

Recent results of B decays at Belle II

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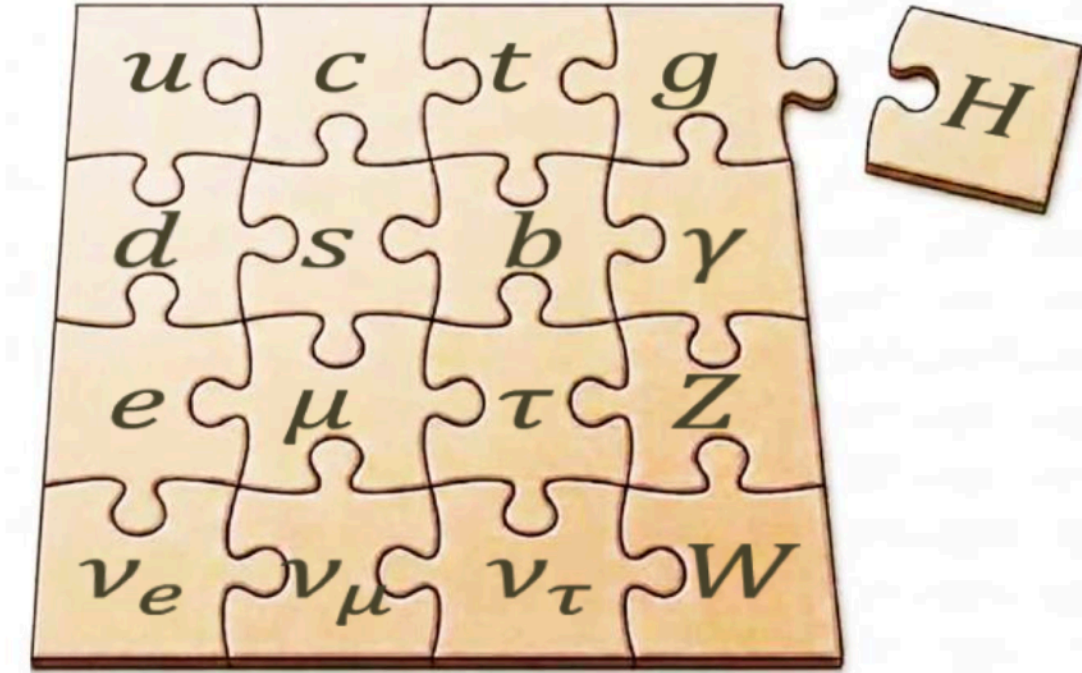
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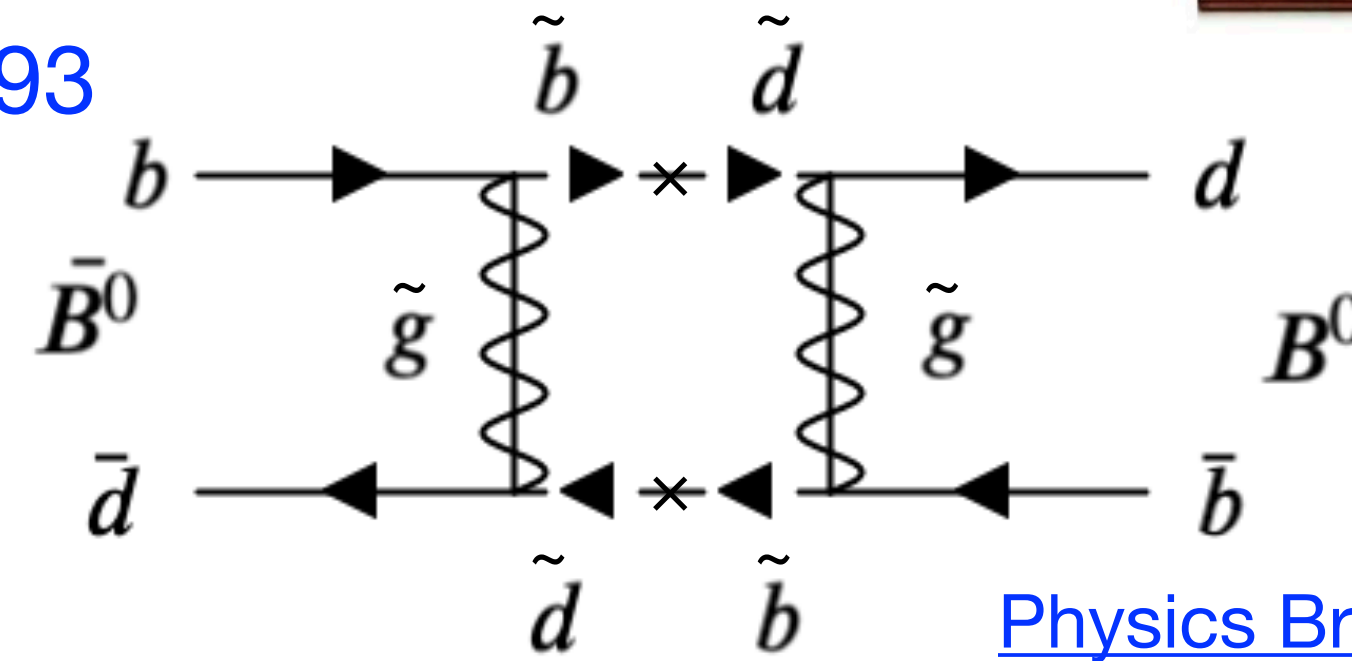
2026年4月25-28日，山城国际会议中心，重庆大学
第八届重味物理理论与实验联合研讨会



Probing the next scale

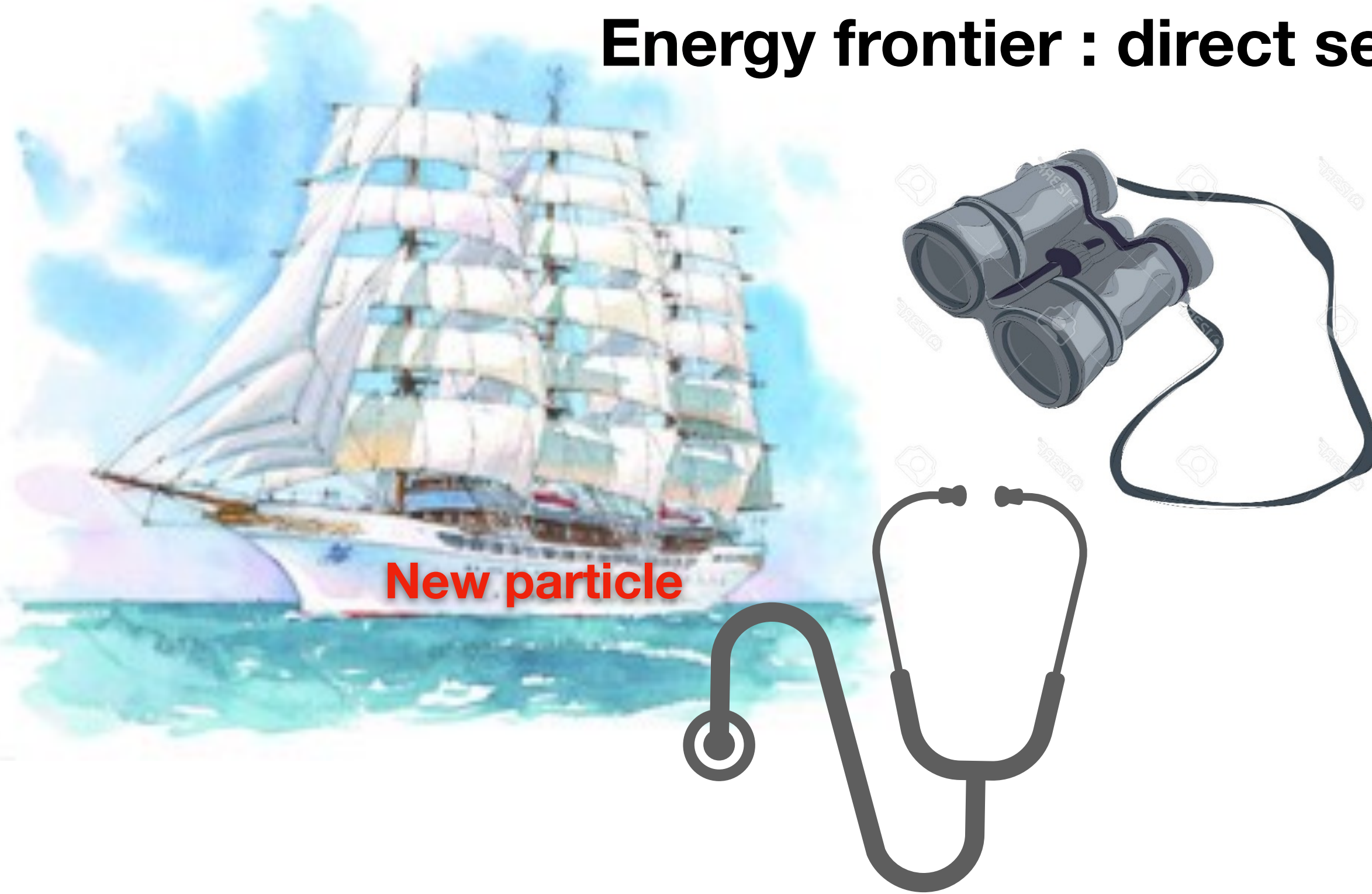


- Flavor physics to access higher scales searching for UV extension
- Indirect search for New Physics (NP) in quantum effect
 - Sensitivity of NP detection up to **~1000 TeV** in B^0 mixing ($\mathcal{L} = \mathcal{L}_{\text{SM}} + 1/\Lambda^2 \mathcal{O}_{\Delta F=2}$) (depending on the NP coupling constant) [arXiv:1309.2293](https://arxiv.org/abs/1309.2293)



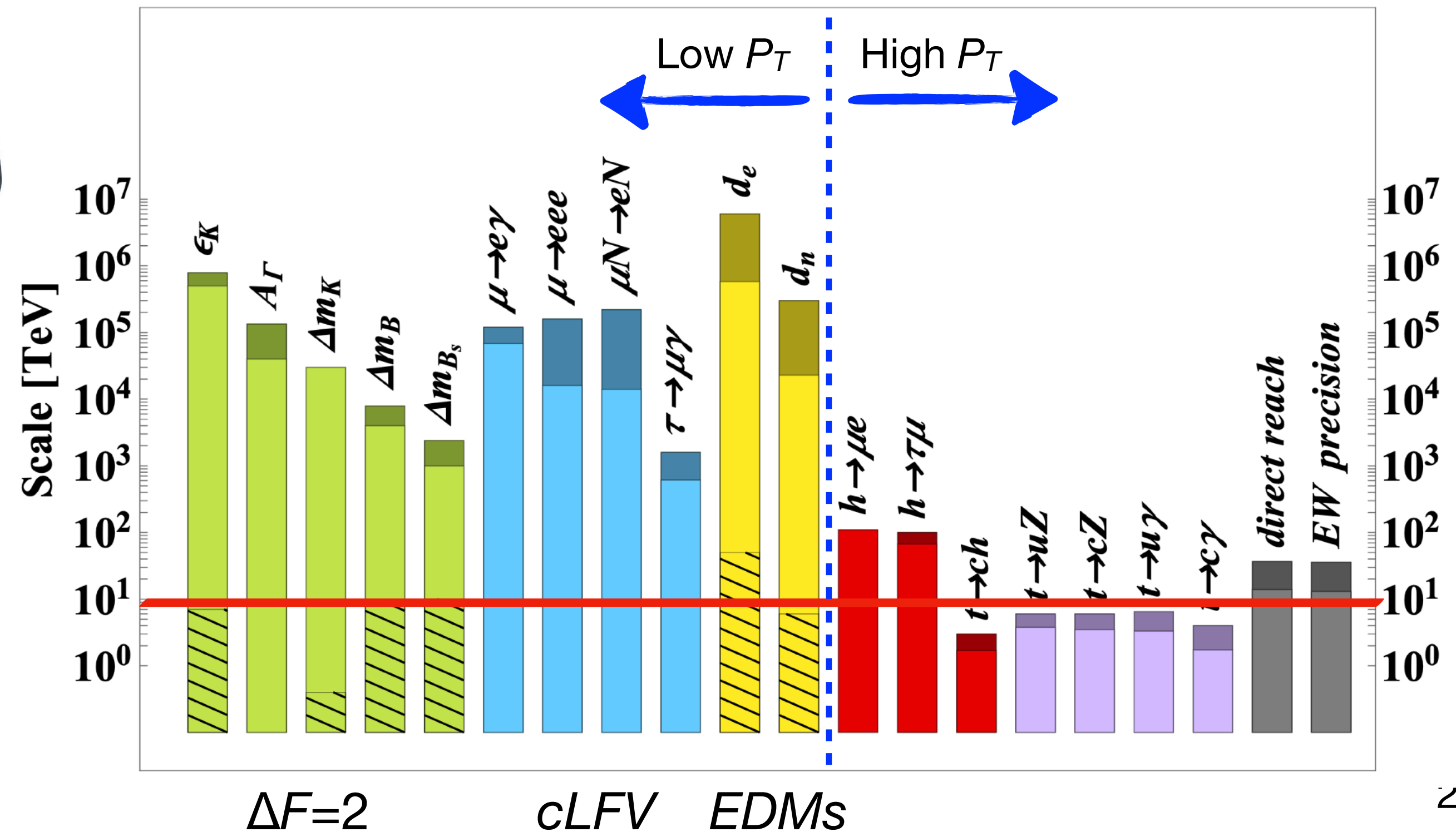
[Physics Briefing Book, 1910.11775](#)

Energy frontier : direct search



Luminosity frontier : indirect search

Name of the game is precision



Luminosity frontier: SuperKEKB

- Asymmetric e^+e^- collider
 - $e^+e^- \rightarrow \gamma(4S) \rightarrow B\bar{B}$
 - very clean and well-known initial state

Final target : $6 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$

- x30 Belle luminosity

Integrated luminosity: 50 ab^{-1}

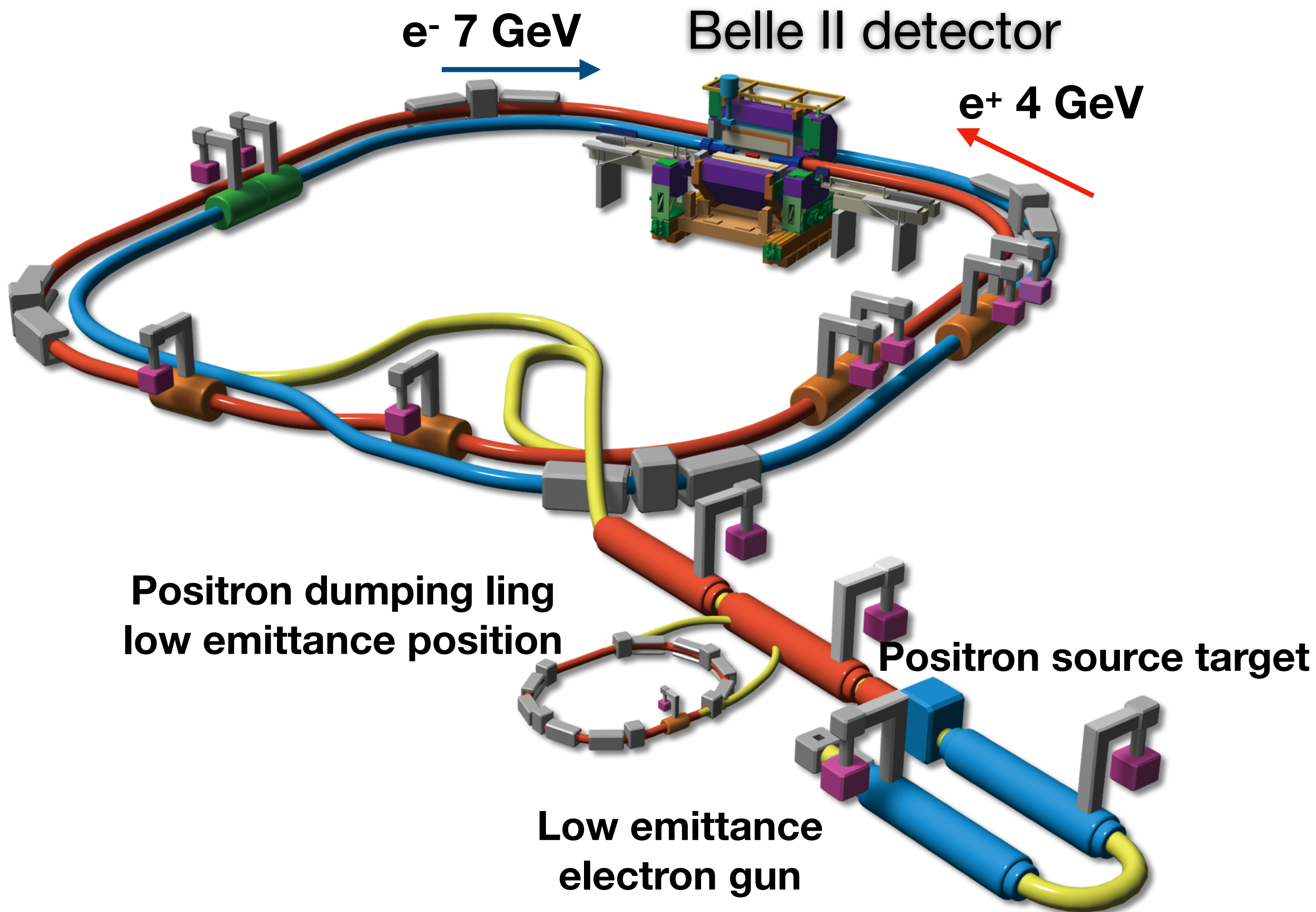
- x 50 Belle data

Beam current: KEKB x ~ 1.5

$$L = \frac{\gamma_{\pm}}{2er_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right) \frac{I_{\pm} \xi_{\pm y}}{\beta_y^*} \left(\frac{R_L}{R_y}\right)$$

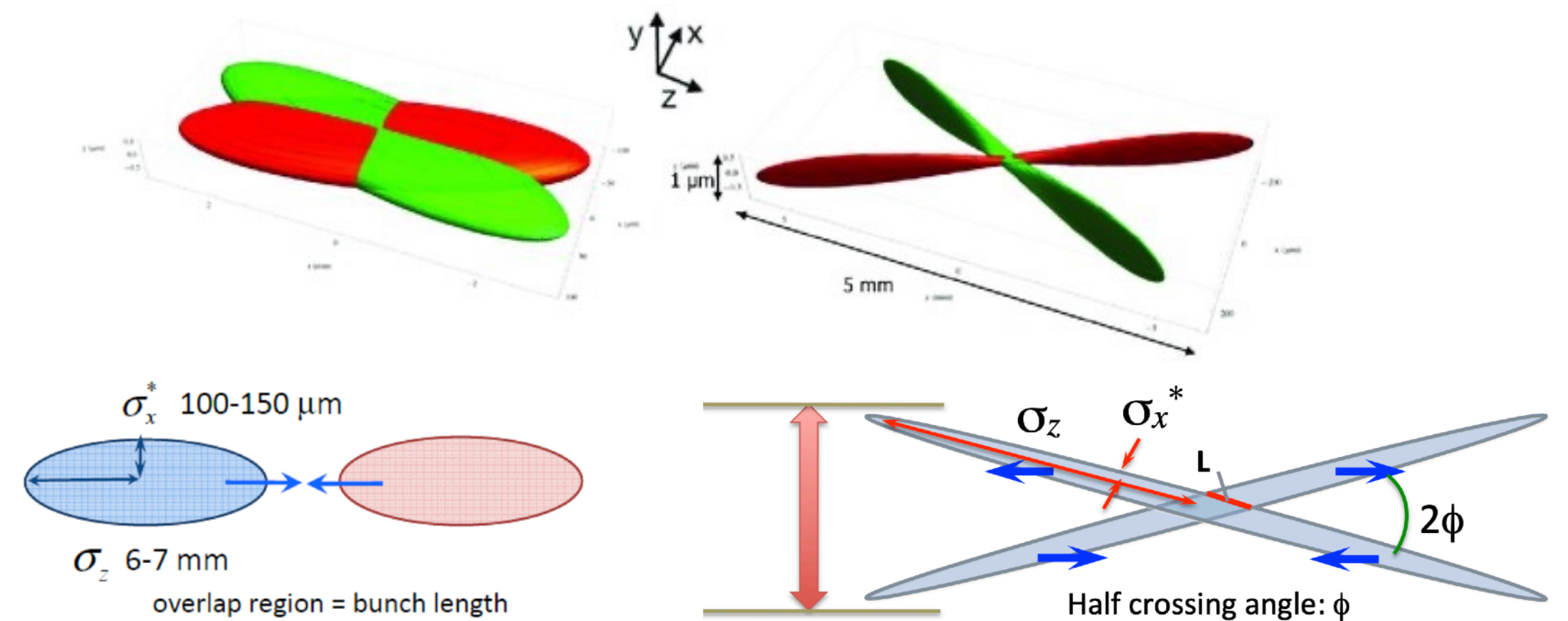
Beam squeeze: KEKB / ~ 20

Nano beam scheme



Belle

Belle II



The Belle II detector

Vertex detector (VXD)

Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)

e^- (7GeV)

Central Drift Chamber (CDC)

He (50%), C₂H₆ (50%), small cells, long lever arm

ElectroMagnetic Calorimeter (ECL)

CsI(Tl) + waveform sampling

Particle Identification

Barrel: Time-Of-Propagation counters (TOP)
Forward: Aerogel RICH (ARICH)

e^+ (4GeV)

K_L/μ detector (KLM)

Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

• Features:

