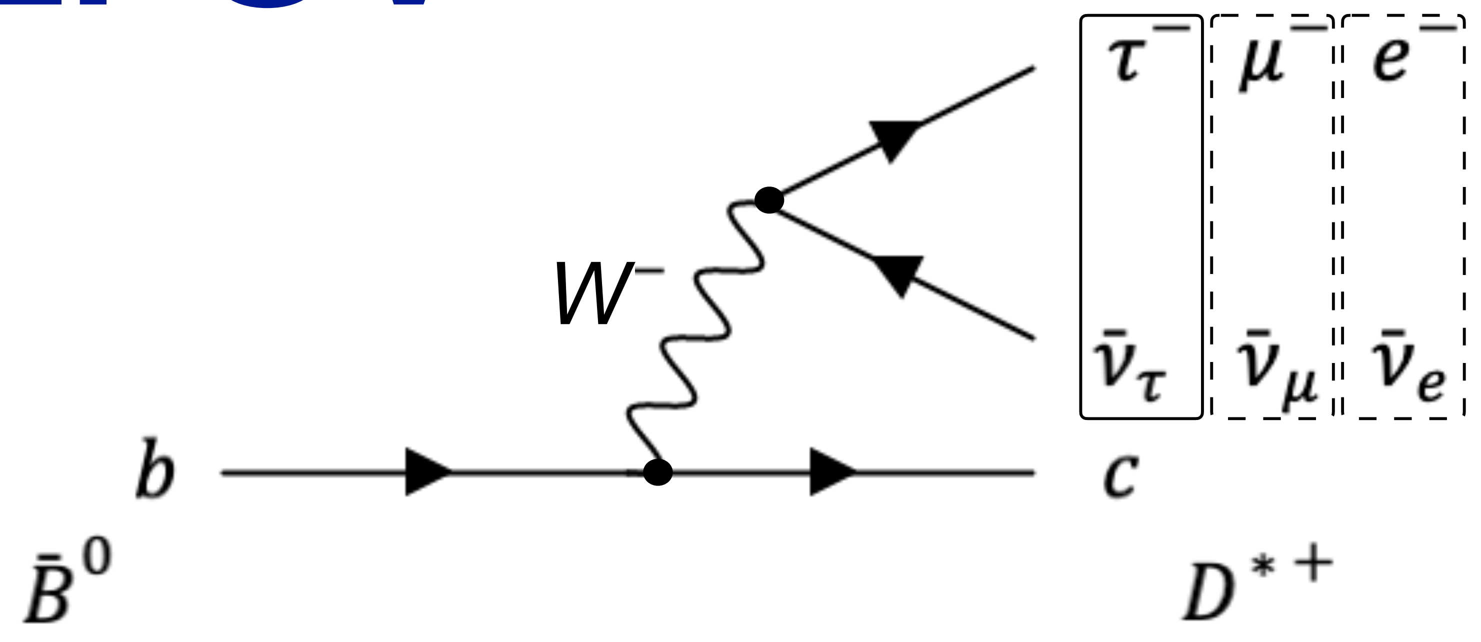
Testing Lepton Flavor Universality with the Belle and Belle II experiments

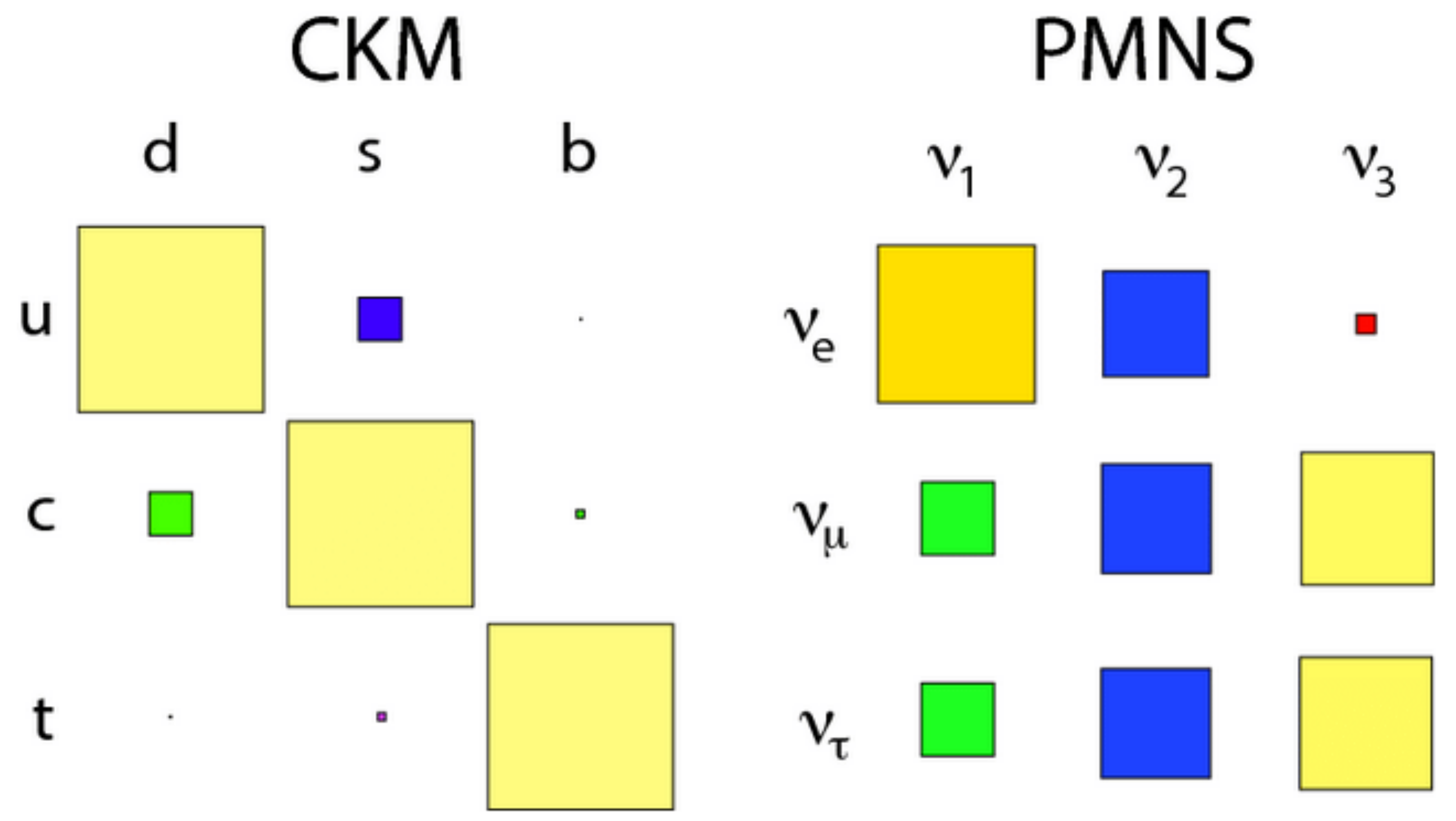
周启东(ZHOU Qi-Dong)
Institute of Frontier and Interdisciplinary Science,
Shandong Univ. (Qingdao)

