Portorož 2023: Particle Physics from Early Universe to Future Colliders, April 11-14, 2023

B flavour physics – experimental status

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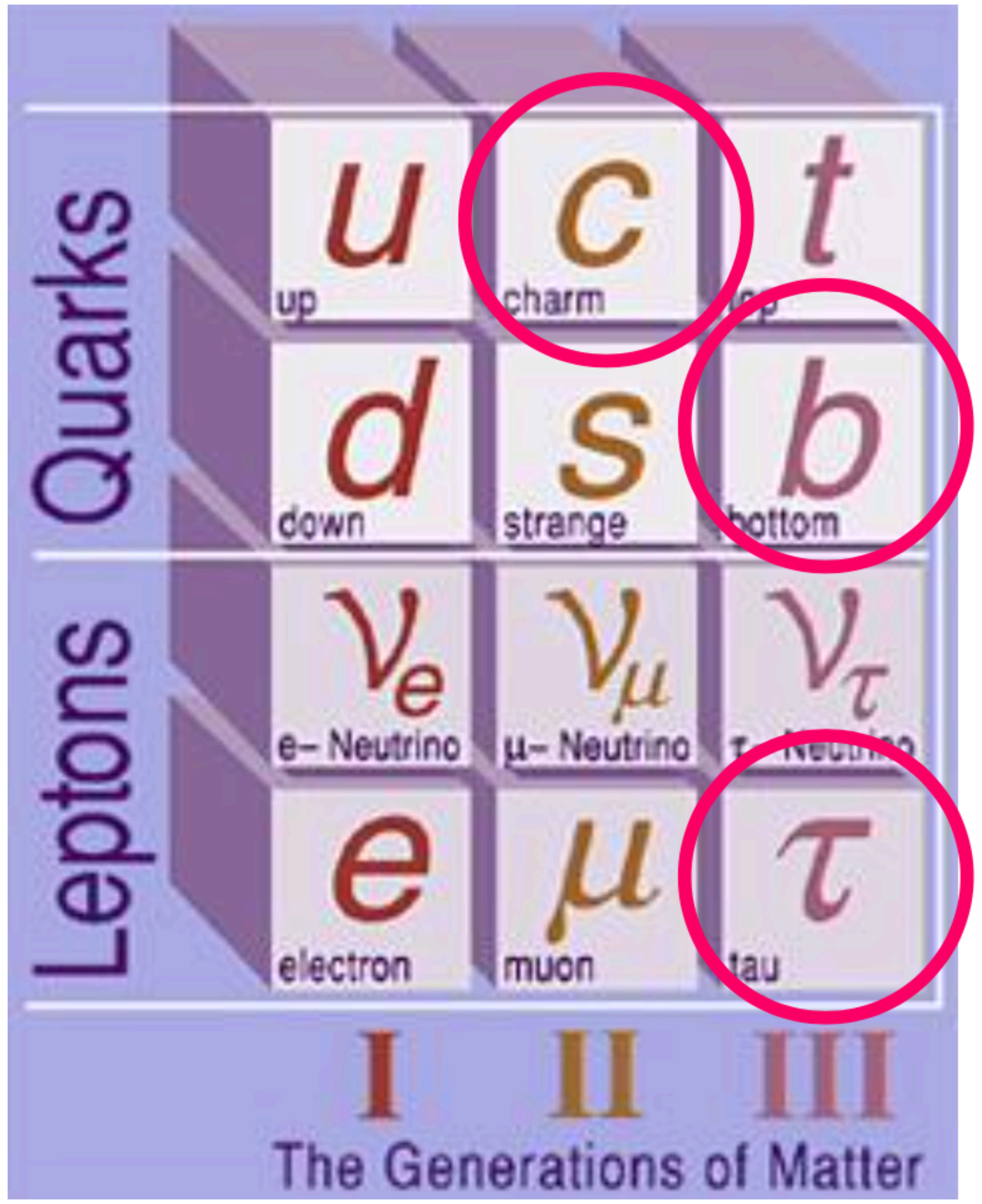
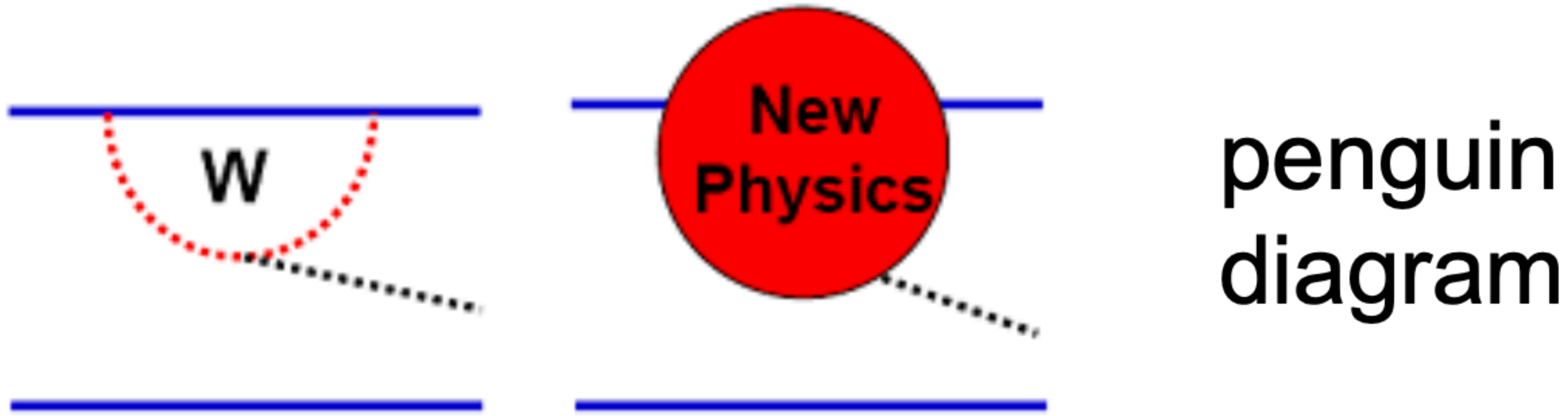
Anomaly hunting

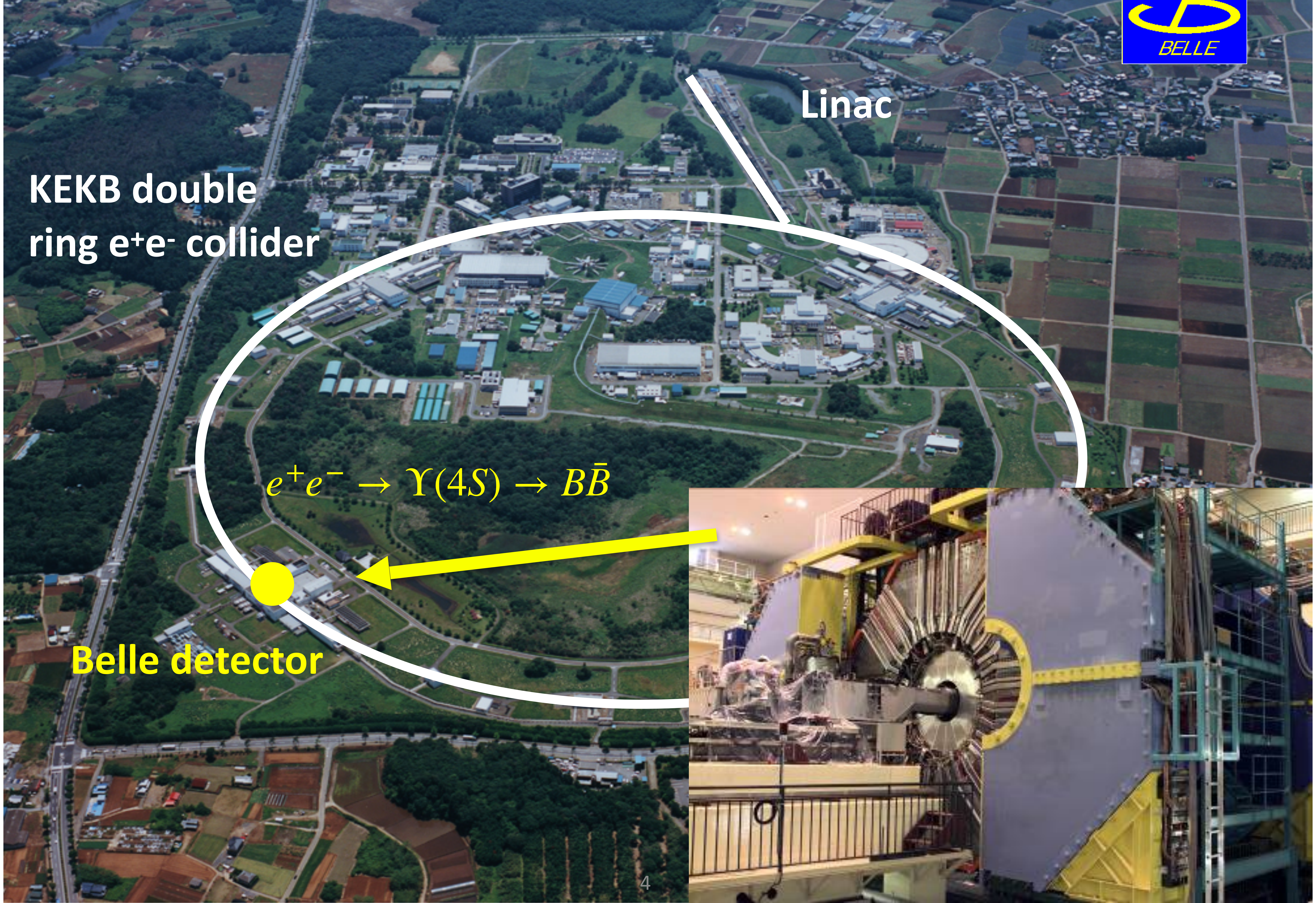


- Presently the interest in heavy flavour physics, *i.e.*, the physics of b, c and τ weak decays, is mainly triggered by 'anomalies' or otherwise probing models beyond the SM
- Anomalies, significant differences between the SM theory expectation and the experiment, can hint at new physics of higher scales (BSM)
- However, to be weighted by
  - how challenging is to perform experimental measurement
  - role of theoretical predictions

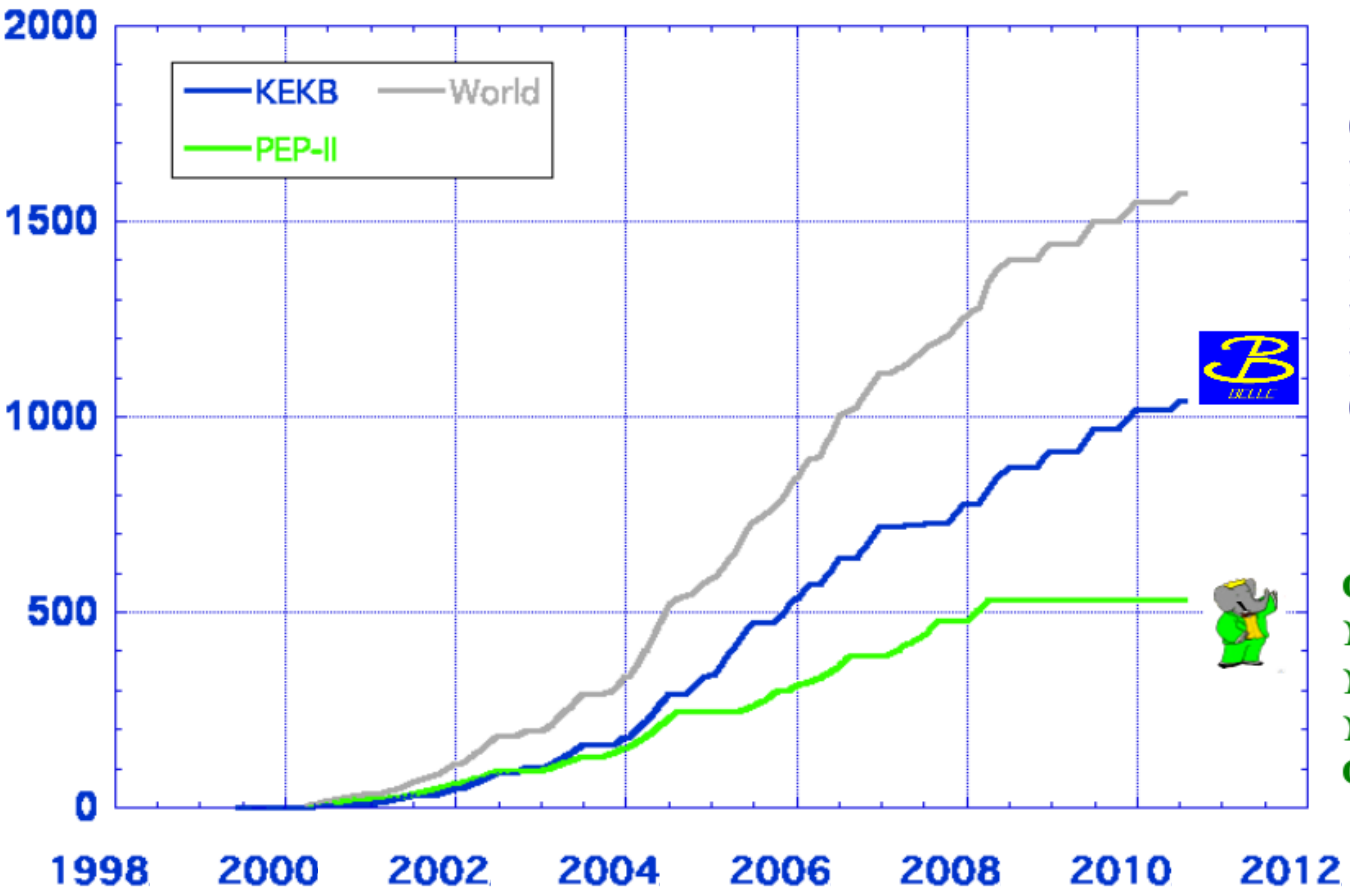


The facilities
(I will cover here)

1999 – 2010: B factory at KEK (Japan)



Comparison of B factories (1999-2010)



$> 1\ ab^{-1}$

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1}

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim 100\ fb^{-1}$

$\sim 550\ fb^{-1}$

On resonance:

$\Upsilon(4S)$: 433 fb^{-1}

$\Upsilon(3S)$: 30 fb^{-1}

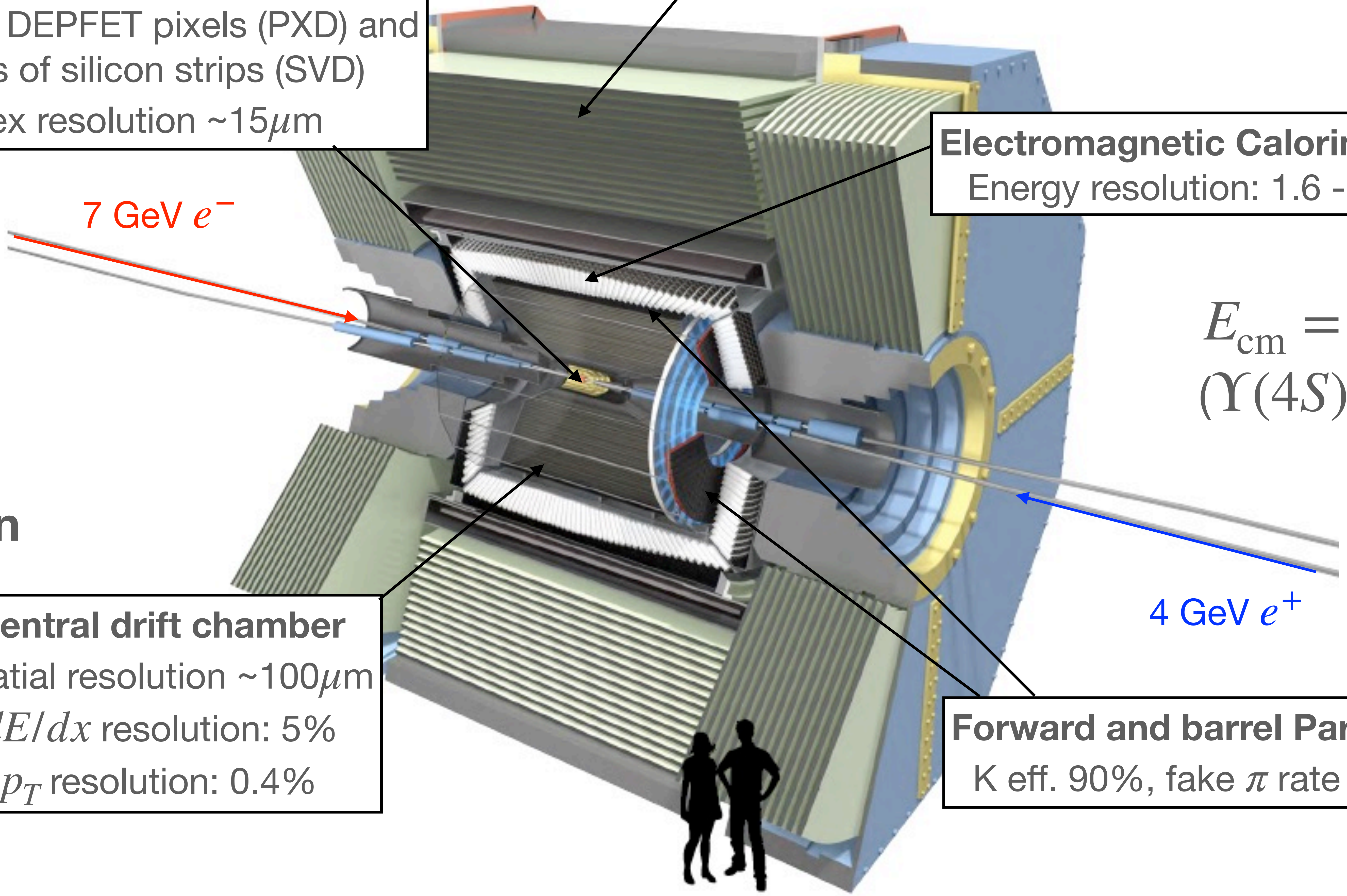
$\Upsilon(2S)$: 14 fb^{-1}

Off resonance:

$\sim 54\ fb^{-1}$

The Belle II detector

KEK
Tsukuba, Japan



KLM
Instrumented flux return

Vertex detector
2 layers of DEPFET pixels (PXD) and
4 layers of silicon strips (SVD)
Vertex resolution ~15μm

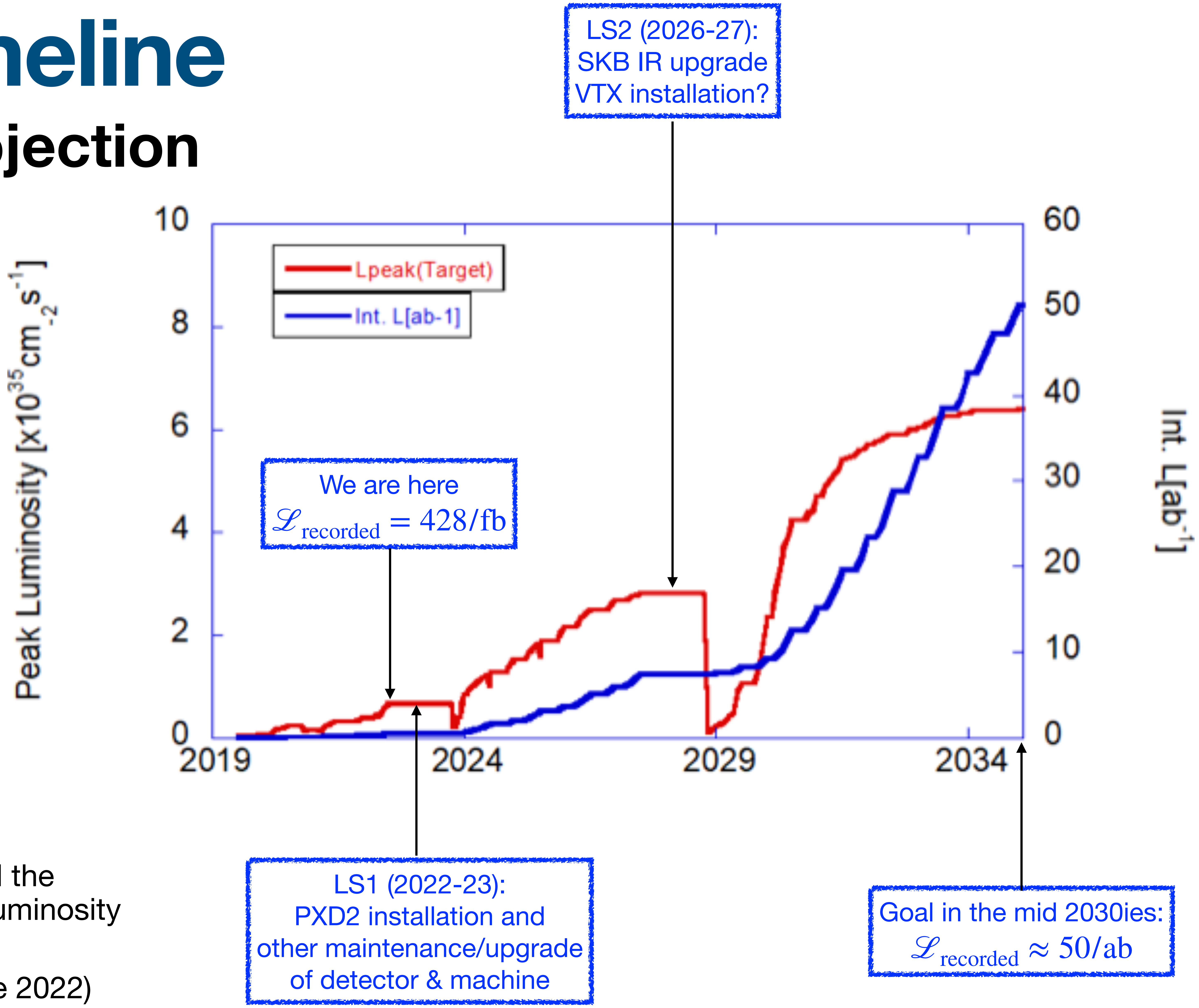
Electromagnetic Calorimeter
Energy resolution: 1.6 - 4%

$E_{\rm cm} = 10.58$ GeV
($\Upsilon(4S)$ resonance)

Central drift chamber
Spatial resolution ~100μm
dE/dx resolution: 5%
p_T resolution: 0.4%

Forward and barrel Part. Id.
K eff. 90%, fake π rate 5%

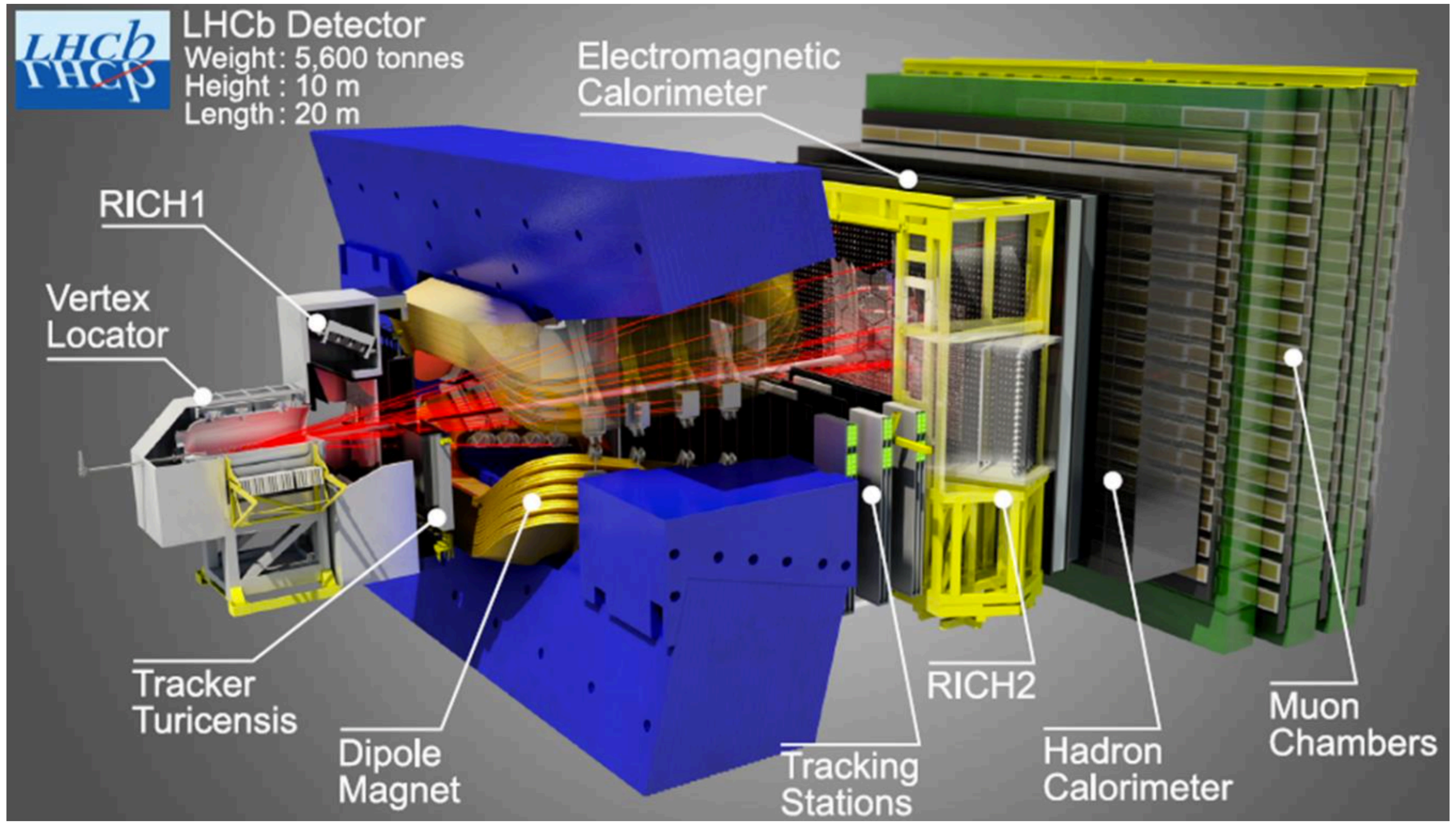
Belle II timeline
Luminosity projection



- Super-KEKB already delivered the world highest instantaneous luminosity at an e^+e^- machine ($4.71 \times 10^{34}\ \text{cm}^{-2}\text{s}^{-1}$ in June 2022)