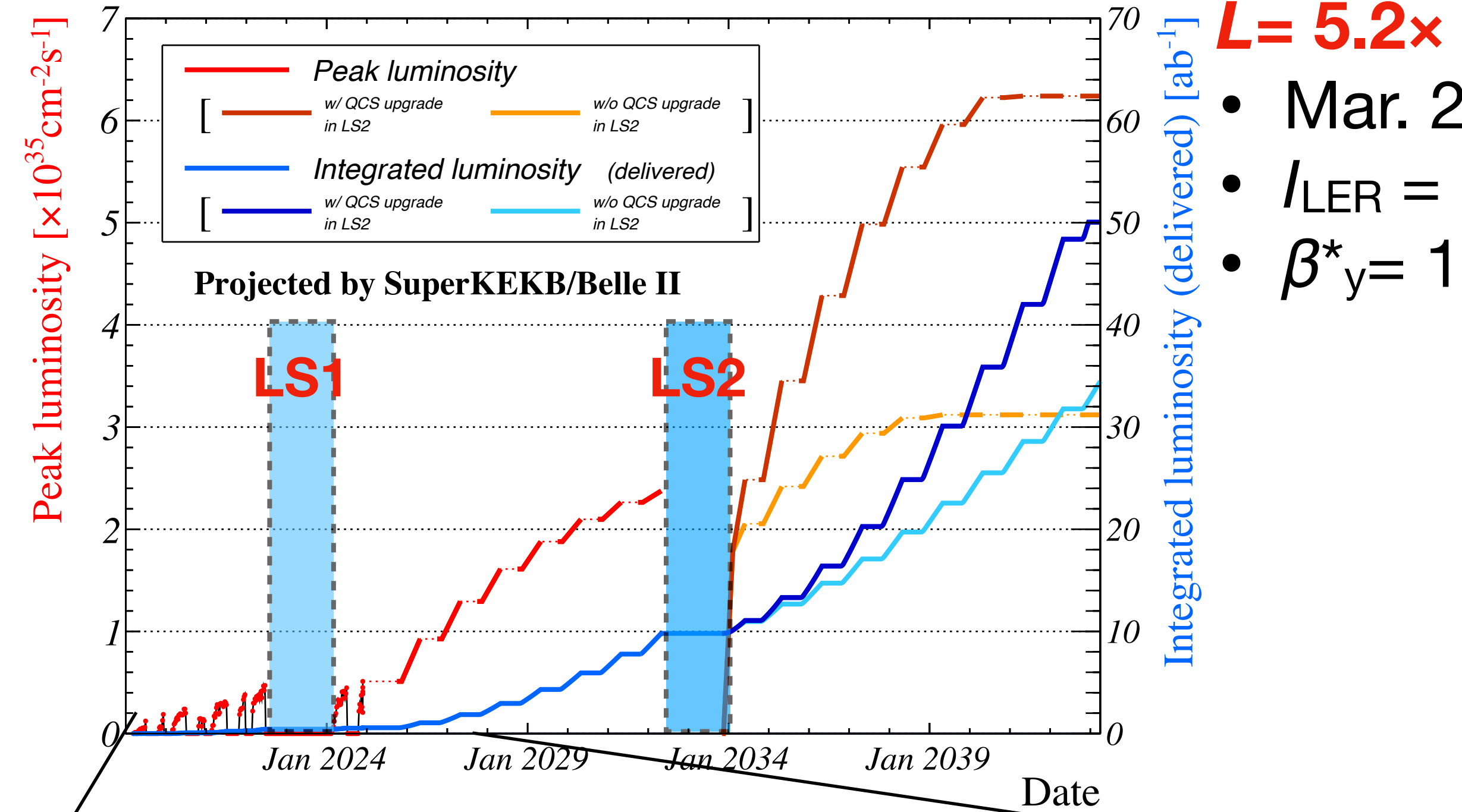
- Near-hermetic detector
- Vertexing and tracking: σ vertex $\sim 15\mu\text{m}$, CDC spatial res. $100\mu\text{m}$ $\sigma(P_T)/P_T \sim 0.4\%$
- Good at measuring neutrals, π^0 , γ , $K_L\dots$ $\sigma(E)/E \sim 2\text{-}4\%$

Run status and luminosity

$L = 5.2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ (World record)

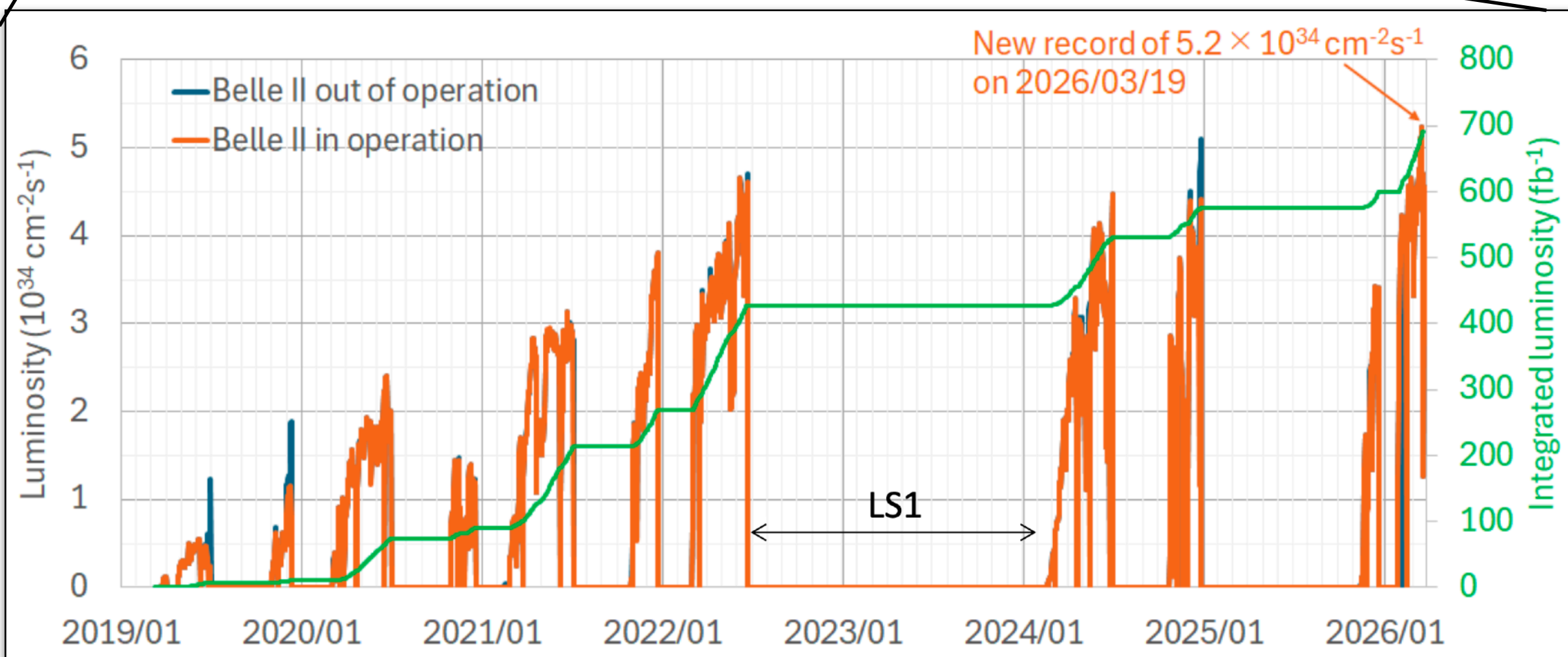
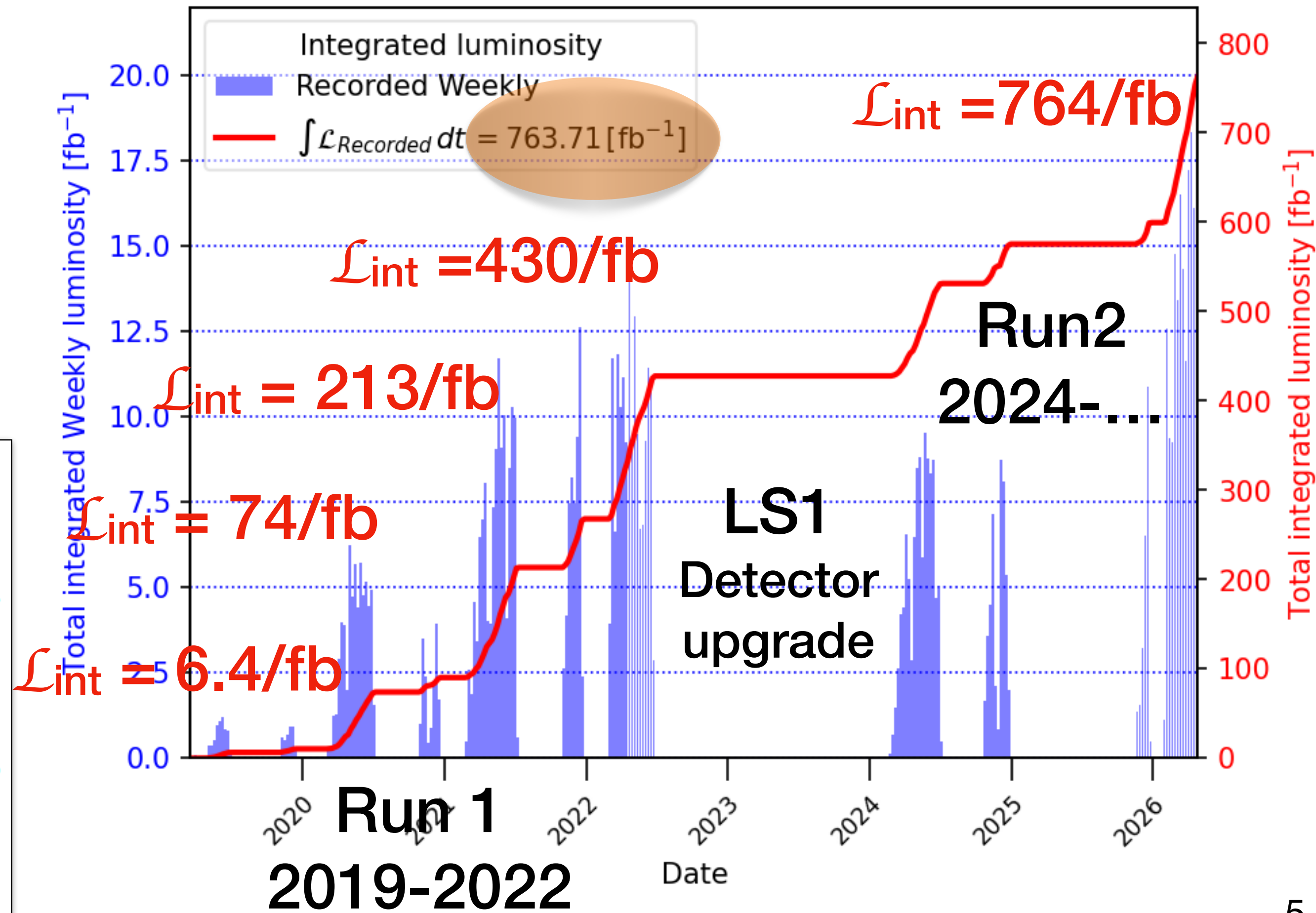
- Mar. 2026
- $I_{\text{LER}} = 1.72\text{A}$, $I_{\text{HER}} = 1.36\text{A}$
- $\beta_y^* = 1\text{mm}$

Data at $\Upsilon(4S)$:
 ~700 fb^{-1} (Belle II)
 <-> 711 fb^{-1} (Belle)



Belle II Online luminosity

Exp: 7-41 - All runs



Physics program and Belle II China

Belle II Data

Bottomonium

New hadrons
QCD

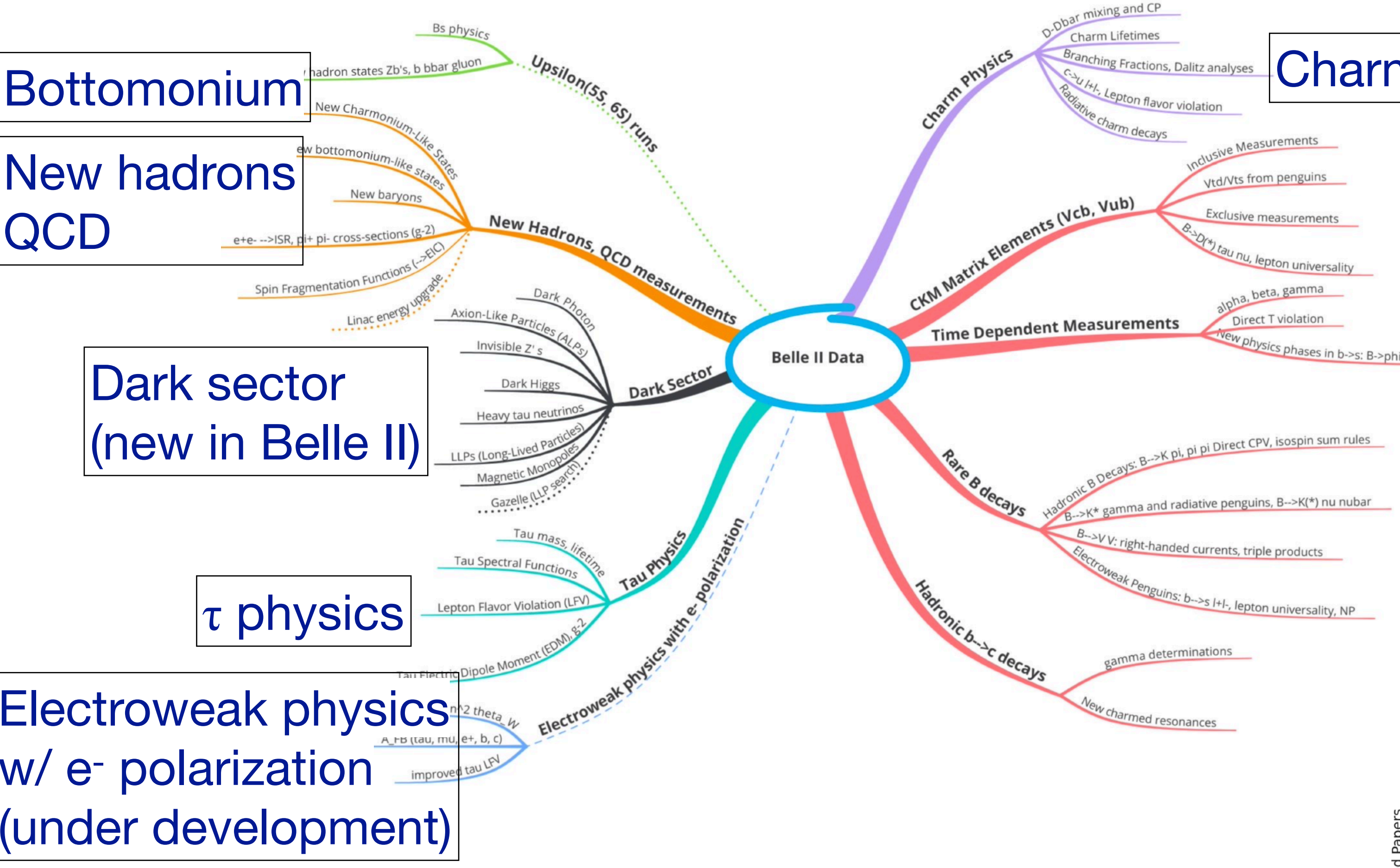
Dark sector
(new in Belle II)

τ physics

Electroweak physics
w/ e^- polarization
(under development)

Belle II China Group:

- 15 institutes, ~150 members (incl. Postdoc, students)
- Charm, Bottomonium dominate contribution
- B, τ , detector development, etc. is developing



Charm physics

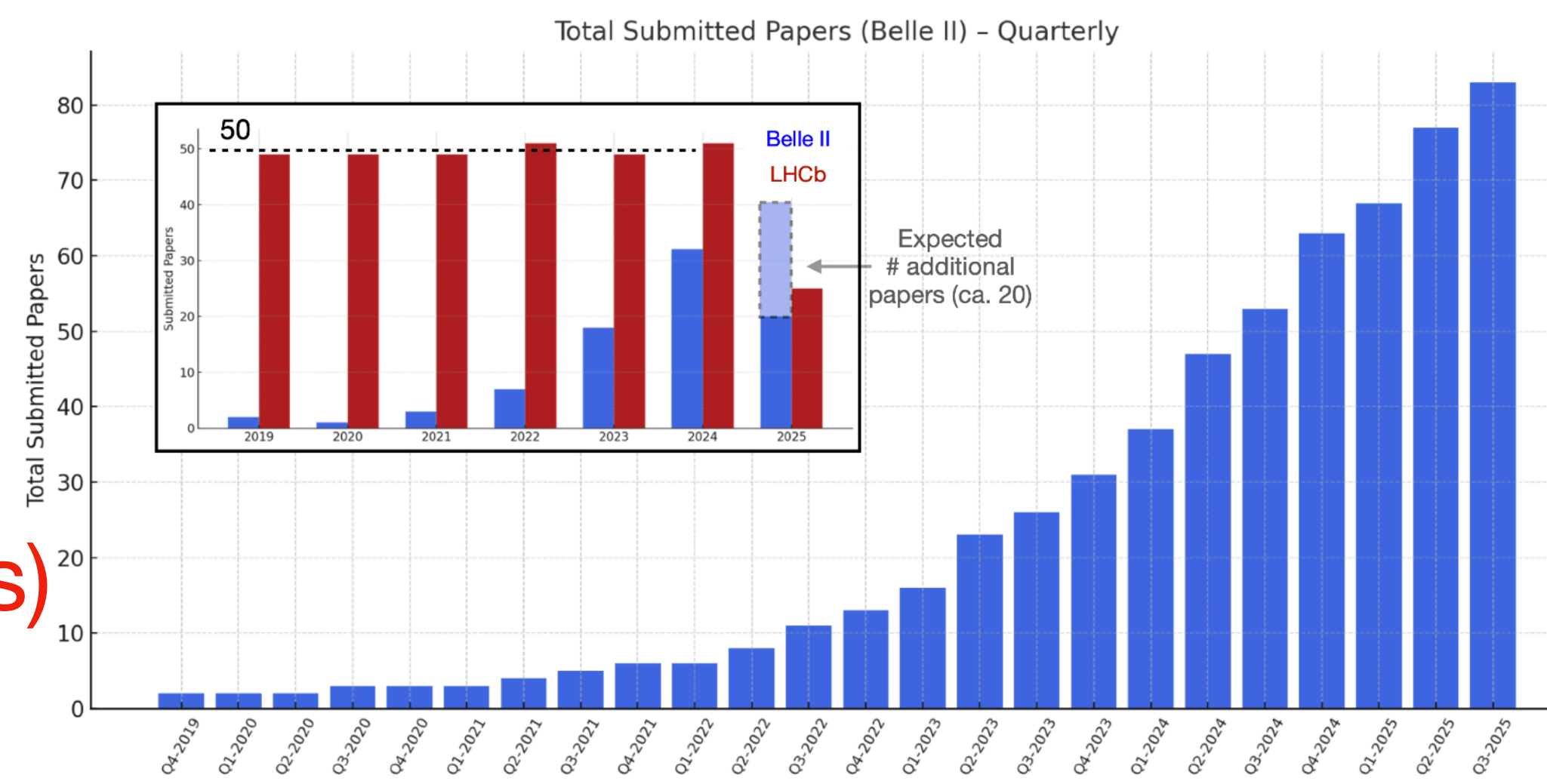
李郁博
Belle II上tau-charm物理进展
4月26日 会场II

殷俊昊
Review of bottomonium results on Belle II
4月26日 会场II

LHCb: ~50 papers/year

B physics

84 papers submitted & 76 accepted as of last week



Our goal is to achieve 40 - 45 papers / year

Unitarity triangle (UT) test

$$V^\dagger V = 1 \rightarrow V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$$

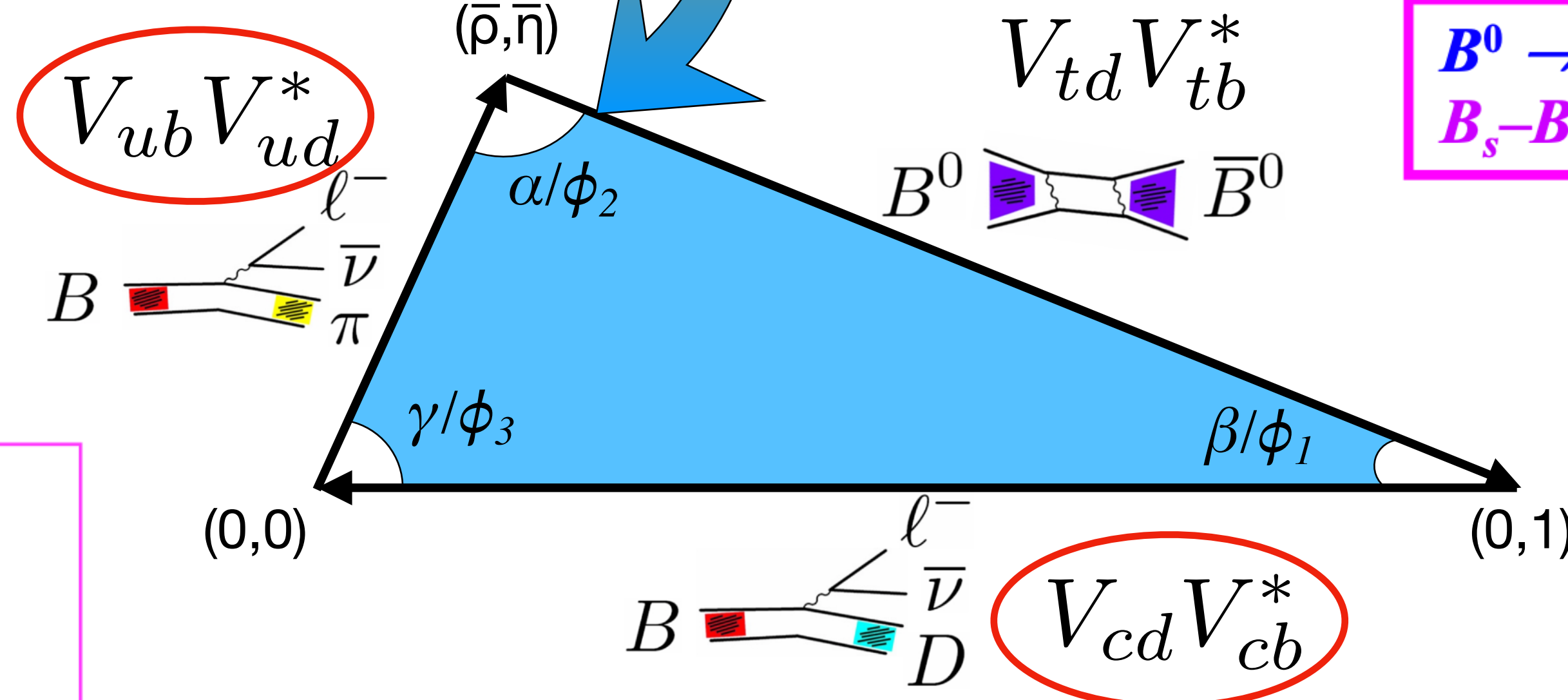
$$\lambda^3 \cdot 1 \quad \lambda^2 \cdot \lambda \quad 1 \cdot \lambda^3$$

- Comprehensive test by Belle II
 - Measure **all sides and angles**
- Search NP in mixing (**tree**, **loop**) by precise measurement of UT

$B \rightarrow \pi^+ \pi^- / \pi^+ \pi^0 / \pi^0 \pi^0$
 $B \rightarrow \rho^+ \rho^- / \rho^+ \rho^0 / \rho^0 \rho^0$
 $B^0 \rightarrow \rho \pi$
 $B^0 \rightarrow a_1(\rho\pi)^+ \pi$

Complex phase

$B^0 \rightarrow \pi \ell^+ \nu$
 $B^0 \rightarrow X_u \ell \nu$
 $B^+ \rightarrow \tau^+ \nu$
 $\Lambda_b \rightarrow p \ell^+ \nu$



$B^0 \rightarrow \rho^0 \gamma$
 $B_s - B_s$ mixing

Belle II
LHCb

$B^- \rightarrow D^{(*)}_{CP} K^{(*)-}$
 $B^0 \rightarrow D_{CP} K^{*0}$
 $B^- \rightarrow D^{(*)}(K^+ \pi^-) K^{(*)-}$
 $B^- \rightarrow D^{(*)0} \pi^-$
 $B^- \rightarrow D^{(*)}(K_S \pi^+ \pi^-) K^{(*)-}$
 $B^- \rightarrow D(\pi^0 \pi^+ \pi^-) K^-$
 $B^- \rightarrow D(K_S K^+ \pi^-) K^-$