2025年4月18-22日，南京东郊国宾馆， 南京
第七届全国重味物理与量子色动力学研讨会

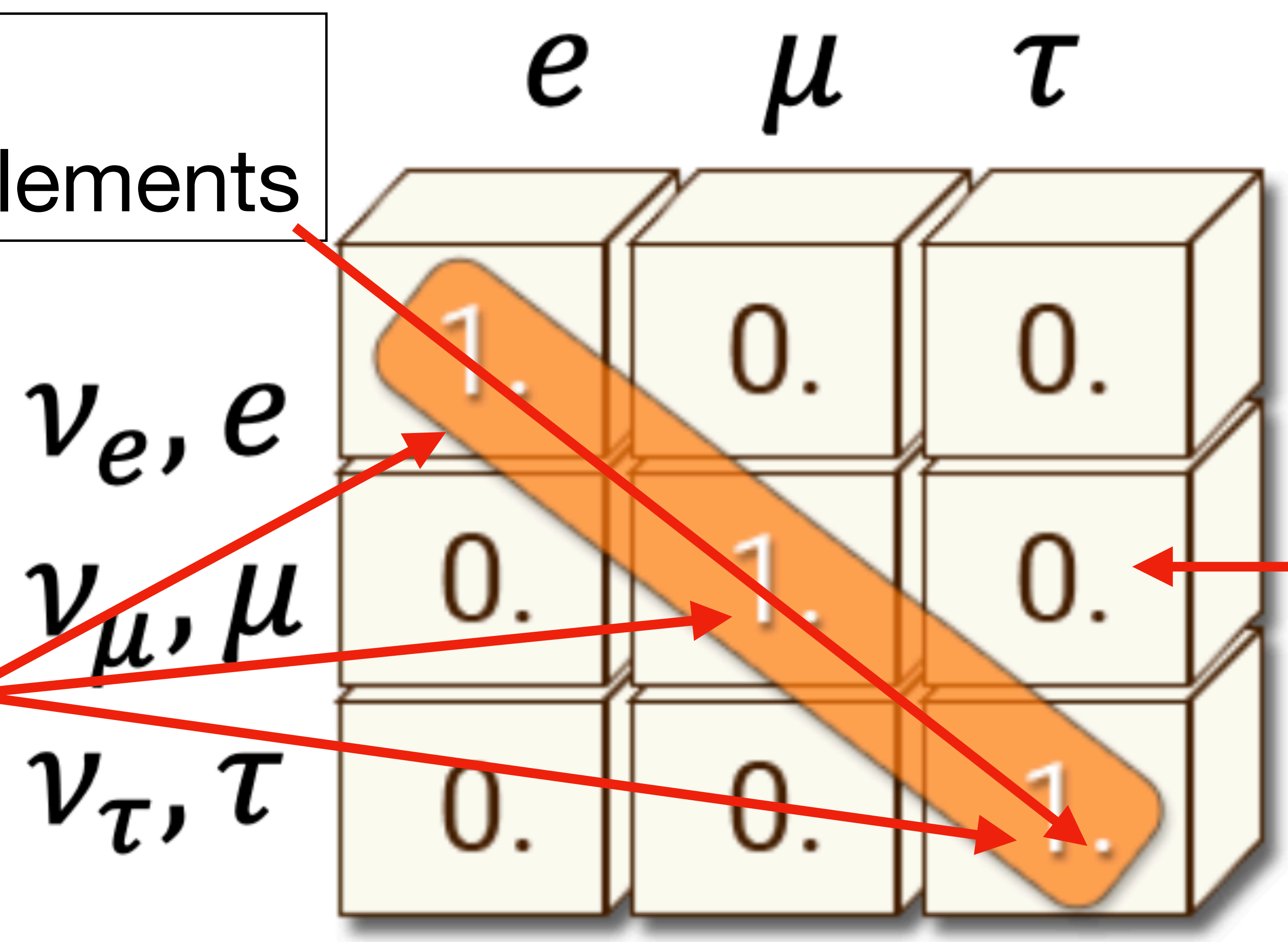
Motivation for studying LFUV

- Lepton Flavor Universality (LFU): *W* boson couples to leptons with equal strength ($m_e < m_\mu < m_\tau$)
- SM fields do mix:
  - Quarks sector -> CKM matrix
  - Neutrinos sector -> PMNS matrix
- Charged leptons -> the matrix diagonal-like?(neutrino mass)
- LFUV: diagonal terms not all equal