The LHCb experiment

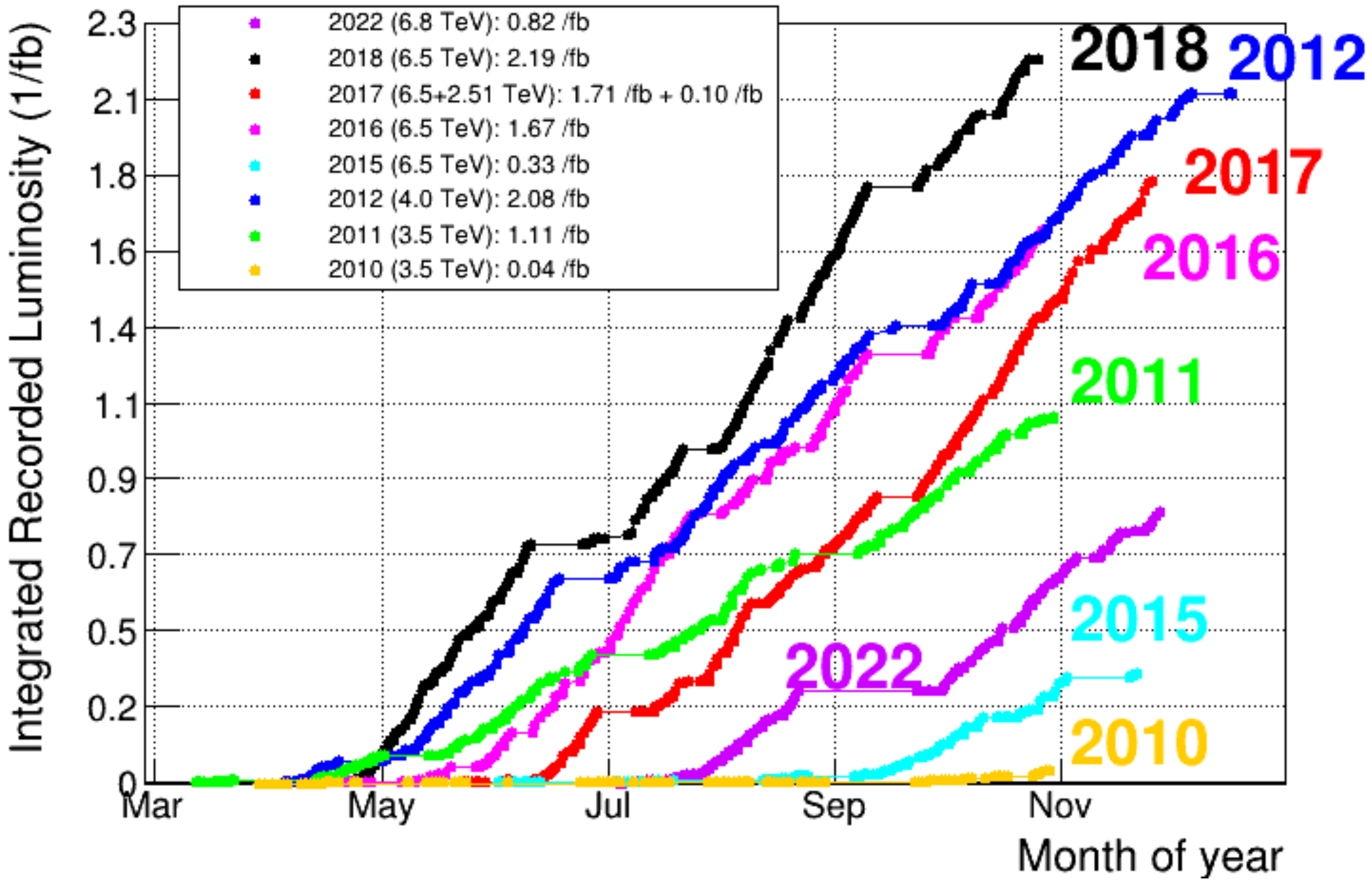
LHCb @ LHC (CERN): pp collisions



Run 1-2 detector

- Forward detector optimised for b and c meson studies
- Huge b cross-section
- Events with high multiplicity, reconstruction of neutrals is more difficult
- Excellent vertex resolution (separation of weak decay products) and particle identification (RICH)
- 9/fb accumulated during Run 1-2 (2010-2018)
- Run 3 started in 2022 with an upgraded LHCb detector

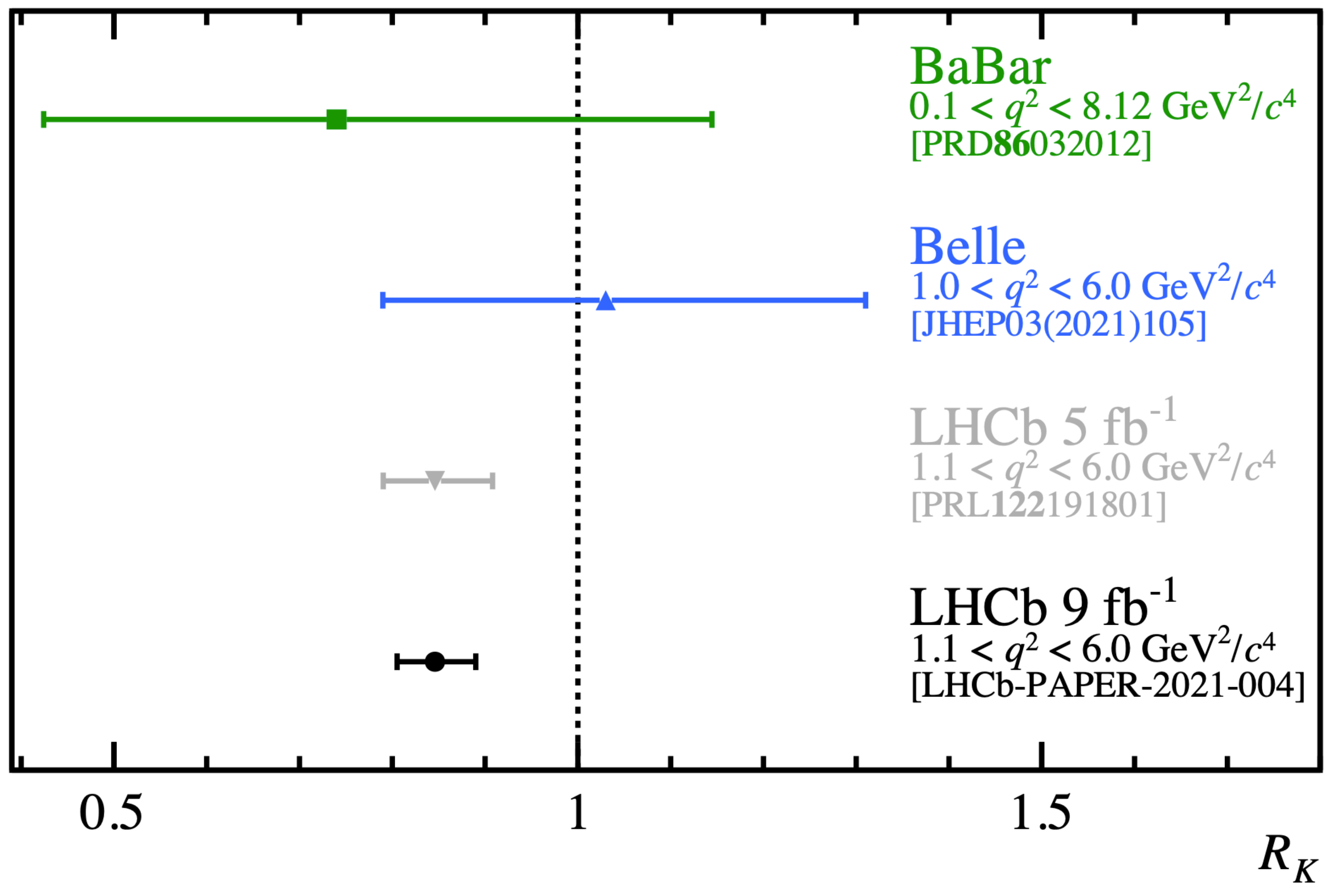
LHCb integrated luminosity



Test of lepton flavour universality

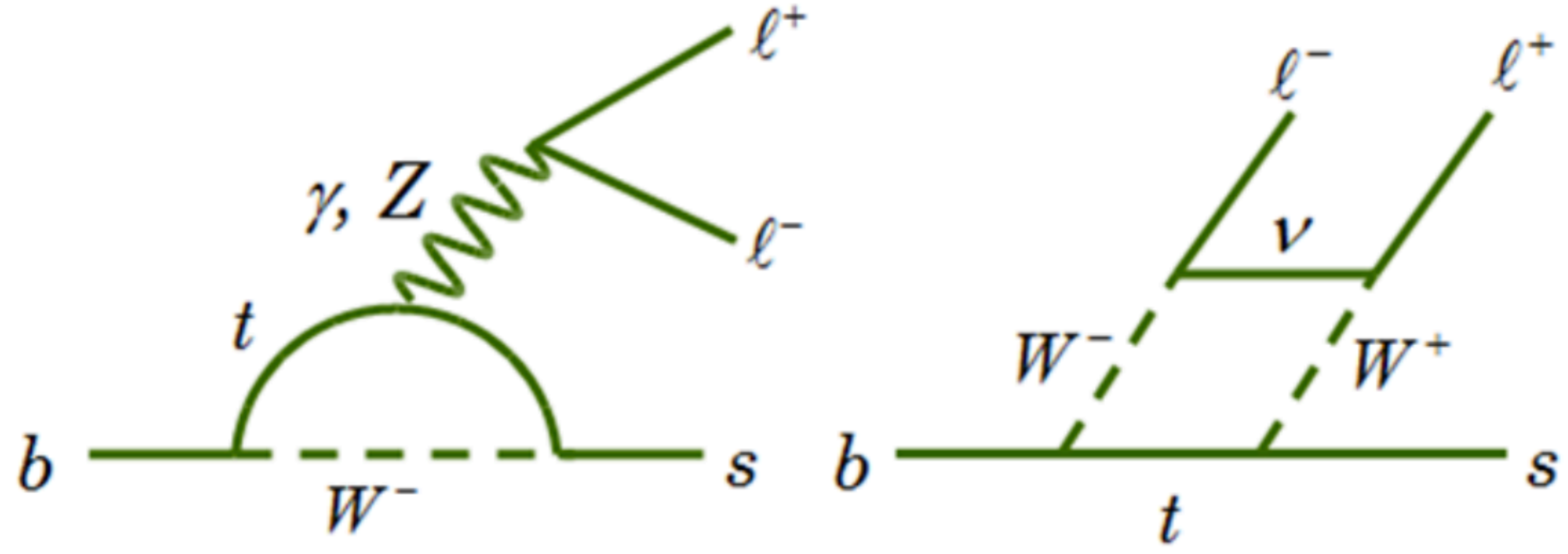
LFU in $B \to K^{(*)}\ell\ell$

- In the SM, all lepton flavours couple identically to the weak interaction
  - Up to phase space effects, branching fractions $b \to e, \mu$ and τ should be identical
- Pre-December 2022 situation — 3.1σ anomaly in R_K:



$$R_K = \frac{\mathcal{B}(B \to K\mu\mu)}{\mathcal{B}(B \to Kee)}$$

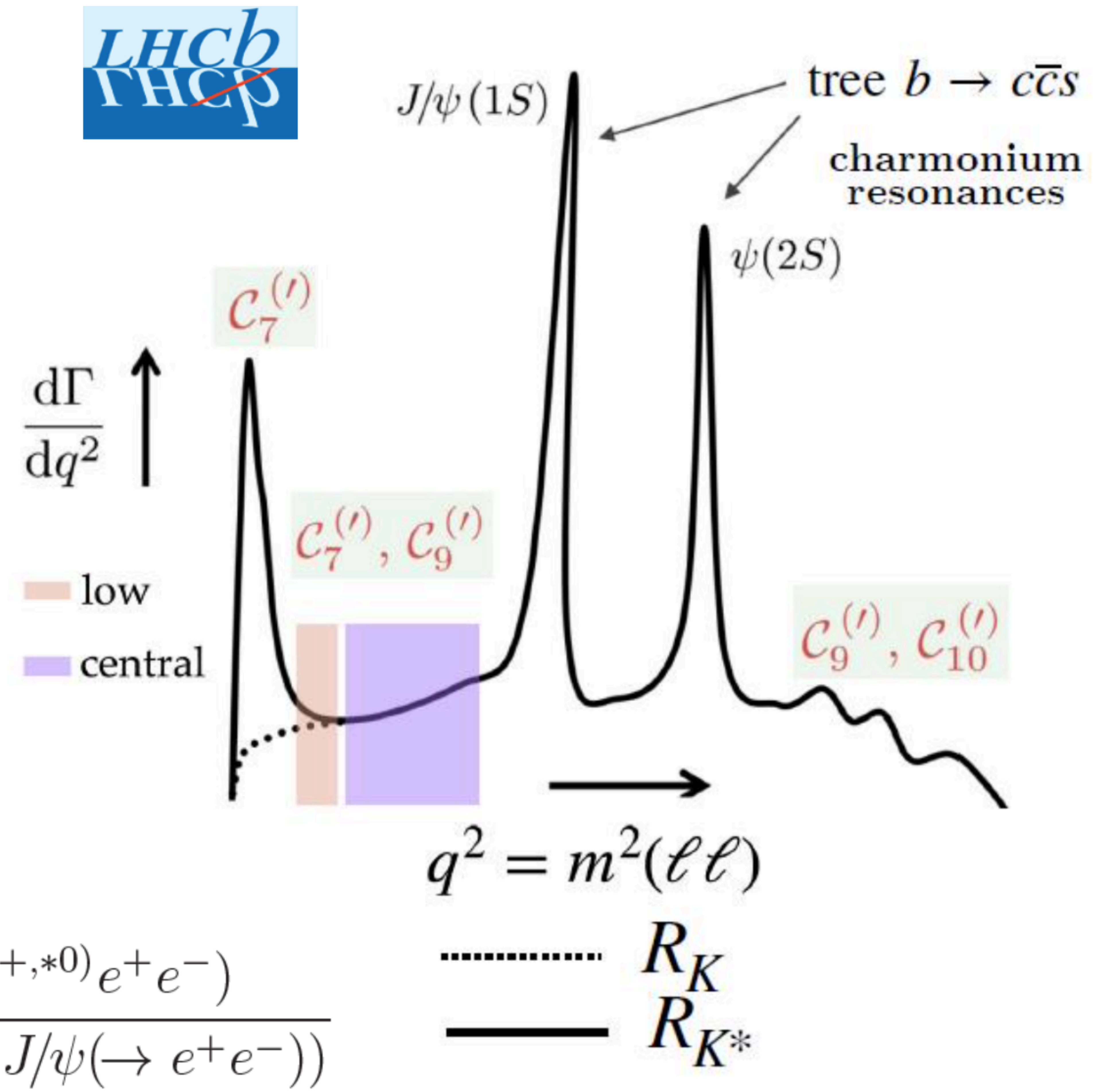
Signature of New Physics?



New LHCb analysis of R_K and R_{K^*} (9/fb)

Method

$$R_{K,K^*}(q_a^2, q_b^2) = \frac{\displaystyle\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\displaystyle\int_{q_a^2}^{q_b^2} \frac{\mathrm{d}\Gamma(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2}$$

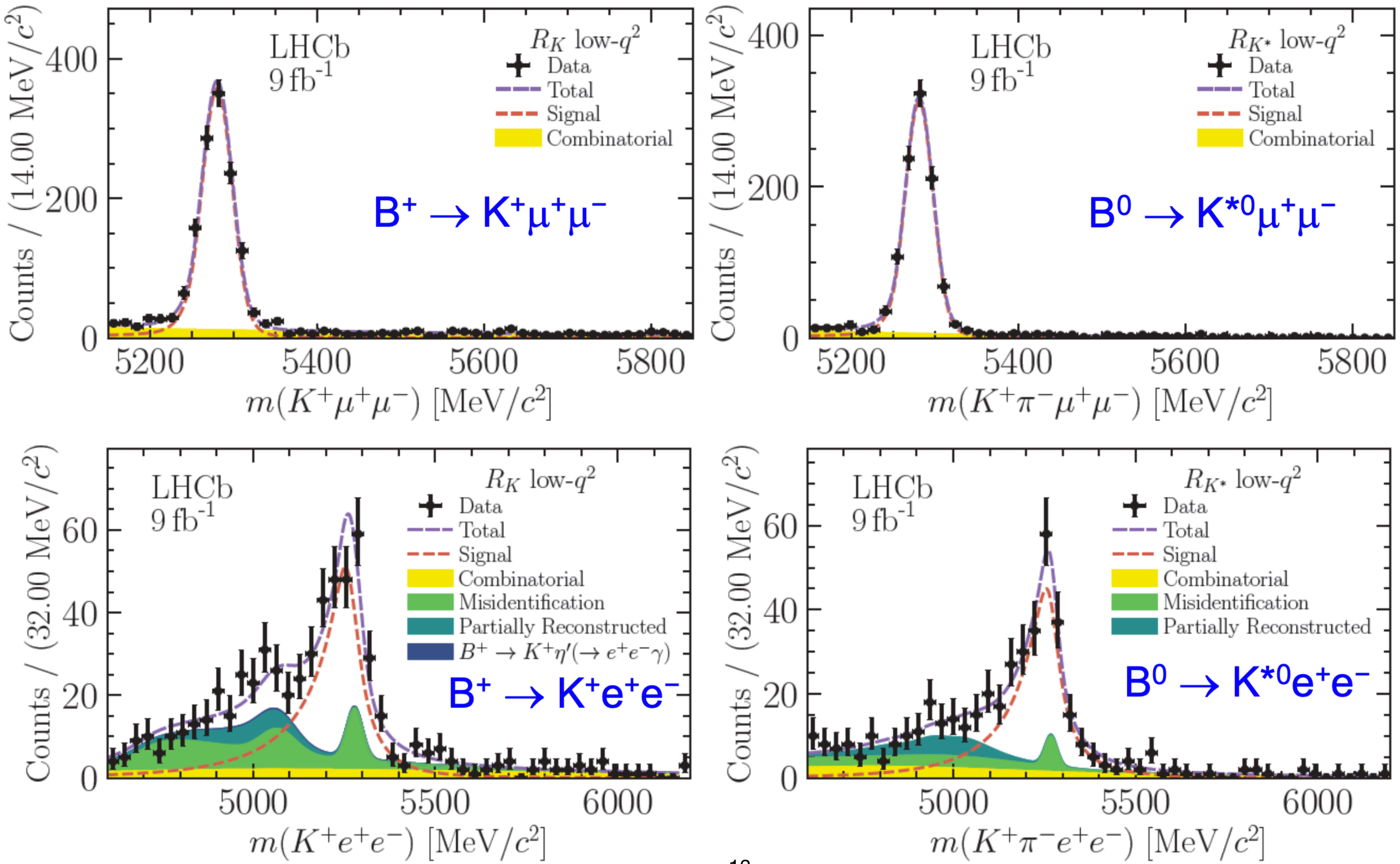


- Simultaneous measurement of R_K and R_{K^*} in two q^2 bins with full available dataset
- LHCb uses a double ratio to measure the R-ratio quantity to cancel out efficiency-related systematics

$$R_{(K,K^*)} \equiv \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-)}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(\to \mu^+\mu^-))} \Big/ \frac{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}e^+e^-)}{\frac{\mathcal{N}}{\varepsilon}(B^{(+,0)} \to K^{(+,*0)}J/\psi(\to e^+e^-))}$$

New LHCb analysis of R_K and R_{K*} (9/fb)

Low q^2 region (0.1 to 1.1 GeV^2)



New LHCb analysis of R_K and R_{K^*} (9/fb)

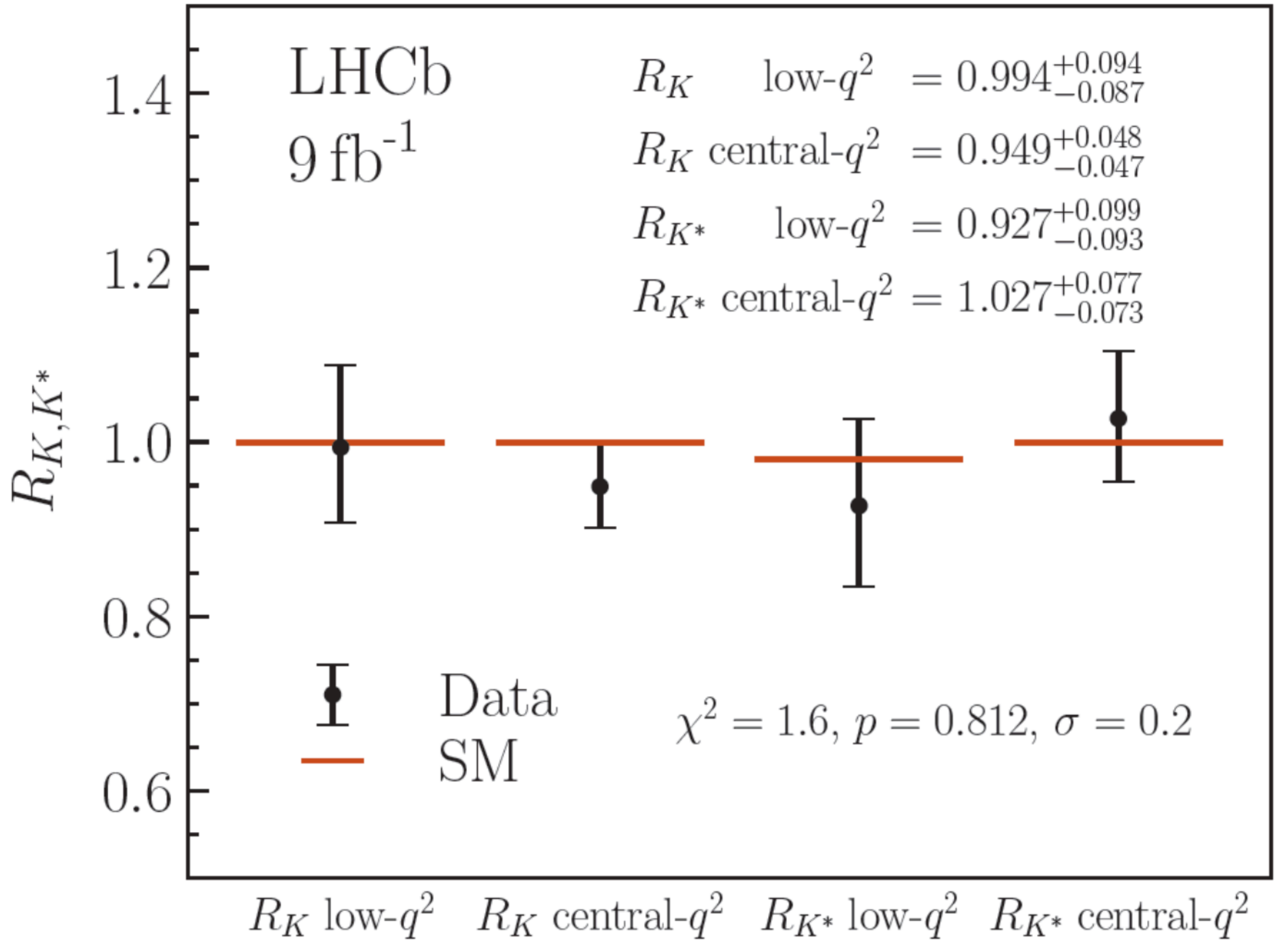
Results

$$\text{low-}q^2 \begin{cases} R_K = 0.994\ ^{+0.090}_{-0.082}\,(\text{stat})\ ^{+0.029}_{-0.027}\,(\text{syst}) \\ R_{K^*} = 0.927\ ^{+0.093}_{-0.087}\,(\text{stat})\ ^{+0.036}_{-0.035}\,(\text{syst}) \end{cases}$$

$$\text{central-}q^2 \begin{cases} R_K = 0.949\ ^{+0.042}_{-0.041}\,(\text{stat})\ ^{+0.022}_{-0.022}\,(\text{syst}) \\ R_{K^*} = 1.027\ ^{+0.072}_{-0.068}\,(\text{stat})\ ^{+0.027}_{-0.026}\,(\text{syst}) \end{cases}$$

low-q^2 : $q^2 \in [0.1, 1.1]\,\text{GeV}^2/c^4$

central-q^2 : $q^2 \in [1.1, 6.0]\,\text{GeV}^2/c^4$



[LHCb-PAPER-2022-046, LHCb-PAPER-2022-045]

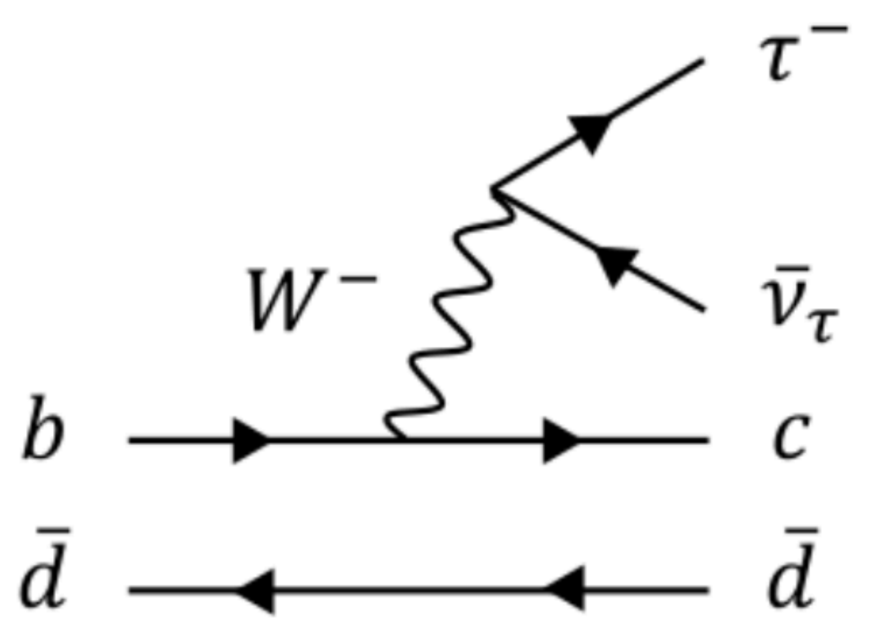
- Most precise LFU test, all four measurements are consistent with the SM (at the 0.2σ level) — the $R_{K^{(*)}}$ anomaly is gone
- Note that LHCb still sees significant anomalies in $b \to s\mu\mu$ (branching fractions and angular distributions) [LHCb-PAPER-2020-041, LHCb-PAPER-2021-014]

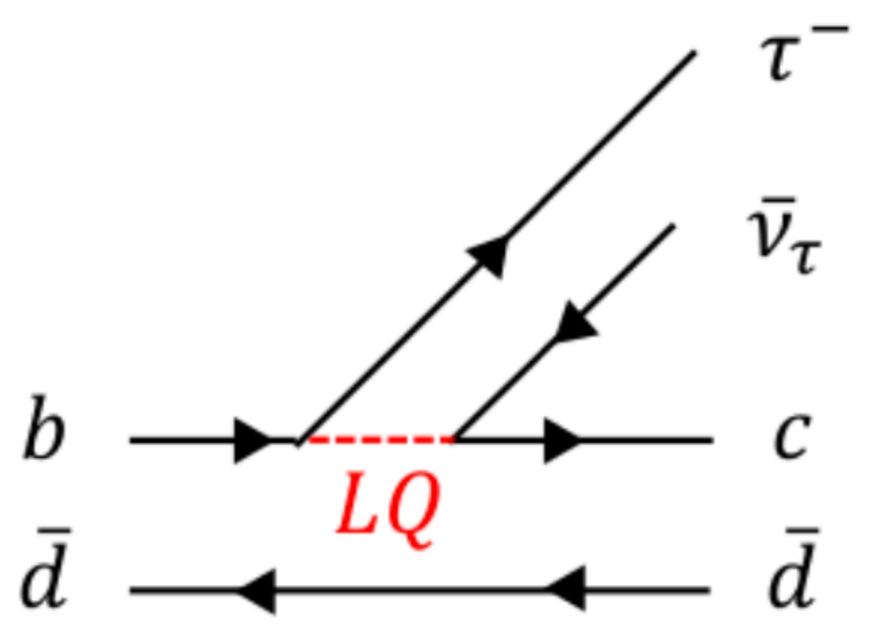
LFU test in $B \to D^{(*)}\tau\nu$

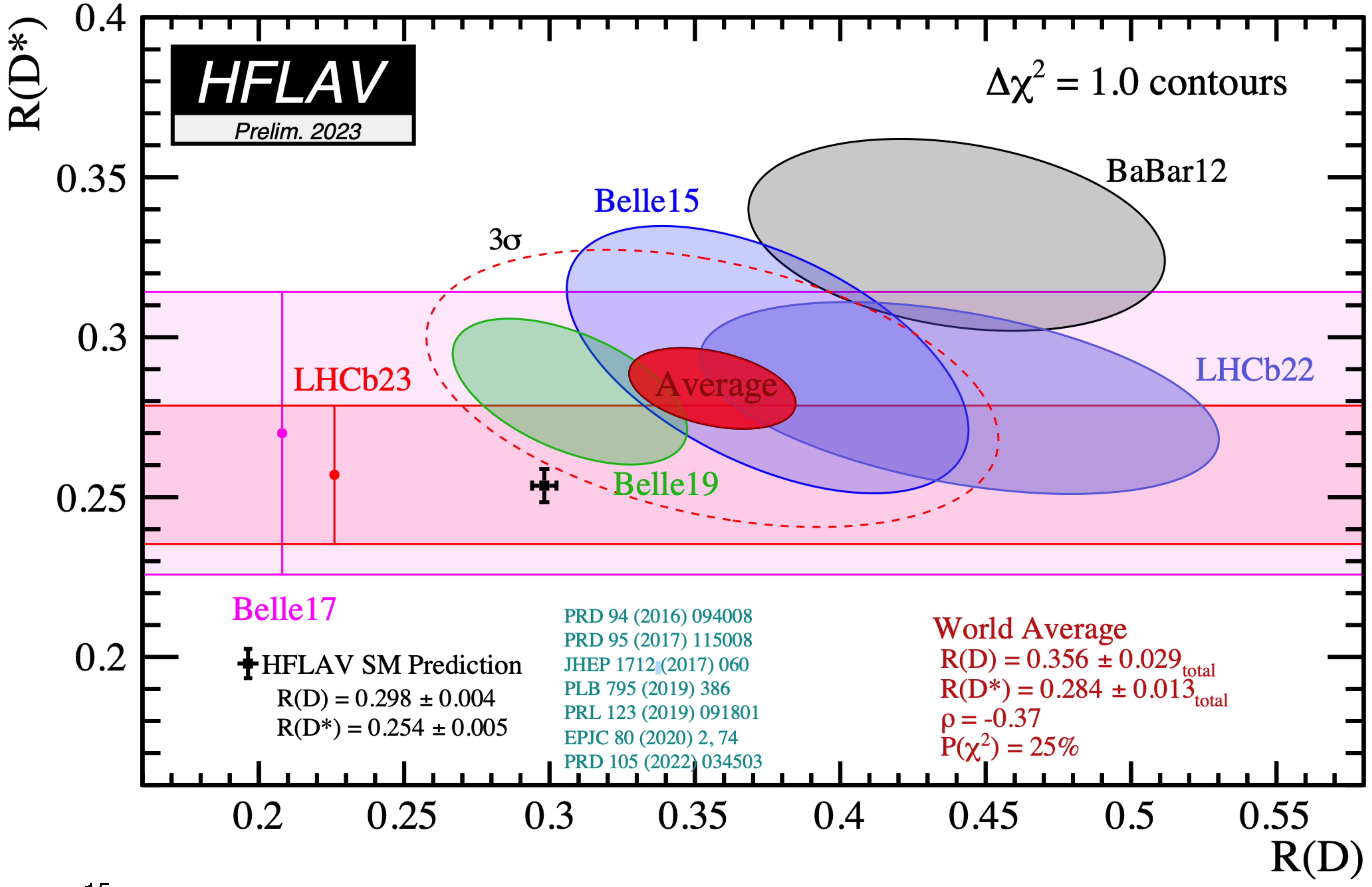
$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

$$(\ell = e \text{ or } \mu)$$

- Long-standing 3σ tension in $R(D^*)$ and $R(D)$
- New LHCb results in both muonic [LHCb-PAPER-2022-039] and hadronic tau decays [LHCb-PAPER-2022-052] (in preparation) reported in Dec/21 and March/23
- This anomaly is still alive, waiting for the word of Belle II, however