$B^0 \rightarrow D^{(*)} \ell \nu$
 $B^0 \rightarrow X_c \ell \nu$ (ℓ energy, hadron mass moments)
 $B^0 \rightarrow X_s \gamma$ (γ energy moments)

$B^0 \rightarrow J/\psi K_S$
 $B^0 \rightarrow J/\psi K_L$
 $B^0 \rightarrow \psi' K_S$
 $B^0 \rightarrow \chi_c K_S$
 $B^0 \rightarrow \eta_c K_S$
 $B^0 \rightarrow D^{(*)}_{CP} h^0$
 $B^0 \rightarrow (\phi/\eta'/\pi^0/f^0) K^0$
 $B^0 \rightarrow (K_S K_S / \rho^0/\omega) K_S$

ϕ_1 : Time dependent CPV

TDCPV measurement:

- Precise measurement of Δt
- B flavor tagger

$$A_{CP} = \frac{\Gamma(\bar{B}^0(t) \rightarrow f_{CP}) - \Gamma(B^0(t) \rightarrow f_{CP})}{\Gamma(\bar{B}^0(t) \rightarrow f_{CP}) + \Gamma(B^0(t) \rightarrow f_{CP})} = S \sin(\Delta mt) - C \cos(\Delta mt)$$

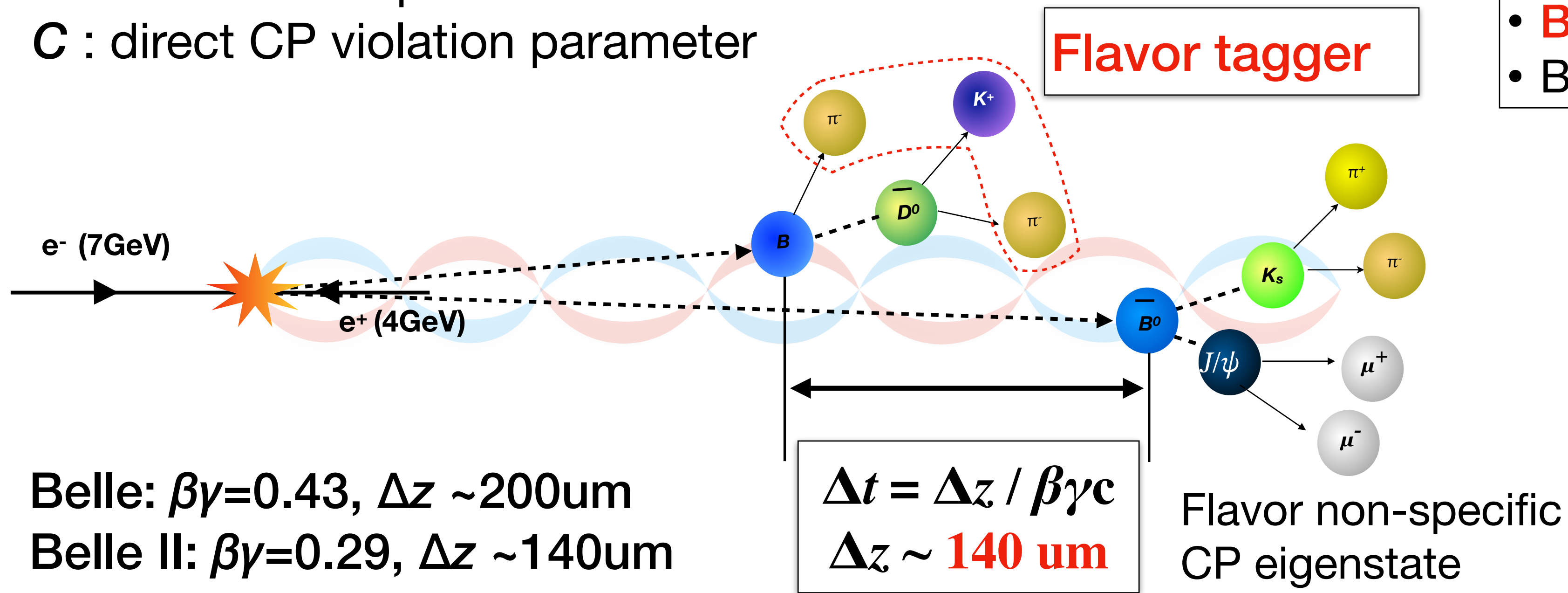
EPJC 82 (2022) 83

S : indirect CPV parameter

C : direct CP violation parameter

$$C = -A$$

Flavor tagger



Belle: $\beta\gamma=0.43$, $\Delta z \sim 200\mu\text{m}$

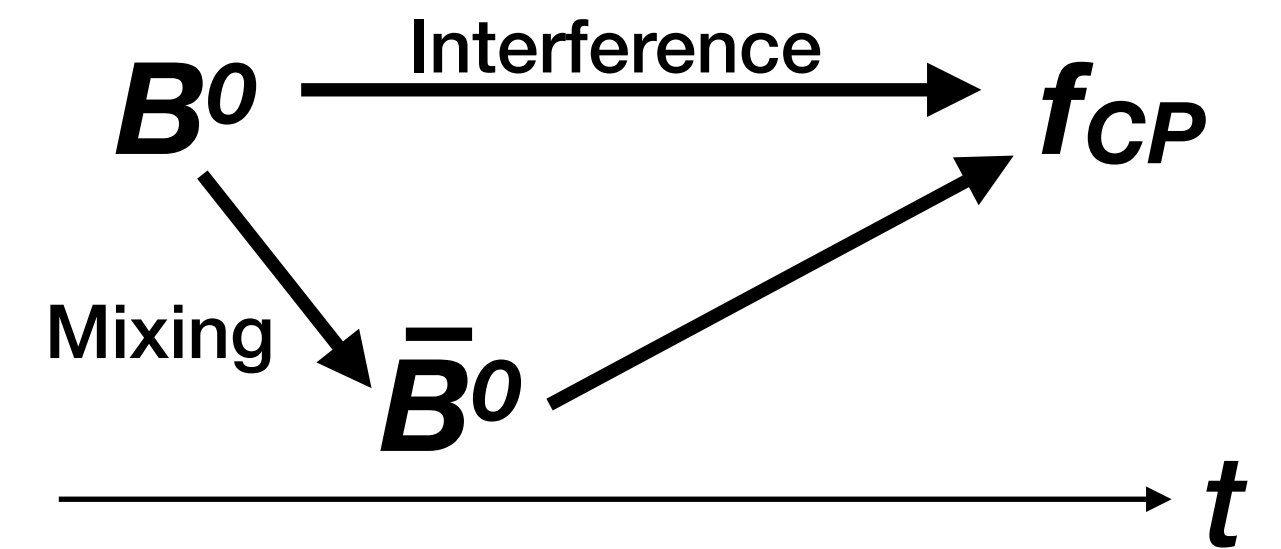
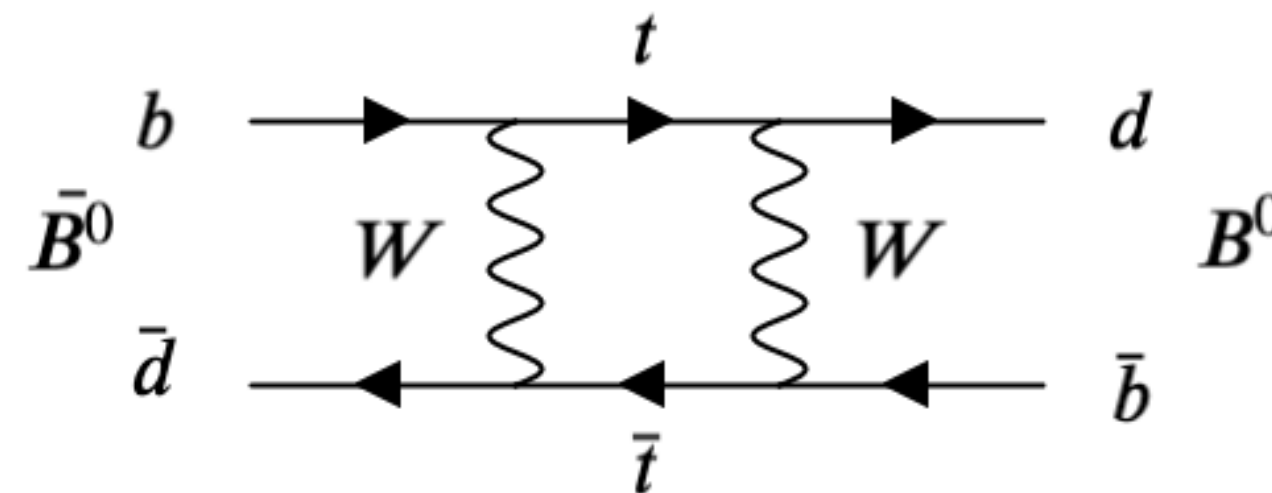
Belle II: $\beta\gamma=0.29$, $\Delta z \sim 140\mu\text{m}$

$$\Delta t = \Delta z / \beta\gamma c$$

$$\Delta z \sim 140 \mu\text{m}$$

Flavor non-specific CP eigenstate

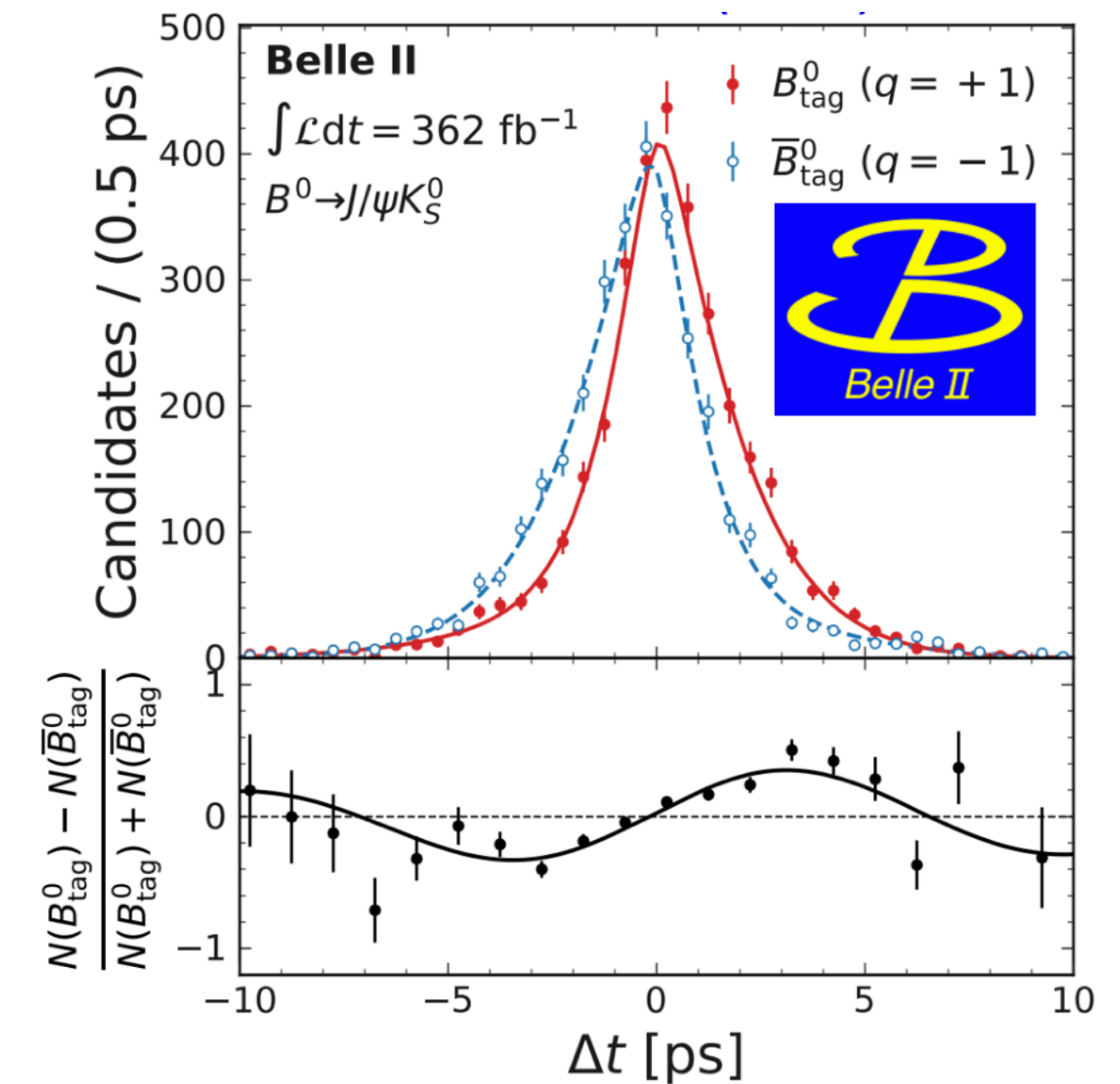
$$\phi_1 = (23.2 \pm 1.5 \pm 0.6)^\circ \quad \text{HFLAV WA: } \phi_1 = (22.63^{+0.45}_{-0.44})^\circ$$



GNN based flavor tagging efficiency enhance 18% vs. FBBDT:

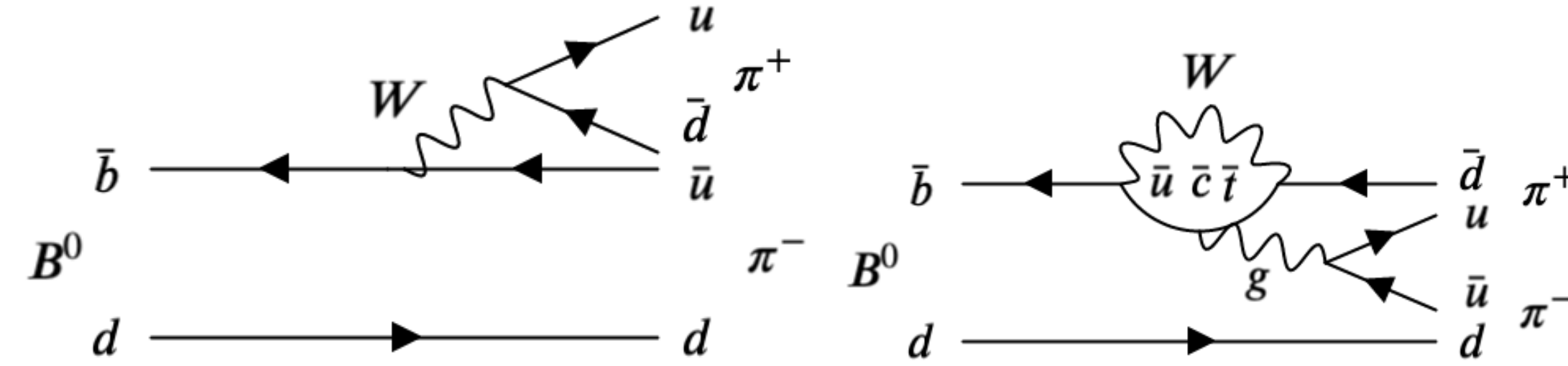
- Belle II : $(37.40 \pm 0.43 \pm 0.36)\%$
- Belle : $(30.1 \pm 0.4)\%$

PRD 110 (2024) 012001



ϕ_2 measurement ($B \rightarrow \pi^0 \pi^0$)

- ϕ_2 least known angle of UT, precision $\sim 3.7^\circ$, determined from an isospin analysis
 - Measure **time integrated** A_{CP} and branching fractions of all $B \rightarrow \pi\pi$ ($\pi^+\pi^-$, $\pi^\pm\pi^0$, $\pi^0\pi^0$),
 - ϕ_2 determination based on $B \rightarrow \pi\pi$ limited by $B \rightarrow \pi^0\pi^0$
 - 8-fold ambiguity of ϕ_2 can be reduced to 2-fold with TDCPV in $B^0 \rightarrow \pi^0\pi^0$ [PRL 65\(1991\) 3381](#)

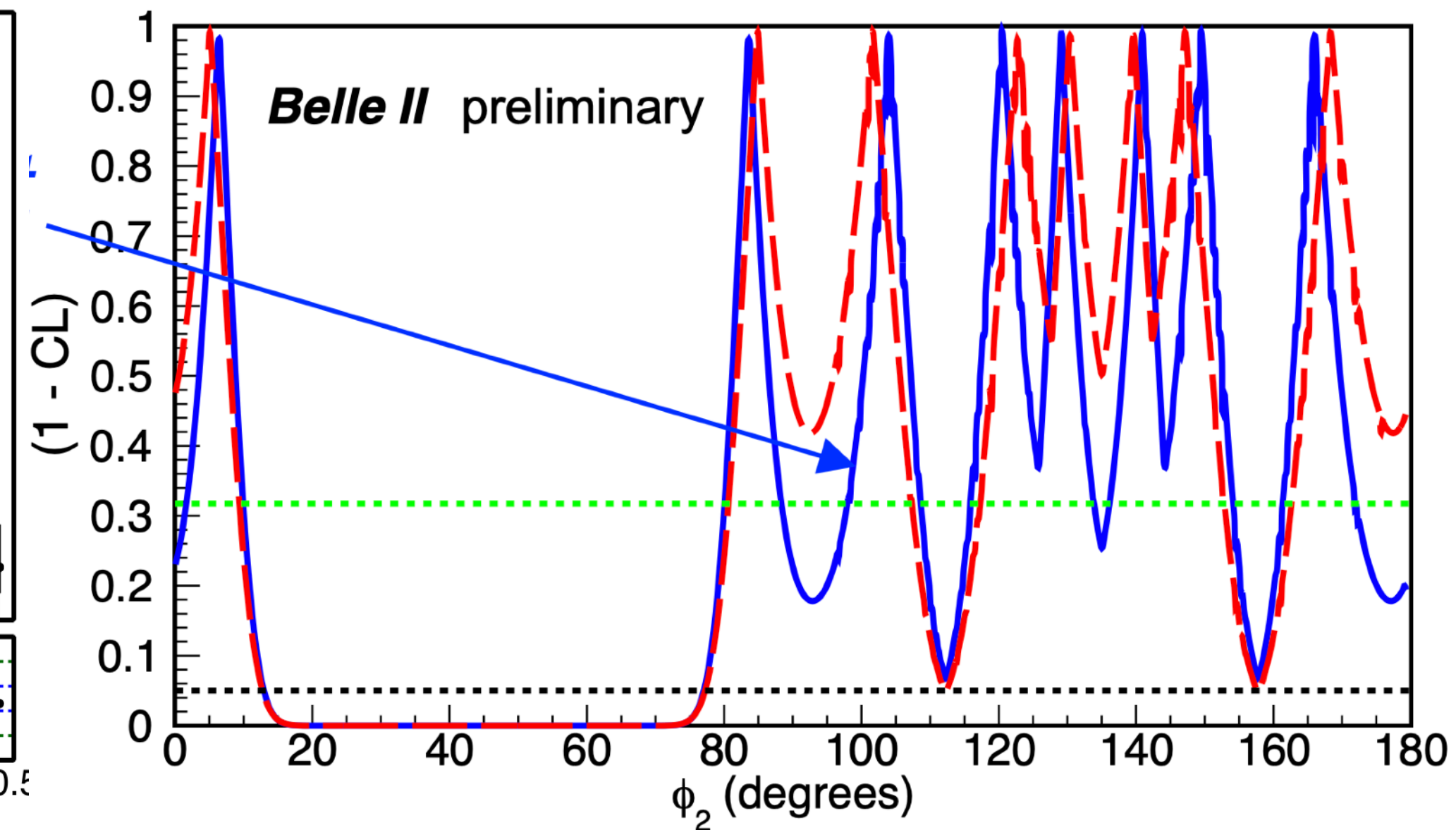
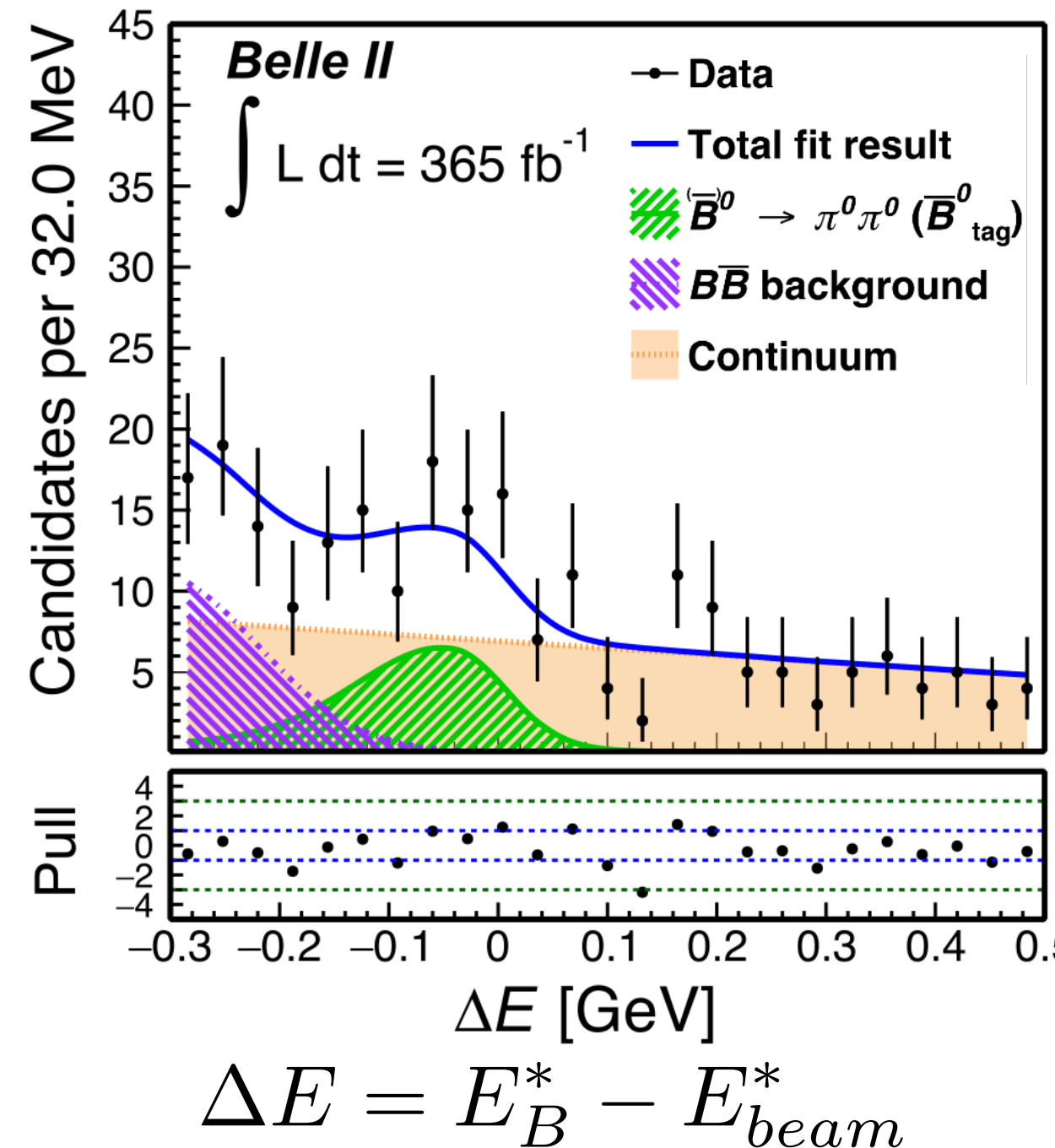
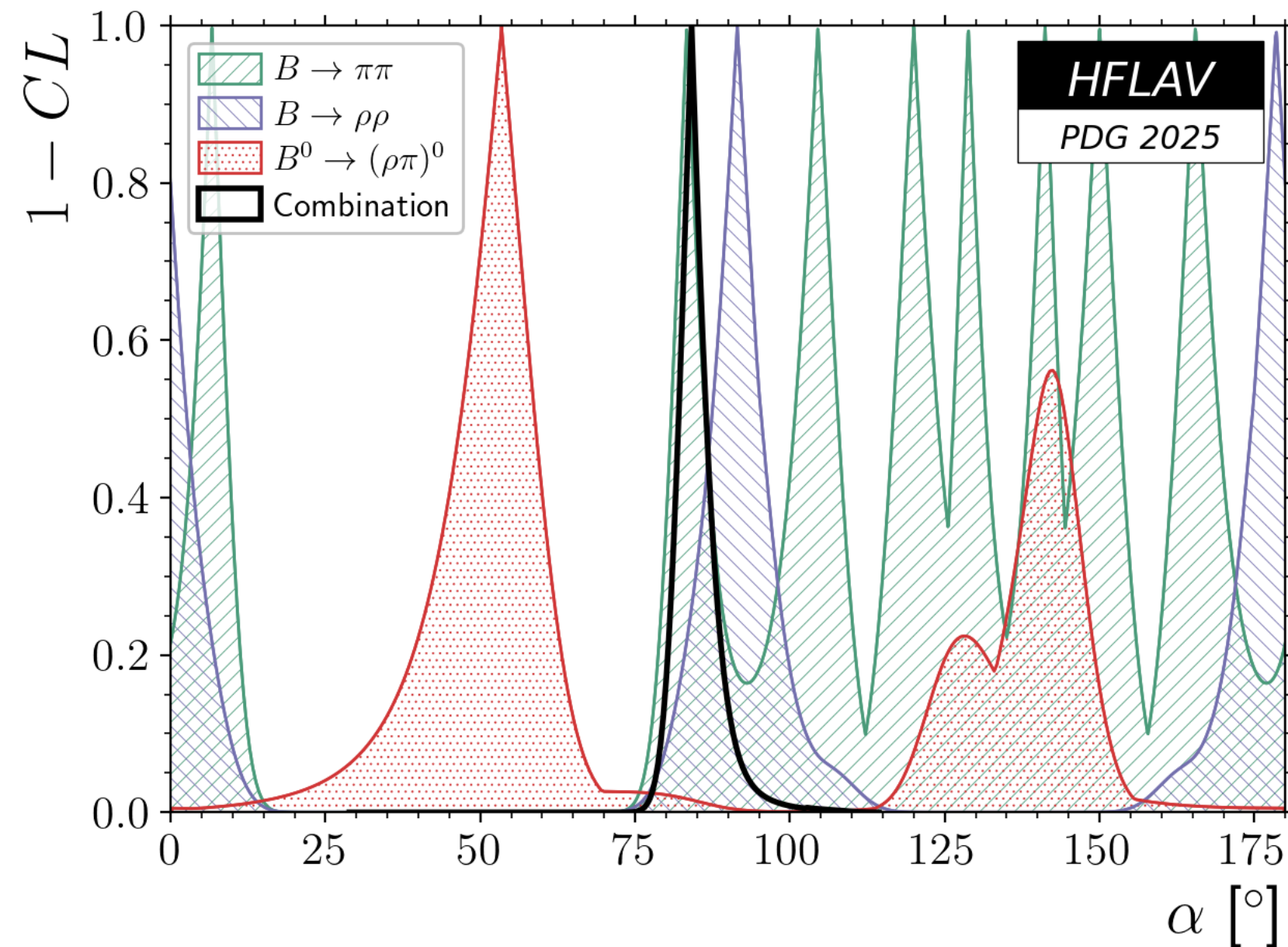