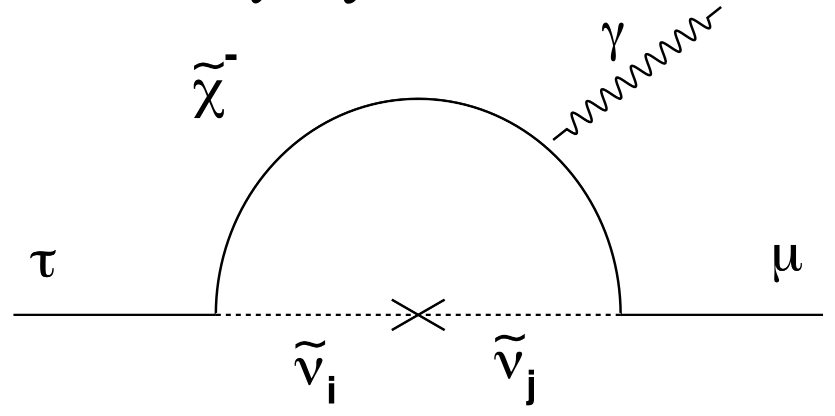
g-2, EDM: diagonal elements



LFUV: Relation among diagonal elements

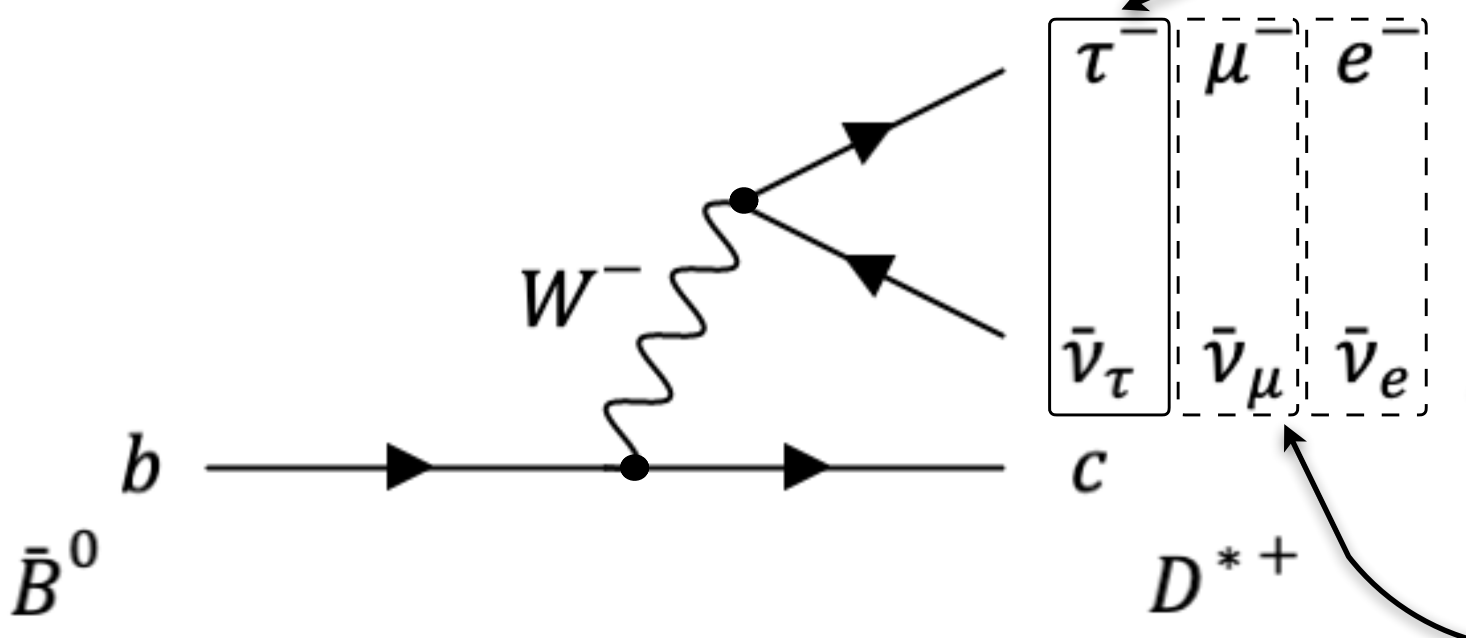
Lepton Flavor Violation (LFV): off diagonal term

$\tau \to \mu\gamma$



LFU test with semileptonic B decays

- Ratios of $b \to q\tau\nu/q\mu\nu/qe\nu$ branch fractions cancel out the uncertainties on **$|V_{cb}|$,** most uncertainties of **form factors** and the **experimental systematics**



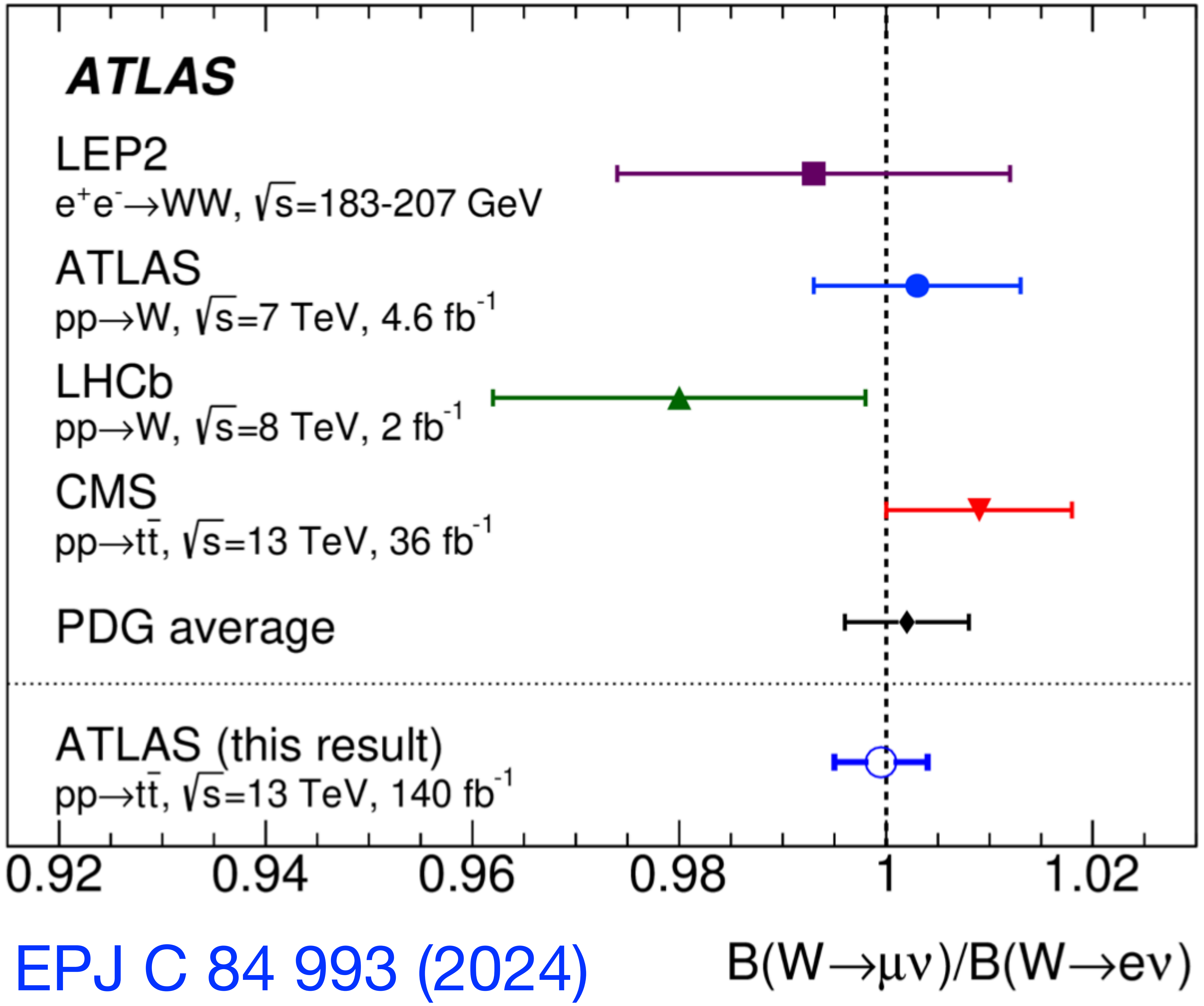
$$R(D^{(*)}) = \frac{Br(\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}_\tau)}{Br(\bar{B}^0 \to D^{(*)+}\ell^-\bar{\nu}_\ell)}$$

- LFU is broken in Yukawa interaction
  - Charged lepton mass changes kinematics and modifies form factors in the hadronization
- Long-distance QED corrections depend on lepton velocity (τ vs. ℓ (***e***, ***μ***))
- $B \to D^{(*)}\tau\nu$ sensitive to New Physics (NP) because the massive 3rd generation *b* quark and τ lepton are involved
- Sensitivities to high energy scale; ~10 TeV [Belle II phys. book]