Other tests of LFU

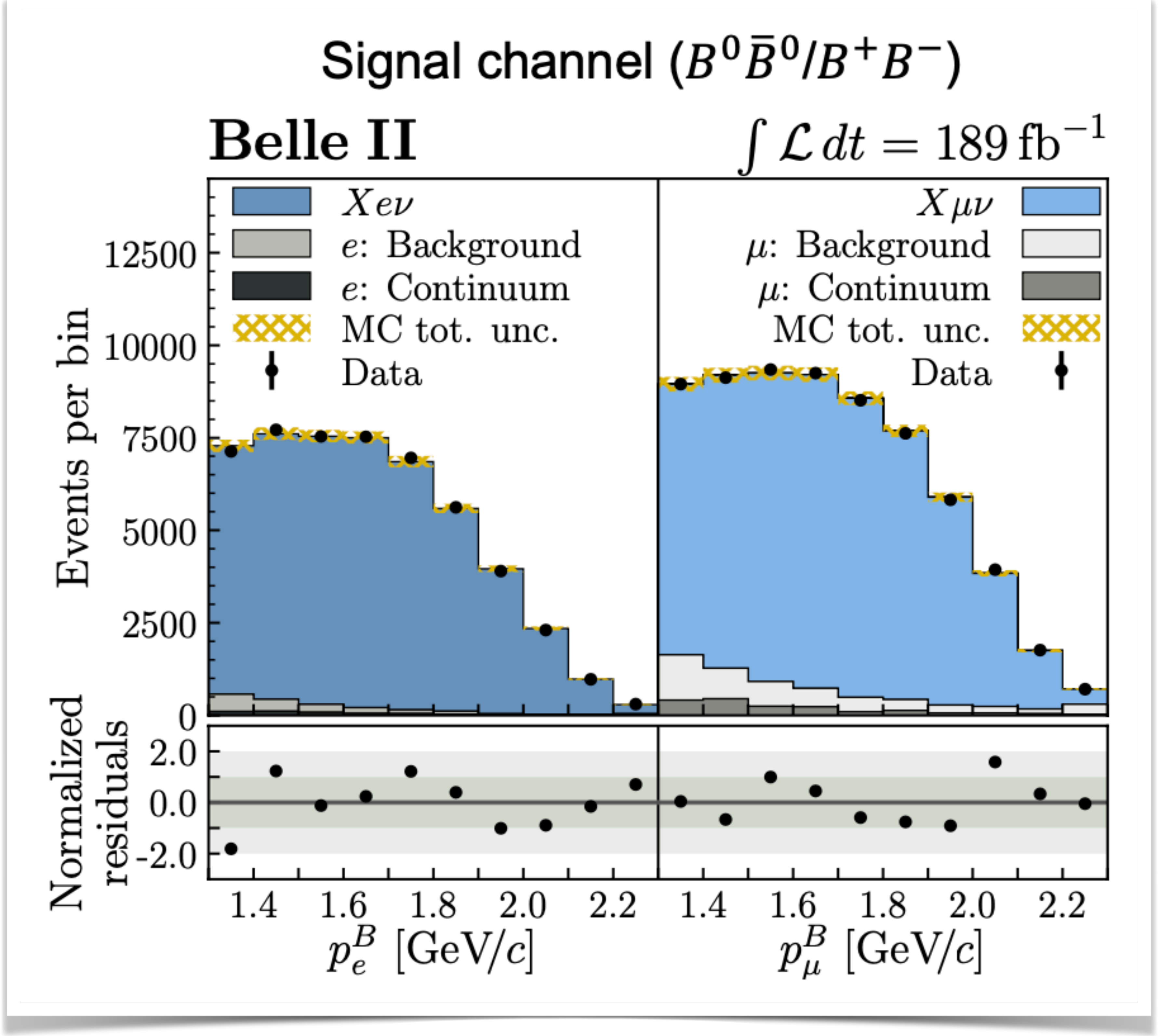
Light lepton flavour universality

Preliminary

$$R(X_{e/\mu}) = \frac{\mathcal{B}(\bar{B} \to X e^- \bar{\nu}_e)}{\mathcal{B}(\bar{B} \to X \mu^- \bar{\nu}_\mu)} = 1.033 \pm 0.010\,(\text{stat}) \pm 0.019\,(\text{syst})$$

Submitted to PRL [arXiv:2301.08266]

- Most precise $e - \mu$ universality test using inclusive semileptonic B decays in the region $p_\ell^B > 1.3\ \text{GeV}/c$
- Consistent with SM expectation within 1.2σ [JHEP 11, 007 (2022)]



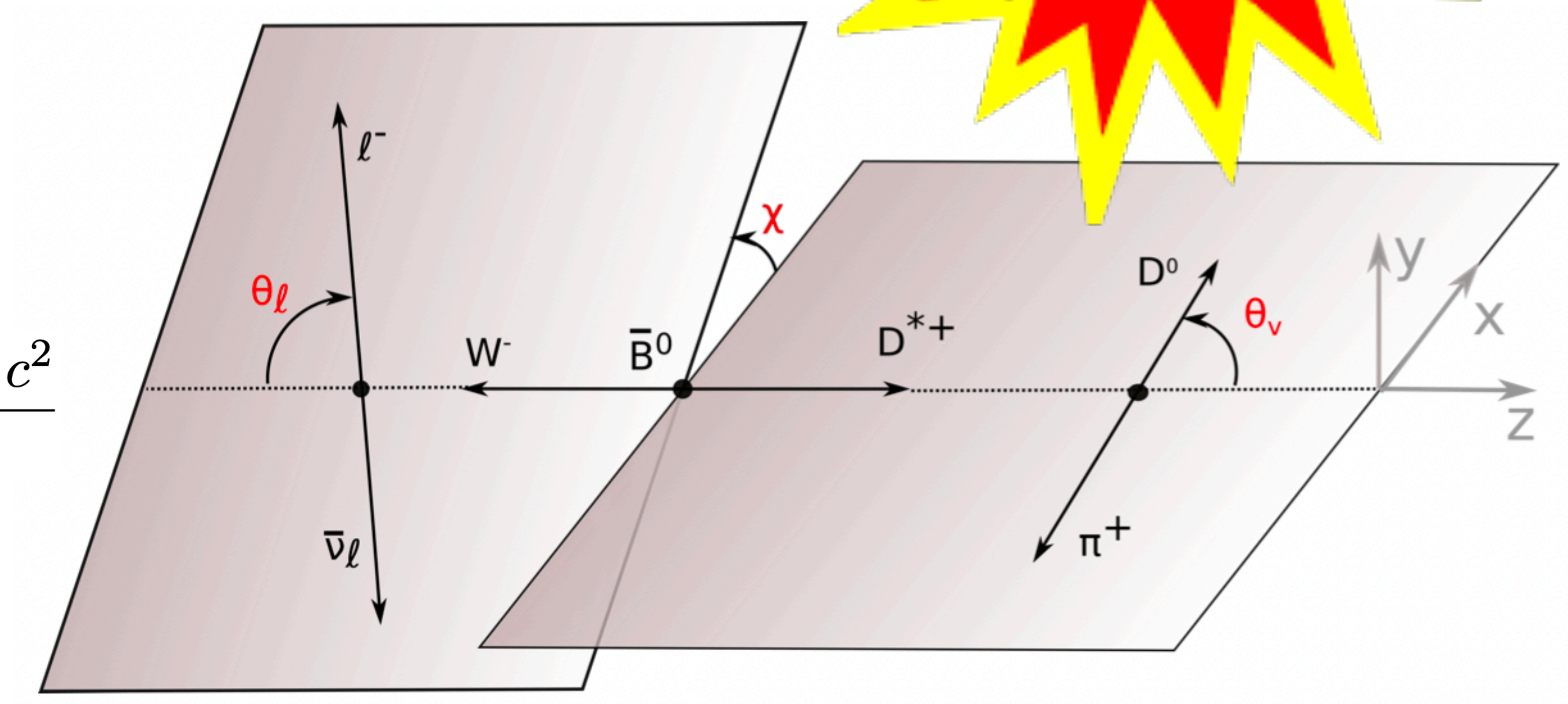
Other tests of LFU

Angular observables in $B \to D^* \ell \nu$

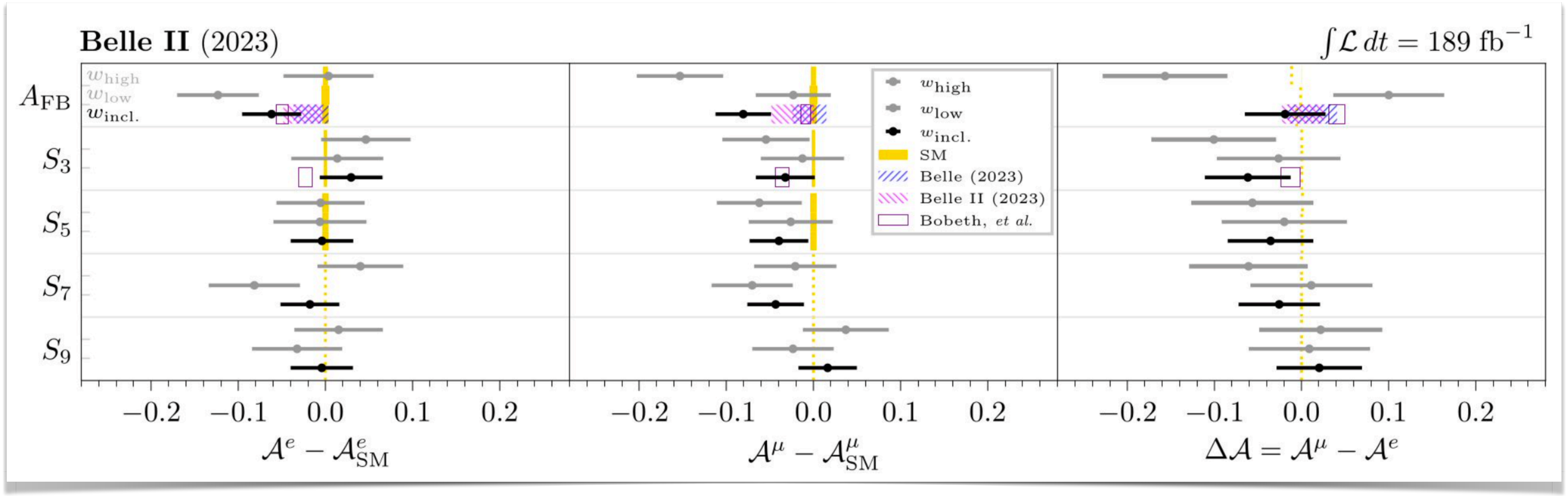
$$\mathcal{A}_x(w) \equiv \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}w}\right)^{-1} \left[\int_0^1 - \int_{-1}^0\right] \mathrm{d}x \frac{\mathrm{d}^2\Gamma}{\mathrm{d}w\mathrm{d}x}$$

$$w \equiv \frac{m_B^2 + m_{D^*}^2 - q^2c^2}{2m_B m_{D^*}}$$

New !



with $x = \cos\theta_\ell$ for A_{FB}, $\cos 2\chi$ for S_3, $\cos\chi\cos\theta_V$ for S_5, $\sin\chi\cos\theta_V$ for S_7, and $\sin 2\chi$ for S_9



Belle II

Preliminary

To be submitted to PRL

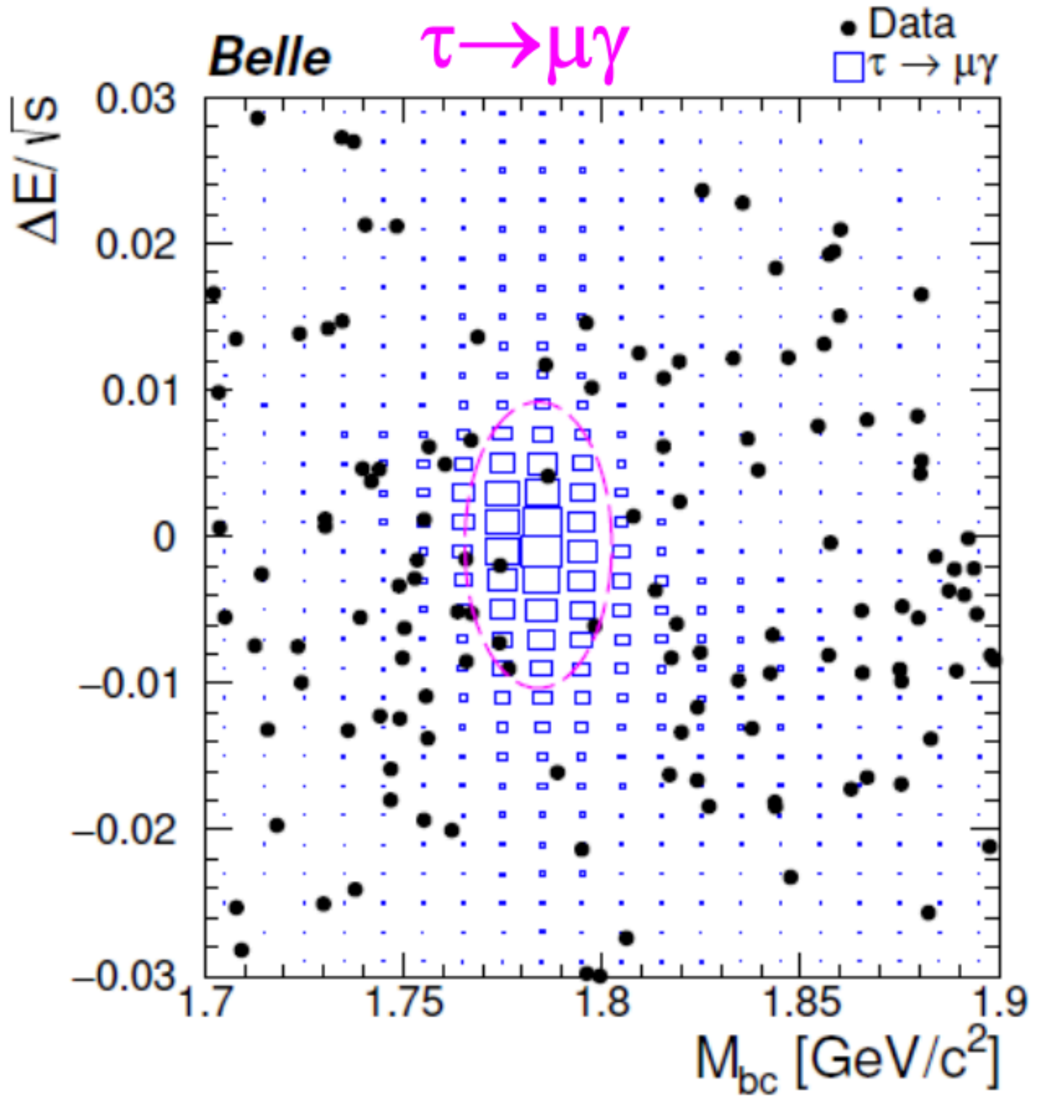
Search for lepton flavour violation

all limits presented at 90% CL

New Belle results for the LFV modes $\tau \to \ell\gamma$, $B \to K\tau\ell$ and $B_s \to \ell\tau$

$\tau \to l\gamma$ [JHEP10(2021)019]

982 fb^{-1} : 912 M $\tau\tau$



$B(\tau \to \mu\gamma) < 4.2\times10^{-8}$

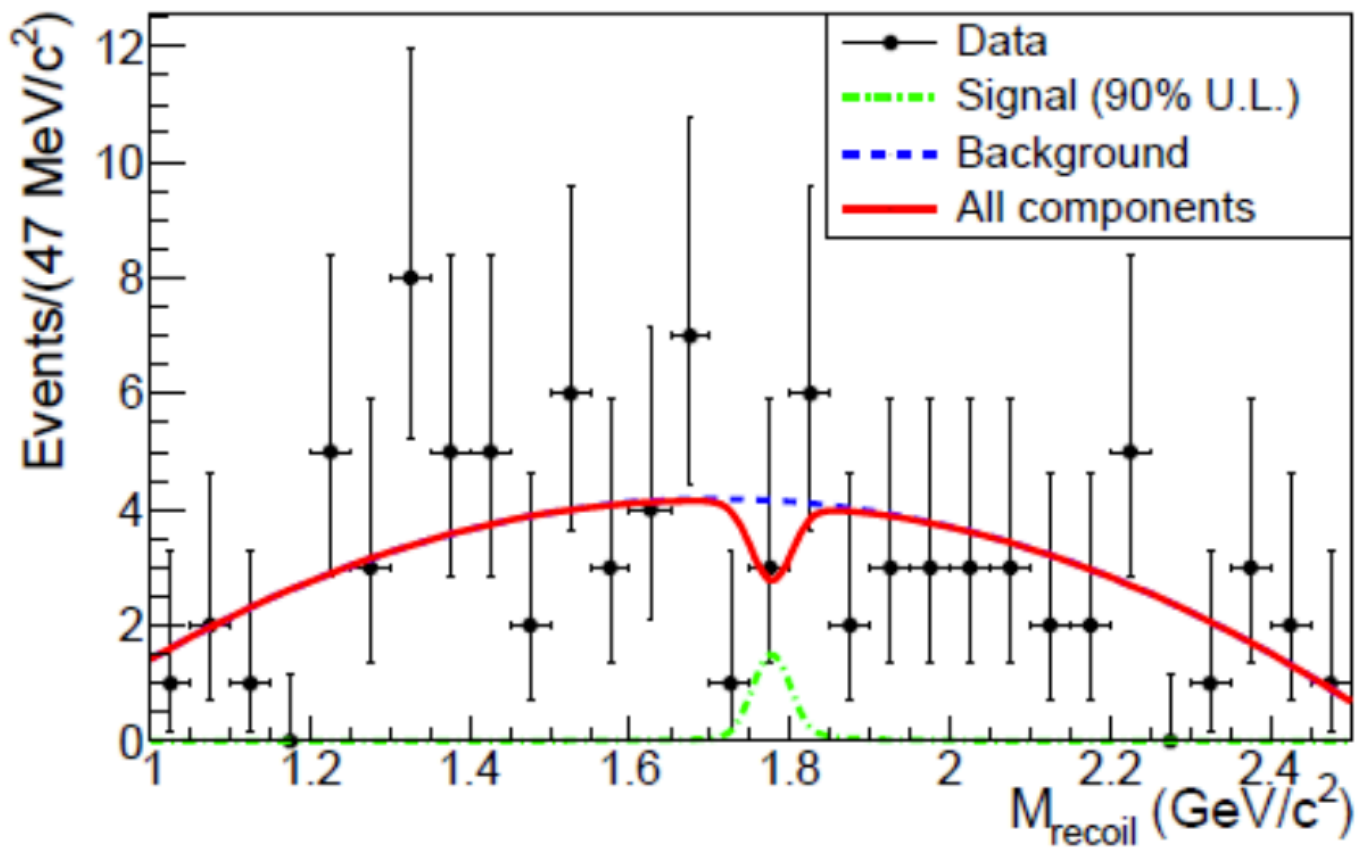
$B(\tau \to e\gamma) < 5.6\times10^{-8}$

most stringent limit of $\tau \to \mu\gamma$

$B \to K\tau l$ [arXiv:2212.04128]

711 fb^{-1} : 772 M BB

- Look at τ recoil mass



$B(B^+ \to K^+\tau^+\mu^-) < 0.59\times10^{-5}$

$B(B^+ \to K^+\tau^+e^-) < 1.51\times10^{-5}$

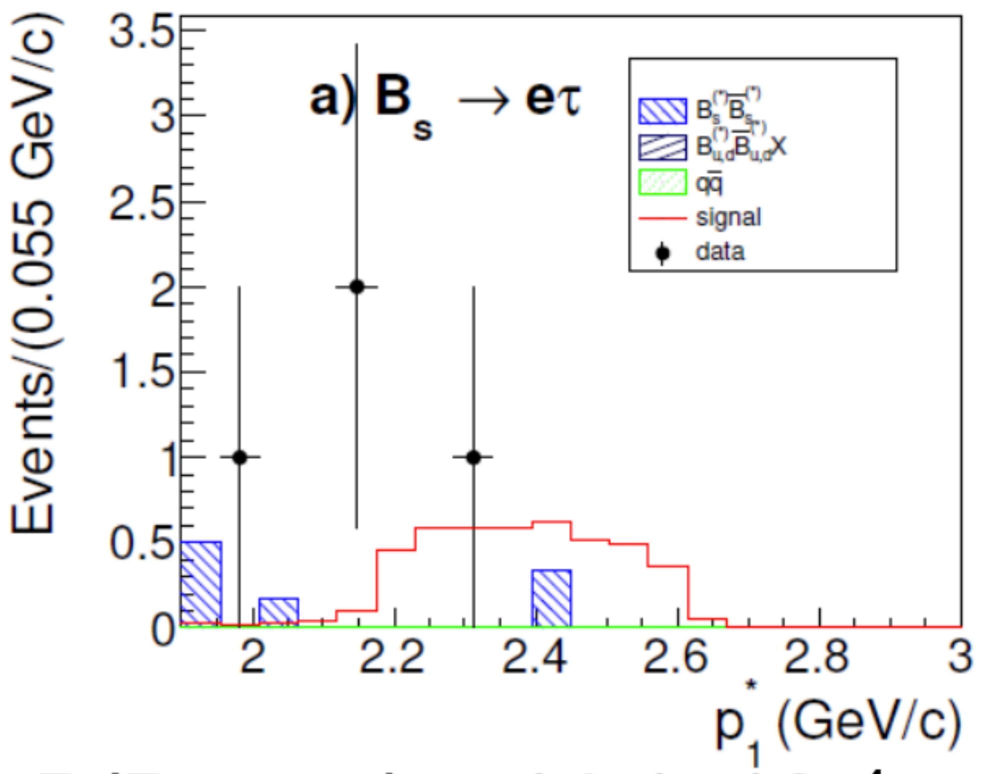
$B(B^+ \to K^+\tau^-\mu^+) < 2.45\times10^{-5}$

$B(B^+ \to K^+\tau^-e^+) < 1.53\times10^{-5}$

$B_s \to l\tau$ [arXiv:2301.10989]

121 fb^{-1}@$\Upsilon(5S)$: 16 M B_sB_s

- Tag B_s with $B_s \to D_sXl\nu$



$B(B_s \to e\tau) < 14.1\times10^{-4}$

$B(B_s \to \mu\tau) < 7.3\times10^{-4}$

- First measurement of $B_s \to e\tau$
- $B(B_s \to \mu\tau) < 3.4\times10^{-5}$ @LHCb [PRL 123, 211801(2019)]

Other recent LHCb LFV test results: [LHCb-PAPER-2022-021, LHCb-PAPER-2022-008, LHCb-PAPER-2022-008]

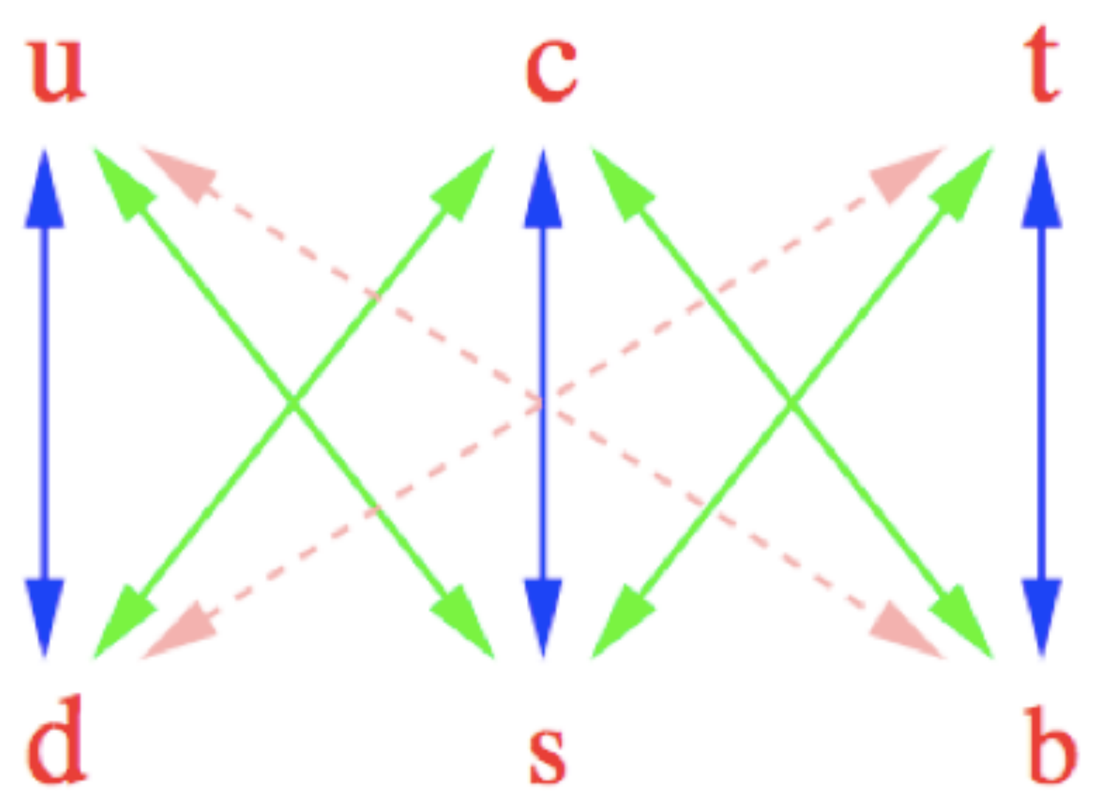
Test of the Cabibbo-Kobayashi-Maskawa mechanism