$$S_f = \sqrt{1 - A_f^2} \sin(2\phi_2 + 2\Delta\phi_2)$$

Interference between tree and penguin

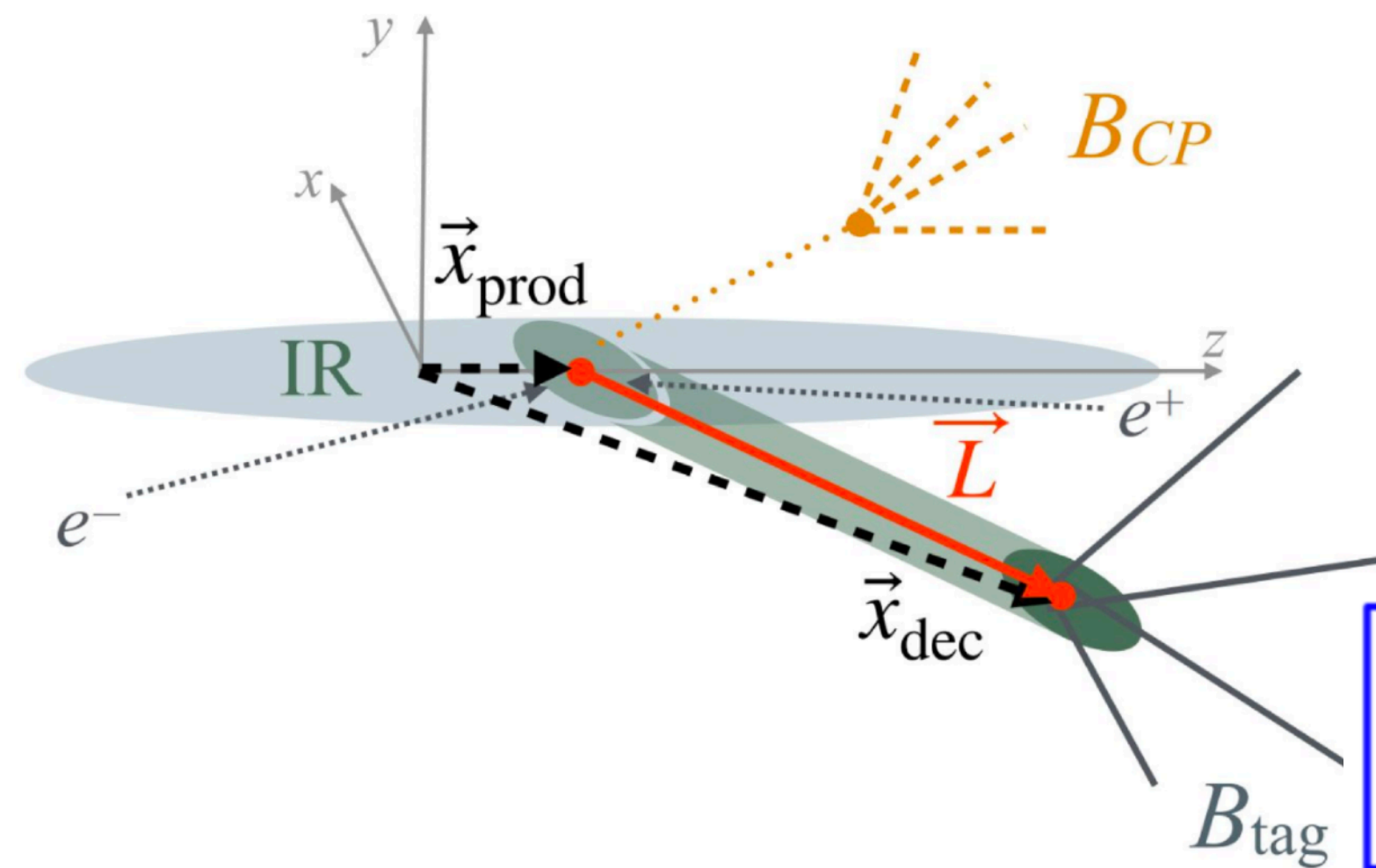
$B^0 \rightarrow \pi^0 \pi^0$ [PRD 111 \(2025\) L071102](#)

HFLAV WA $\phi_2 = (84.1_{-3.0}^{+3.7})^\circ$



ϕ_2 measurement w/ time-dependent CPV ($B \rightarrow \pi^0 \pi^0$)

- **Novel approach**, along with SuperKEKB **nano-beam** and **PXD**, enables measurement of CPV in $B \rightarrow \pi^0 \pi^0$ for the first time. (Would require **20x** more data with the conventional approach.)
- Technique requires compact interaction region and excellent vertexing enabled by Belle II PXD ~ 1.5 ps resolution

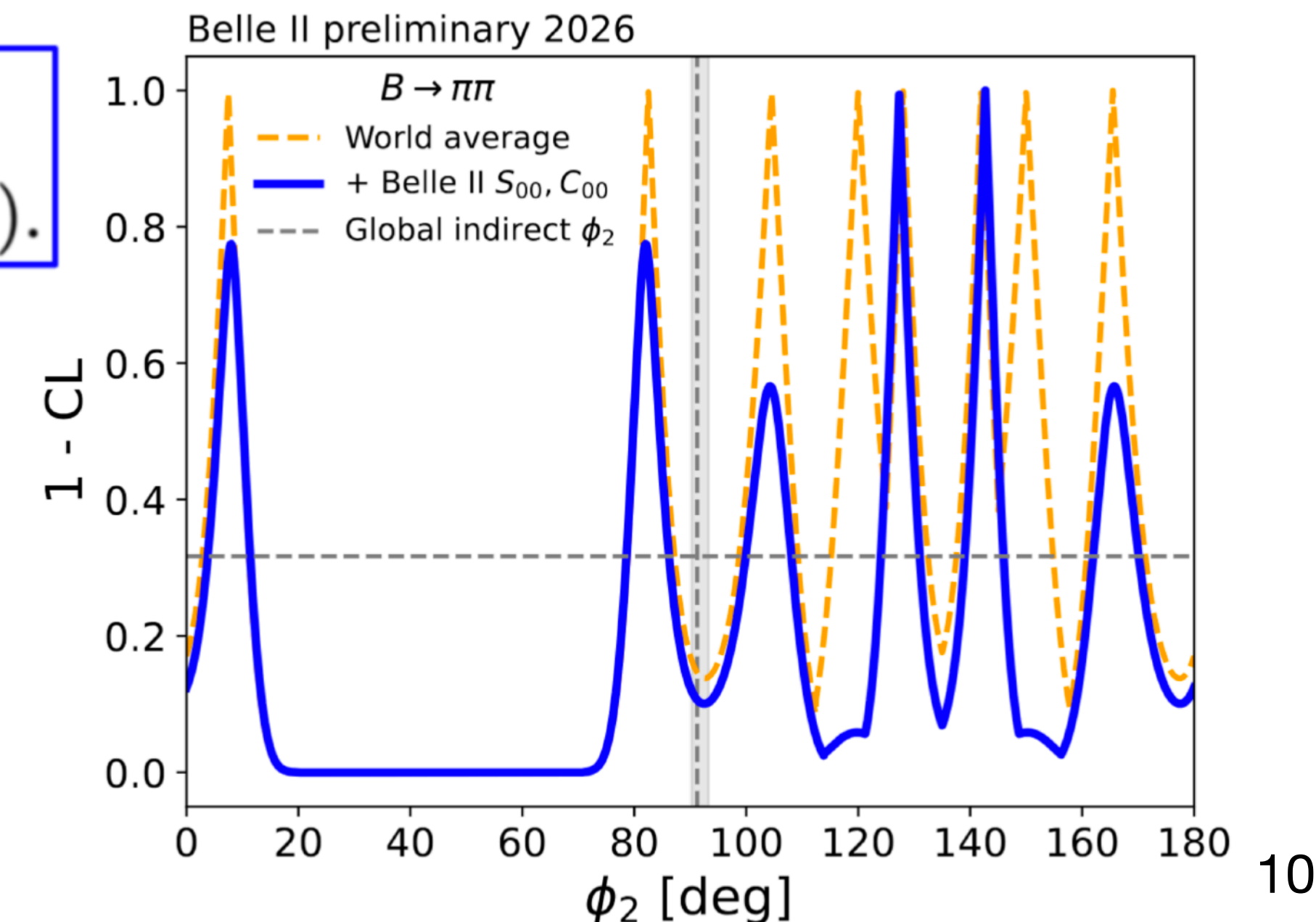


	Belle II	Belle	BaBar
Momenta of beams			
e^- (e^+) beam energy [GeV]	7.0 (4.0)	8.0 (3.5)	9.0 (3.0)
Beam energy spread [MeV]	5.45	5.36	4.63
Crossing angle [mrad]	83	22	0
IP size			
Interaction region x width [μm]	13	70	148
Interaction region y width [μm]	0.2	1.0	6.9
Interaction region z width [μm]	350	6000	15150
vtx resolution			
B_{tag} vertex x - y resolution [μm]	30	80	80
B_{tag} vertex z resolution [μm]	30	100	125

$$S_{00} = 0.61_{-0.79}^{+0.75} \text{ (stat)} \pm 0.11 \text{ (syst)},$$

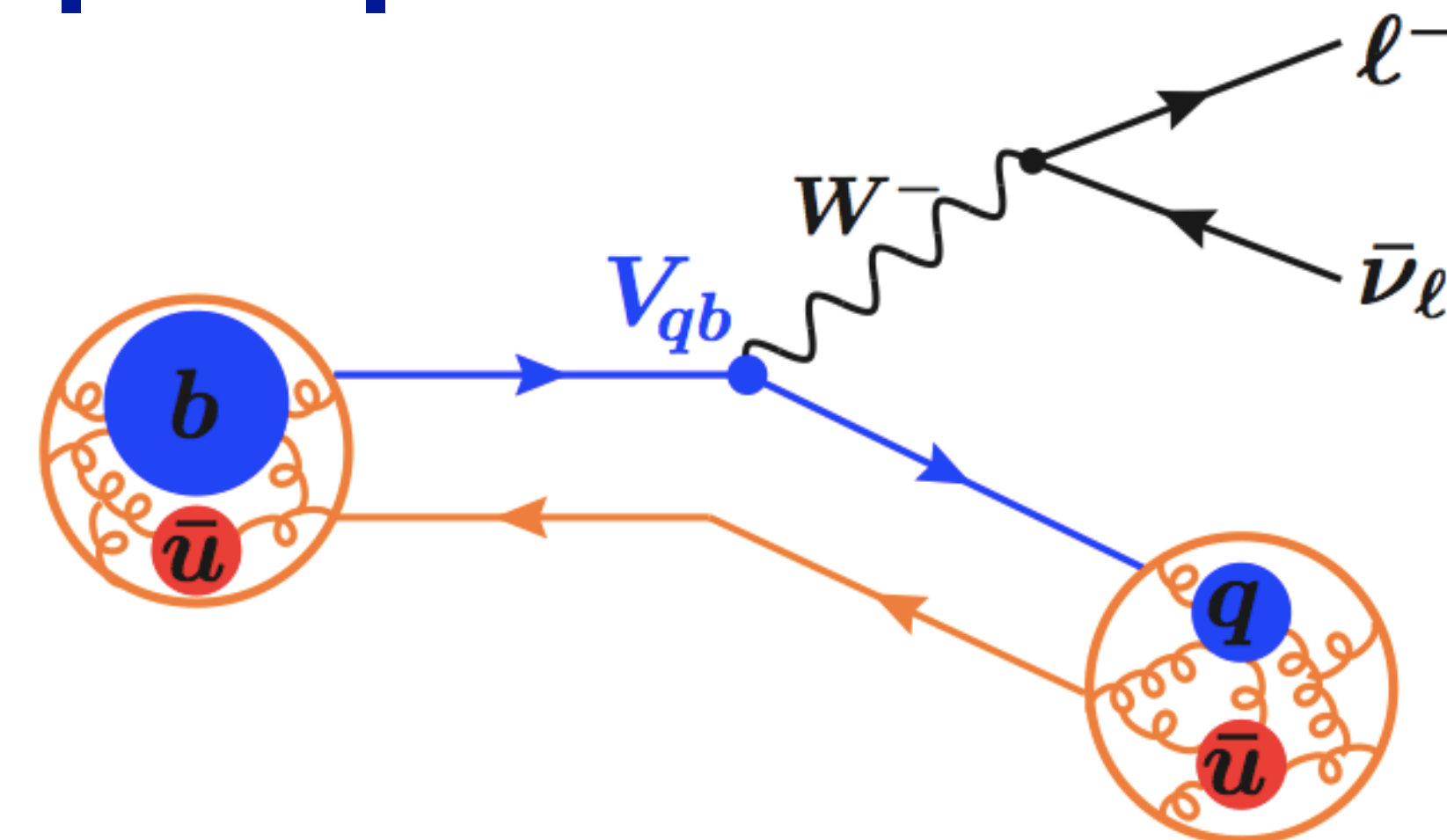
$$C_{00} = 0.05 \pm 0.28 \text{ (stat)} \pm 0.07 \text{ (syst)}.$$

- Reduces ambiguity in ϕ_2 from 8 to 6 solns
- Improves determination of ϕ_2 from $B \rightarrow \pi\pi$ by $\sim 40\%$
- $\Delta\phi_2 \sim 2.5^\circ @ 5-10 \text{ ab}^{-1}$, $\sim 0.6^\circ @ 50 \text{ ab}^{-1}$ data (current 3.7°)
 - $B \rightarrow \pi\pi$, $B \rightarrow \rho\rho$ isospin analysis and $B \rightarrow \rho(\pi\pi)\pi$ Dalitz analysis of 3 body decays

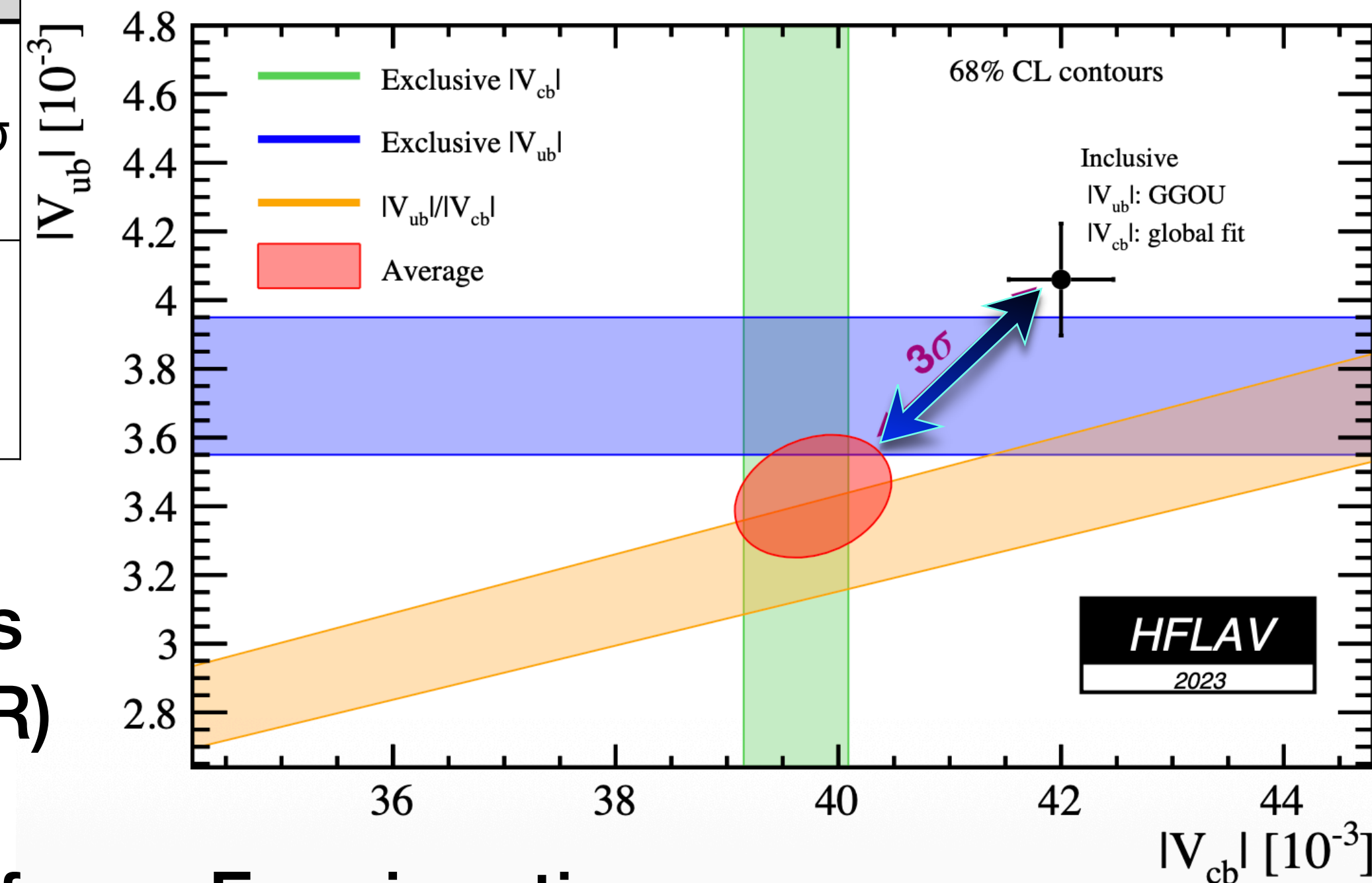


Status of $|V_{cb}|$ and $|V_{ub}|$

Side	Observable		Dominant uncertainties
$ V_{cb} $	$Br(b \rightarrow c l \nu)$	$Br(B \rightarrow D^{(*)} l \nu)$	Exclusive: Lattice QCD
		$Br(B \rightarrow X_c l \nu)$	
$ V_{ub} $	$Br(b \rightarrow u l \nu)$	$Br(B \rightarrow \pi/\rho l \nu)$	Inclusive: experiment vs. phenomenology (LQCD)
		$Br(B \rightarrow X_u l \nu)$	



Side	Exclusive (x10 ⁻³)	Inclusive (x10 ⁻³)	Differenc
$ V_{cb} $	40.2 ± 0.6 (D*lv, BGL form factor) 38.9 ± 0.7 (Dlv, BGL form factor)	41.97 ± 0.48 (kinetic scheme) M _{X+E} +q ² moments	2.3σ, 3.6σ
$ V_{ub} $	3.75 ± 0.06 ± 0.19 (πlv, BCL form factor + LQCD)	4.06 ± 0.12 ± 0.11 GGOU kinetic scheme	1.2σ



Exclusive:

$$\frac{d\mathcal{B}}{dq^2}(B \rightarrow \pi l \nu) \propto |V_{ub}|^2 f_+^2(q^2) \quad \text{Theory input: Form Factors (LQCD, LCSR)}$$