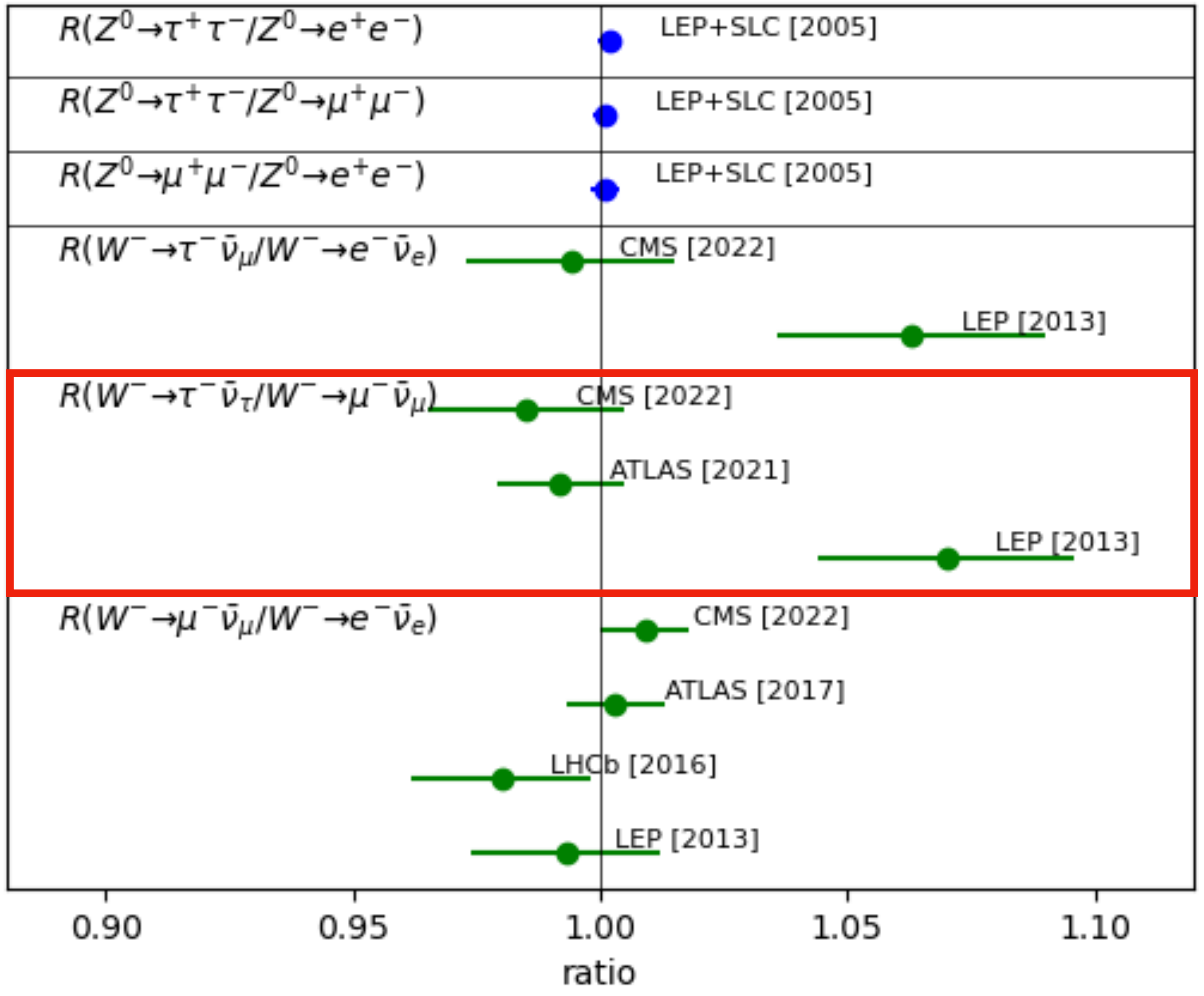
LFU test with *W/Z* decays

- Existing tension from LEP in $W \to \tau\nu / W \to (e, \mu)\nu$
- CMS and ATLAS can use tt events

scholarpedia.org

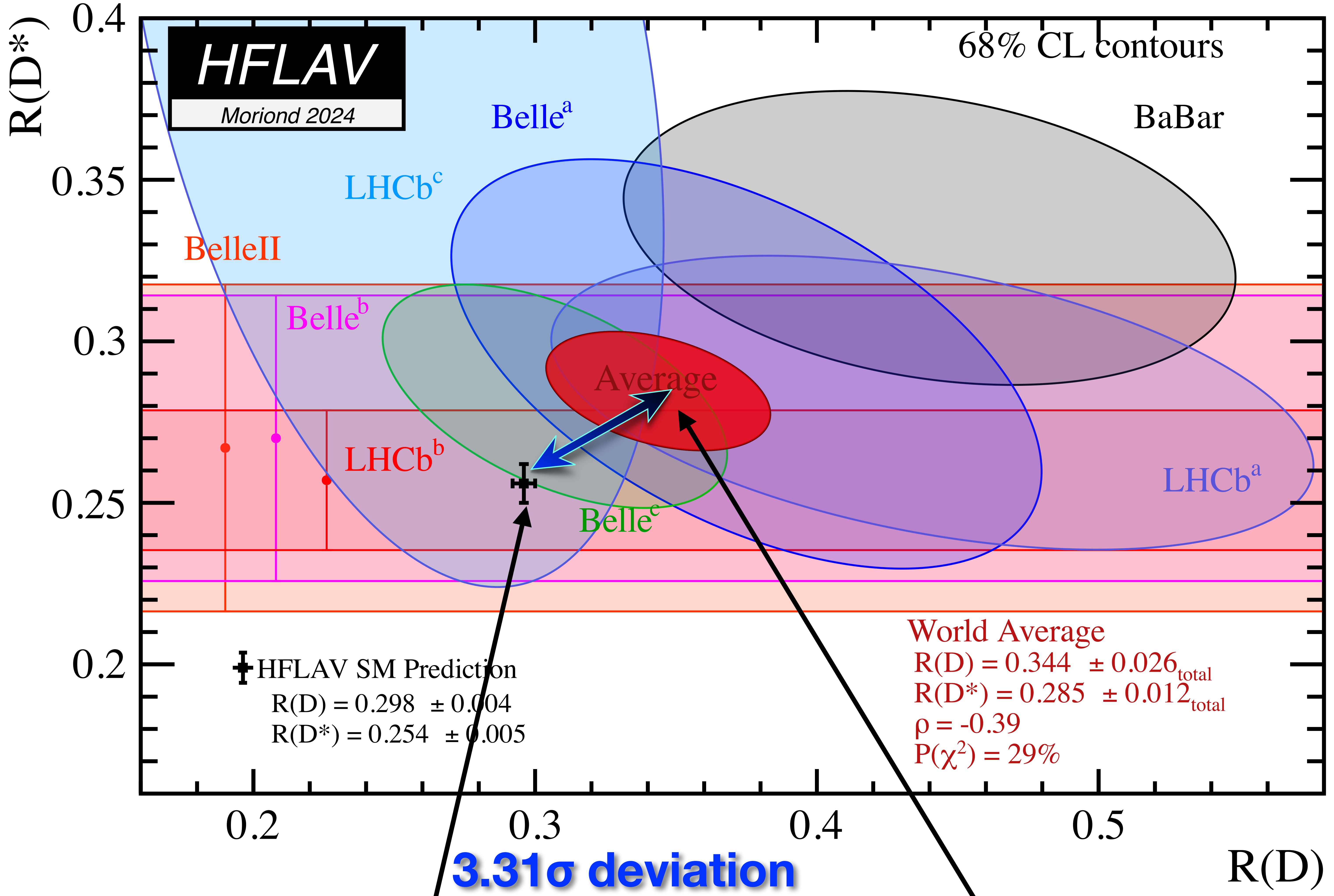


EPJ C 84 993 (2024)