Cabibbo-Kobayashi-Maskawa quark mixing

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \mathbf{V} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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

$$\mathbf{V}\,\mathbf{V}^{\dagger} = \mathbf{V}^{\dagger}\,\mathbf{V} = 1$$



- The weak interaction down-type doublet partners are a mixture of the mass (flavour) eigenstates described by the unitary Cabibbo-Kobayashi-Maskawa (CKM) matrix
- The CKM element magnitudes squared determine the rate of quark flavour transitions in charged current processes

$$-\mathcal{L}_{W^{\pm}} = \frac{g}{\sqrt{2}}\, \overline{u_{Li}}\, \gamma^{\mu}\, (V_{\rm CKM})_{ij}\, d_{Lj}\, W_{\mu}^{+} + \text{h.c.}$$

CP violation

Wolfenstein parametrization of V_{CKM}

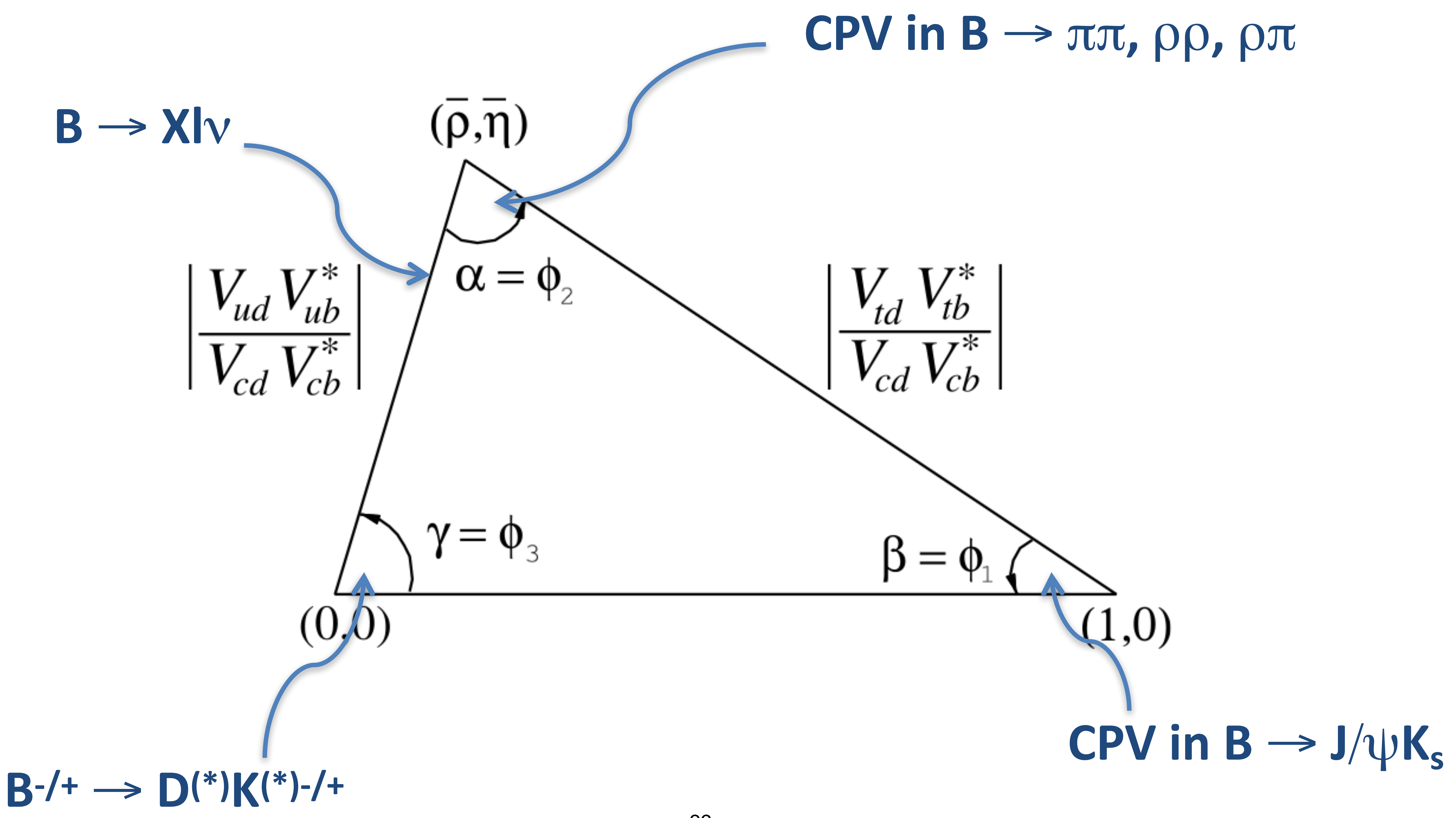
$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

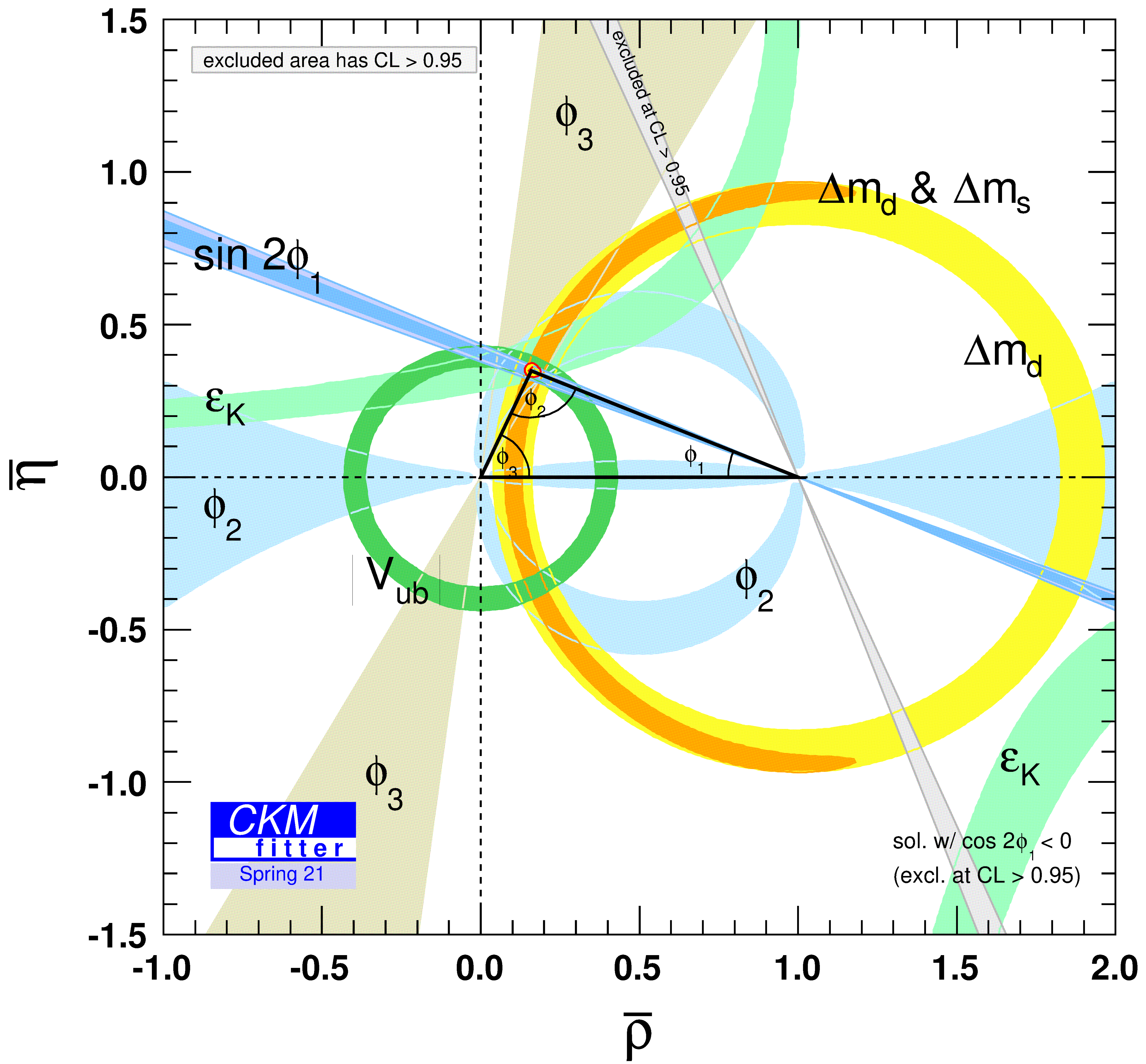
- However, V_{CKM} also contains a complex phase, responsible for all CP-violating phenomena in the quark sector of the SM, and consistent with observations in K, D and B meson decays so far
- New physics would typically disturb the SM pattern of CPV

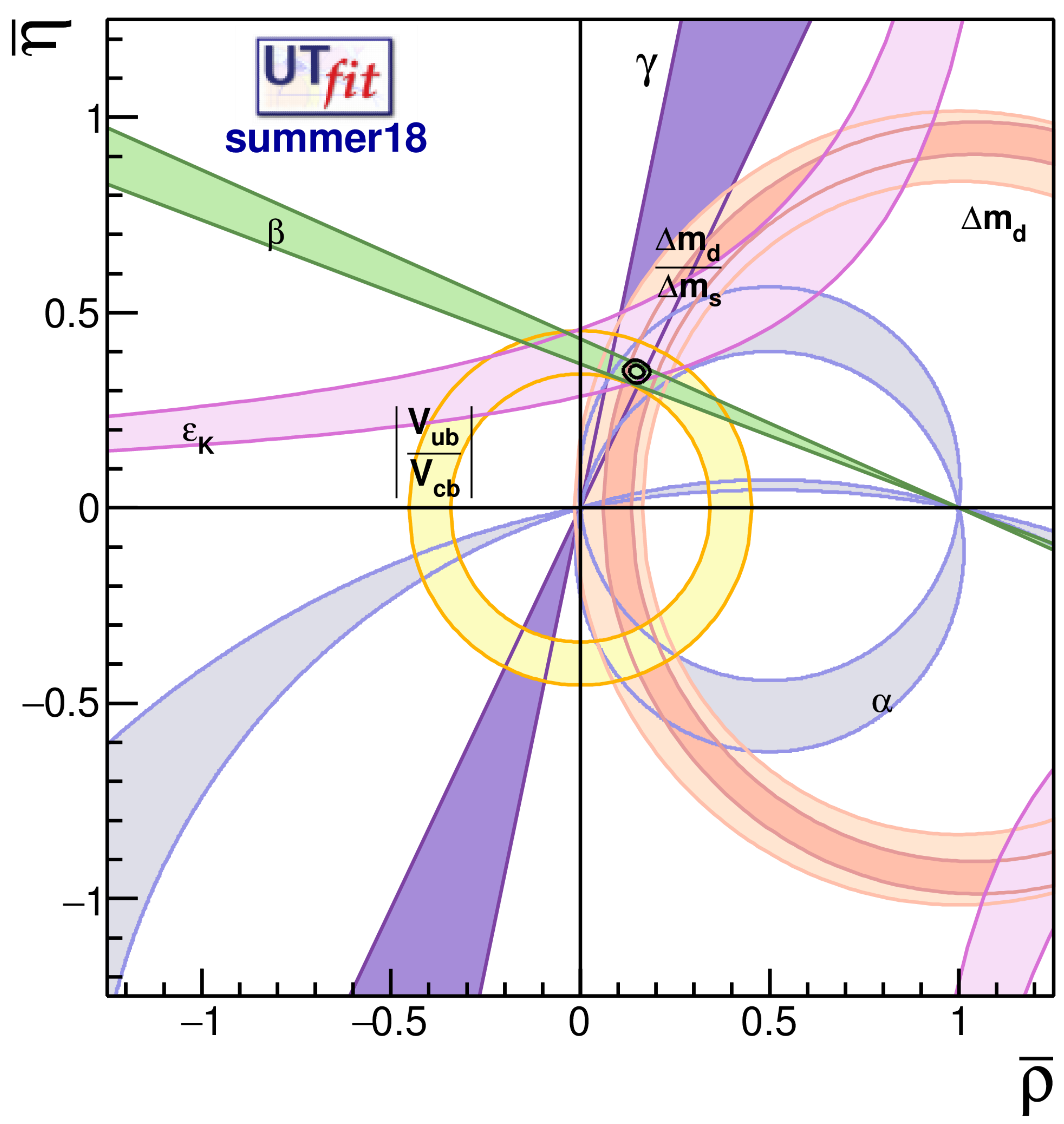
The CKM unitarity triangle

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

…and how to probe it with B mesons

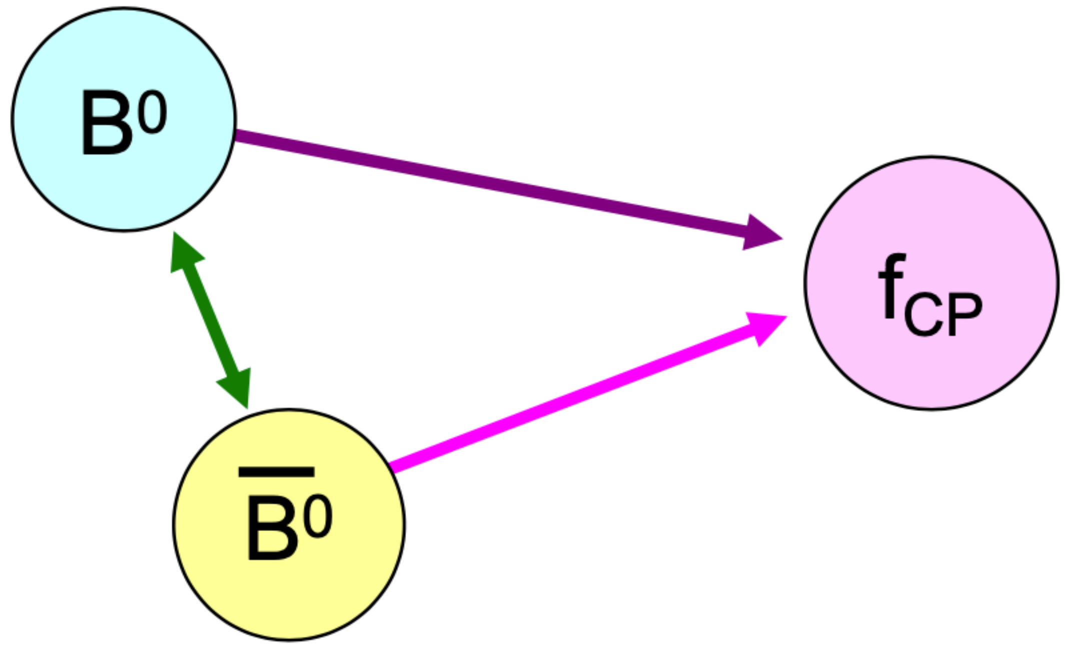



excluded area has CL > 0.95
excluded at CL > 0.95
sin 2φ1
φ3
Δmd & Δms
Δmd
εK
φ2
Vub
sol. w/ cos 2φ1 < 0
(excl. at CL > 0.95)
CKM fitter
Spring 21
η̄
ρ̄


UTfit
summer18
γ
β
Δmd
Δmd/Δms
εK
Vub/Vcb
α
η̄
ρ̄

Mixing-induced CP violation in B decays

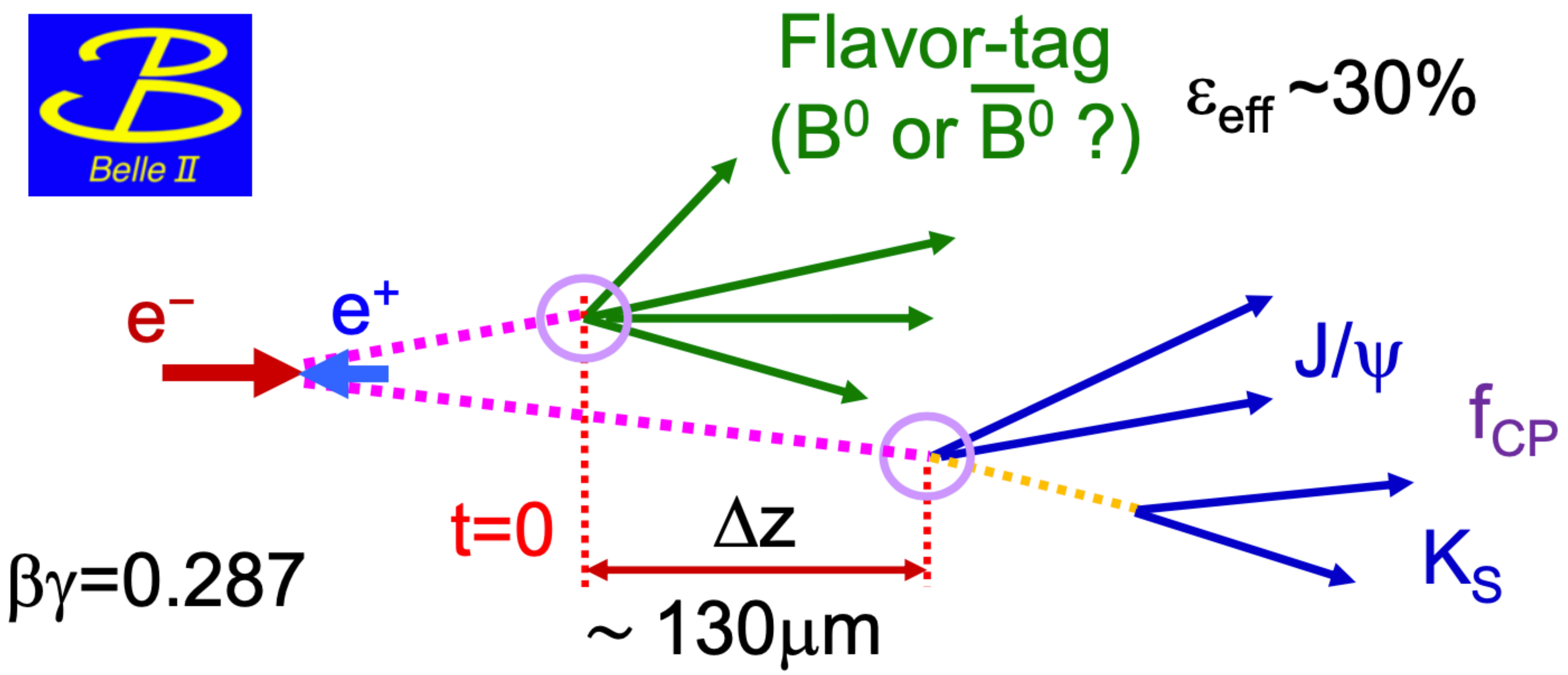
- B^0 and $\bar{B}^0$ decay to a common CP eigenstate f_{CP}
- There is a non-vanishing CP asymmetry as a function of the decay time difference Δt,



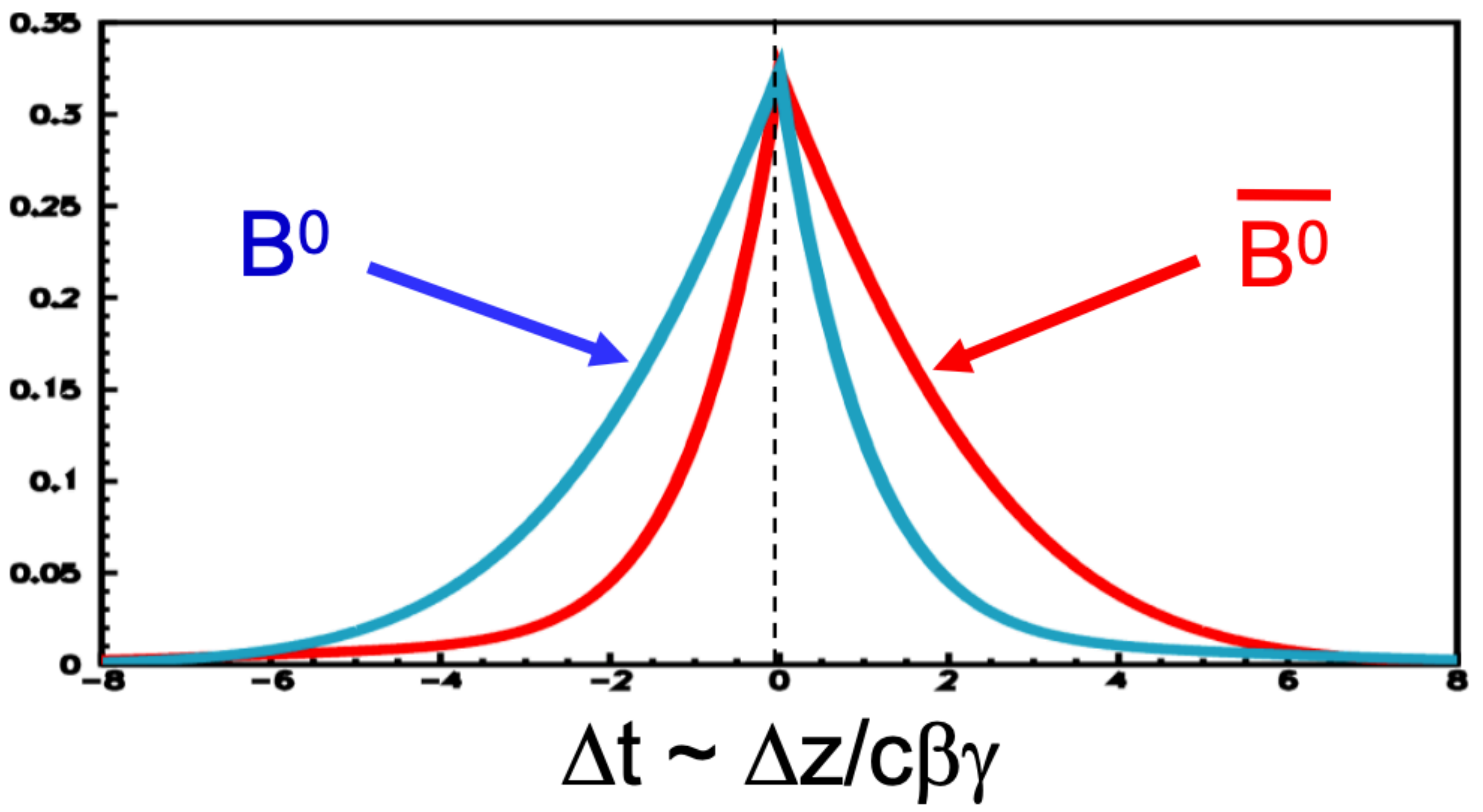
$$A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) - \Gamma(B^0(\Delta t) \to f_{CP})}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}) + \Gamma(B^0(\Delta t) \to f_{CP})} = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

S : mixing induced CPV
A : direct CPV (=−C)

- For $B^0 \to J/\psi K_S$, $S = -\xi \sin(\phi_1)$ and $A = 0$



measure position instead of time

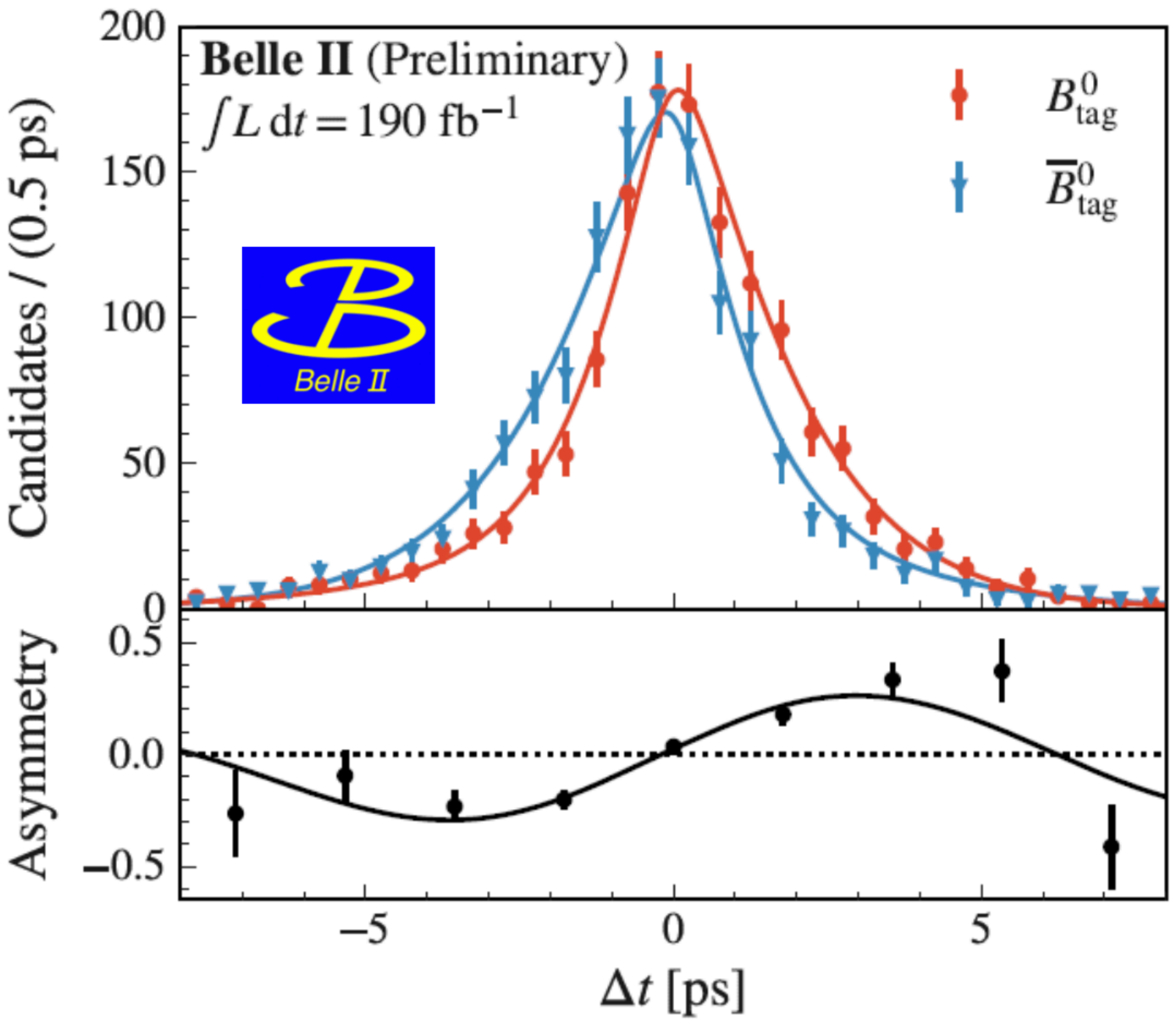


CP violation in $B^0 \to J/\psi K_S$

- Belle result

$\sin(2\phi_1) = 0.667 \pm 0.023 \pm 0.012$
$A = 0.006 \pm 0.016 \pm 0.012$

[PRL 108, 171802 (2012)]



- First measurement by Belle II is done with 189/fb
- Statistically limited

$\sin(2\phi_1) = 0.720 \pm 0.062 \pm 0.016$
$A = 0.094 \pm 0.044 ^{+0.047}_{-0.017}$