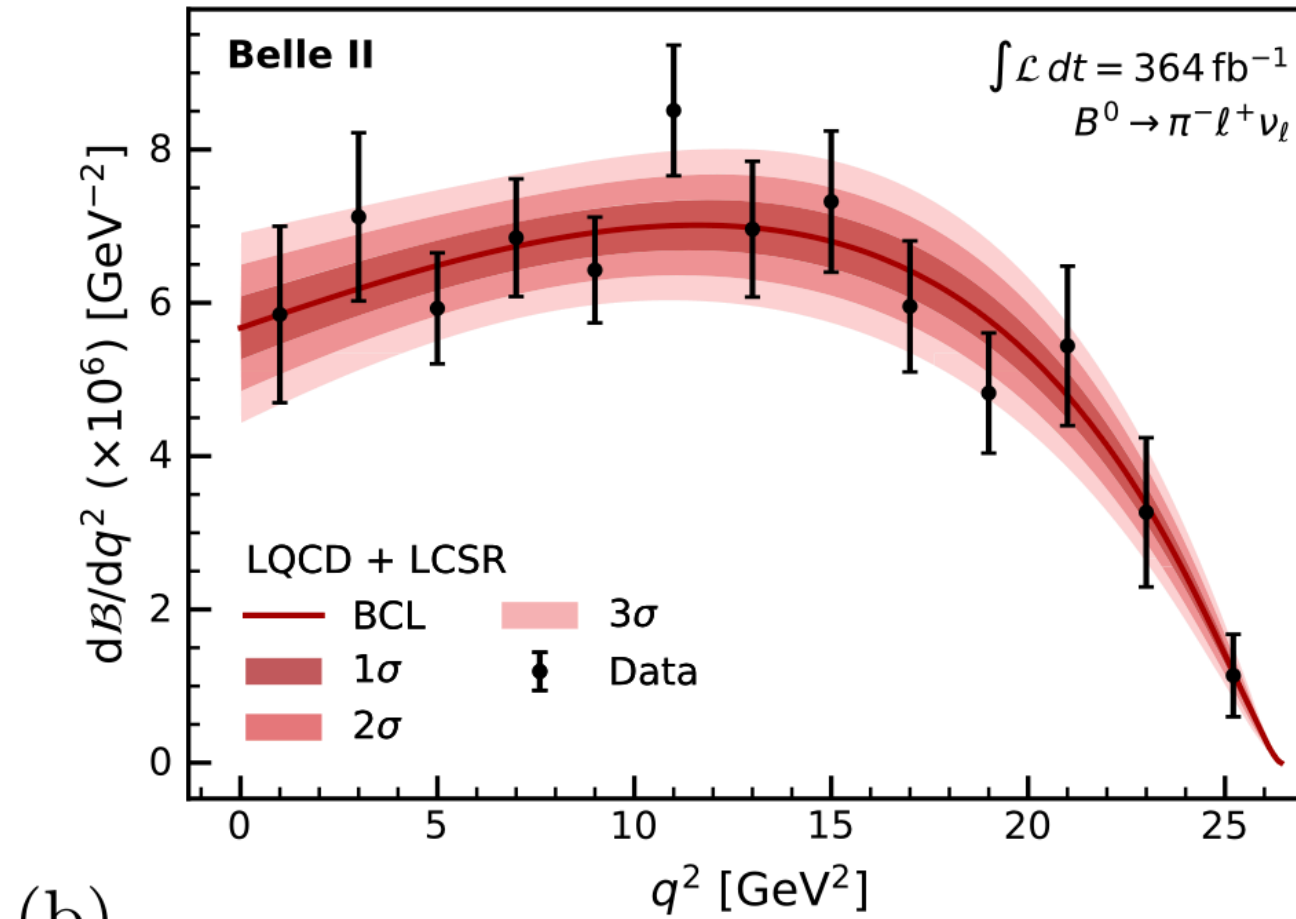
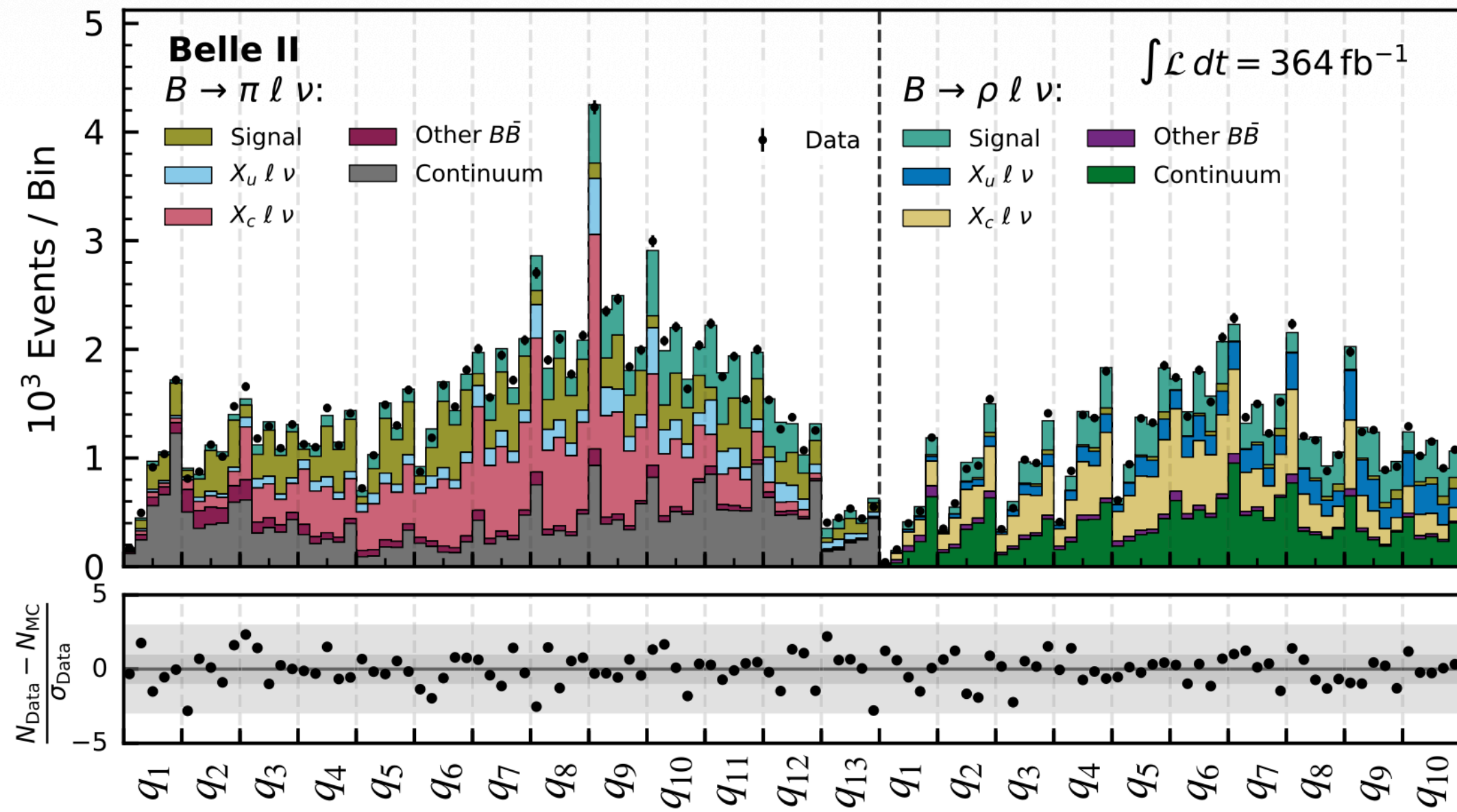
Inclusive:

$$\mathcal{B} = |V_{qb}|^2 \left[\Gamma(b \rightarrow q l \bar{\nu}_l) + 1/m_{c,b} + \alpha_s + \dots \right] \quad \text{Theory input: Shape func., Fermi motion (OPE)}$$

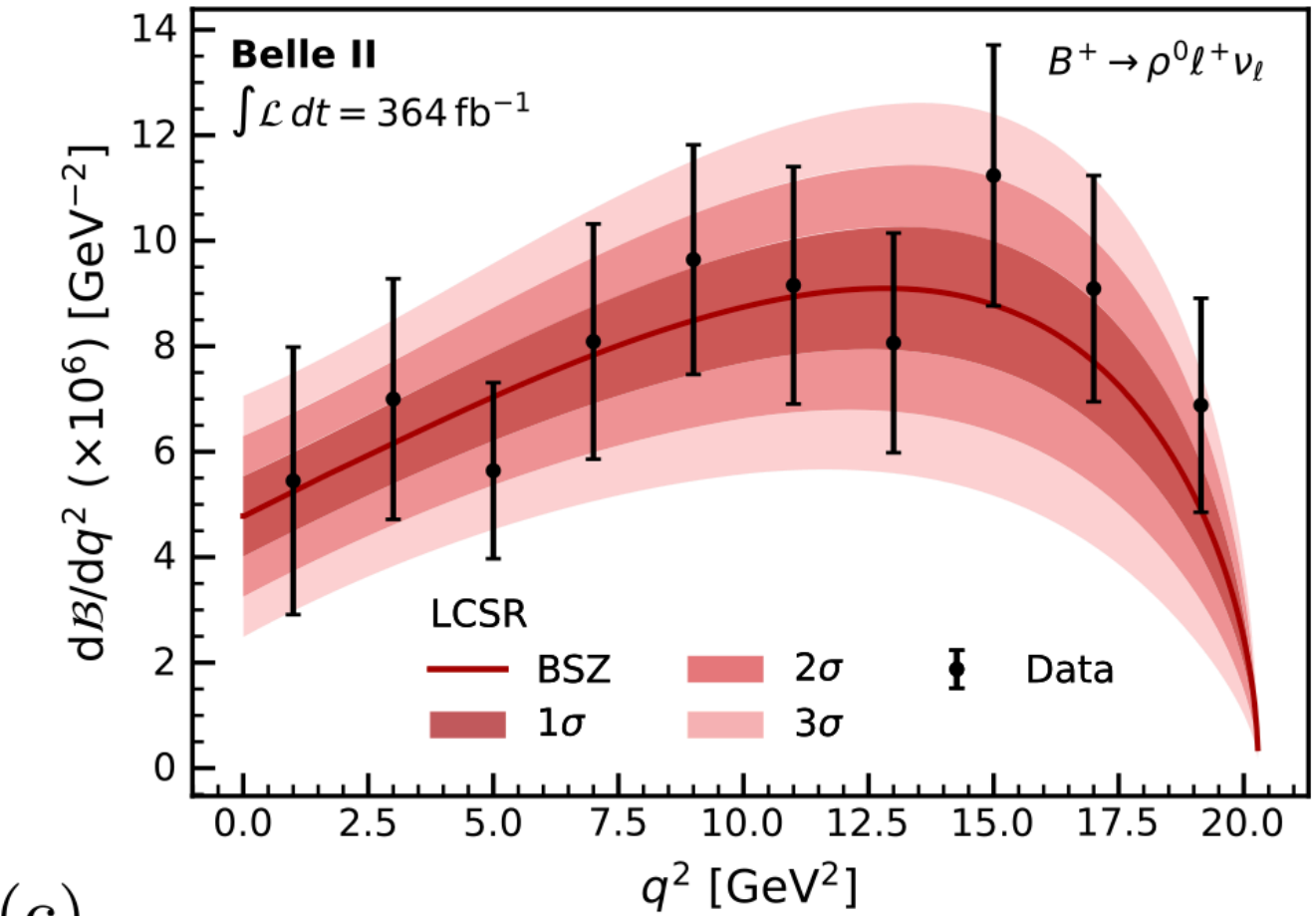
Measurement of $|V_{ub}|$ with $b \rightarrow ul\nu$

- Untagged simultaneous measurement of $B^0 \rightarrow \pi^- l \nu$, $B^+ \rightarrow \rho^0 l \nu$
 - Simultaneous 3D fit in ΔE , M_{bc} , and q^2

[PRD 111 112009 \(2025\)](#)



(b)

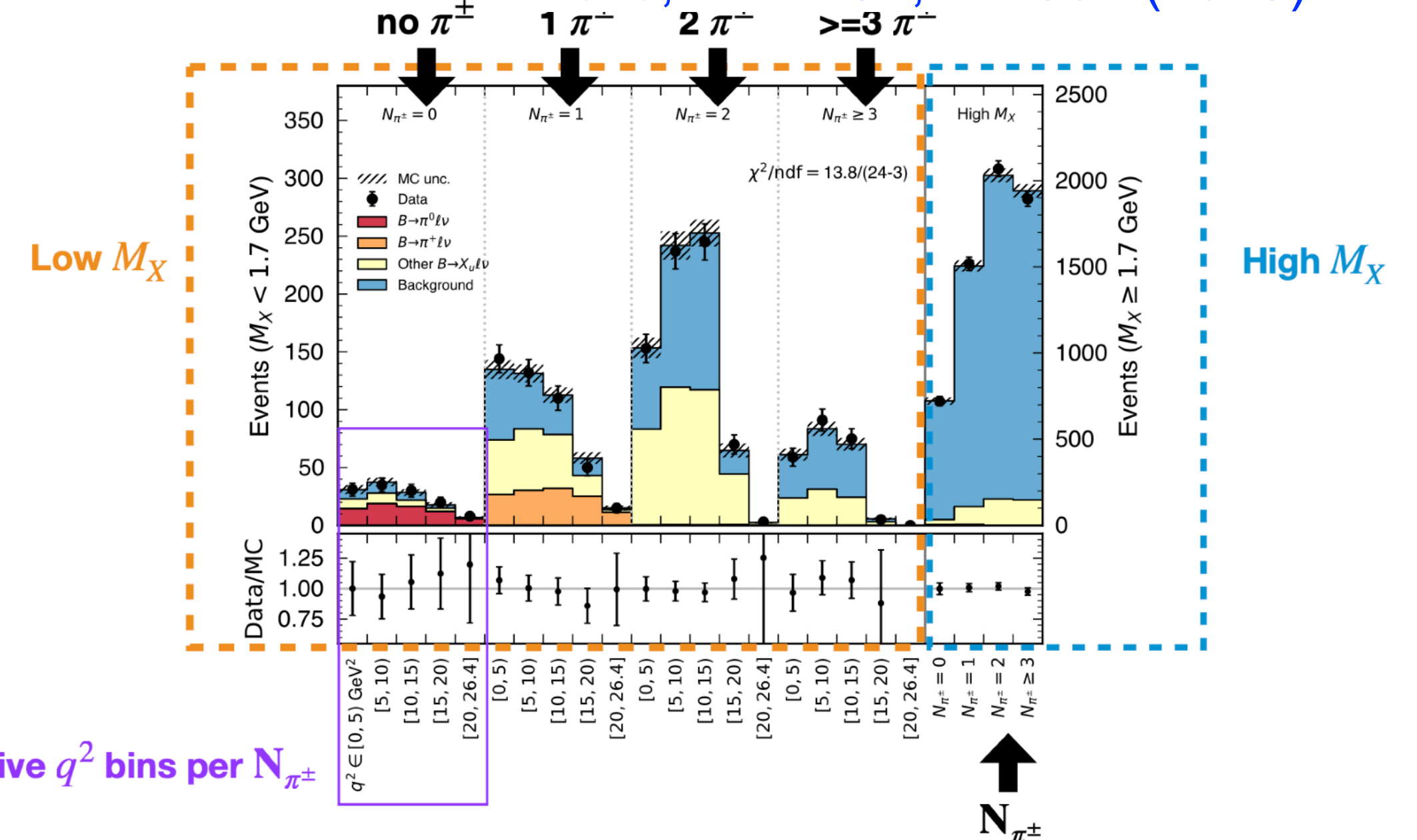


(c)

$$|V_{ub}|_{B \rightarrow \pi l \nu} = (3.93 \pm 0.09 \pm 0.13 \pm 0.19) \times 10^{-3}$$

$$|V_{ub}|_{B \rightarrow \rho l \nu} = (3.19 \pm 0.12 \pm 0.17 \pm 0.26) \times 10^{-3}$$

[Belle, PRL 131, 211801 \(2023\)](#)



- Simultaneous measurement of $B^0 \rightarrow \pi^- l \nu$, $B^+ \rightarrow X_u l \nu$
 - Excl.** $(3.78 \pm 0.23_{\text{stat}} \pm 0.16_{\text{syst}} \pm 0.14_{\text{theo}}) \times 10^{-3}$
 - Incl.** $(3.88 \pm 0.20_{\text{stat}} \pm 0.31_{\text{syst}} \pm 0.09_{\text{theo}}) \times 10^{-3}$

Measurement of $|V_{ub}|$ with $B \rightarrow X_u \ell \nu$

- **Reconstruction:** Combined signal lepton on the **signal side** with fully reconstructed hadronic B on **tag side**
- **Large backgrounds** from dominant decays $B \rightarrow X_c \ell \nu$
- Determine from the measured **partial** $|V_{ub}|$ **branching fractions** in the 3 different phase space regions:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \rightarrow X_u \ell \nu)}{\tau_B \Delta\tilde{\Gamma}(B \rightarrow X_u \ell \nu)}}$$

- Nominal result: $E_l > 1$ GeV with GGOU,
- covering 87% of phase space

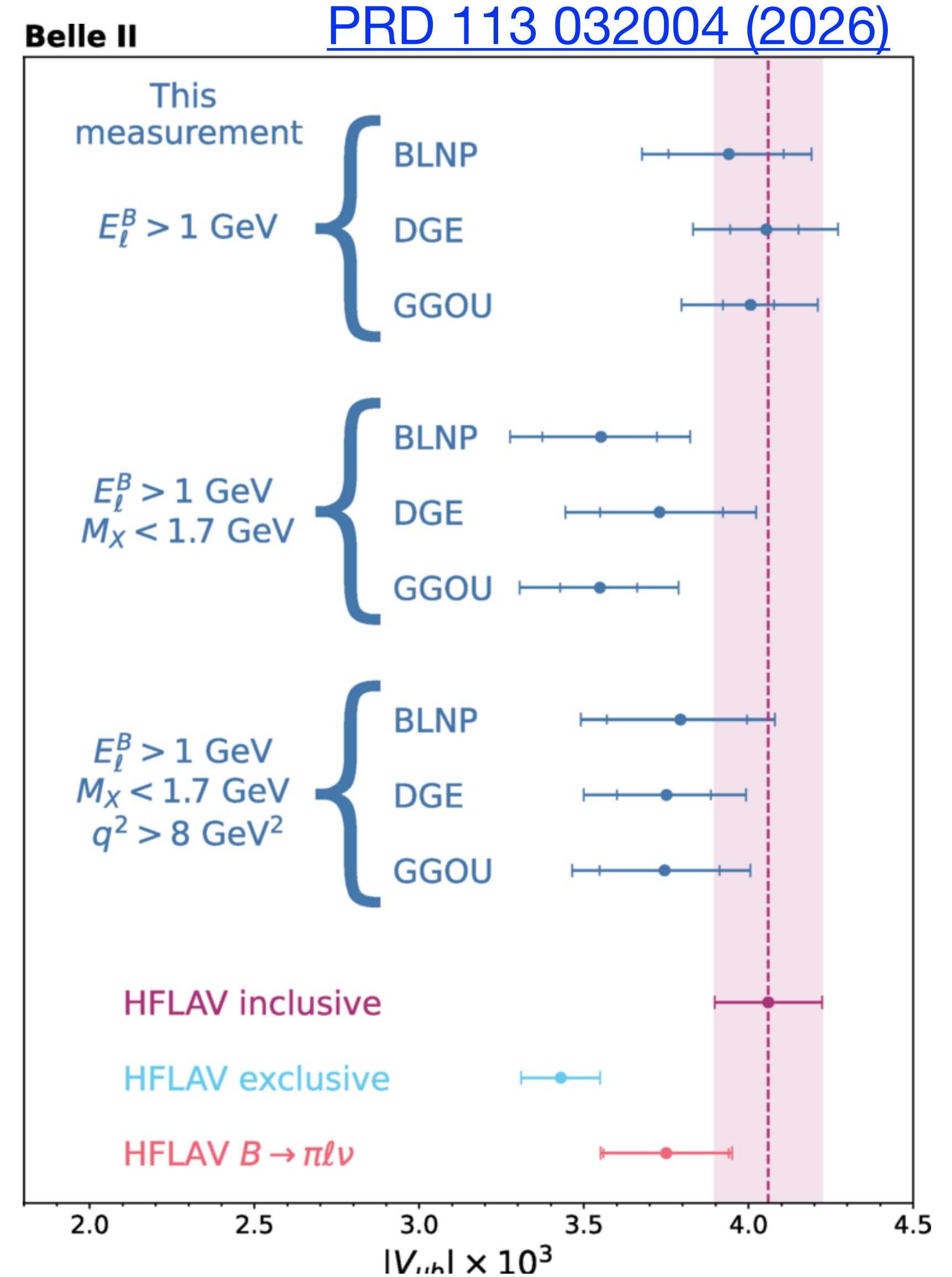
$$|V_{ub}| = 4.01 \pm 0.11(\text{stat.}) \pm 0.16(\text{syst.})_{-0.08}^{+0.07}(\text{theo})$$

- Dominant systematics

$B \rightarrow X_u \ell \nu$ modelling: (m_b, a) where $a = f(m_b, \mu_\pi^2)$ in Kagan-Neubert scheme