- LFU confirmed in Z/W decays with high precision, especially also for $W \to \tau\nu / W \to (e, \mu)\nu$

"*B* anomaly" in semileptonic decays



3.31σ deviation

Standard Model prediction

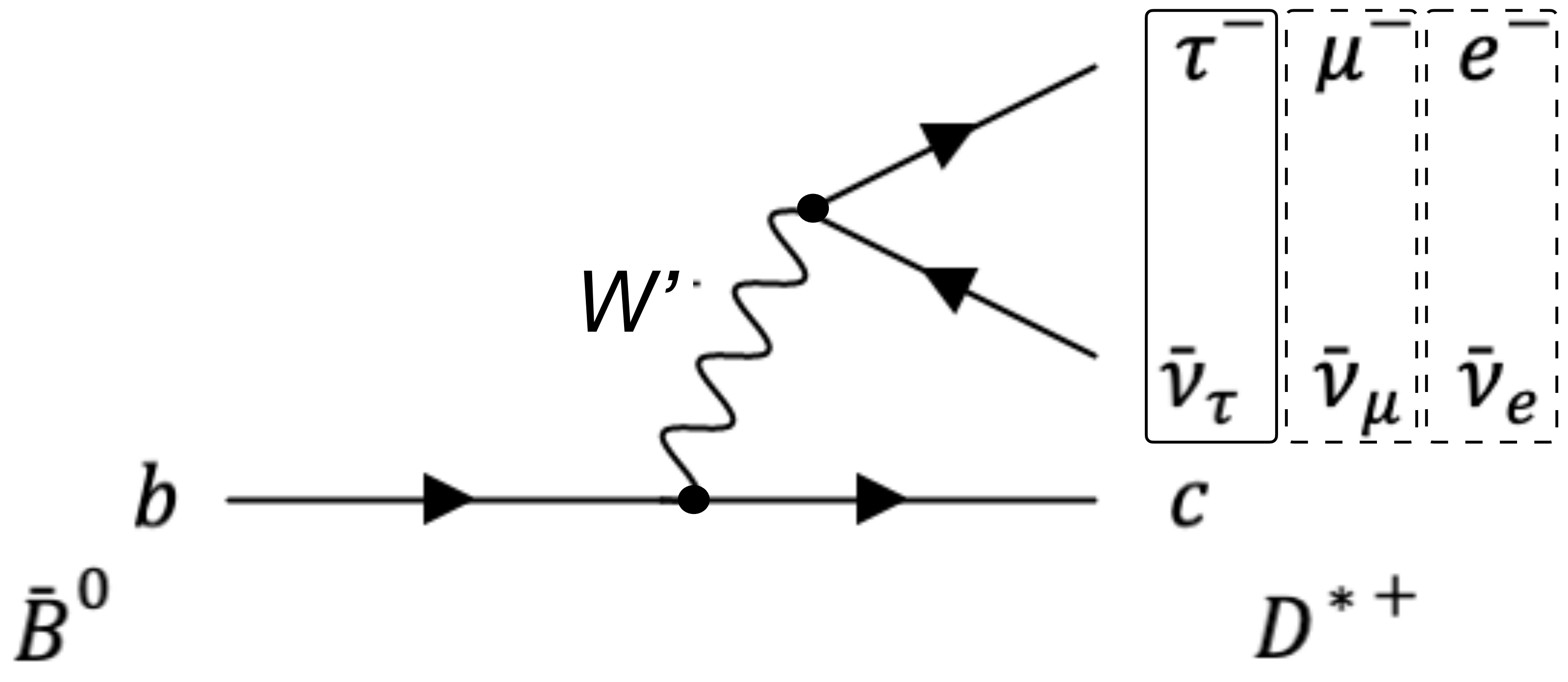
Experimental average results

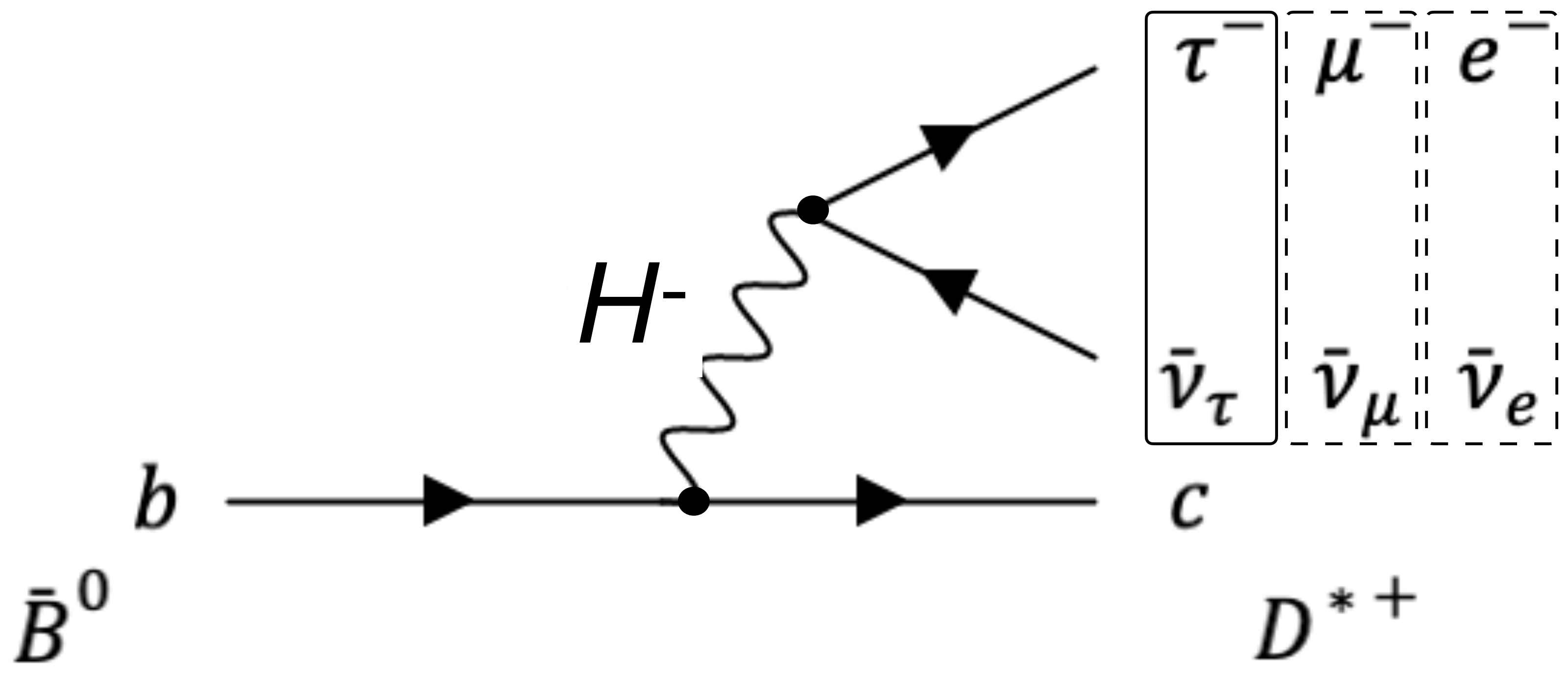
New physics scenarios for the $R(D^{(*)})$ anomaly