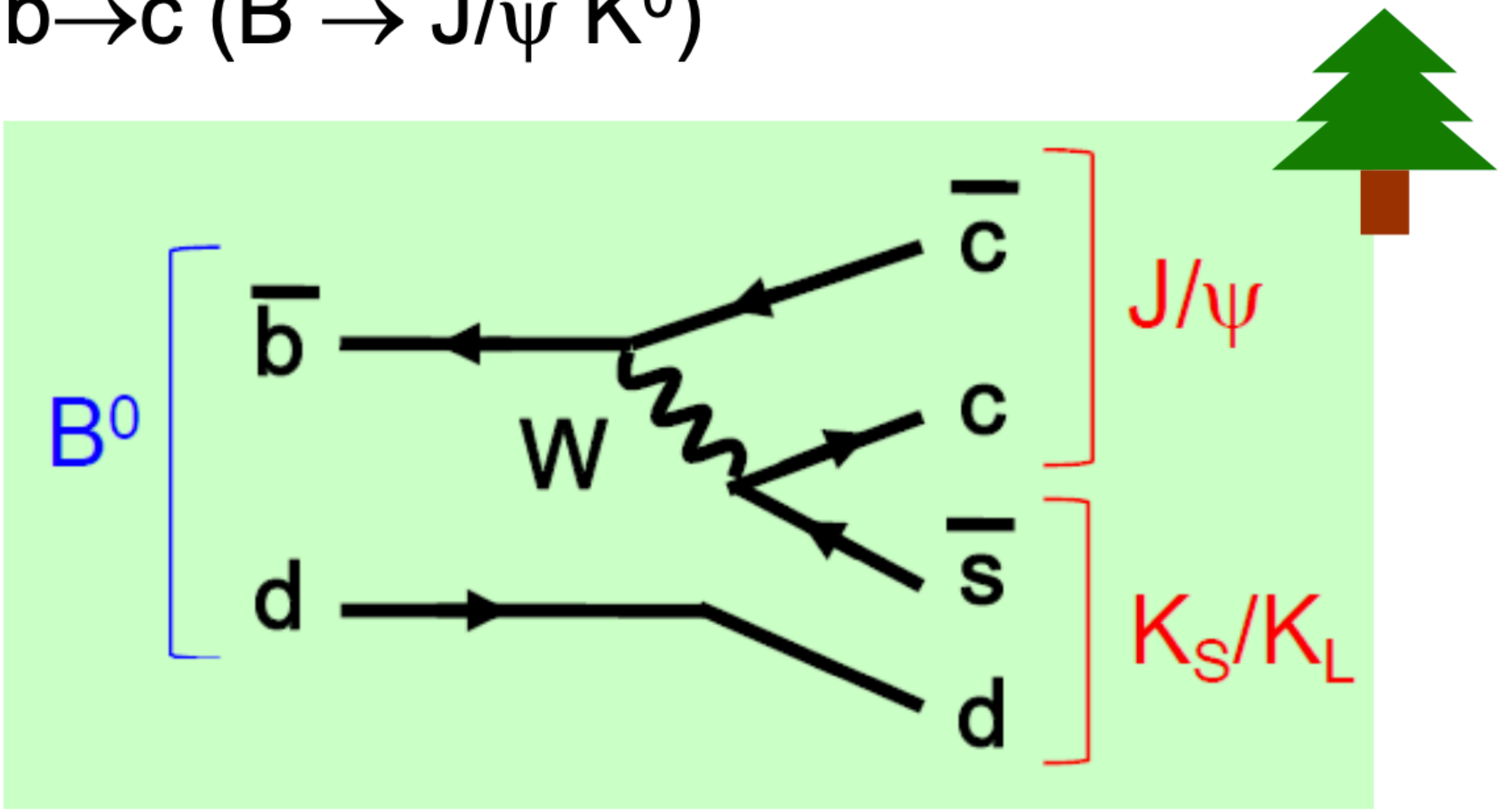
Preliminary

[arXiv:2302.12898]

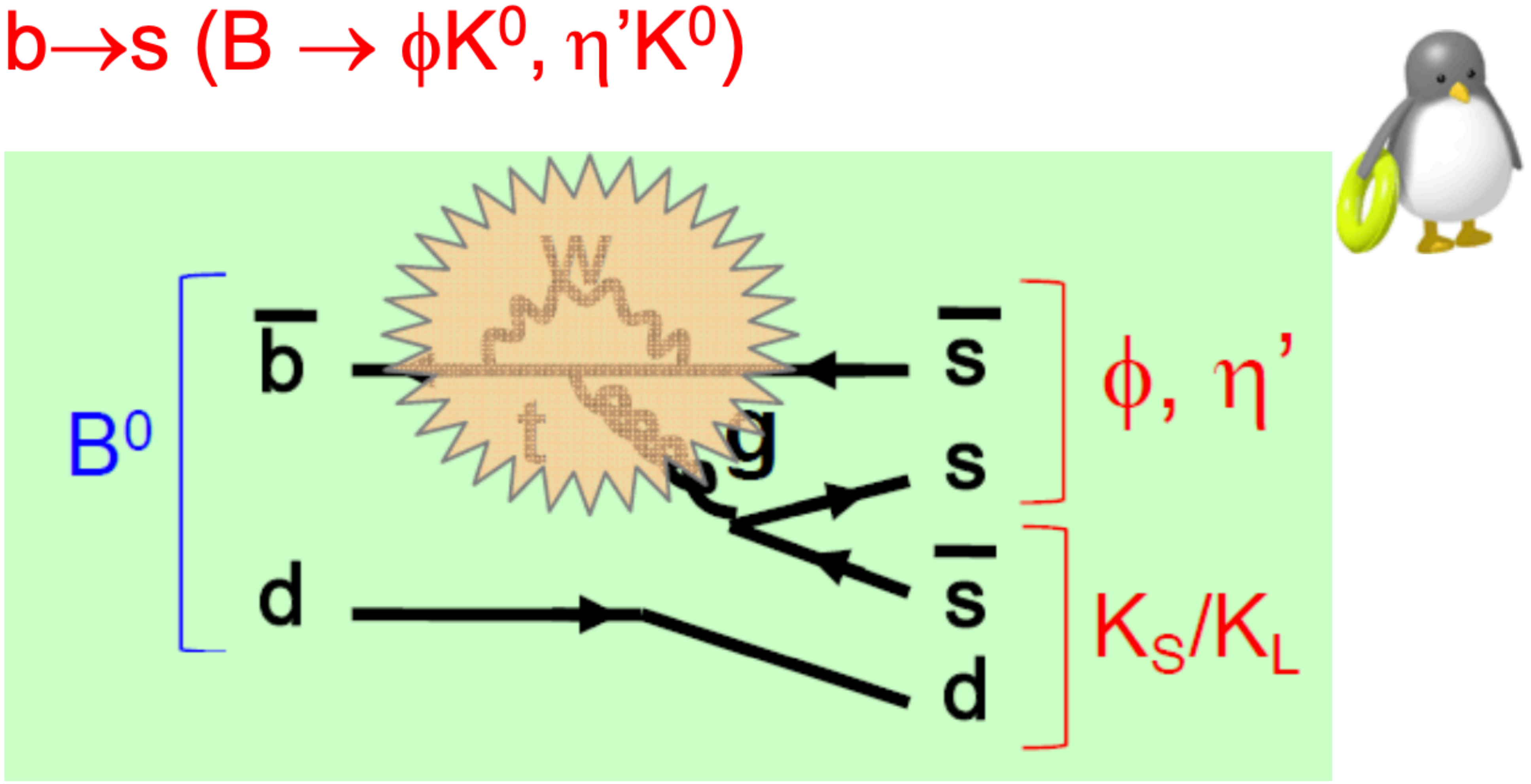
New !

CP violation in $b \to s$

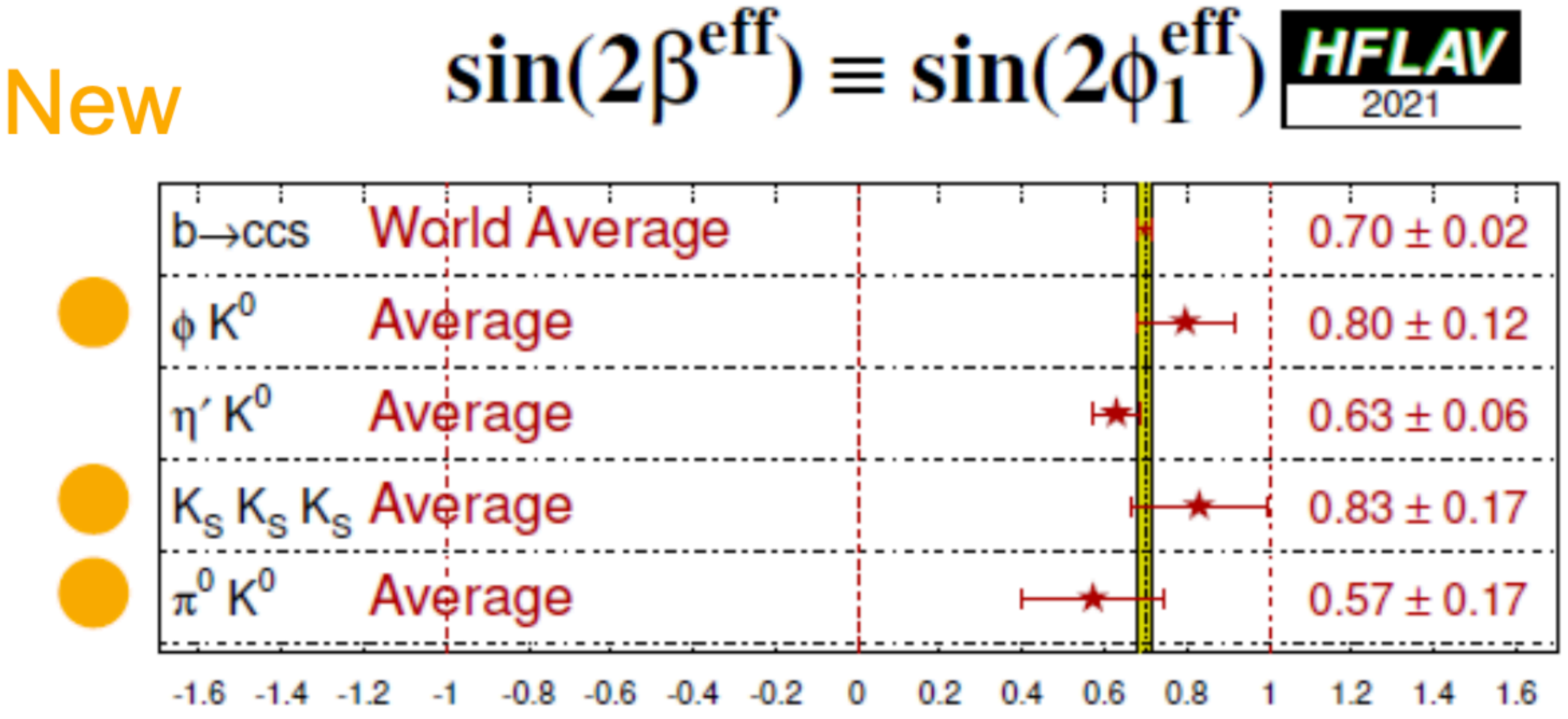
b→c (B → J/ψ K^0)



b→s (B → ϕK^0, η'K^0)



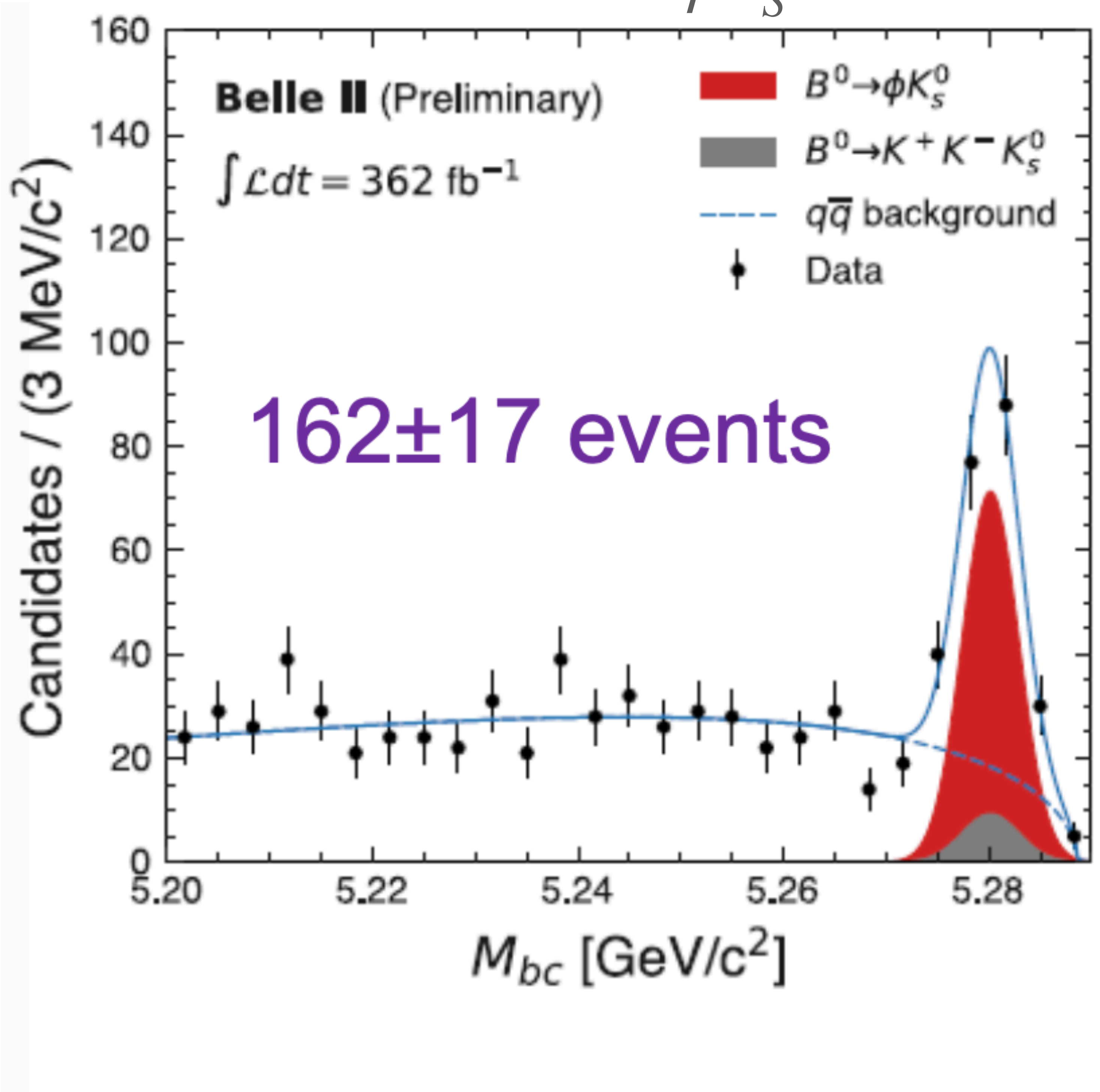
- In the SM, $S = -\xi \sin(2\phi_1)$ for $b \to s$
- However, NP could cause this to shift
- The theoretical uncertainty in the SM depends on the final state ($K_S K_S K_S$, ϕK^0, $\eta' K^0$) are cleanest



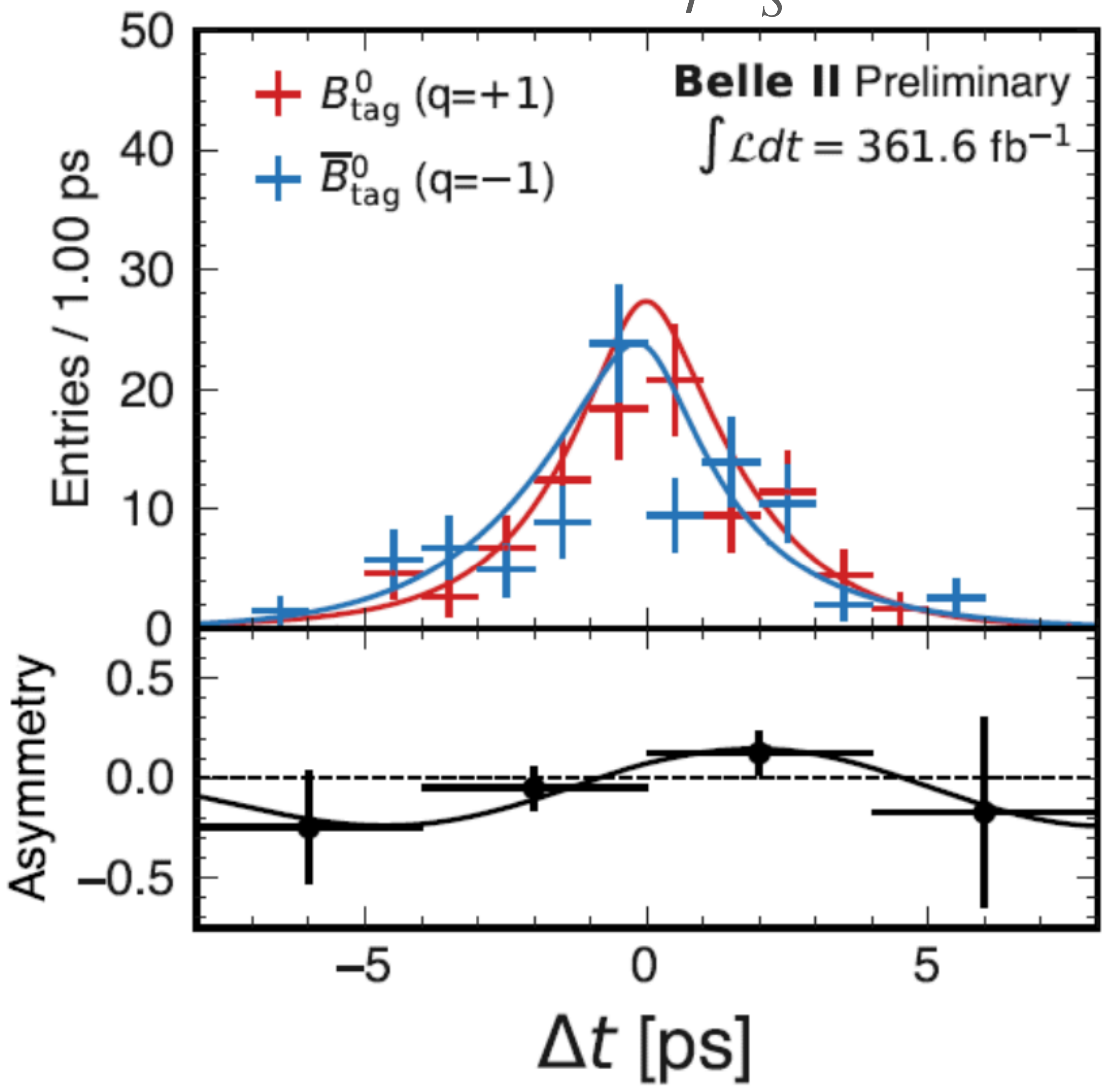
$B^0 \to \phi K_S$ at Belle II (362/fb)

New !

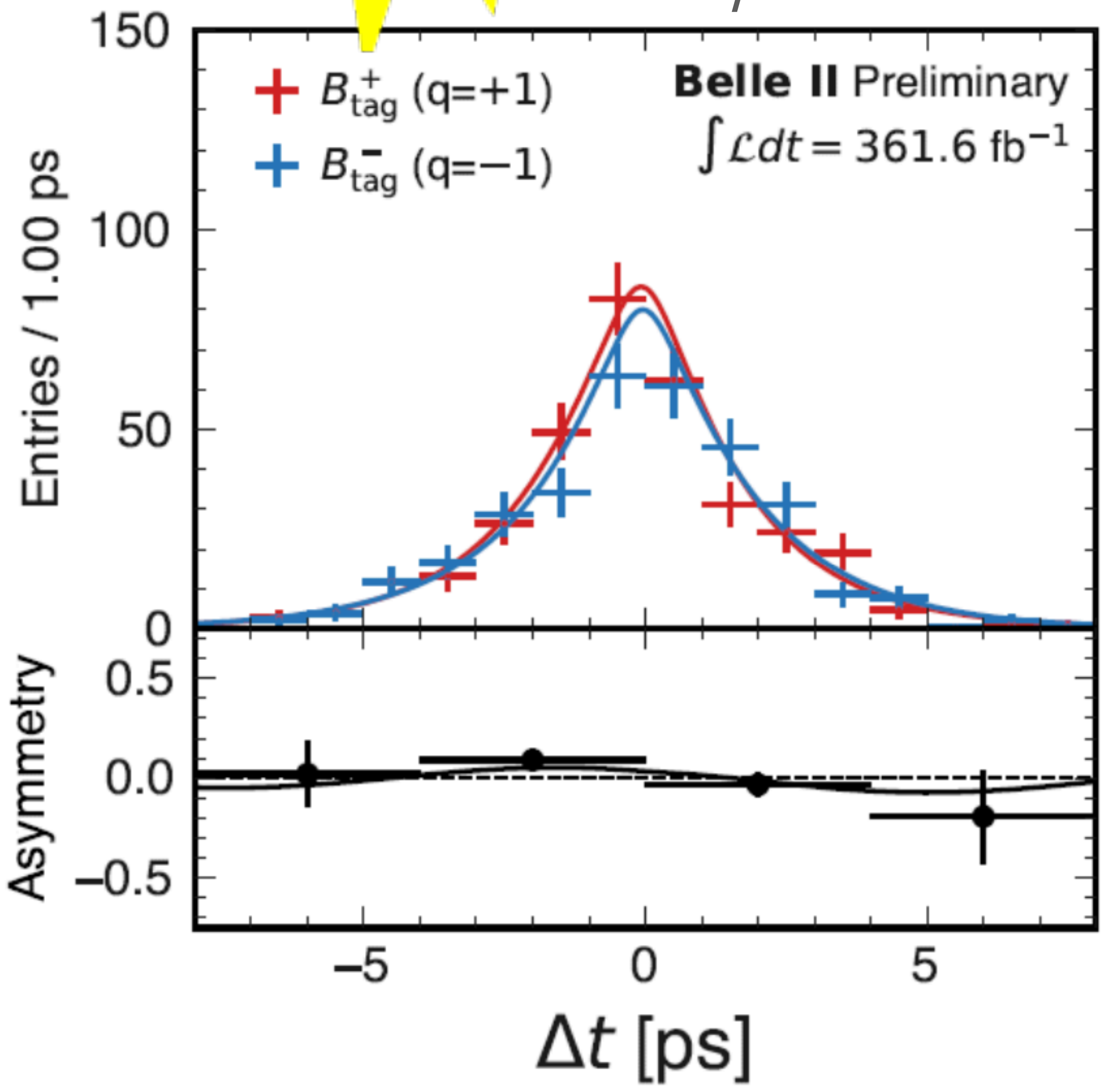
$B^0 \to \phi K_S$



$B^0 \to \phi K_S$



$B^+ \to \phi K^+$



- Consistent with BaBar/Belle average

$S = 0.54 \pm 0.26\ ^{+0.06}_{-0.08}$

$A = 0.31 \pm 0.20\ ^{+0.05}_{-0.06}$

Preliminary

HFLAV $S = 0.74\ ^{+0.11}_{-0.13}$

$A = -0.01 \pm 0.14$

$S = -0.09 \pm 0.12$
$A = 0.12 \pm 0.10$
(control sample)

CP violation in $B_s \to \phi\phi$

New !

LHCb-PAPER-2023-001

Run 2 results

Polarisation independent

$$\phi_s^{s\bar{s}s} = -0.042 \pm 0.075 \pm 0.009 \text{ rad}$$
$$|\lambda| = 1.004 \pm 0.030 \pm 0.009\,,$$

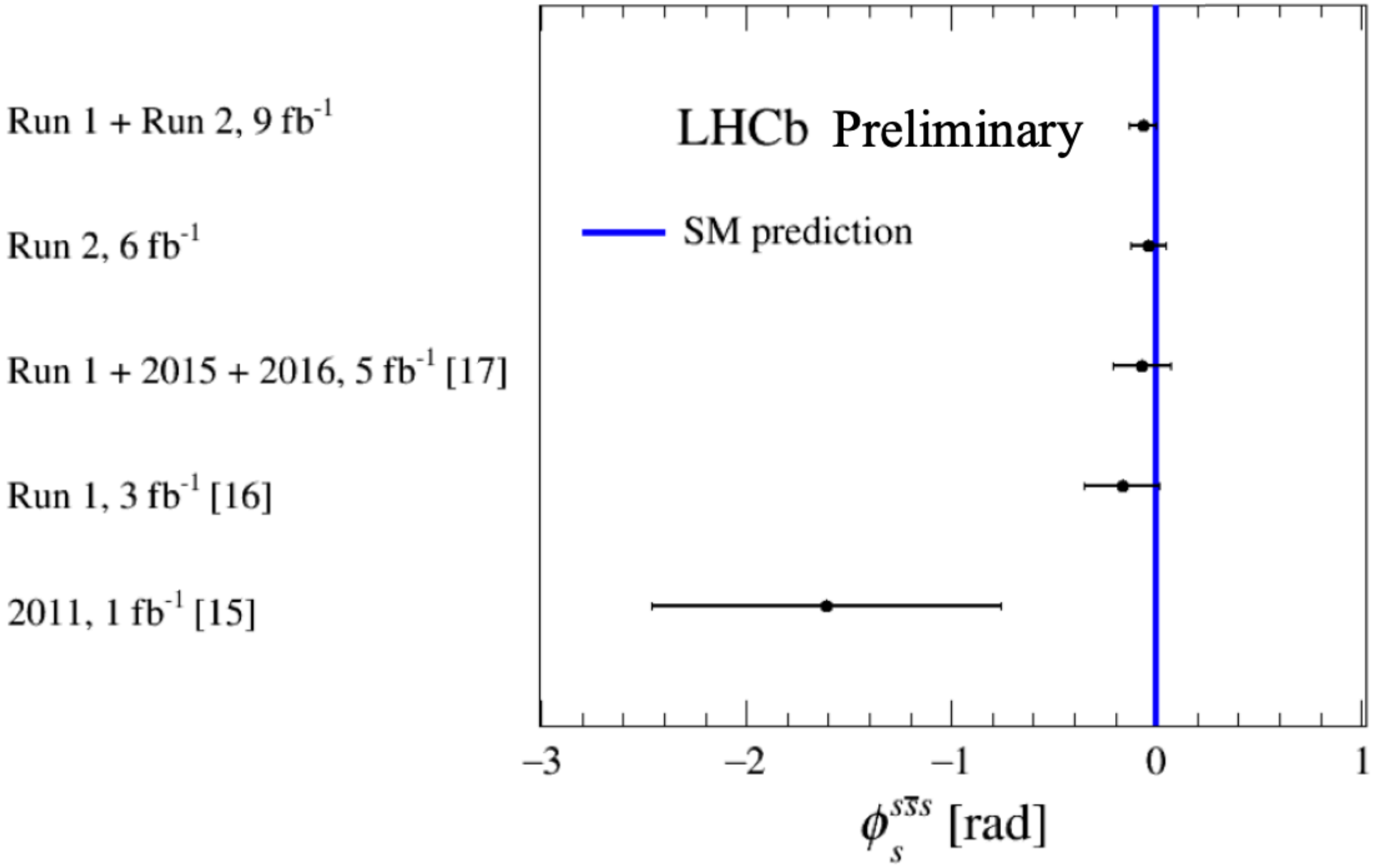
Polarisation dependent

$$|\lambda_0| = 1.02 \pm 0.17 \qquad \phi_{s,0} = -0.18 \pm 0.09 \text{ rad}$$
$$|\lambda_\perp/\lambda_0| = 0.97 \pm 0.22 \qquad \phi_{s,\|} - \phi_{s,0} = 0.12 \pm 0.09 \text{ rad}$$
$$|\lambda_\|/\lambda_0| = 0.78 \pm 0.21 \qquad \phi_{s,\perp} - \phi_{s,0} = 0.17 \pm 0.09 \text{ rad}$$

- Combination with run 1

$$\phi_s^{s\bar{s}s} = (-0.074 \pm 0.069) \text{ rad}$$
$$|\lambda| = 1.009 \pm 0.030$$

- In agreement with SM
- No difference between different polarisation states
- Further recent LHCb result: τ_L of $B_s \to J/\psi\eta$ (stringent test of consistency between direct measurements of $|\Delta\Gamma_s|$ and those inferred from effective lifetimes) [LHCb-PAPER-2022-010]