$B \rightarrow X_c \ell \nu$ composition differences between SR and CR

X_u fragmentation modelling



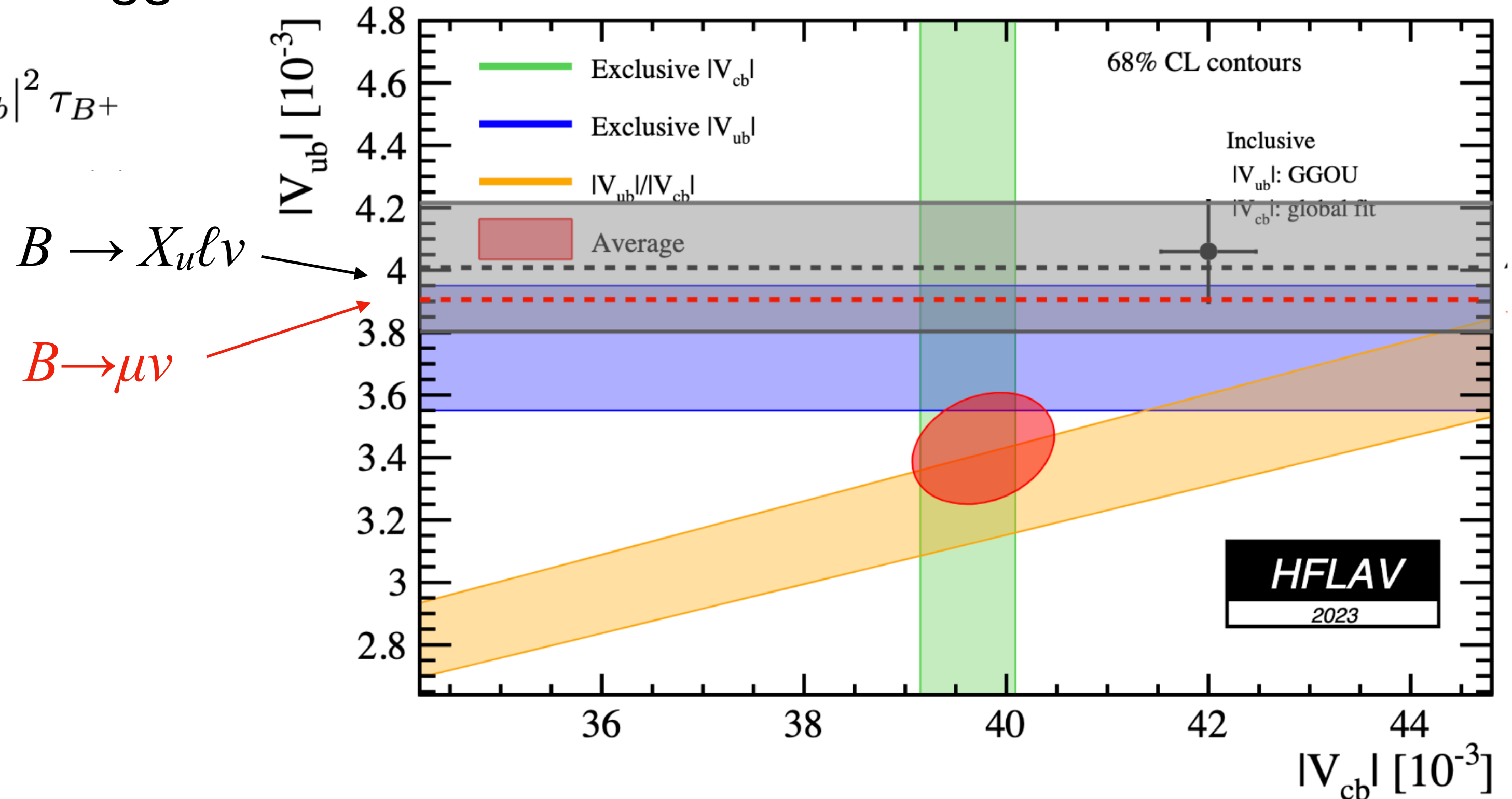
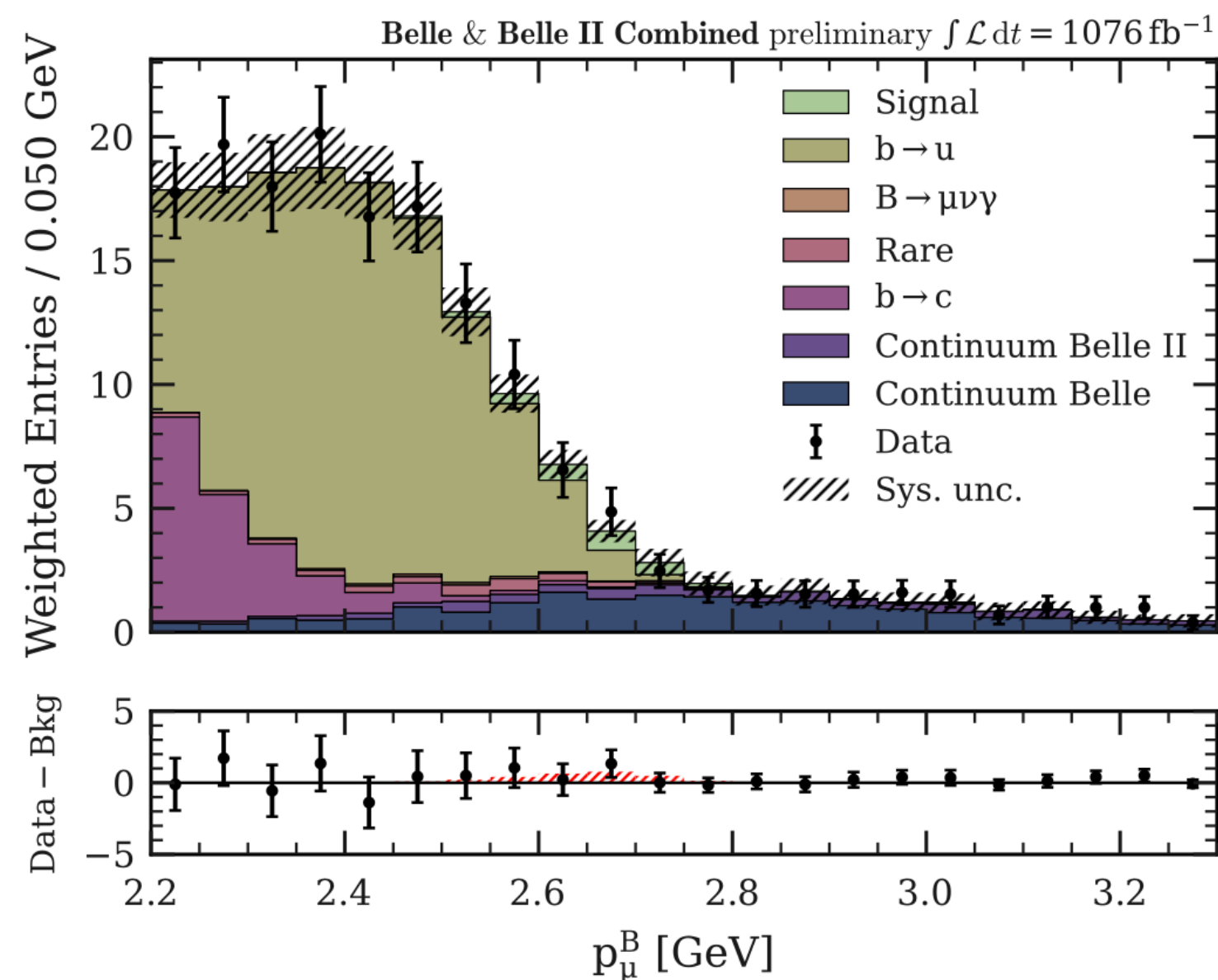
Exclusive Average for $B \rightarrow \pi \ell \nu$:

$$|V_{ub}| = (3.75 \pm 0.06_{\text{exp}} \pm 0.19_{\text{theo}}) \times 10^{-3}$$

$Br(B \rightarrow \mu \nu)$ result with inclusive tag

- Belle&Belle II $Br(B \rightarrow \mu \nu)$ measurement w/ inclusive tagging @ 1076 fb⁻¹ [arXiv:2602.09800](https://arxiv.org/abs/2602.09800)
 - Theoretical clean
 - Rare decay
 - Sensitive to new physics, e.g. charged Higgs

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



2.4σ over background-only hypothesis
Most precise measurement to date

$$Br(B \rightarrow \mu \nu) = (4.4 \pm 1.9 \text{ (stat)} \pm 1.0 \text{ (syst)}) \times 10^{-7}$$

Determination of exclusive $|V_{ub}|$

$$|V_{ub}| = 3.92^{+0.77}_{-0.96} \text{ (stat.)}^{+0.44}_{-0.49} \text{ (syst.)} \pm 0.03 \text{ (theo)}$$

Compatible with both inclusive and exclusive determinations 14

Measurement of $B \rightarrow D^{(*)} \ell \nu$ for $|V_{cb}|$

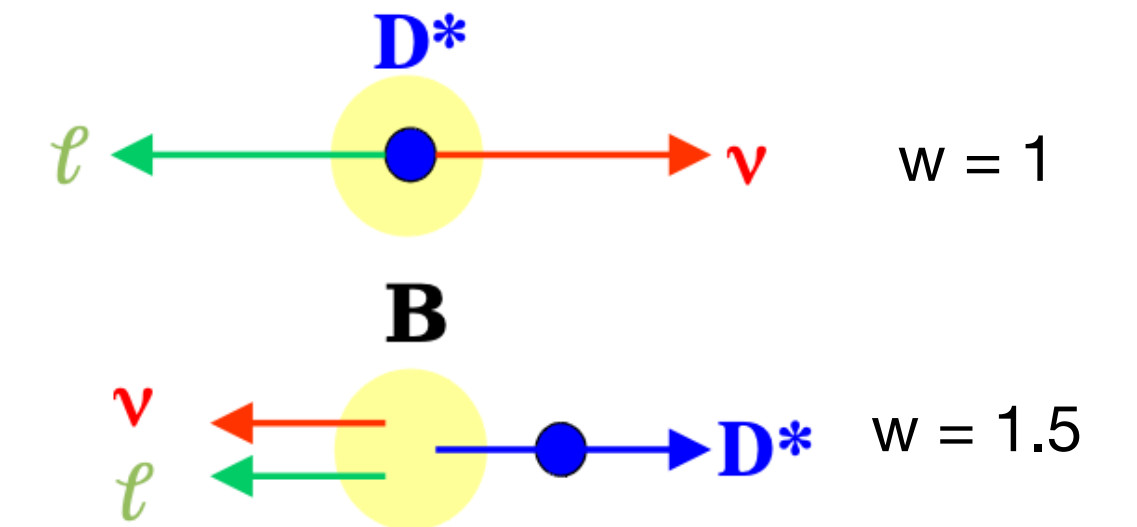
- $|V_{cb}|_{B \rightarrow D^{*} \ell \nu}$ precision $\sim 2.5\%$ limited by systematics: low momentum pion $\sim 1.5\%$, $f_{+}/f_{00} \sim 1.3\%$
 - LQCD used only for normalization at zero recoil ($w=1$)

$$|V_{cb}|_{\text{CLN}} = (40.13 \pm 0.27 \pm 0.93 \pm 0.58) \times 10^{-3}$$

$$|V_{cb}|_{\text{BGL}} = (40.57 \pm 0.31 \pm 0.95 \pm 0.58) \times 10^{-3}$$

[PRD 108 092013 \(2023\)](#)

- BGL: Boyd, Grinstein, Lebed, PRD56(1997)6895
- CLN: Caprini, Lellouch, Neubert, Nucl. Phys. B530(1998) 153

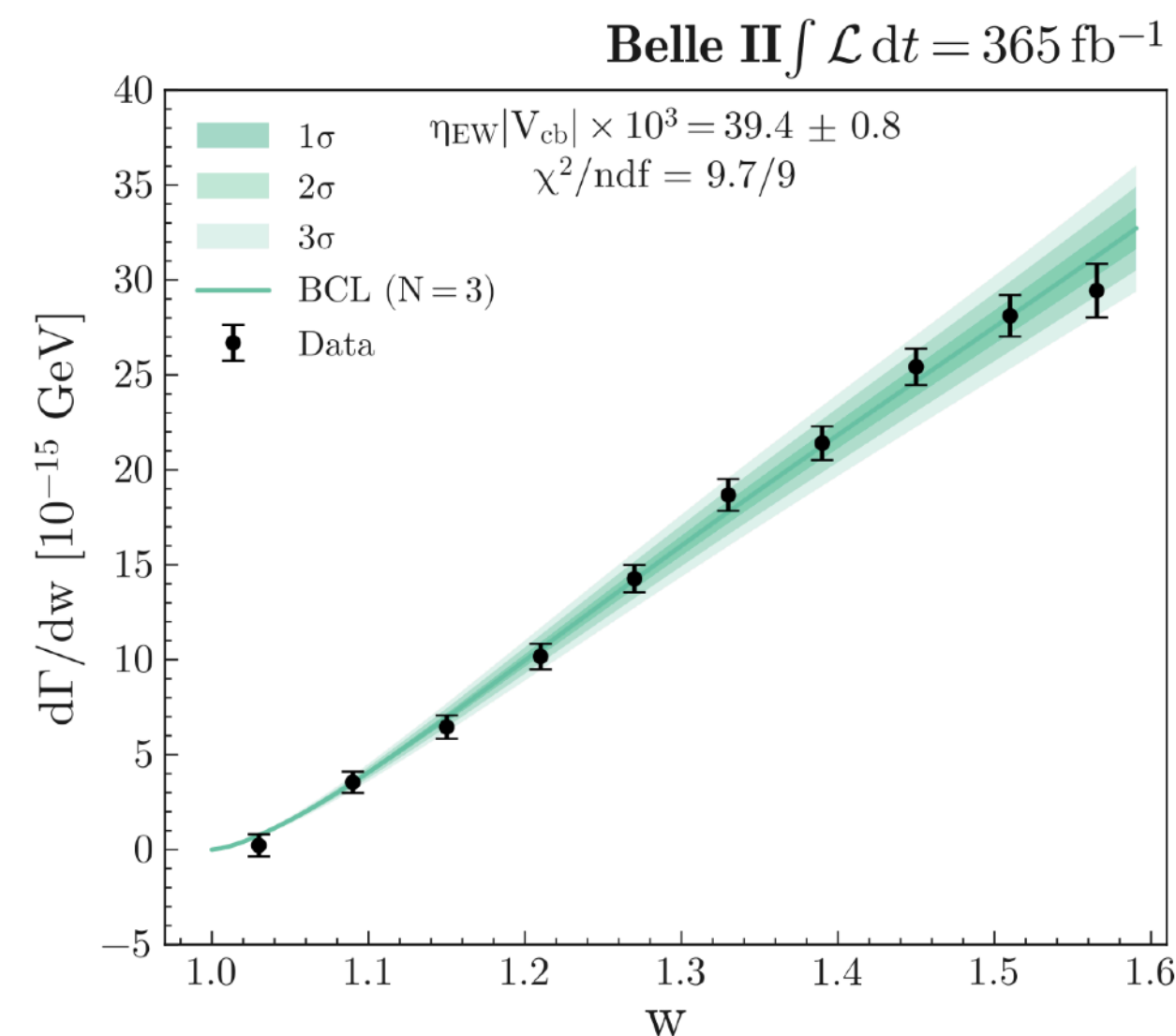
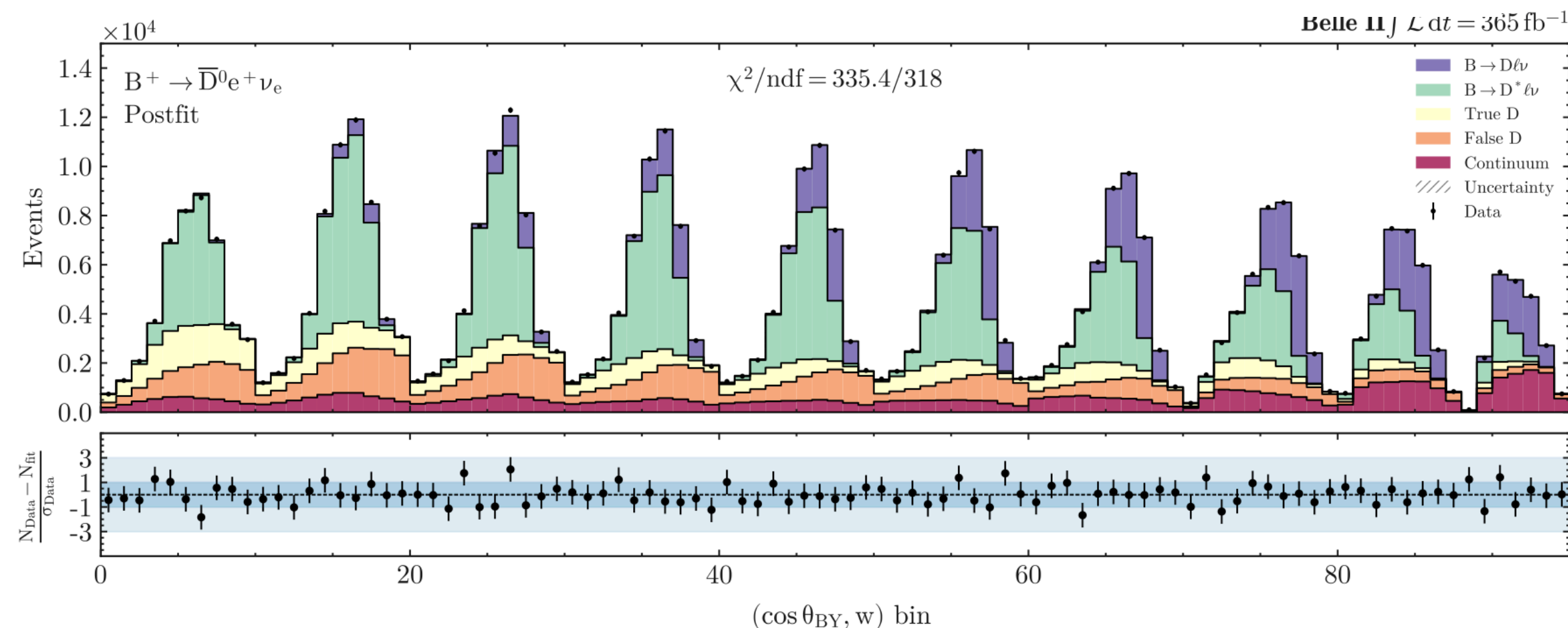


$$\frac{d\Gamma(B \rightarrow \bar{D} \ell^+ \nu_\ell)}{dw} \propto (w-1)^{3/2} \eta_{\text{EW}}^2 (1 + \delta_C^{+,0}) \mathcal{G}^2(w) |V_{cb}|^2$$

\propto signal yield QED correction form factor

- Most precise $|V_{cb}|_{B \rightarrow D \ell \nu}$ consistent with excl. WA
- $|V_{cb}|_{B \rightarrow D \ell \nu}$ precision $\sim 2.2\%$
- One form factor better consistency with LQCD

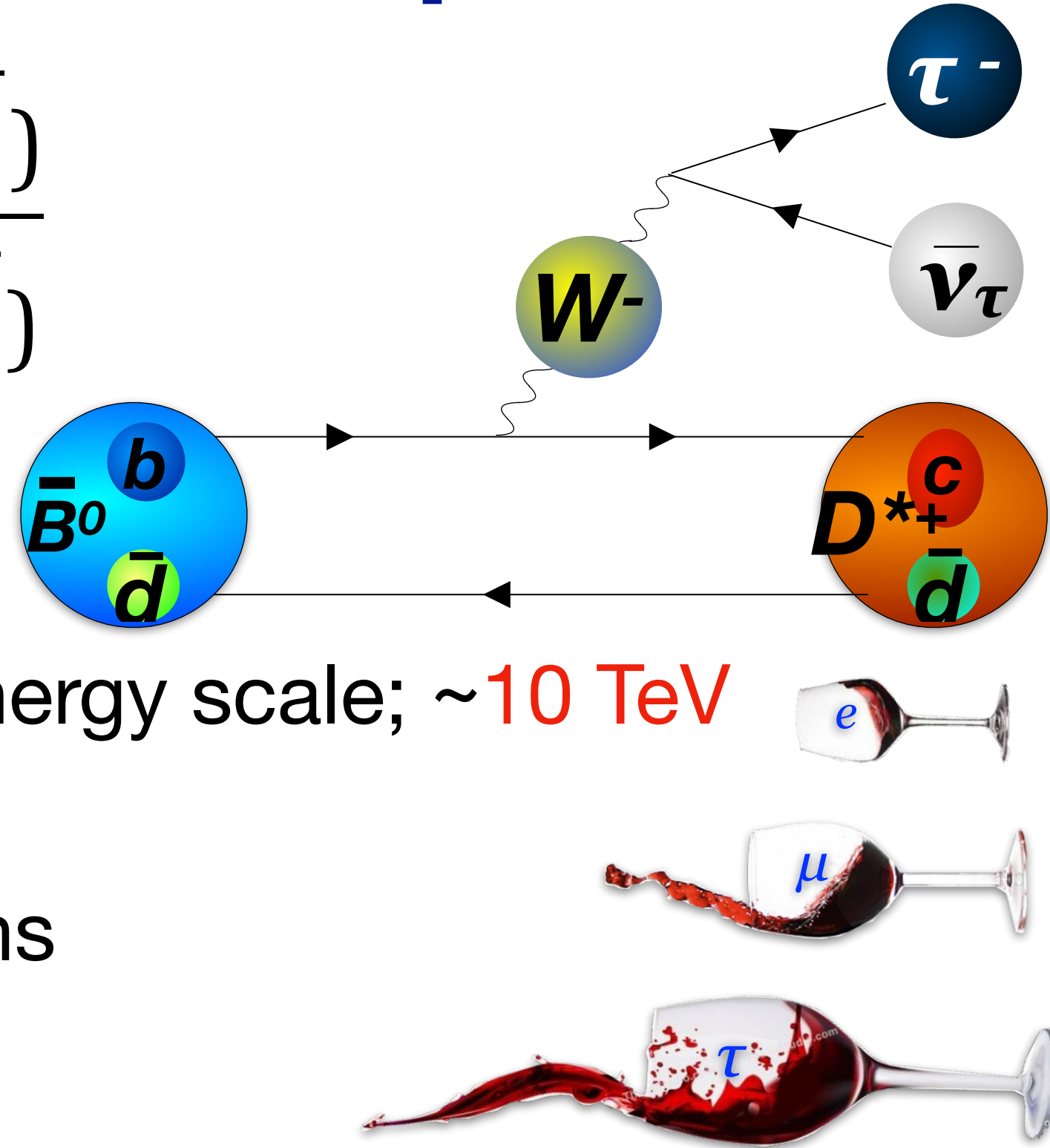
$$|V_{cb}| = (39.2 \pm 0.4 (\text{stat.}) \pm 0.6 (\text{sys.}) \pm 0.5 (\text{th.})) \times 10^{-3}$$



[PRD 112 112009 \(2025\)](#)

Test of lepton flavor universality

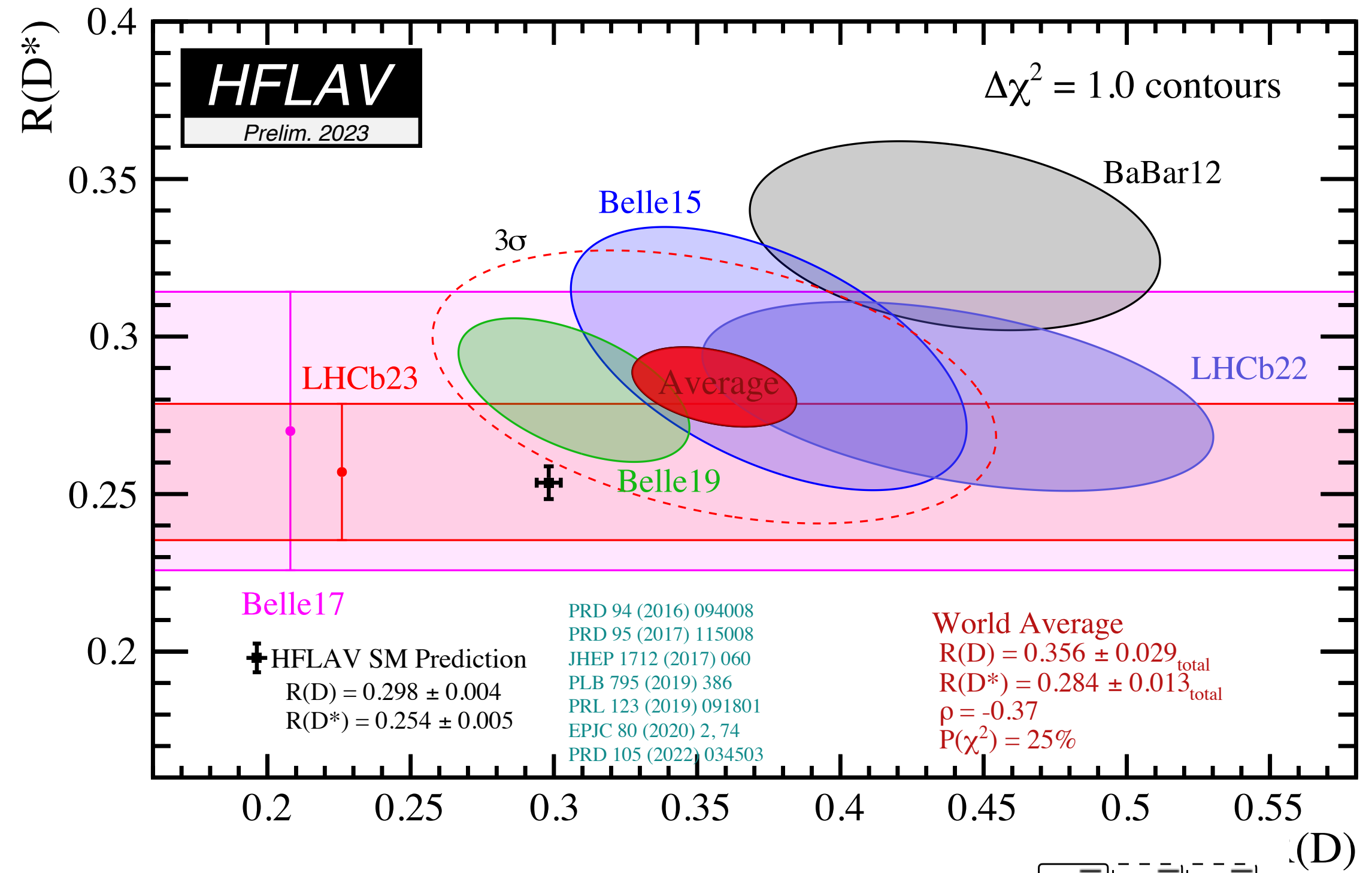
$$R_{(D^*)} = \frac{Br(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)}{Br(\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}_\tau)}$$