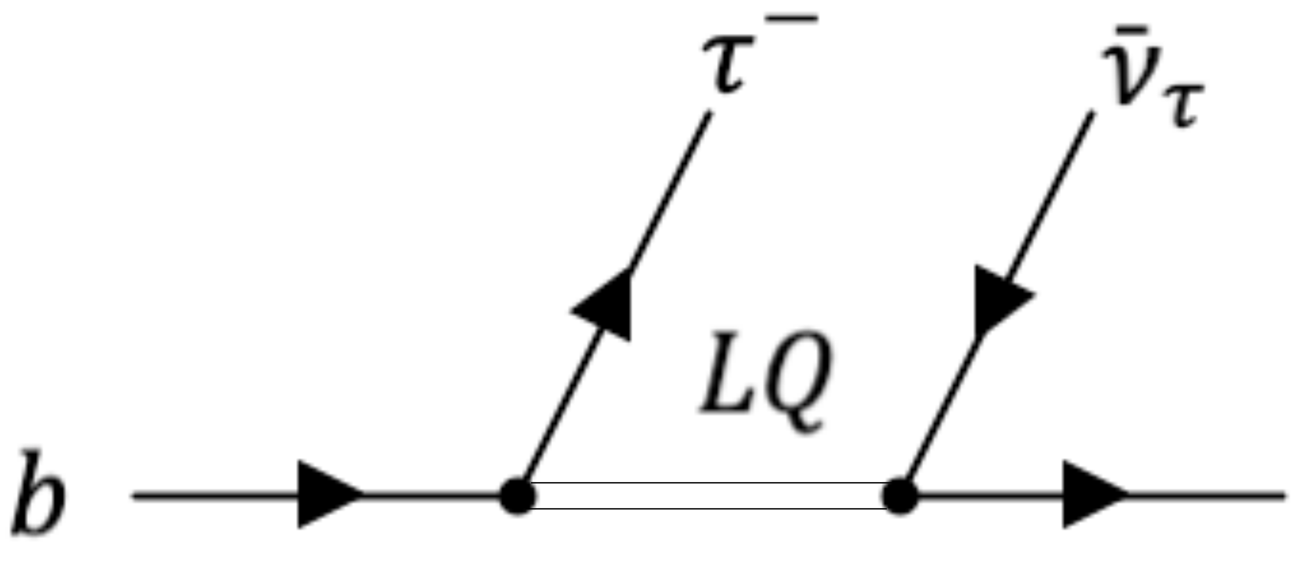
In general, there are three typical candidate scenarios to explain the anomaly observed in $R(D^{(*)})$

- Heavy vector bosons
  - Constrained from $W' \to \tau\nu$ and $Z' \to \tau\tau$ search
- Charged Higgs
  - Constrained from $B_c \to \tau\nu$ and $H^{\pm} \to \tau\nu$,still allowed
  - Previously, it was rejected by $B_c \to \tau\nu$ measurement, however, recovered by recalculating the B_c lifetime.

    [PRD 105 095011(2022)]
- Leptoquark
  - $gg \to LQ\ LQ^*$, still broad parameter regions are allowed







Recent results related with $R(D^{(*)})$

Experiment	Observable	Tag method	τ decay	Reference
Belle II	$R(D^{+(*)})$	Semileptonic	$\ell\nu\nu$	arXiv: 2504.1122 (2025)
Belle II	$R(D^{*})$	Hadronic	$\ell\nu\nu$	PRD 110 072020 (2024)
Belle II	$R(X_{\tau/\ell})$	Hadronic	$\ell\nu\nu$	PRL 132 211804 (2024)
Belle II	$R(X_{e/\mu})$	Hadronic	-	PRL 131 051804 (2023)
Belle II	**Augular**	Hadronic	-	PRL 131 181801 (2023)
LHCb	$R(D^{(*)})$	-	$\mu\nu\nu$	PRL 131 111802 (2023)
LHCb	$R(D^{*})$	-	$\pi\pi\pi\nu$	PRD 108 012018 (2023)
LHCb	$R(D^{+(*)})$	-	$\mu\nu\nu$	PRL 134 061801 (2024)
LHCb	$R(\Lambda_c)$	-	-	PRL 128 191803 (2022)
LHCb	$R(J/\psi)$	-	-	PRL 120 121801 (2018)