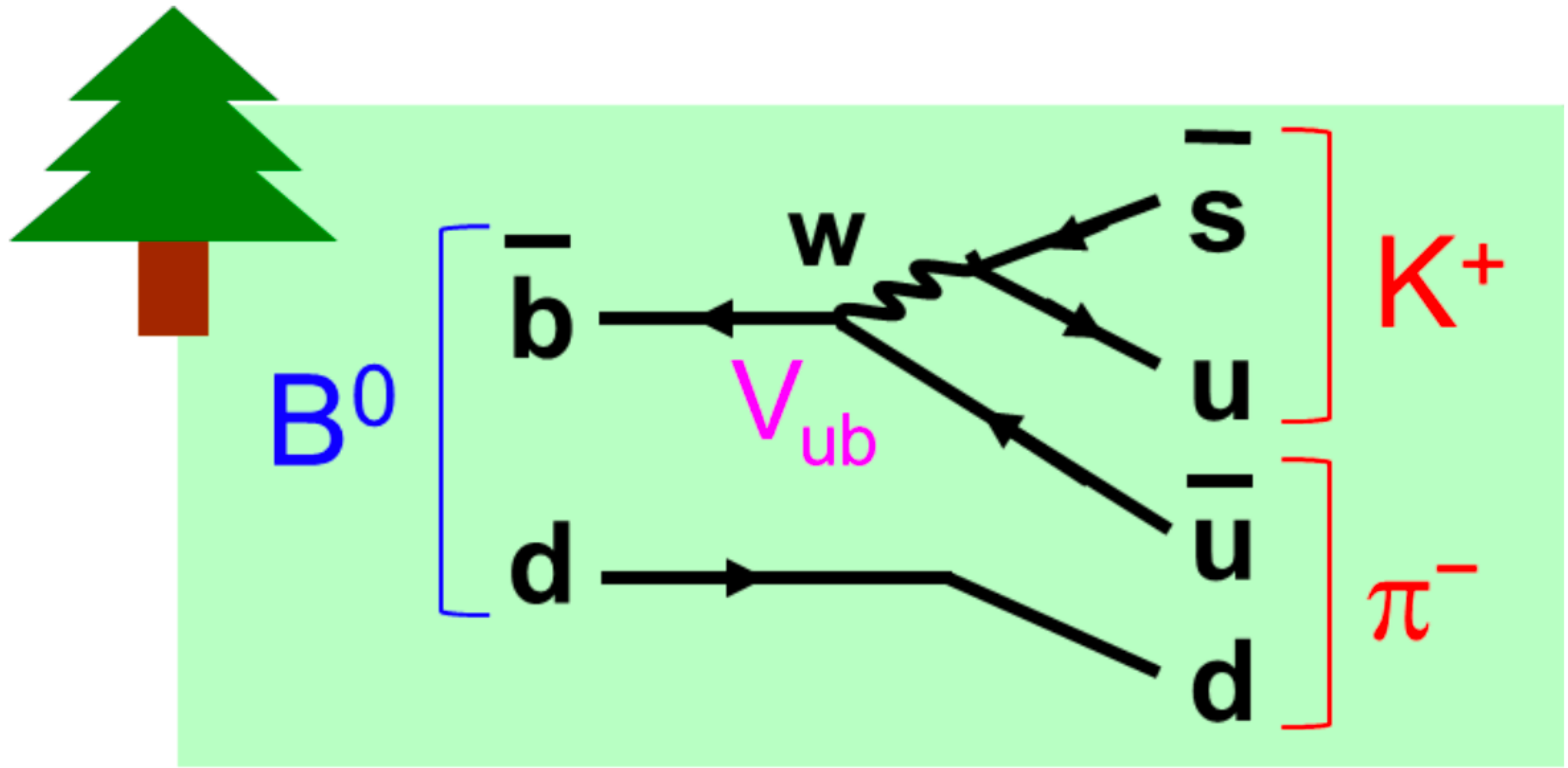
$B \to K\pi$

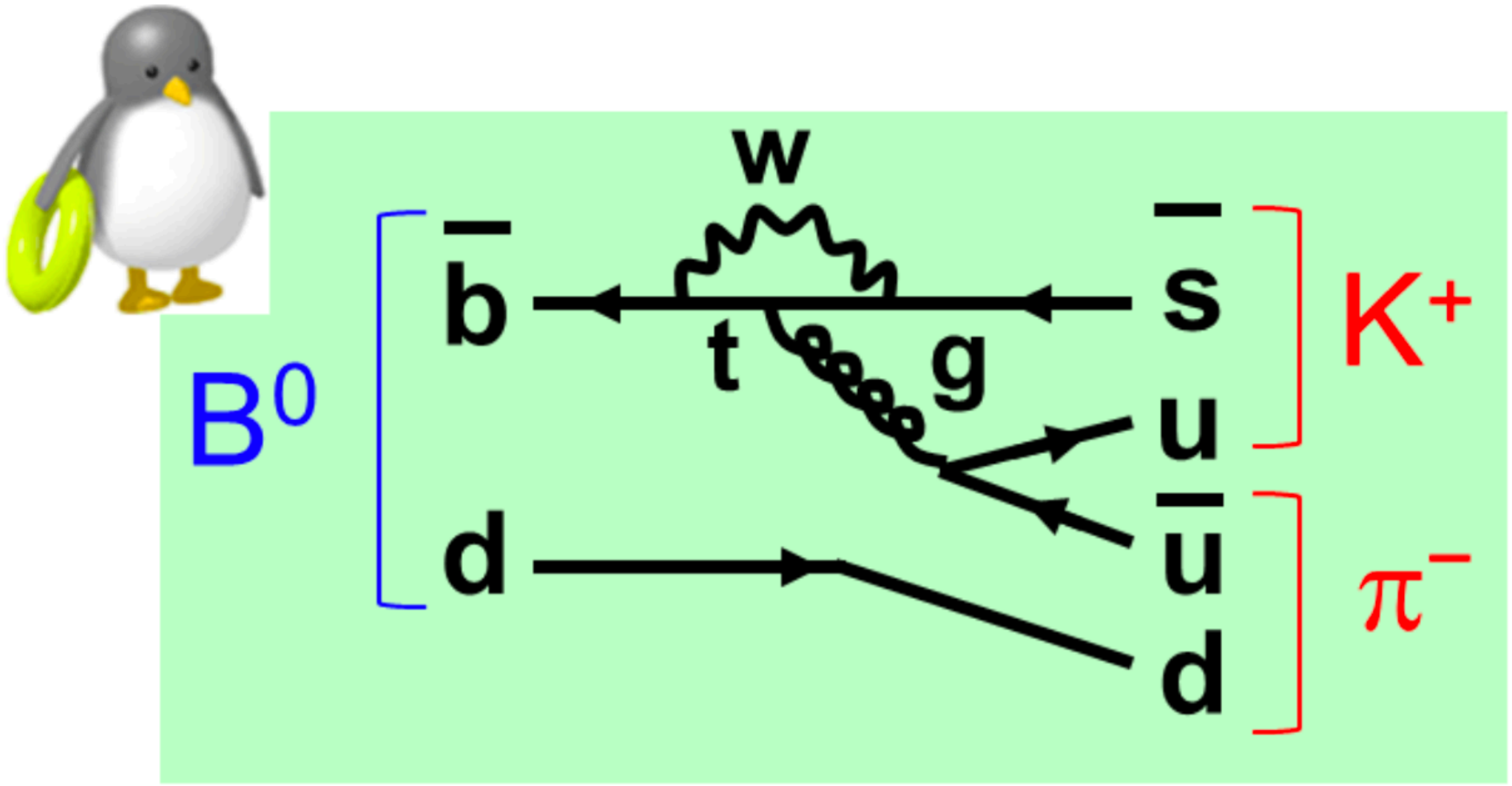
Gronau sum rule

- Rare decay with relatively high branching fraction ($\approx 10^{-5}$)
- Tree and penguin contributions (direct CP violation)
- The sum-rule provides precise prediction of the relation of the branching fractions and A_{CP} [M.Gronau, PLB627 (2005) 82]

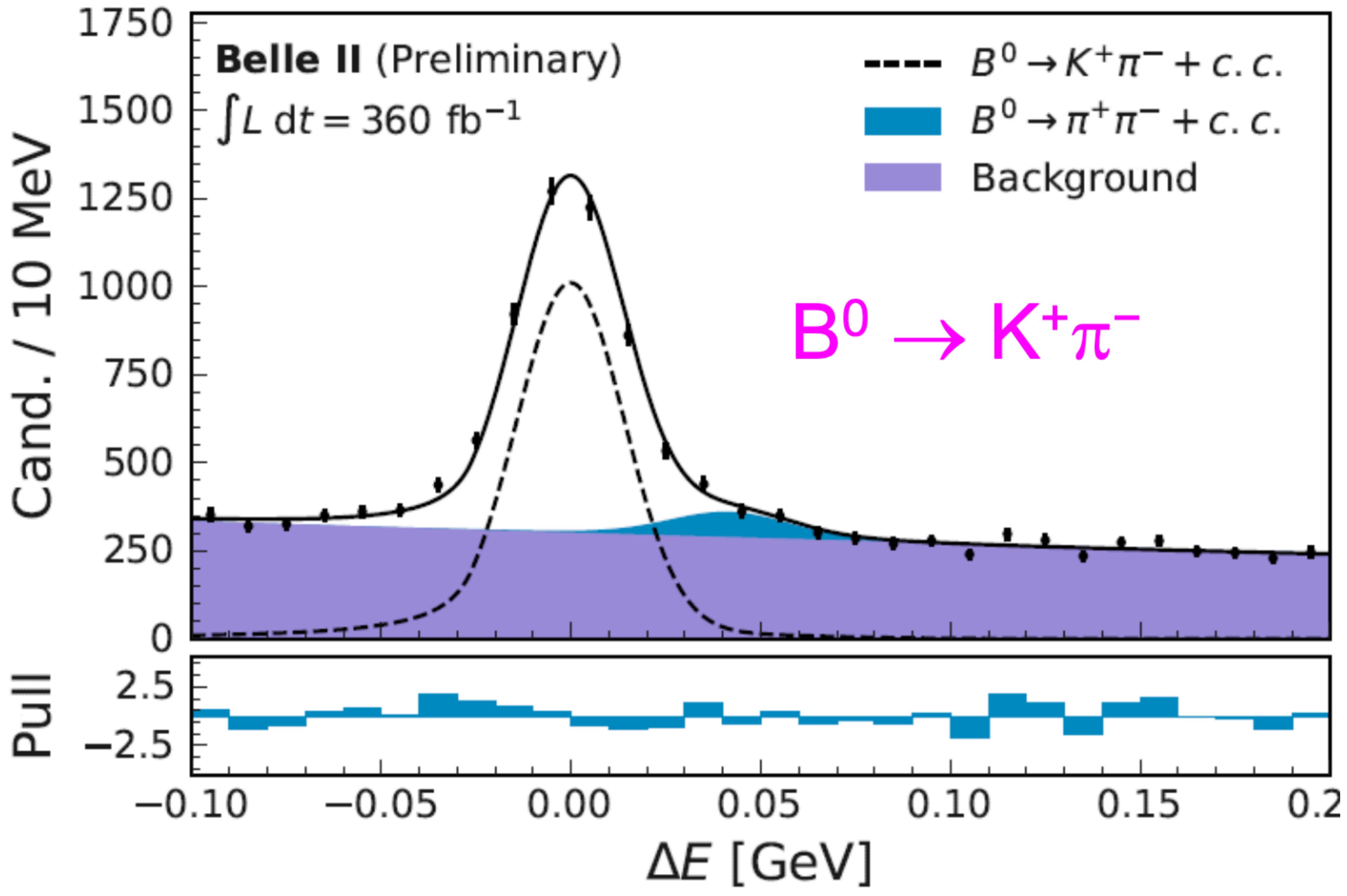
$$I_{K\pi} = \mathcal{A}_{CP}^{K^+\pi^-} + \mathcal{A}_{CP}^{K^0\pi^+} \frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^+\pi^0} \frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{CP}^{K^0\pi^0} \frac{\mathcal{B}_{K^0\pi^0}}{\mathcal{B}_{K^+\pi^-}}$$

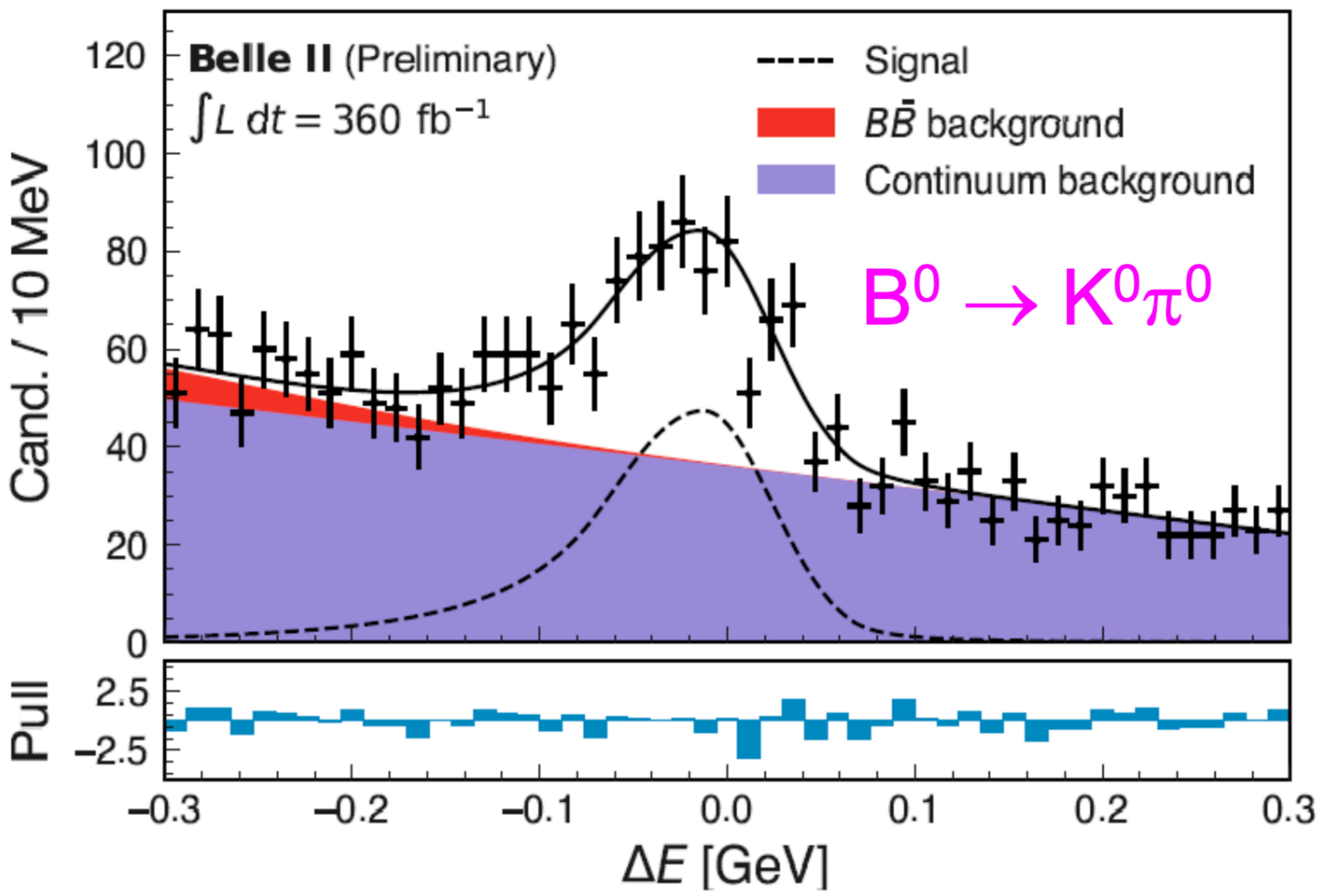
- $I_{K\pi}$ is predicted to be 0 within 1%, Belle II can measure all observables





$B \to K\pi$ from Belle II





$\mathcal{B}(B^0 \to K^+\pi^-) = (20.7 \pm 0.4 \pm 0.6) \times 10^{-6}$
$A_{CP}(B^0 \to K^+\pi^-) = -0.07 \pm 0.02 \pm 0.01$

$\mathcal{B}(B^0 \to K^0\pi^0) = (10.16 \pm 0.65 \pm 0.65) \times 10^{-6}$
$A_{CP}(B^0 \to K^0\pi^0) = -0.06 \pm 0.15 \pm 0.05$

- Combining time-integrated and time-dependent measurements:

$$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$$

- Consistent with SM prediction (0)
- Competitive with current world average (-0.13 ± 0.11)

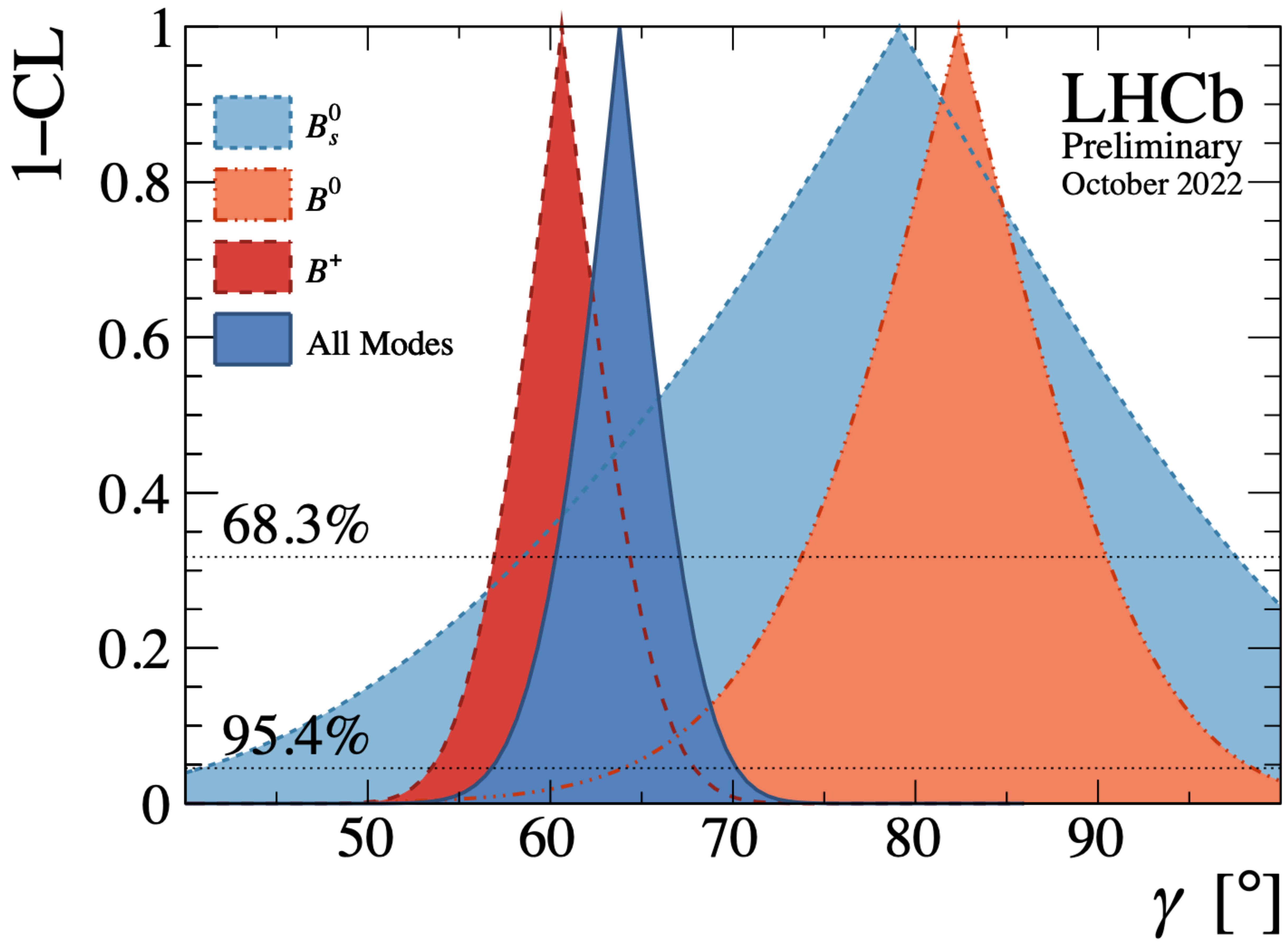
New !

ϕ_3/γ status

Combination of results on $B \to DK$ processes to constraint ϕ_3/γ

BaBar combination:
[PRD 87, 052015 (2013)]
$\gamma = (69^{+17}_{-16})^\circ$

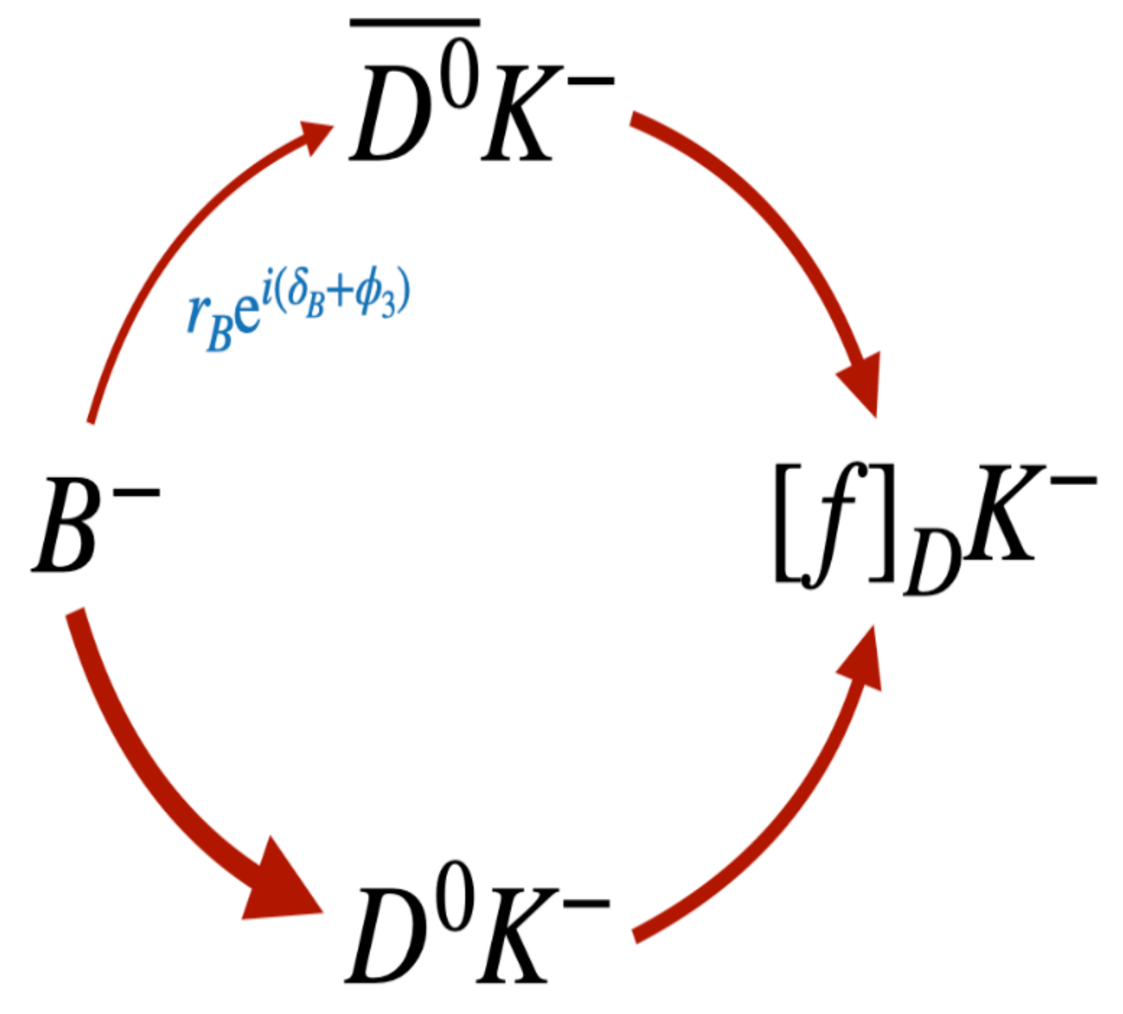
LHCb combination:
[LHCb-CONF-2022-002]
$\gamma = (63.8^{+3.5}_{-3.7})^\circ$

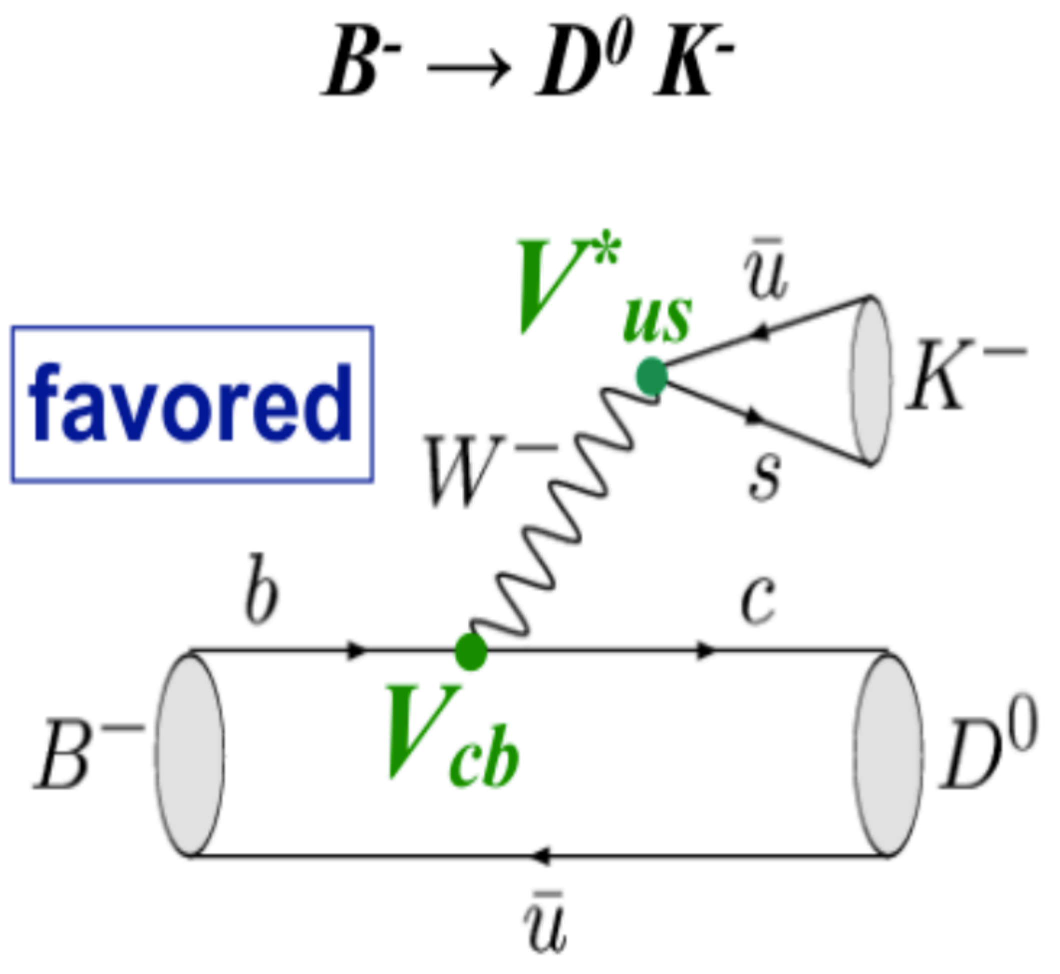


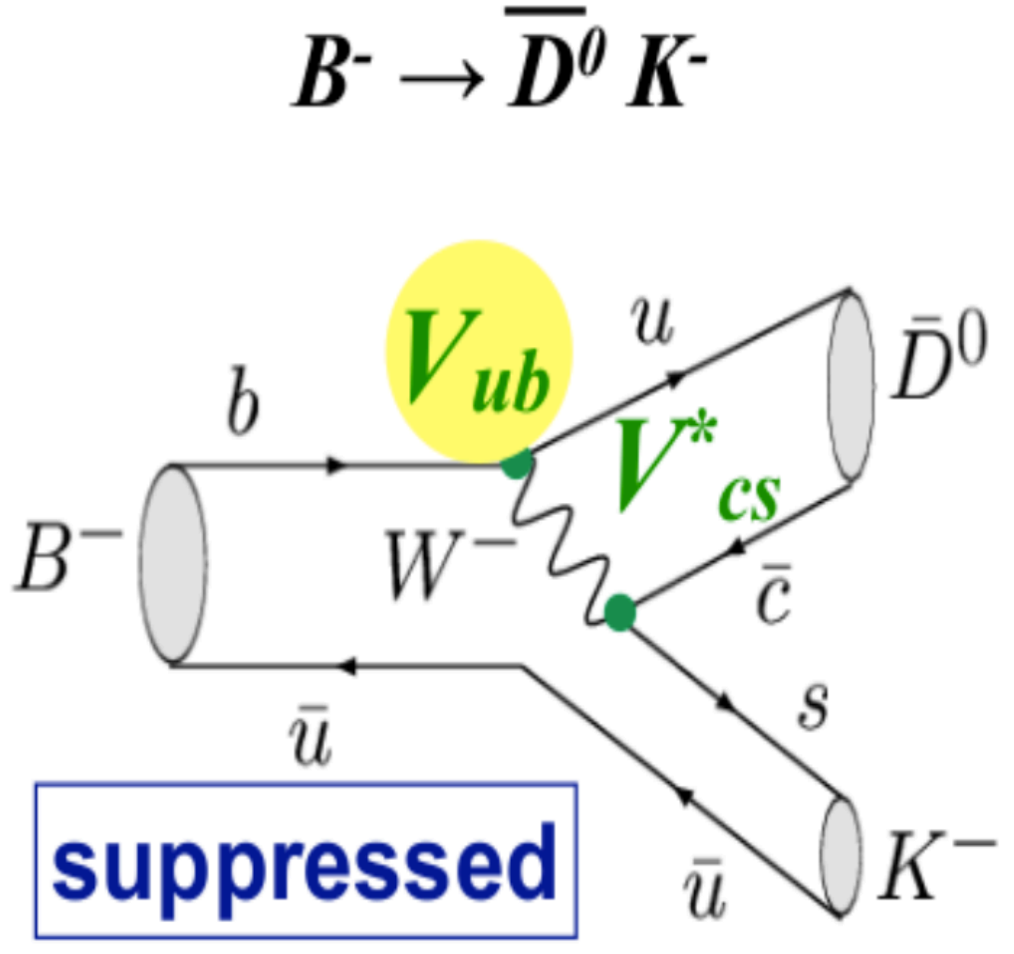
CKM angle ϕ_3/γ

BPGGSZ method (binned model-independent) [Phys.Rev.D68, 054018]

