c$ and $b \to u$ decays	**Belle: arXiv: 2311.00458**