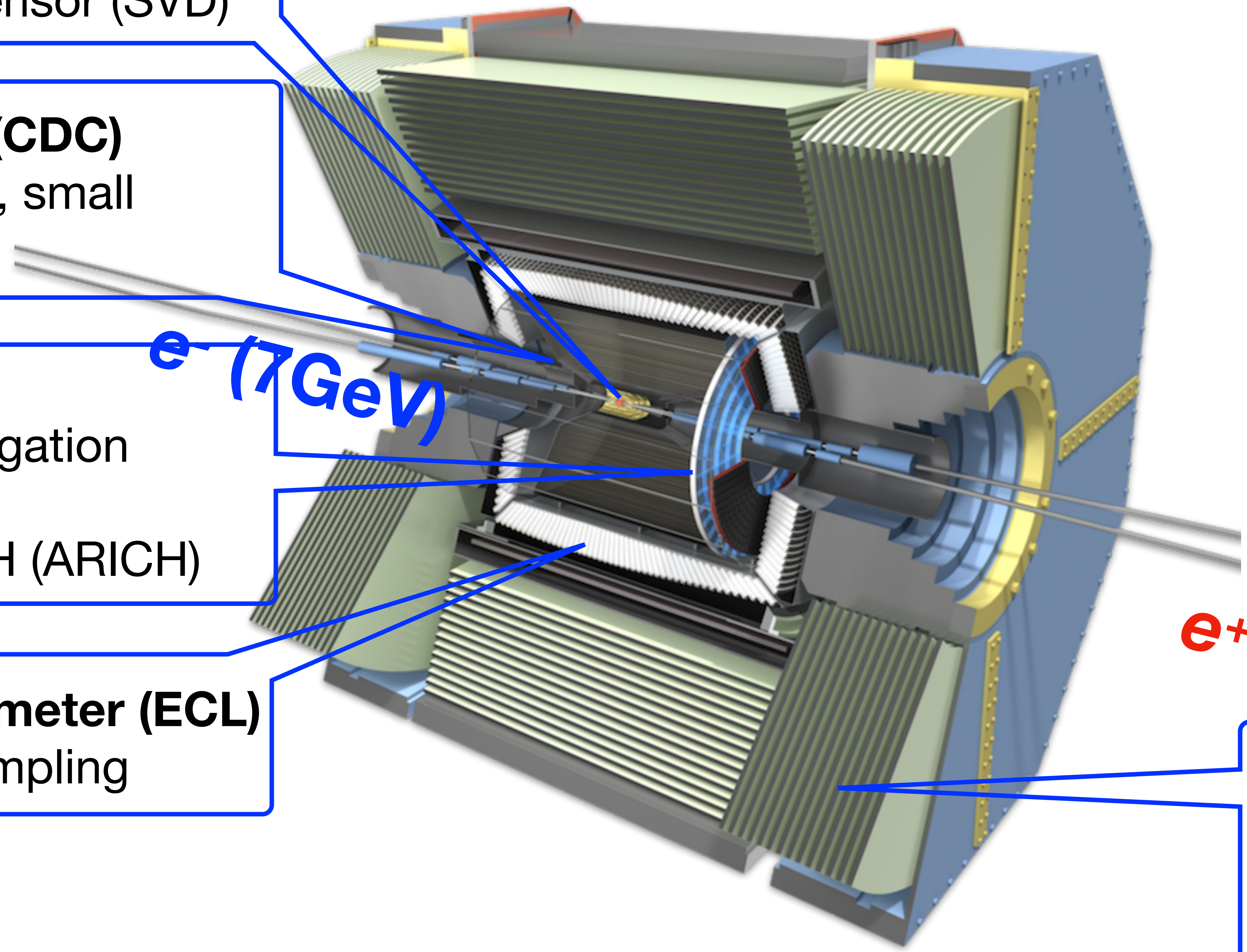
Belle II detector and dataset

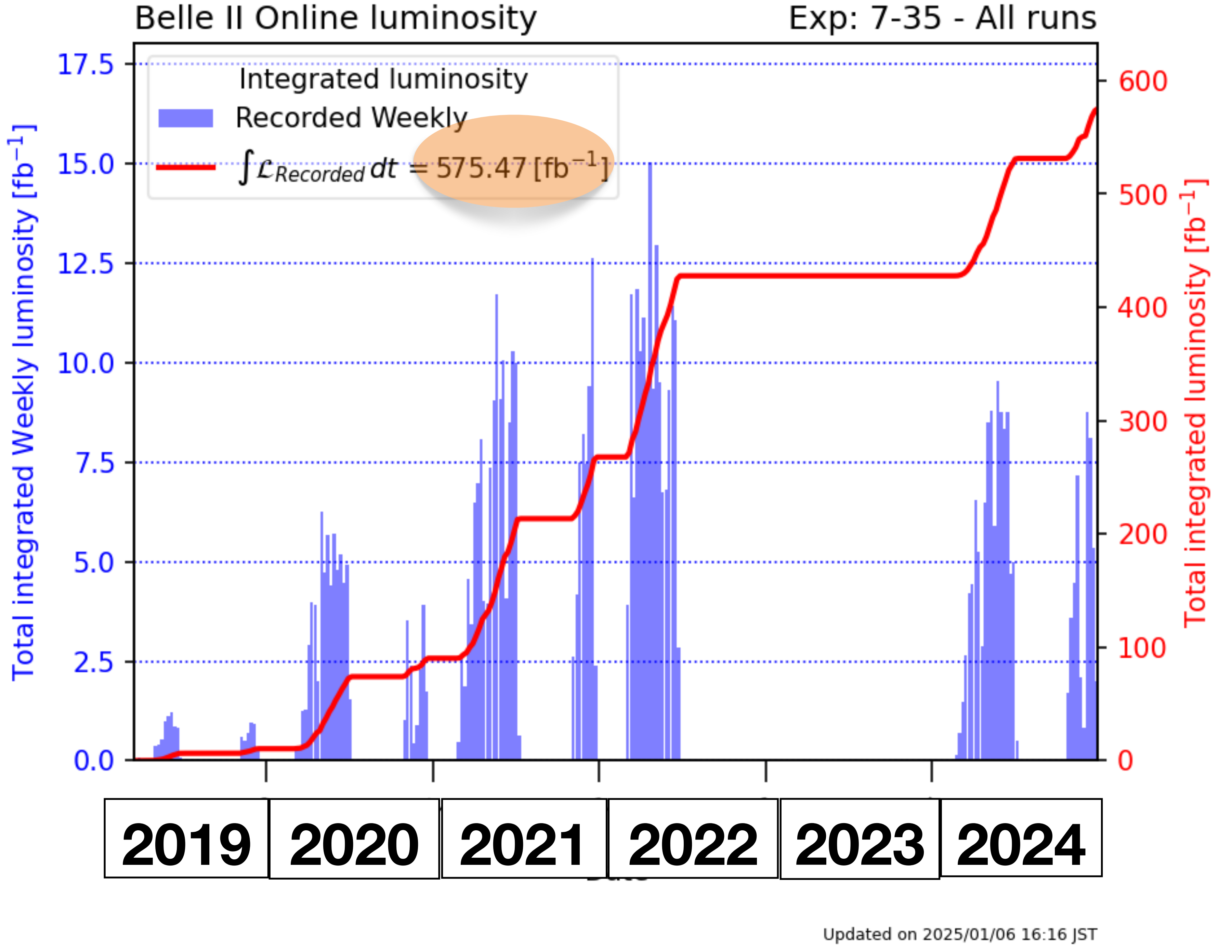
Vertex detector (VXD)
Inner 2 layers: pixel detector (PXD)
Outer 4 layers: strip sensor (SVD)