- ϕ_3/γ is the phase between $b \to u$ and $b \to c$ transitions
- The interference between these two diagrams gives access to the amplitude ratio, which contains ϕ_3/γ





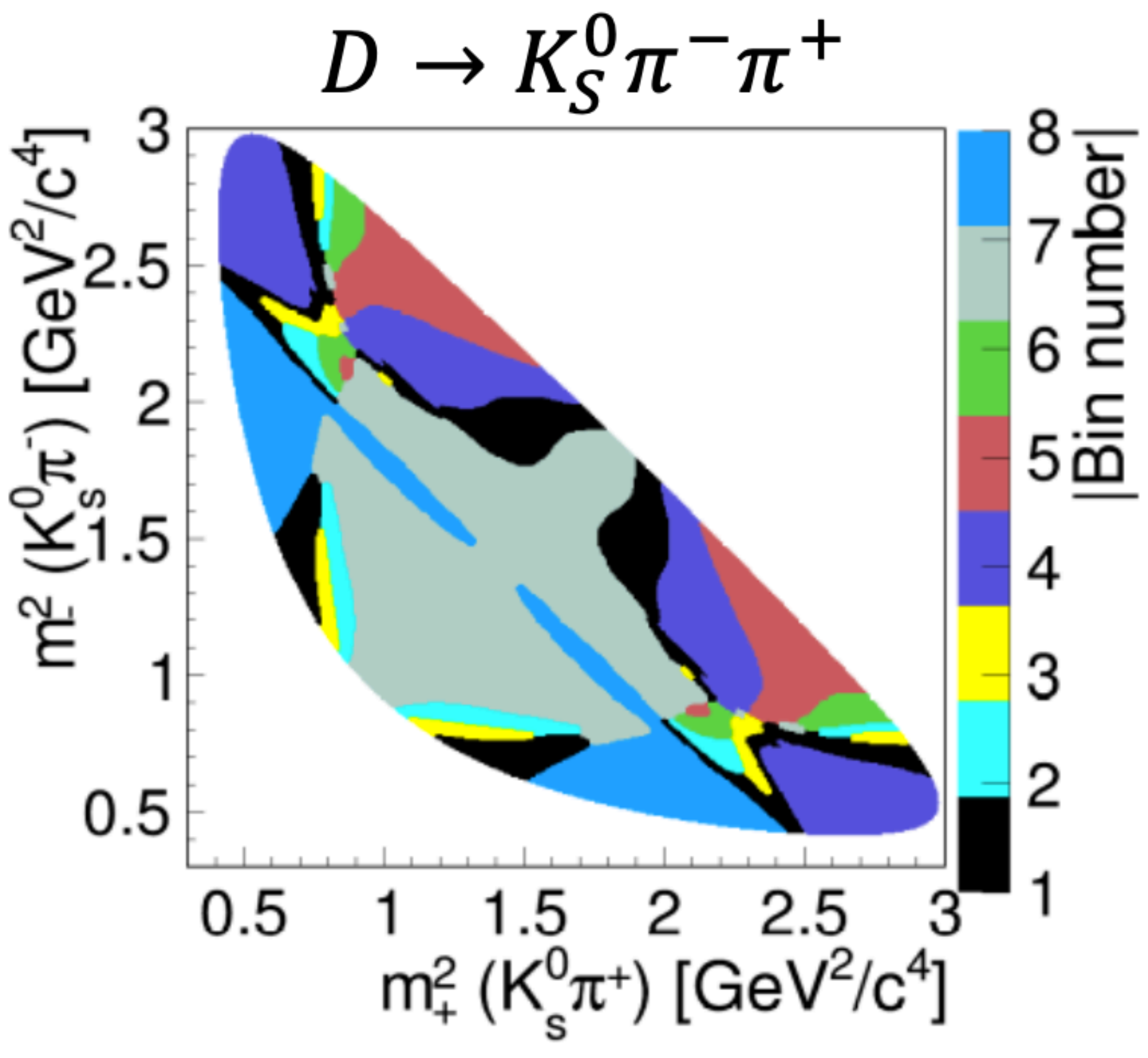


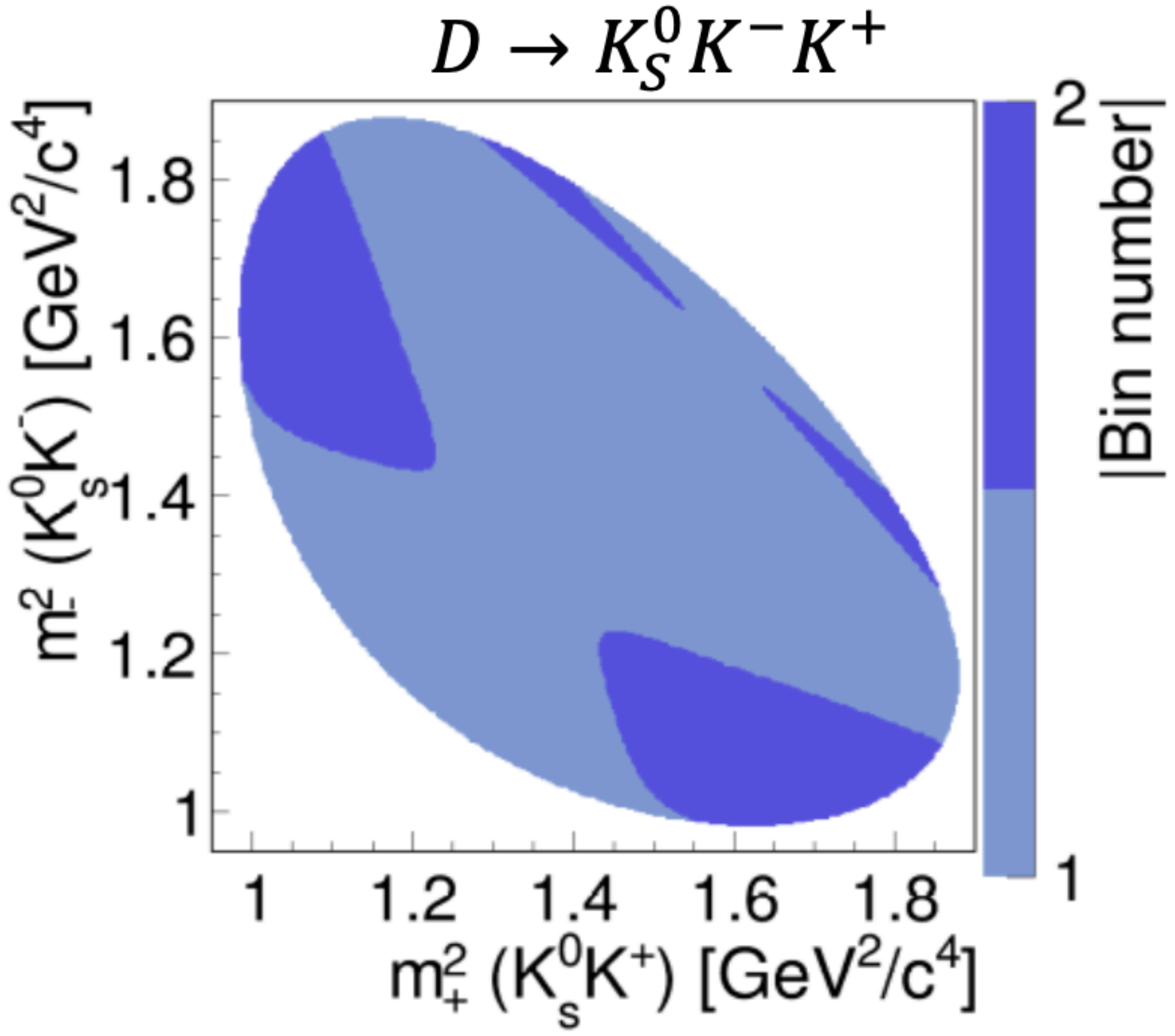
$$\frac{\mathcal{A}^{\text{suppr.}}(B^- \to \overline{D^0}K^-)}{\mathcal{A}^{\text{favor.}}(B^- \to D^0K^-)} = r_B e^{i(\delta_B+\phi_3)}$$

CKM angle ϕ_3/γ

BPGGSZ method (binned model-independent) [Phys.Rev.D68, 054018]

- To observe interference, we need to reconstruct D^0 in a self-conjugate mode
- To avoid model dependence, the strong phase difference between the D^0 and $\bar{D}^0$ decays is taken from CLEO/BES III measurements





$(x_\pm,\ y_\pm) = r_B\left(\cos(\gamma+\delta_B),\ \sin(\gamma+\delta_B)\right)$

c_i, s_i: D^0-$\bar{D}^0$ strong phase differences (inputs from BES III/CLEO)

F_i: fraction of D decays to i-th bin

$$N_i^\pm = h_{B^\pm}\left[F_i + r_B^2\bar{F}_i + 2\sqrt{F_i\bar{F}_i}(c_i x_\pm + s_i y_\pm)\right]$$

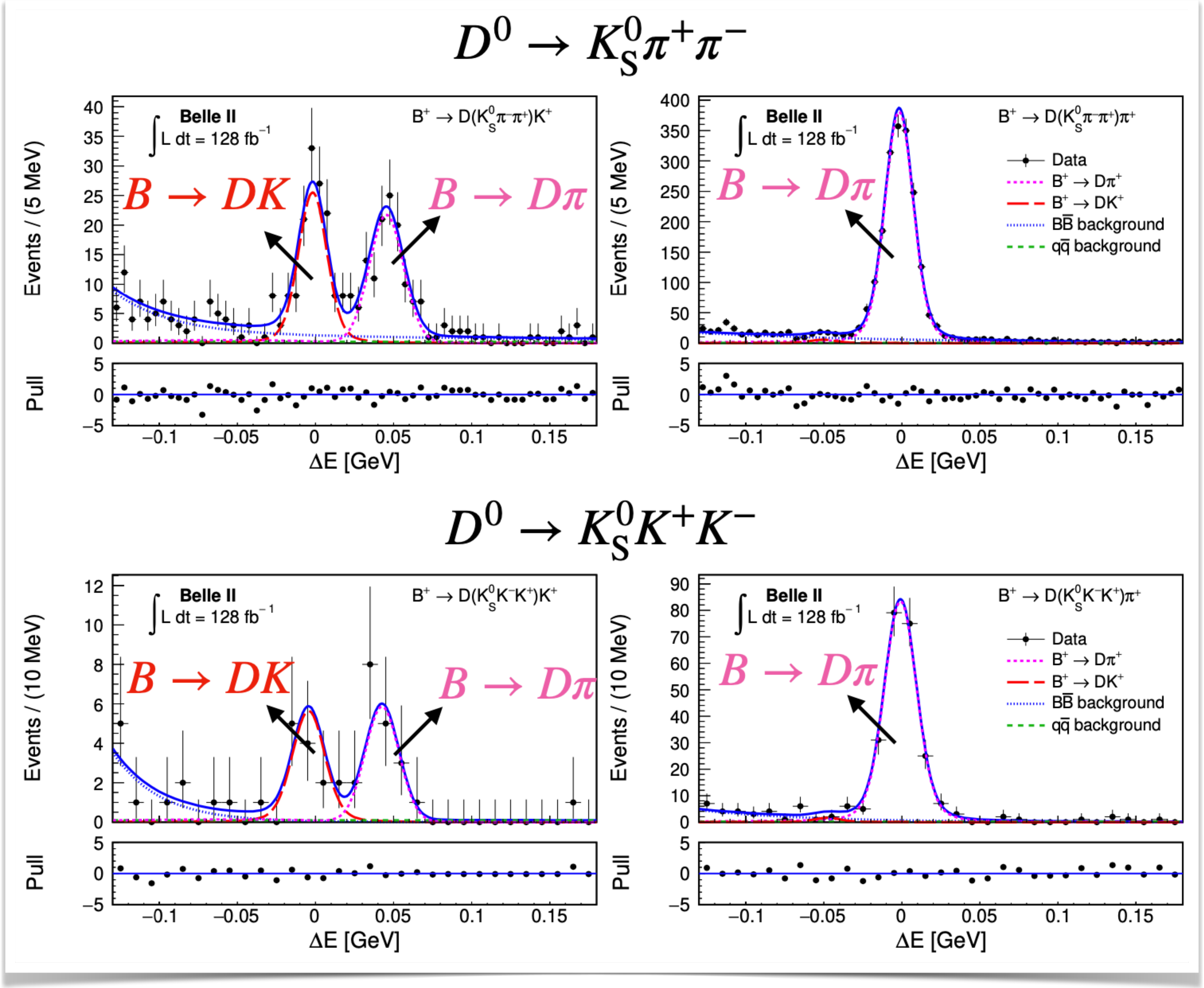
Belle+Belle II measurement of $B \to DK$

JHEP 02, 063 (2022) [arXiv:2110.12125]

- 711/fb of Belle and 128/fb of Belle II data
- Using both $D^0 \to K_S^0\pi^+\pi^-$ and $D^0 \to K_S^0K^+K^-$
- Yields extracted in simultaneous fit to $B \to DK$ and $B \to D\pi$ (misID rate determined from data)

Signal yields:

Belle:	Belle II :
$K_S^0\pi\pi$: 1467 ± 53	$K_S^0\pi\pi$: 280 ± 21
K_S^0KK: 194 ± 17	K_S^0KK: 34 ± 7



Belle+Belle II measurement of $B \to DK$

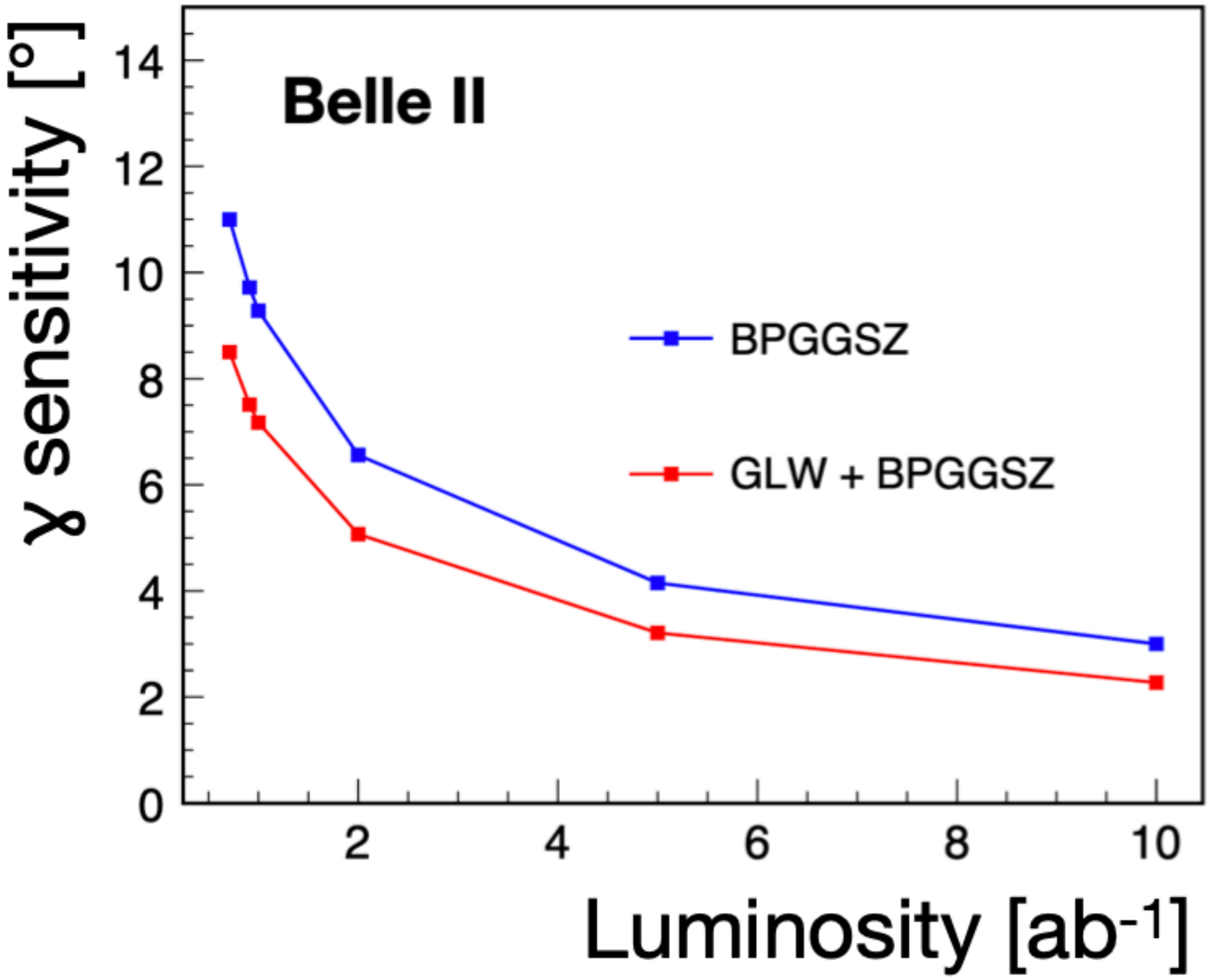
JHEP 02, 063 (2022) [arXiv:2110.12125]

- Simultaneous fit in Dalitz bins to extract CP observables $(x_\pm, y_\pm)$ which contain r_B, δ_B and ϕ_3/γ

$$\delta_B[^\circ] = 124.8 \pm 12.9\ (\text{stat})\ \pm 0.5\ (\text{syst})\ \pm 1.7\ (\text{ext})$$

$$r_B^{DK} = 0.129 \pm 0.024\ (\text{stat})\ \pm 0.001\ (\text{syst})\ \pm 0.002\ (\text{ext})$$

$$\gamma[^\circ] = 78.4 \pm 11.4\ (\text{stat})\ \pm 0.5\ (\text{syst})\ \pm 1.0\ (\text{ext})$$



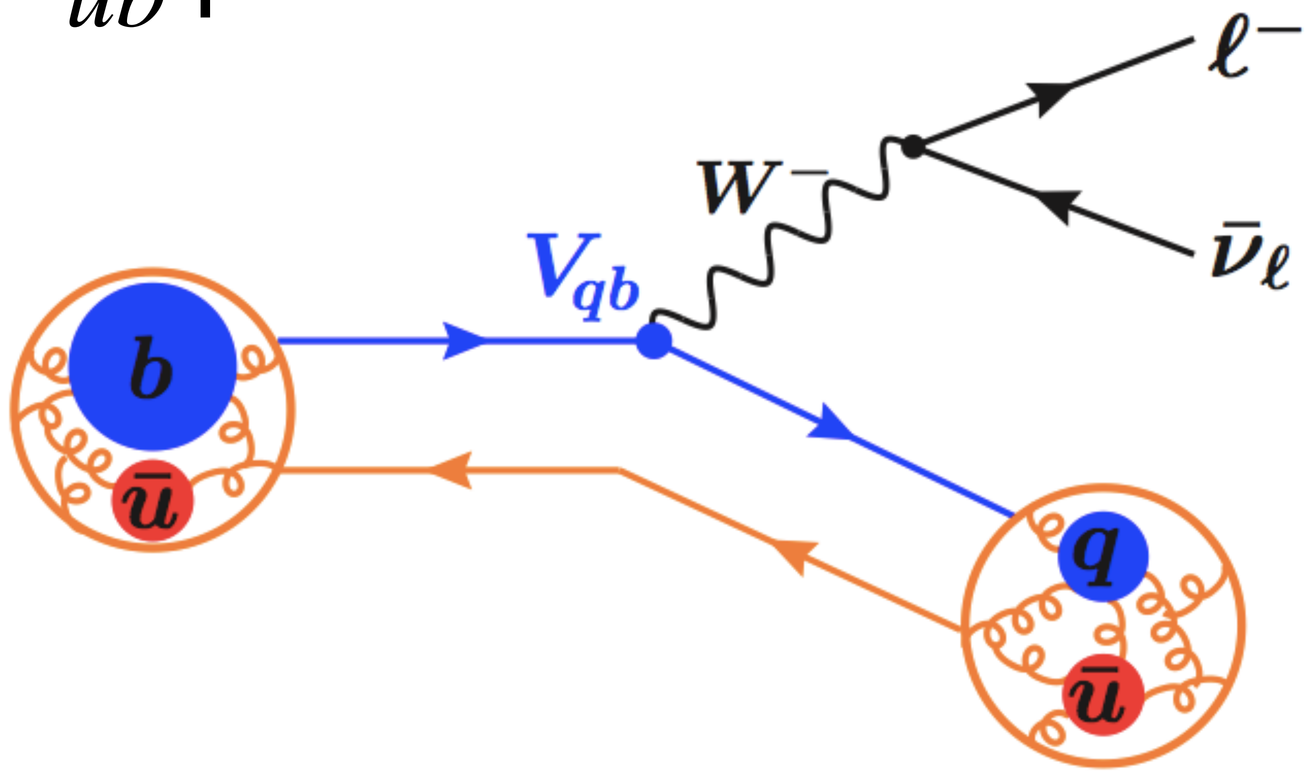
- To be compared to LHCb's result using the same method and channels [JHEP 02 (2021) 169]

$$\begin{aligned}
\gamma &= (68.7^{+5.2}_{-5.1})^\circ, \\
r_B^{DK^\pm} &= 0.0904^{+0.0077}_{-0.0075}, \\
\delta_B^{DK^\pm} &= (118.3^{+5.5}_{-5.6})^\circ, \\
r_B^{D\pi^\pm} &= 0.0050 \pm 0.0017, \\
\delta_B^{D\pi^\pm} &= (291^{+24}_{-26})^\circ.
\end{aligned}$$

Semileptonic B decays

Determination of the CKM elements $|V_{cb}|$ and $|V_{ub}|$

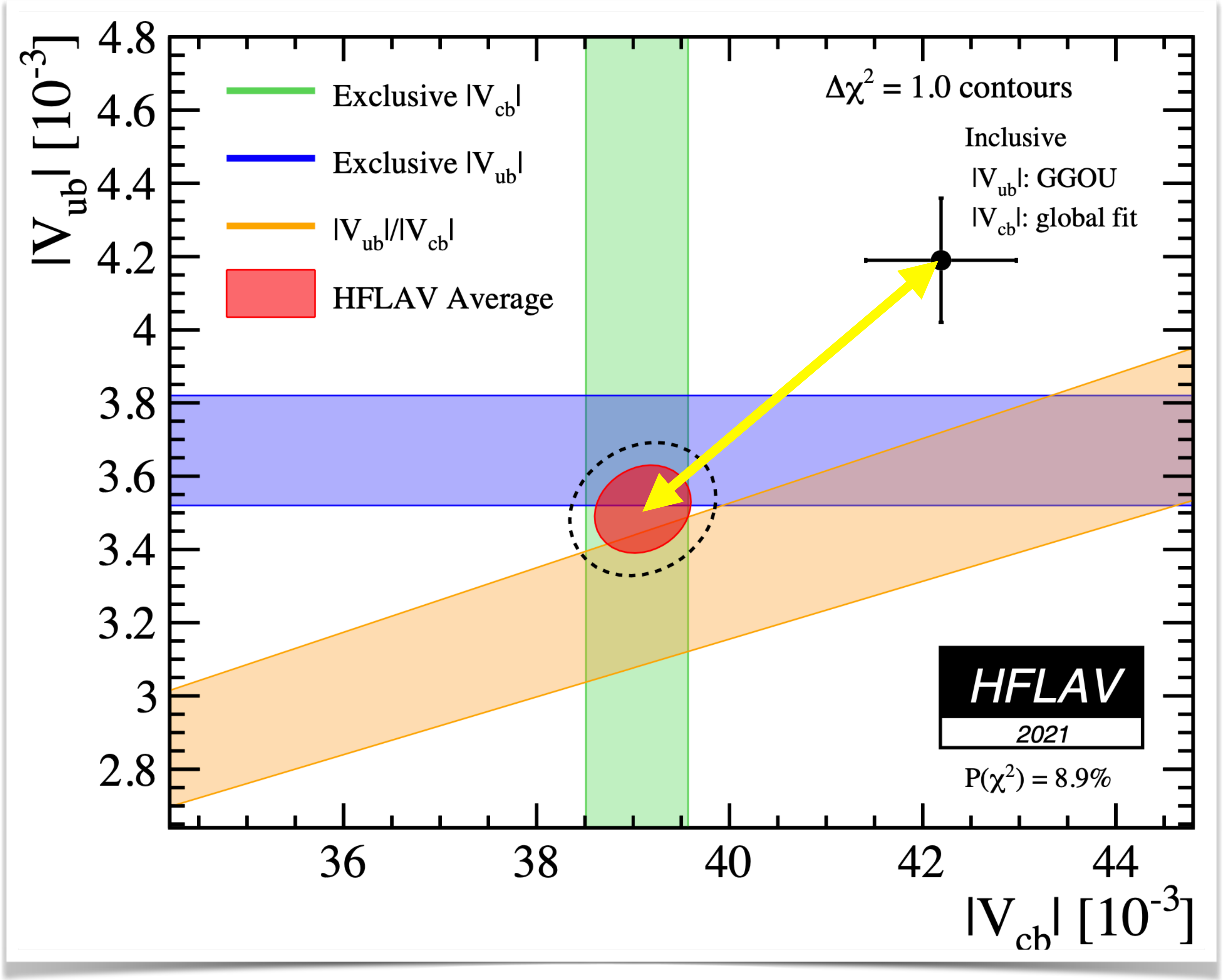
- SL B decays are studied to determine the CKM elements $|V_{cb}|$ and $|V_{ub}|$
  - $|V_{xb}|$ are limiting the global constraining power of UT fits
  - Important inputs in predictions of SM rates for ultrarare decays such as $B_s \to \mu\nu$ and $K \to \pi\nu\nu$
- The determinations can be
  - *Exclusive* — from a single final state
  - *Inclusive* — sensitive to all SL final states



$$d\Gamma \propto G_F^2 |V_{qb}|^2 \left| L_\mu \langle X | \bar{q}\gamma_\mu P_L b | B \rangle \right|^2$$