- Sensitivities to high energy scale; ~ 10 TeV

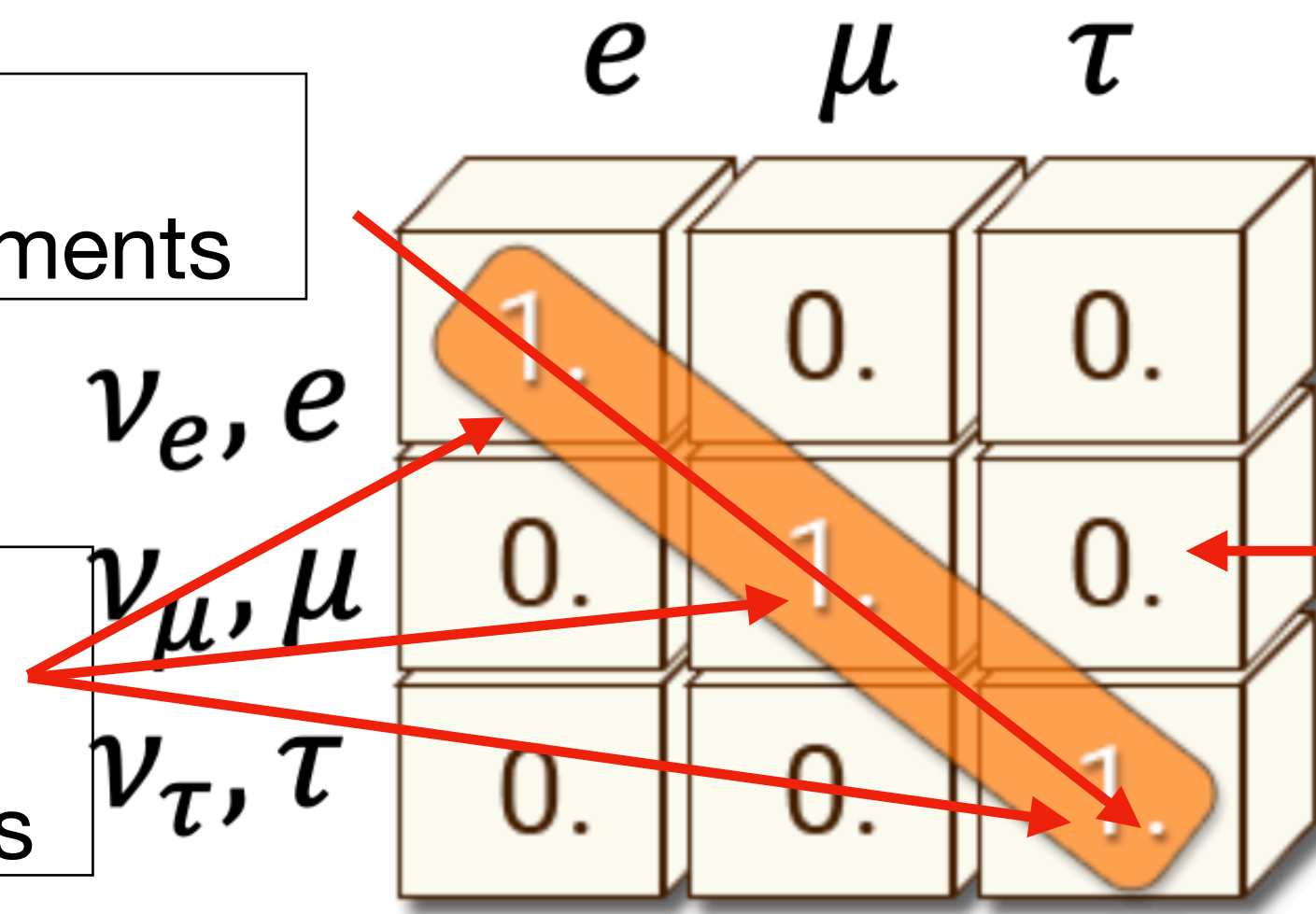
[[Belle II phys. book](#)]

- Heavy vector bosons
- Leptoquark

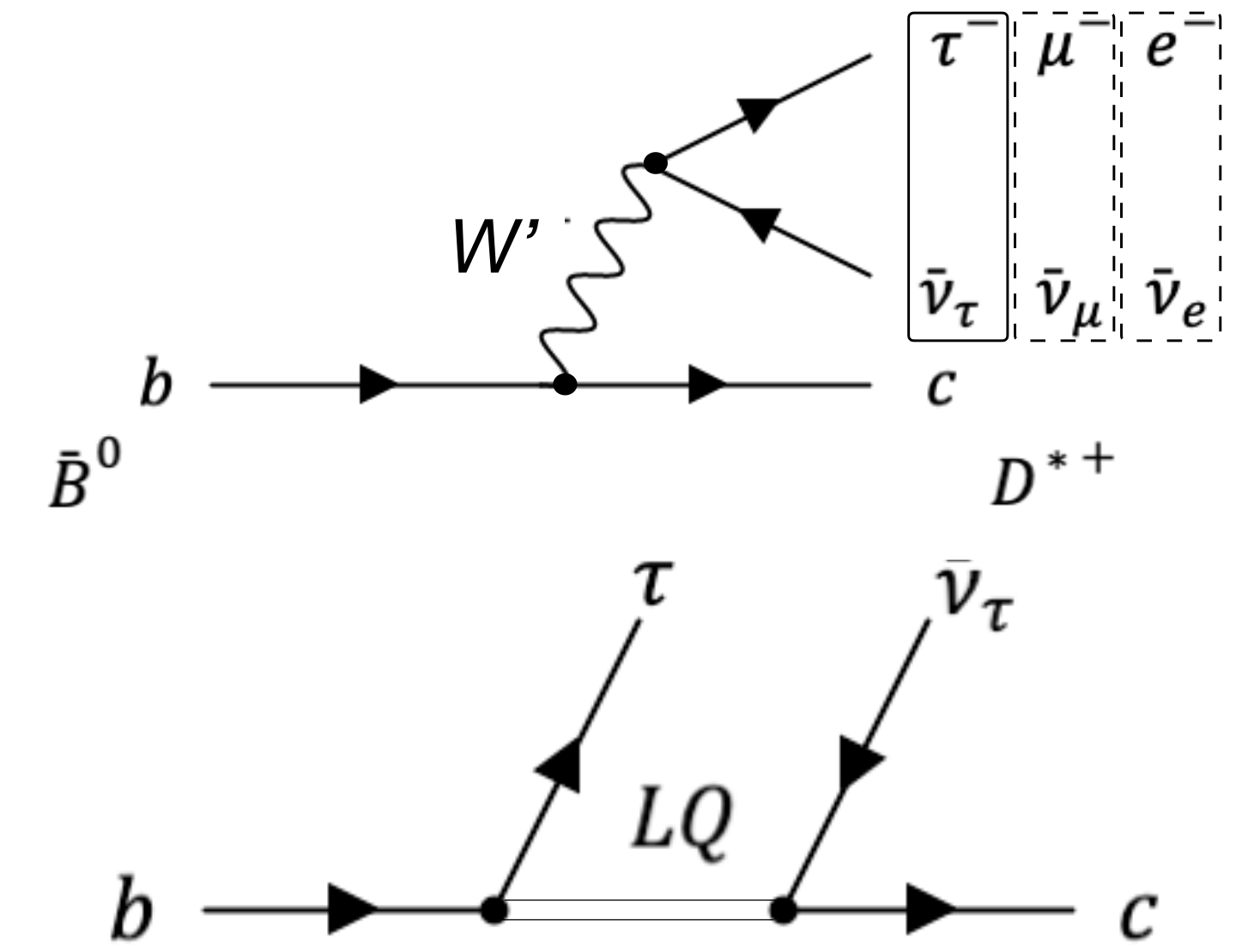
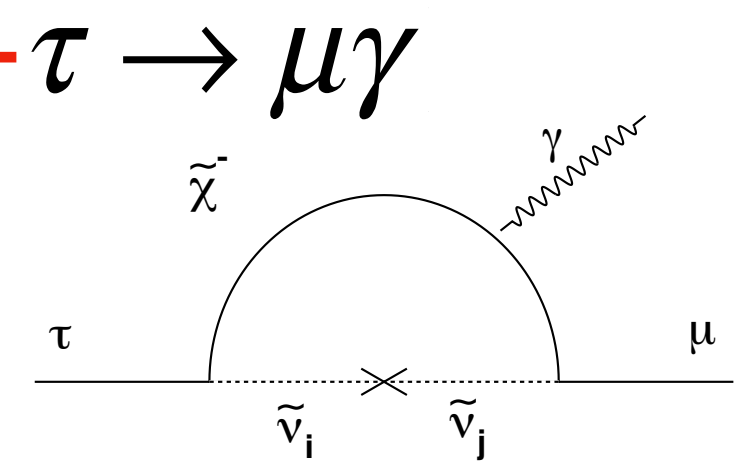


$g-2$, EDM:
diagonal elements

LFUV:
Relation among diagonal elements

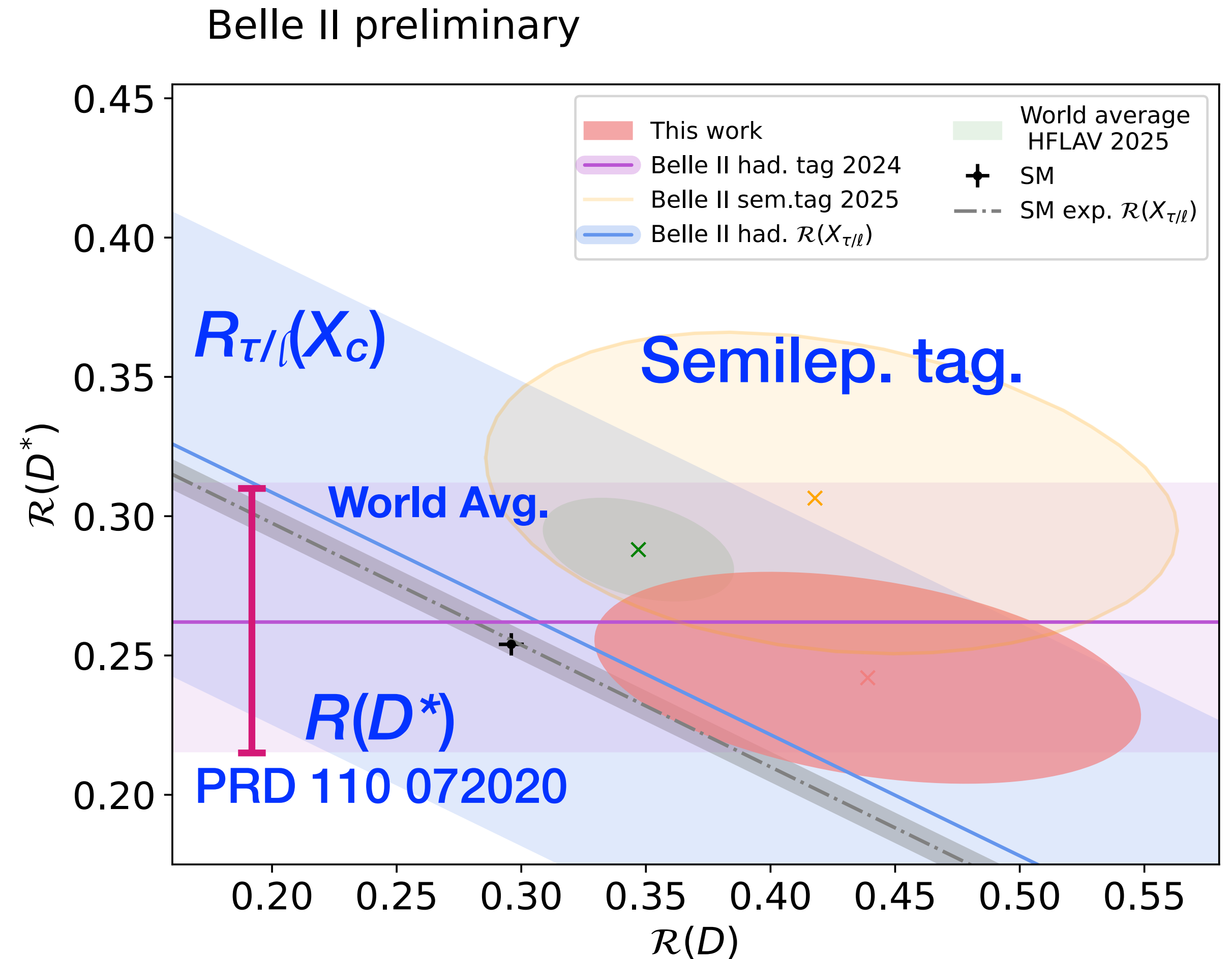


Lepton Flavor Violation (LFV): off diagonal term

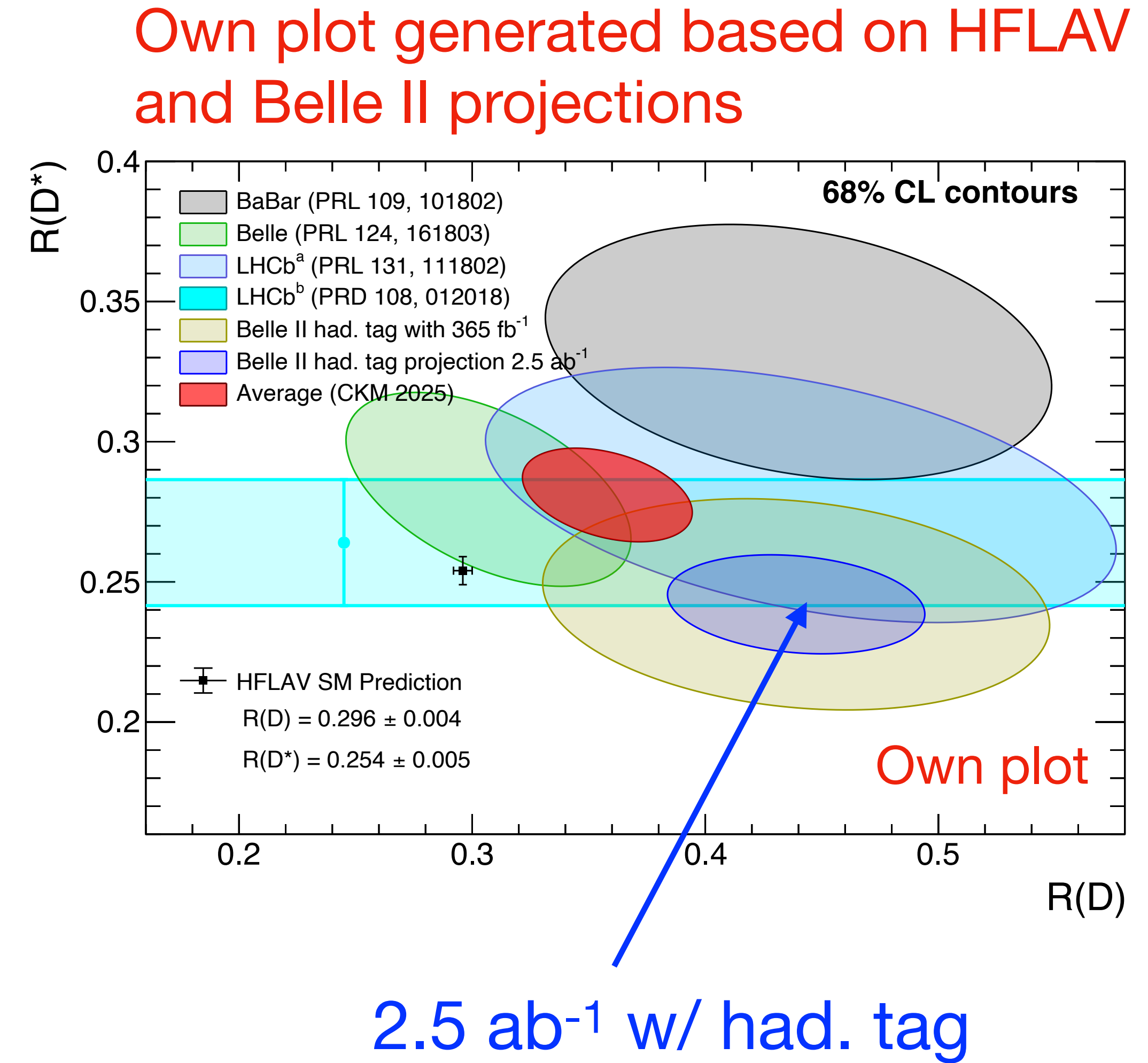
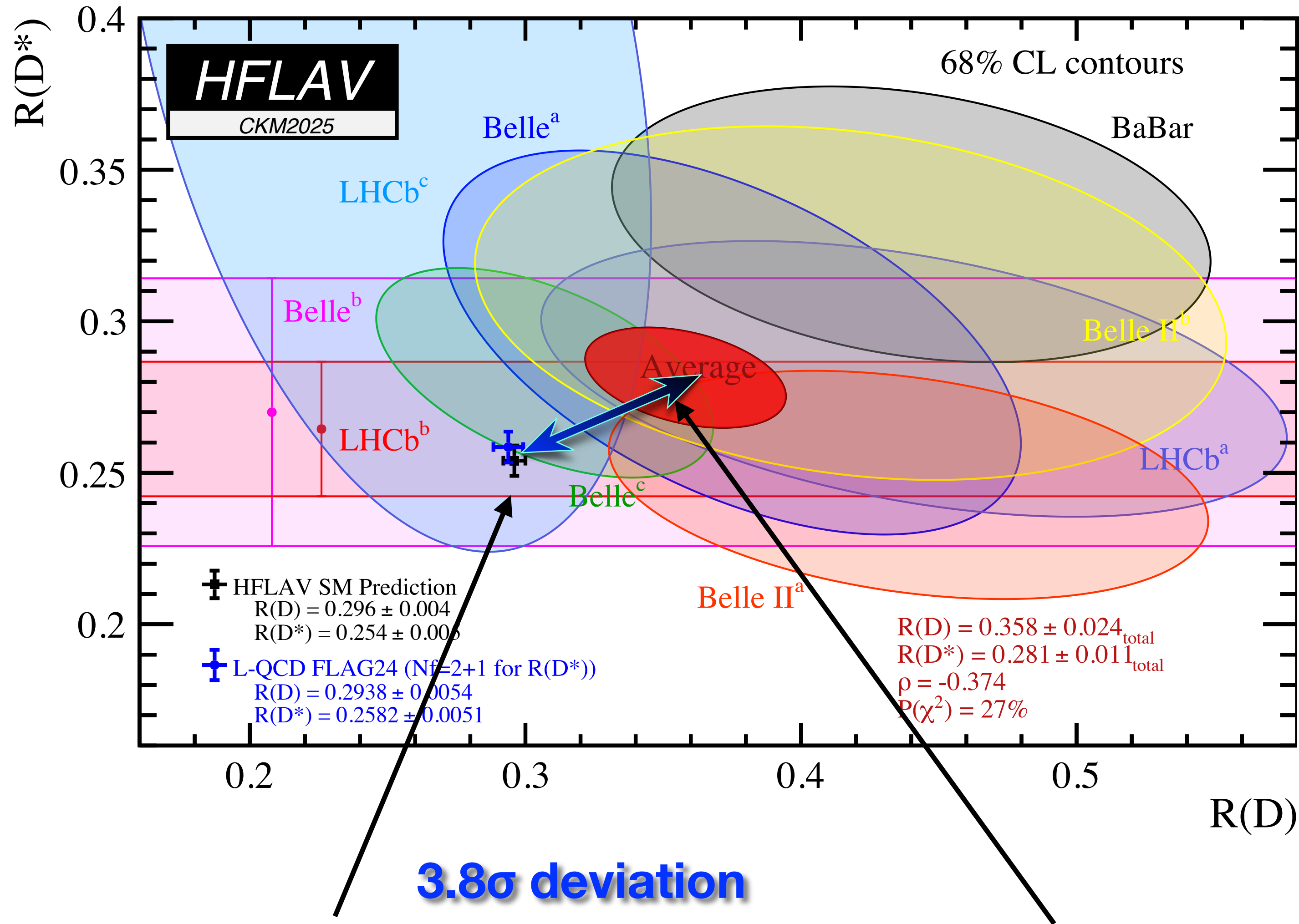


Results LFU test from Belle II

- Belle II **three $R(D^{(*)})$** measurements
 - Hadronic tag with FEI
 - Semileptonic tag with FEI
 - Leptonic τ decays
- Still statistical limited
- Belle II $R(D^{(*)})$ result with had. tag
$$R_{\tau/\ell}(D) = 0.439 \pm 0.055 \text{ (stat)} \pm 0.045 \text{ (syst)}$$
$$R_{\tau/\ell}(D^*) = 0.242 \pm 0.019 \text{ (stat)} \pm 0.016 \text{ (syst)}$$
- Similarly sensitivity as Belle 15' result @ 711 fb^{-1} with only 365 fb^{-1}
 - Thanks for higher tagging eff. and optimized selections
- Performed the **first $R_{\tau/\ell}(X_C)$** measurement at Belle II