	Experiment	Theory
Exclusive $|V_{cb}|$	B → Dlν, D*lν (low backgrounds)	Lattice QCD, light cone sum rules
Inclusive $|V_{cb}|$	B → Xlν (higher background)	Operator product expansion

Experimental status $|V_{cb}|$ and $|V_{ub}|$



- Determinations of both $|V_{cb}|$ and $|V_{ub}|$ exhibit a discrepancy at the level of ~3σ between exclusive and inclusive

- The current experimental focus is on understanding the origin of this discrepancy, as this inconsistency limits the power of precision flavour physics

$B^0 \to D^{*-}\ell^+\nu$ at Belle II (189/fb)

BGL fit result, truncation order determined by Nested Hypothesis Test [Phys. Rev. D100, 013005]

	Values	Correlations				χ^2/ndf
$\tilde{a}_0 \times 10^3$	0.89 ± 0.05	1.00	0.26	−0.27	0.07	40/31
$\tilde{b}_0 \times 10^3$	0.54 ± 0.01	0.26	1.00	−0.41	−0.46	
$\tilde{b}_1 \times 10^3$	-0.44 ± 0.34	−0.27	−0.41	1.00	0.56	
$\tilde{c}_1 \times 10^3$	-0.05 ± 0.03	0.07	−0.46	0.56	1.00	

Preliminary

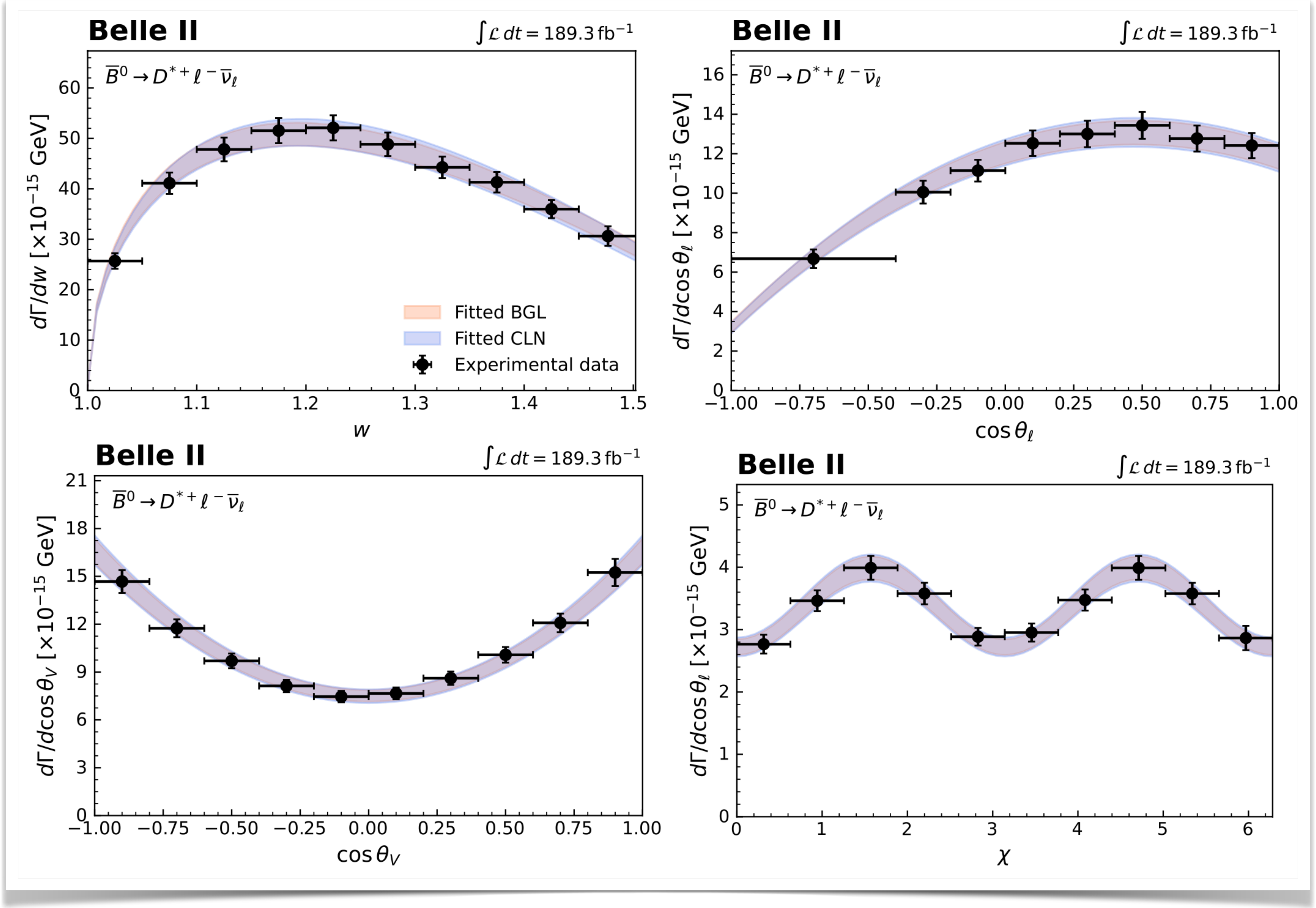
$$|V_{cb}|\eta_{\text{EW}}\mathcal{F}(1) = \frac{1}{\sqrt{m_B m_{D^*}}}\left(\frac{|\tilde{b}_0|}{P_f(0)\phi_f(0)}\right)$$

LQCD data at zero recoil

$\mathcal{F}(1) = 0.906 \pm 0.013$

$$|V_{cb}|_{BGL} = (40.9 \pm 0.3_{stat} \pm 1.0_{syst} \pm 0.6_{theo}) \times 10^{-3}$$

LQCD used only for normalisation at zero recoil ($w = 1$)



To be submitted to PRD

Belle II $|V_{cb}|$ and $|V_{ub}|$

- Recent Belle II results on exclusive decays

WA values [HFLAV 2021]
$$|V_{cb}|_{\text{excl}} = (39.10 \pm 0.50) \times 10^{-3}$$
$$|V_{ub}|_{\text{excl}} = (4.19 \pm 0.17) \times 10^{-3}$$

	$|V_{cb}| \times 10^3$		**Reference**
Belle II $B^0 \to D^{*-}\ell^+\nu$ untagged	40.9 ± 1.2 (BGL)	Preliminary	To be submitted to PRD
Belle II $B^0 \to D^{*-}\ell^+\nu$ tagged	37.9 ± 2.7 (CLN)	Preliminary	[arXiv:2301.04716]
Belle II $B \to D\ell\nu$ untagged	38.28 ± 1.16 (BGL)	Preliminary	[arXiv:2210.13143]

	$|V_{ub}| \times 10^3$		**Reference**
Belle II $B \to \pi e\nu$ tagged	3.88 ± 0.45	Preliminary	[arXiv:2206.08102]
Belle II $B \to \pi\ell\nu$ untagged	3.55 ± 0.25	Preliminary	[arXiv:2210.04224]

$|V_{cb}|$ and $|V_{ub}|$ at LHCb

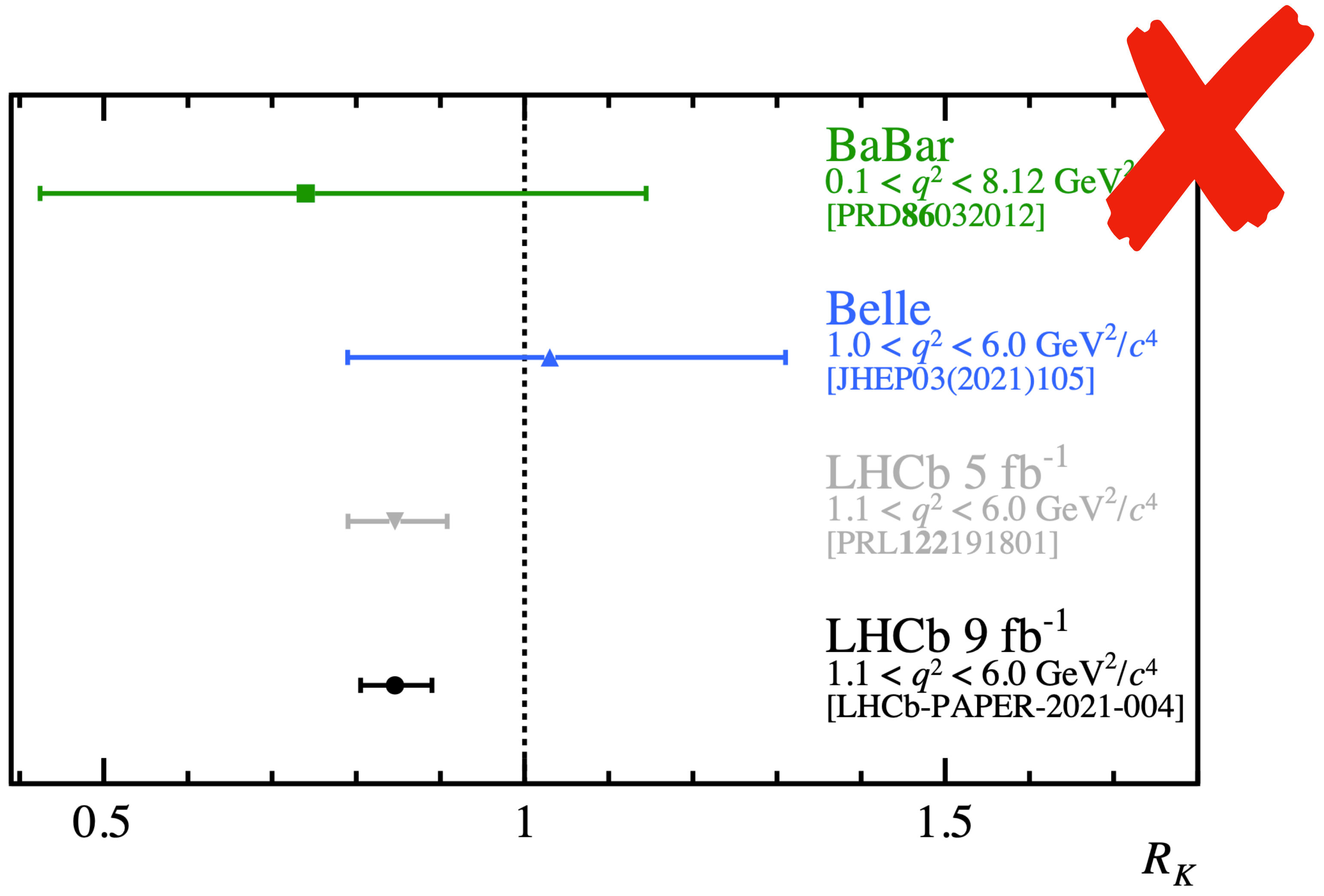
	$\lvert V_{cb}\rvert \times 10^{-3}$	reference
$B^0_s \to D_s^{(*)} \mu^+ \nu_\mu$	41.4±0.6±0.9±1.2 (CLN)	Phys. Rev. D101 (2020) 072004
$B^0_s \to D_s^{(*)} \mu^+ \nu_\mu$	42.3±0.8±0.9±1.2 (BGL)	Phys. Rev. D101 (2020) 072004

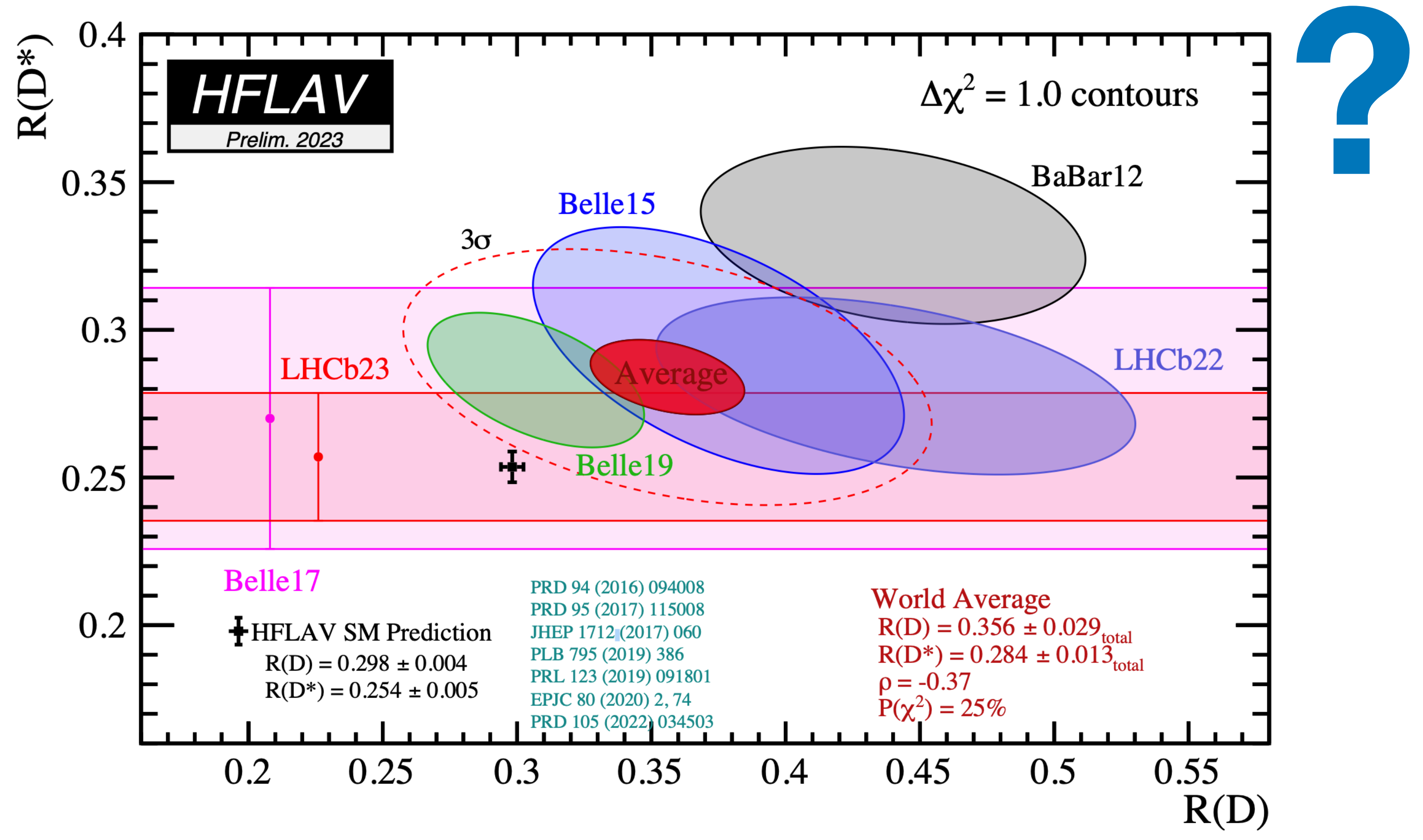
From the LHCb direct measurement of $|V_{ub}|/|V_{cb}|$ and using the world average of exclusive measurements $|V_{cb}|=(39.5 \pm 0.9) \times 10^{-3}$

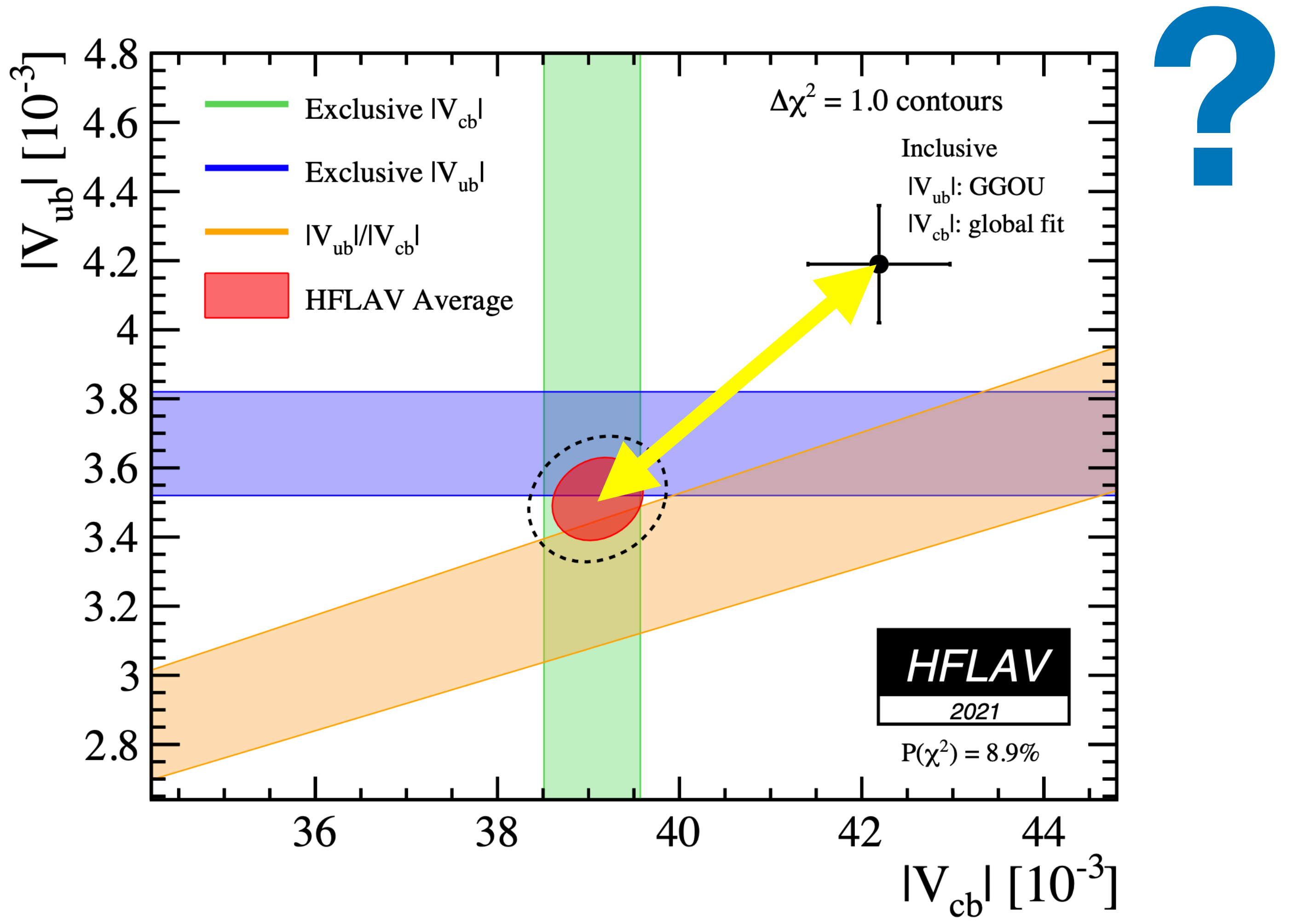
	$\lvert V_{ub}\rvert \times 10^{-3}$	reference
$B^0_s \to K^- \mu^+ \nu_\mu$	2.40±0.16 ($q^2<7$ GeV^2/c^4)	Phys. Rev. Lett. 126 (2021) 081804
$B^0_s \to K^- \mu^+ \nu_\mu$	3.74±0.32 ($q^2>7$ GeV^2/c^4)	Phys. Rev. Lett. 126 (2021) 081804
$\Lambda^0_b \to p\, \mu^- \nu_\mu$	3.27±0.23	Nature Physics 11 (2015) 743

Summary and conclusion

- LHCb and Belle II will improve present SM constraints in the flavour section
  - Tests of lepton flavour universality/violation
  - Test of the CKM mechanism
- While we have seen the demise of some anomalies in the past year,
  others are still present and the experimental situation needs to be clarified with urgency







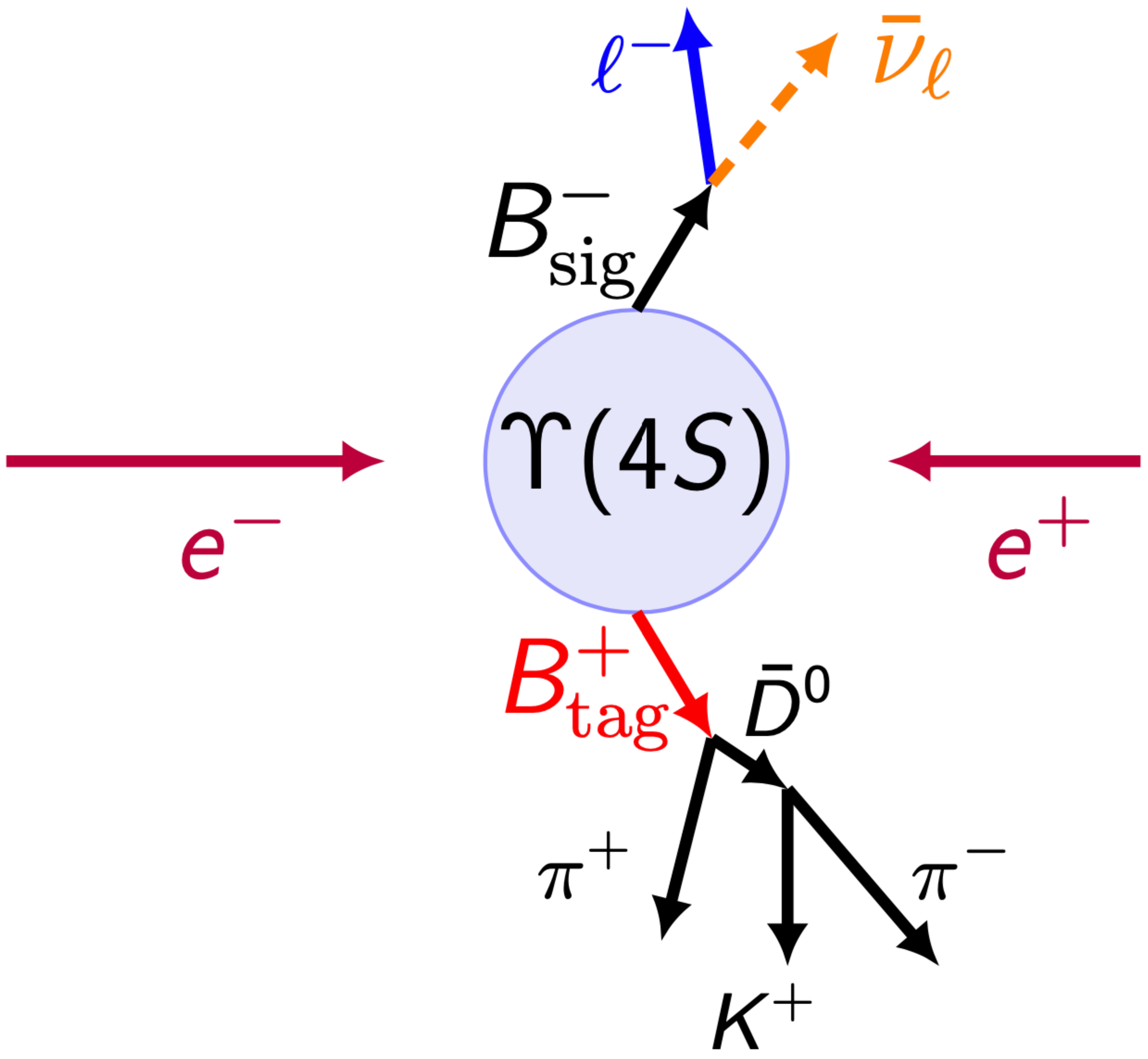
Backup

Untagged vs. Tagged

Untagged:

only B_{sig} is reconstructed

high signal yield (+)
high backgrounds (-)
poor neutrino reconstruction (-)



Tagged:

B_{sig} and B_{tag} are reconstructed

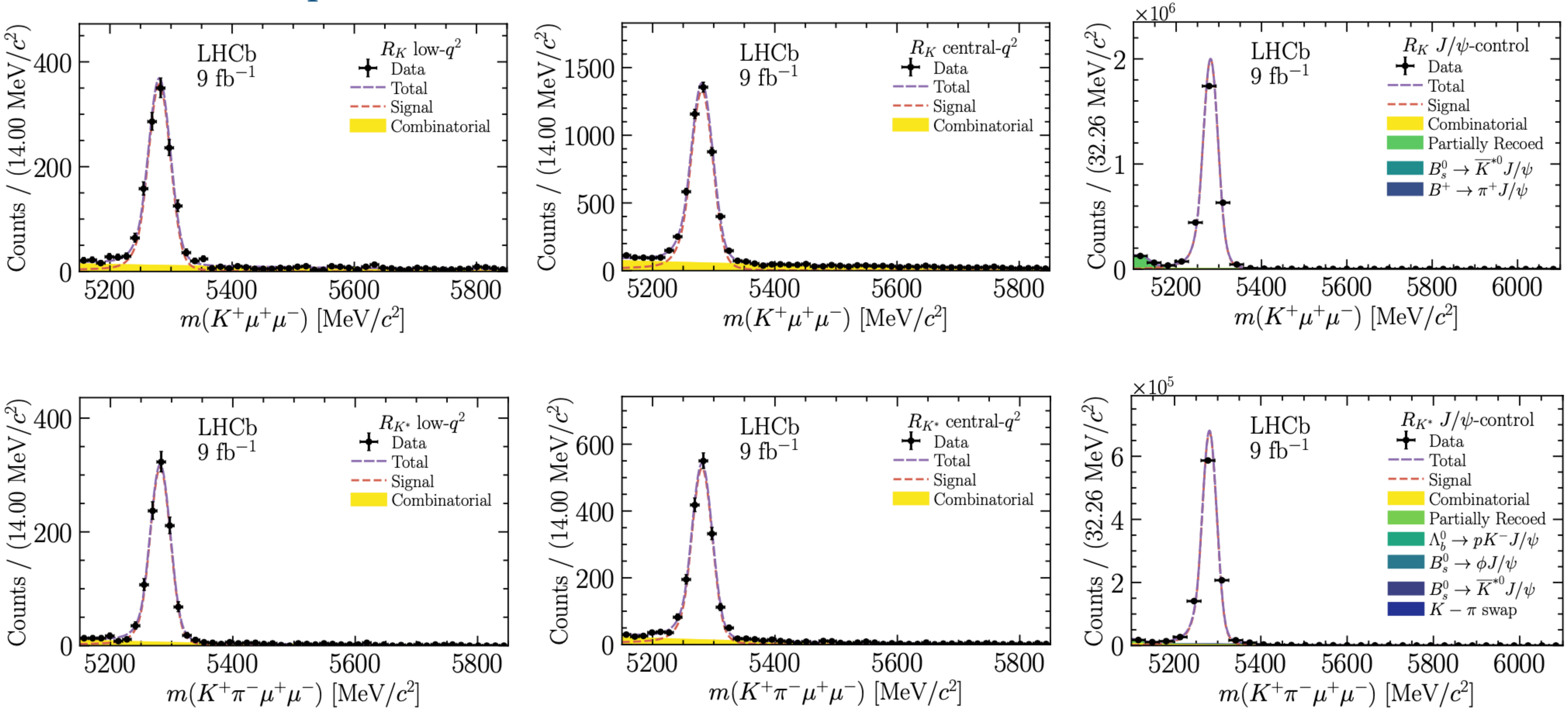
to take advantage of $\Upsilon(4S)$ kinematics

signal yield $O(10^3)$ lower (-)
low backgrounds (+)
good neutrino reconstruction (+)
tag calibration (-)

Simultaneous fit $R_{K,K^{*0}}$

Muons

low-q^2 | central-q^2 | resonant-J/ψ



Simultaneous fit $R_{K,K^{*0}}$

Electrons