“B anomaly” in semileptonic decays 2026

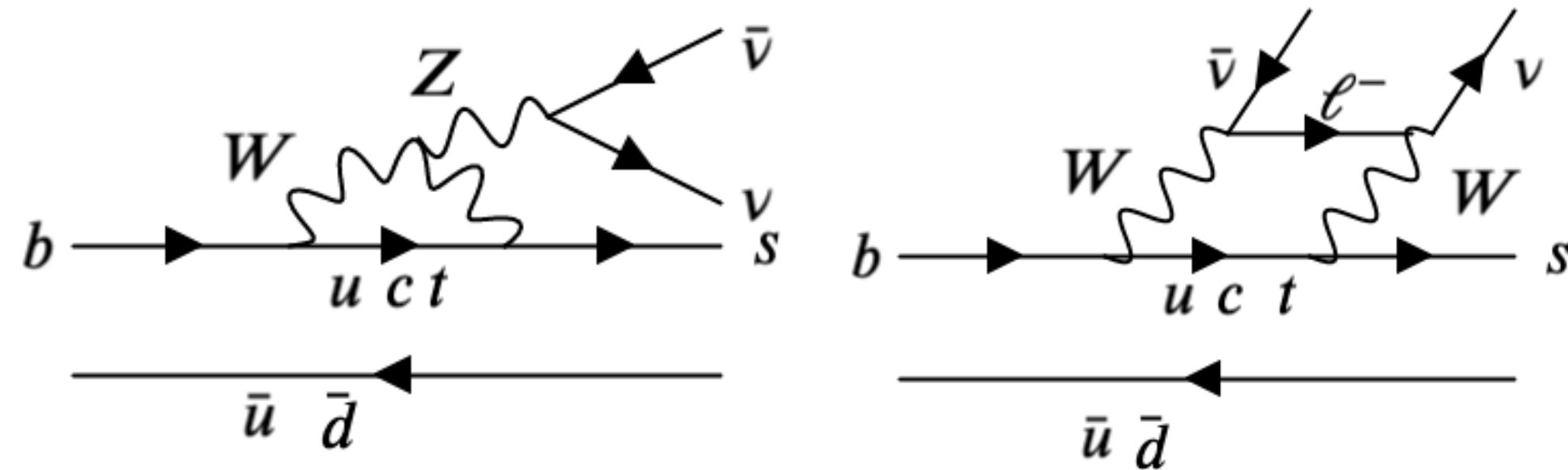


Standard Model prediction

Experimental average results

Evidence of $B^\pm \rightarrow K^\pm \nu \nu$

- Search for flavor-changing neutral current
- A channel unique to Belle II
- $b \rightarrow \bar{s} \nu \nu$ contain the same new physics of $b \rightarrow s / l^-$
- $b \rightarrow \bar{s} \nu \nu$ is theoretically clean than $b \rightarrow s / l^-$

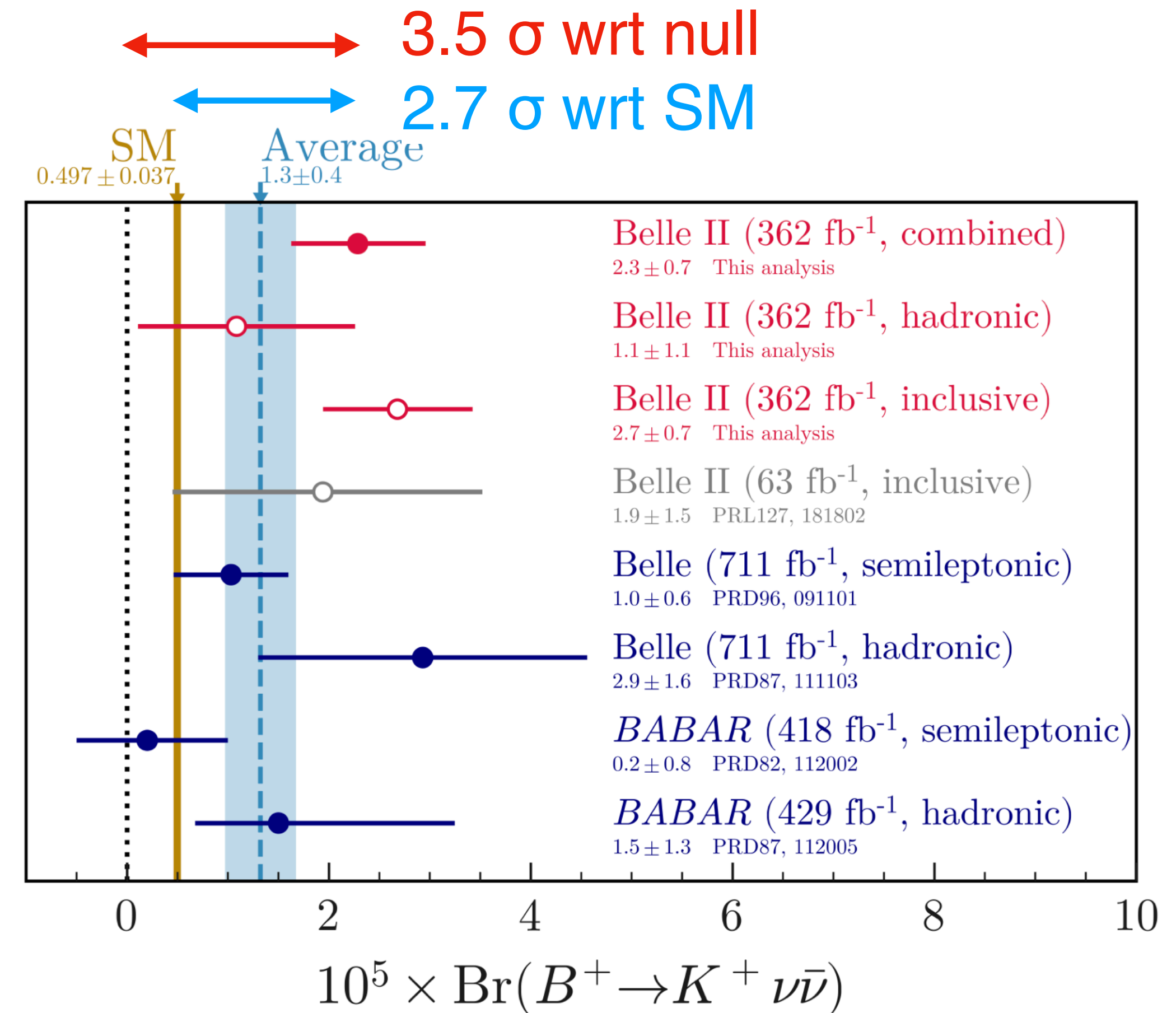


- This method only sensitive to high p_T region of K^+
- New physics: leptoquark, light dark matter, etc.
- Re-interpretation of data provides constraints on WET Wilson coefficients $|C_{VL} + C_{VR}|$, $|C_{SL} + C_{SR}|$ and $|C_{TL}|$
- Extended analysis in preparation $B^0 \rightarrow K_s \nu \nu$, $B^0 \rightarrow K^{*0} \nu \nu$, $B^+ \rightarrow K^{*+} \nu \nu$ (stay tuned)

[PRD 112 \(2025\) 092016](#)

SM prediction:

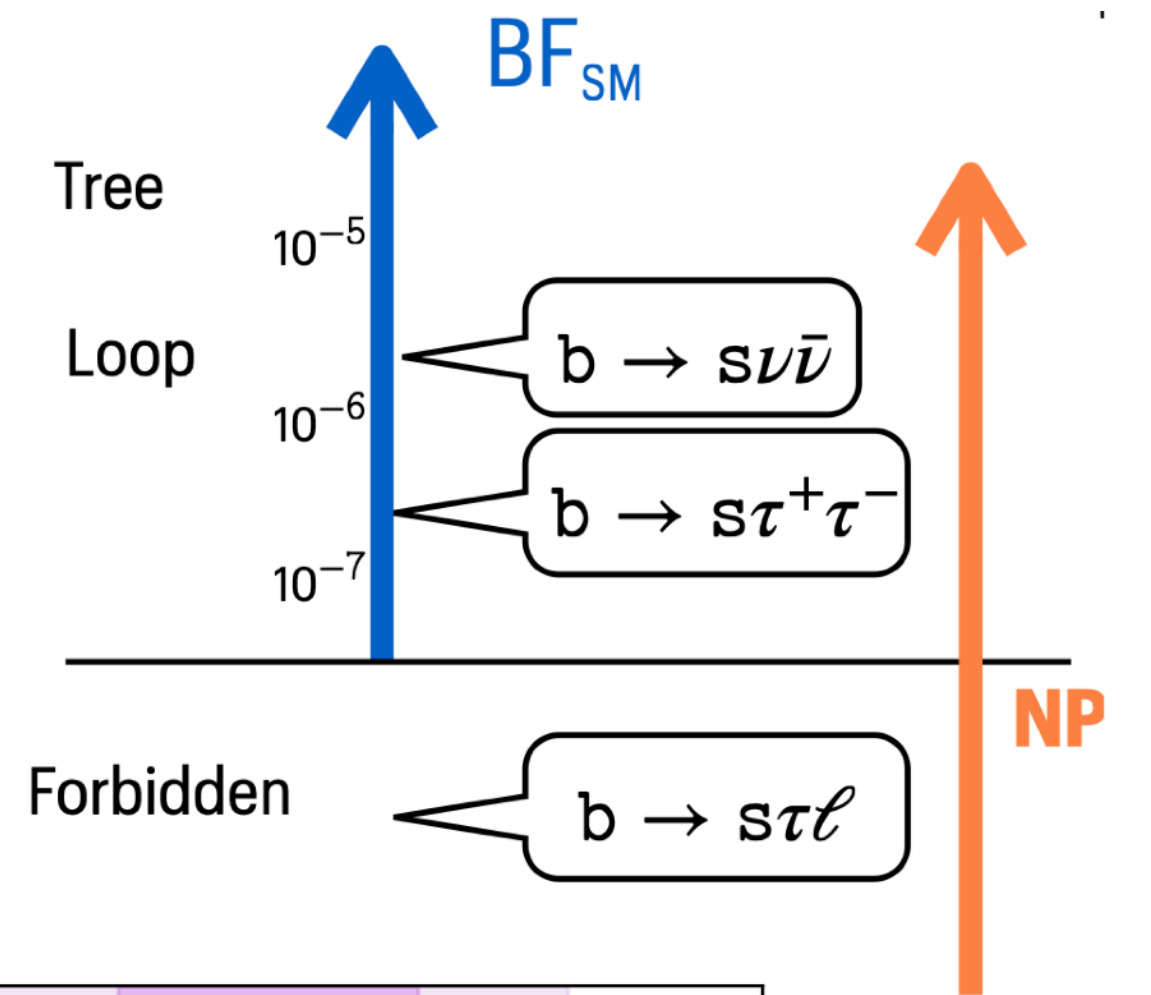
$$Br(B^+ \rightarrow K^+ \nu \bar{\nu})_{SM} = (4.6 \pm 0.5) \times 10^{-6}$$



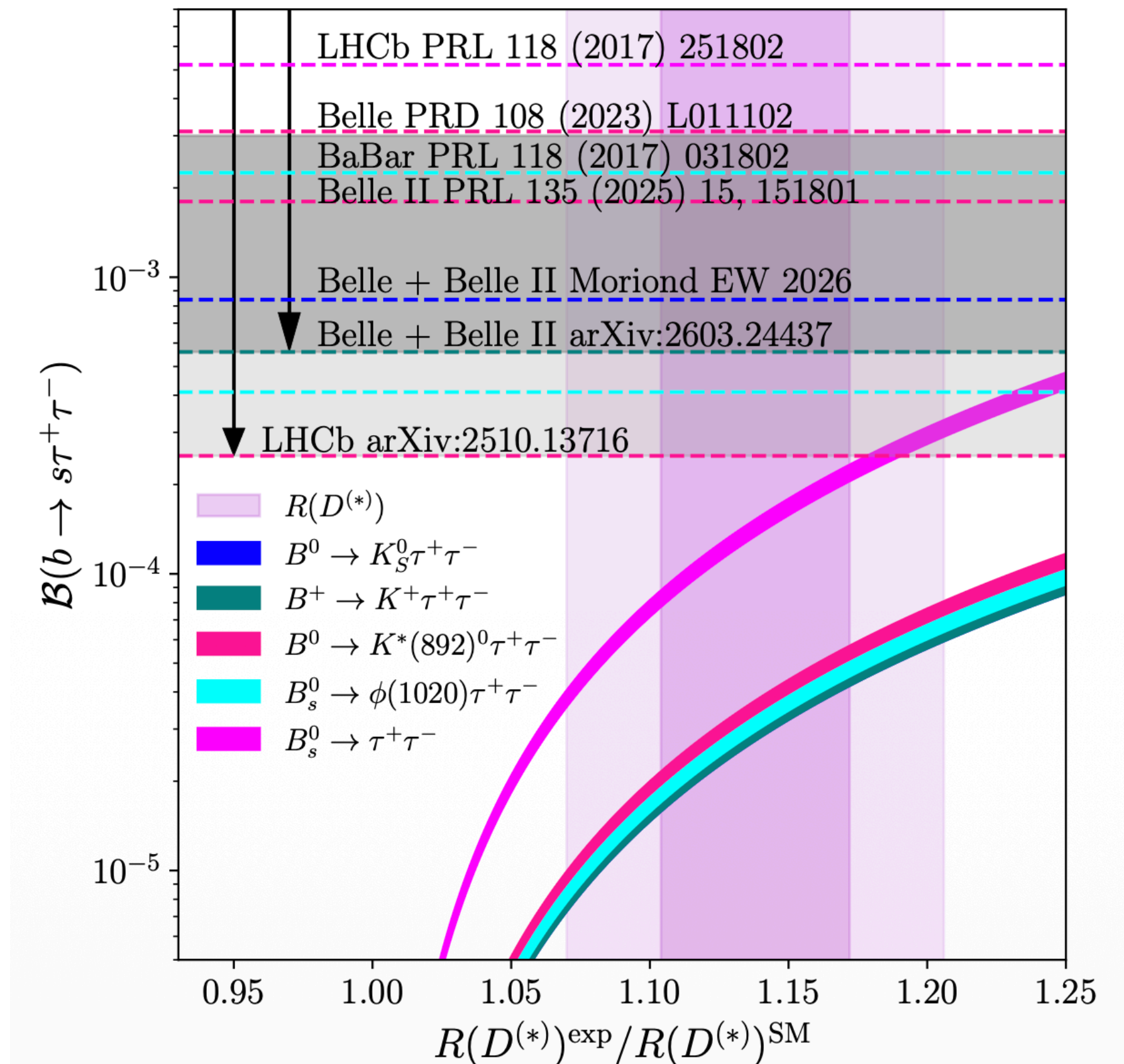
[PRD 119 \(2024\) 112006](#)

LFU and LFV in $b \rightarrow s \ell \ell'$

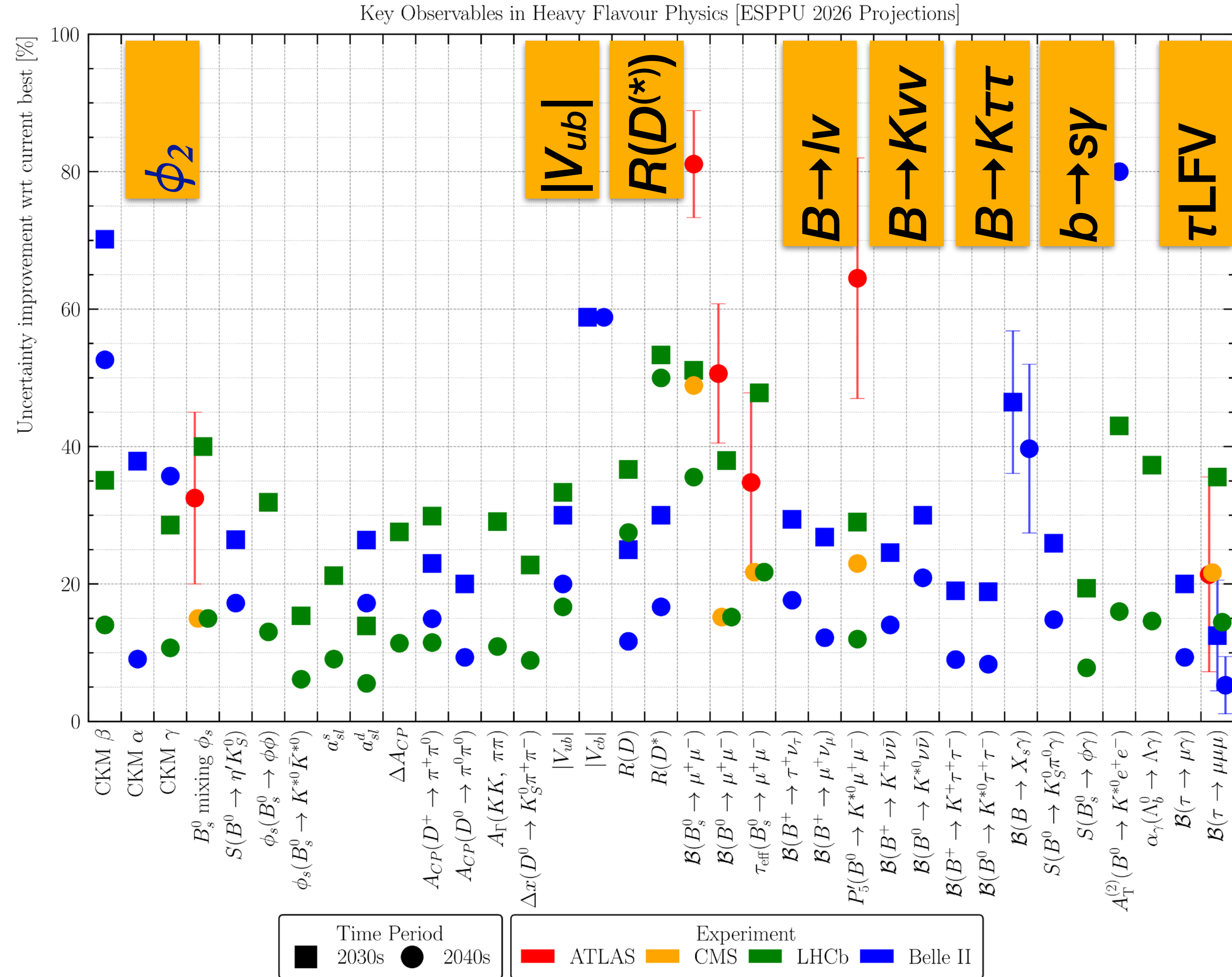
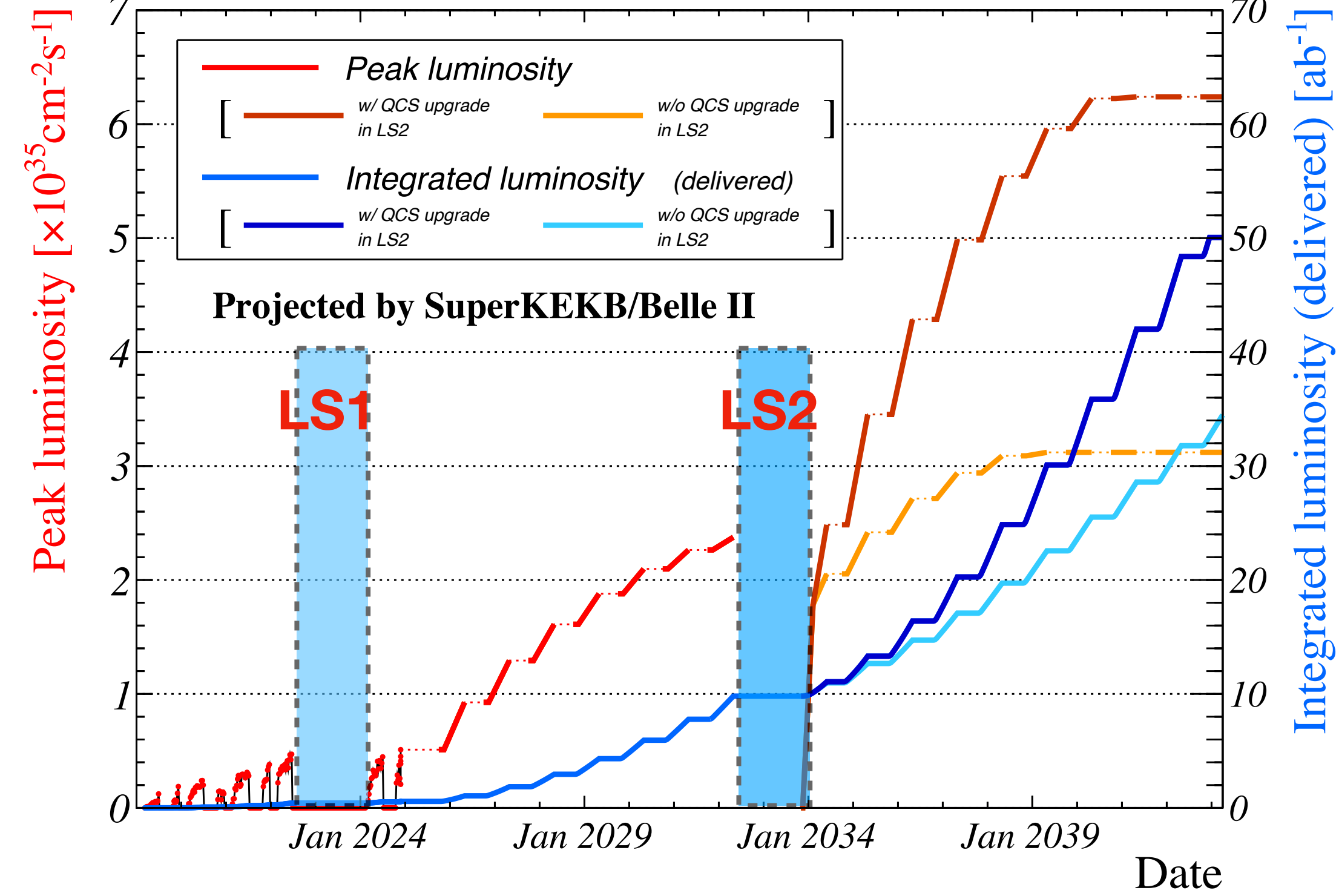
- Can occur in the SM via mixing but highly suppressed due to neutrino mass
- Merge Belle and Belle II samples because of the similar purity and same resolution
- First search for decay $B \rightarrow K_s \tau^\pm \ell^\mp$
- Results are among the most stringent limits for $b \rightarrow s \tau \ell$ transitions to date



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



Expected sensitivities at Belle II



Summary and prospects

- Many challenges at SuperKEKB as it is the luminosity frontier machine, We have overcome them one-by-one through new ideas and technologies.
- Thanks to detector performance and improved analysis methods, we are already producing competitive physics results.
- LS2 upgraded
 - SuperKEKB
 - Extended collision energy: 11.24 → up to 11.6 GeV
 - RF system, HER current limit: 2.0 → 2.6 A (design)
 - QCS: much simpler optics, expand the dynamic aperture
 - Belle II
 - New VTX (5 layers of CMOS pixel detector)
 - New CMOS strip layers + LGAD timing layer
 - New Draft Chamber with improved tolerance
 - FEE upgrades, AI-based trigger