Central Drift Chamber (CDC)
He (50%), C_2H_6 (50%), small cells, long lever arm

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

ElectroMagnetic Calorimeter (ECL)
CsI(Tl) + waveform sampling



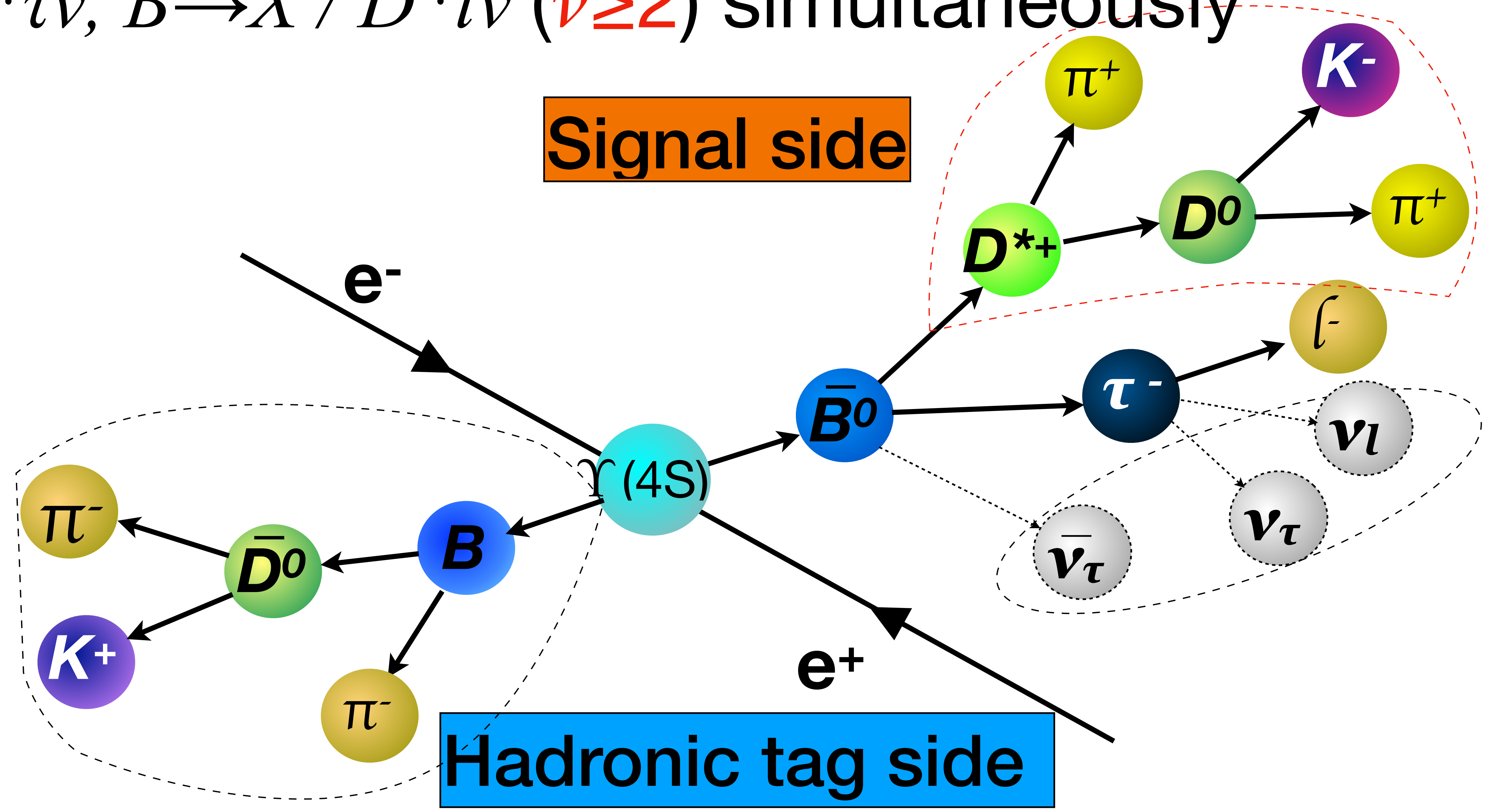


K_L/μ detector (KLM)
Outer barrel: Resistive Plate Counter (RPC)
Endcap/inner barrel: Scintillator

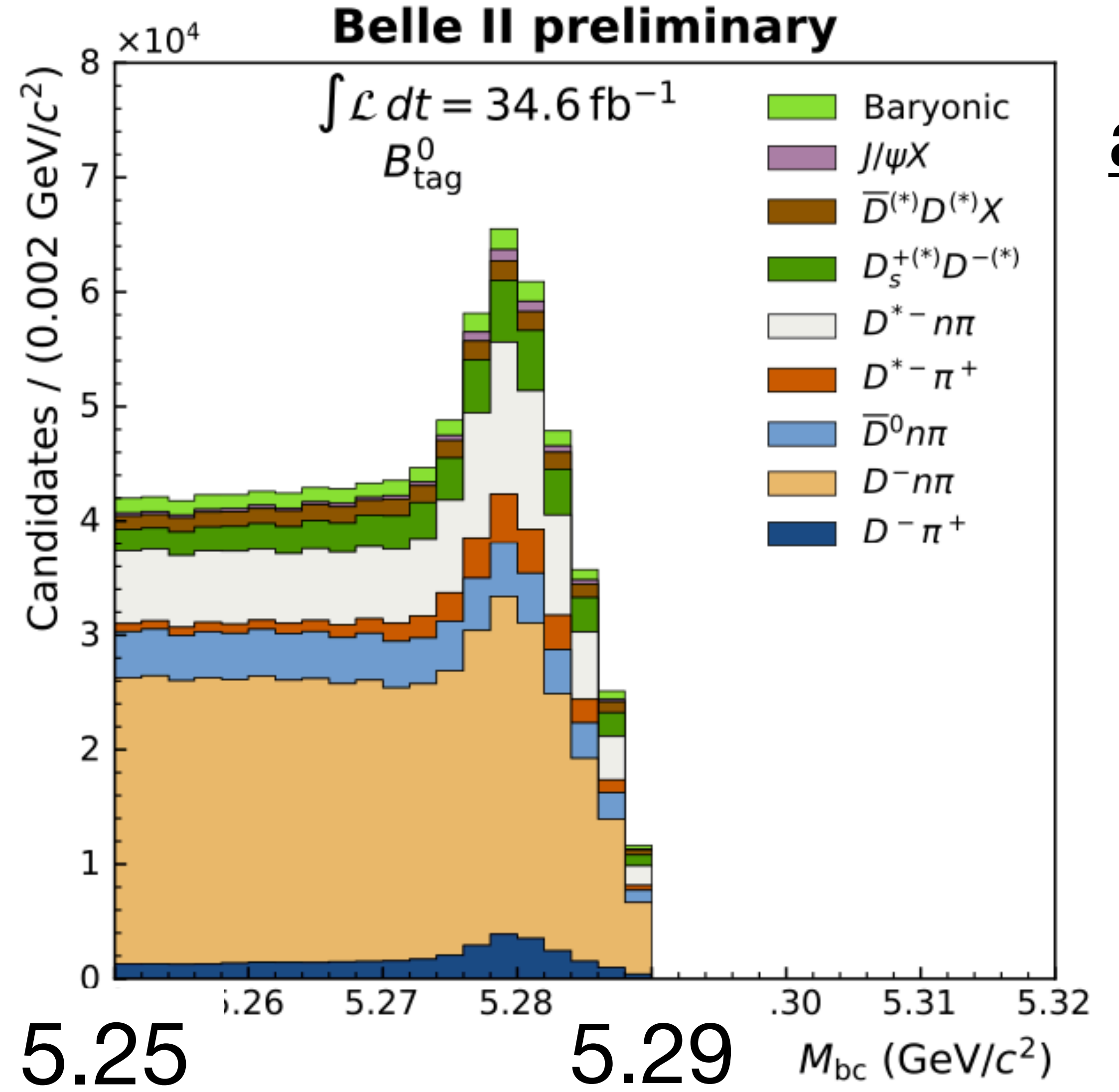
- Features:
  - Near-hermetic detector
  - Vertexing and tracking: σ vertex ~ 15μm, CDC spatial res. 100μm $\sigma(P_T)/P_T$ ~ 0.4%
  - Good at measuring neutrals, π^0, γ, K_L… $\sigma(E)/E$ ~ 2-4%

Tagging methods

- The $B\bar{B}$ pairs are produced near threshold
- *B* tagging is necessary to measure $B \to X / D^* \tau \nu$, $B \to X / D^* l \nu$ ($\nu \geq 2$) simultaneously
- Hadronic tag
  - Fully reconstruct $B \to D^{(*)}(/J/\psi/\Lambda)X$
  - Tagging efficiency 0.2~0.4%
  - less background
- Semileptonic tag
  - Reconstruct $B \to D^{(*)} l \nu$
  - Tagging efficiency 0.5~%
  - More background



- Full Event Interpretation (FEI): trained 200 Boost Decision Tree (BDT) to reconstruct ~100 decay channels, ~10,000 *B* decay chains
  - ε=0.30% for $B^{\pm}$
  - ε=0.23% for B^0



arXiv:2008.06096

$$m_{bc} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2}$$

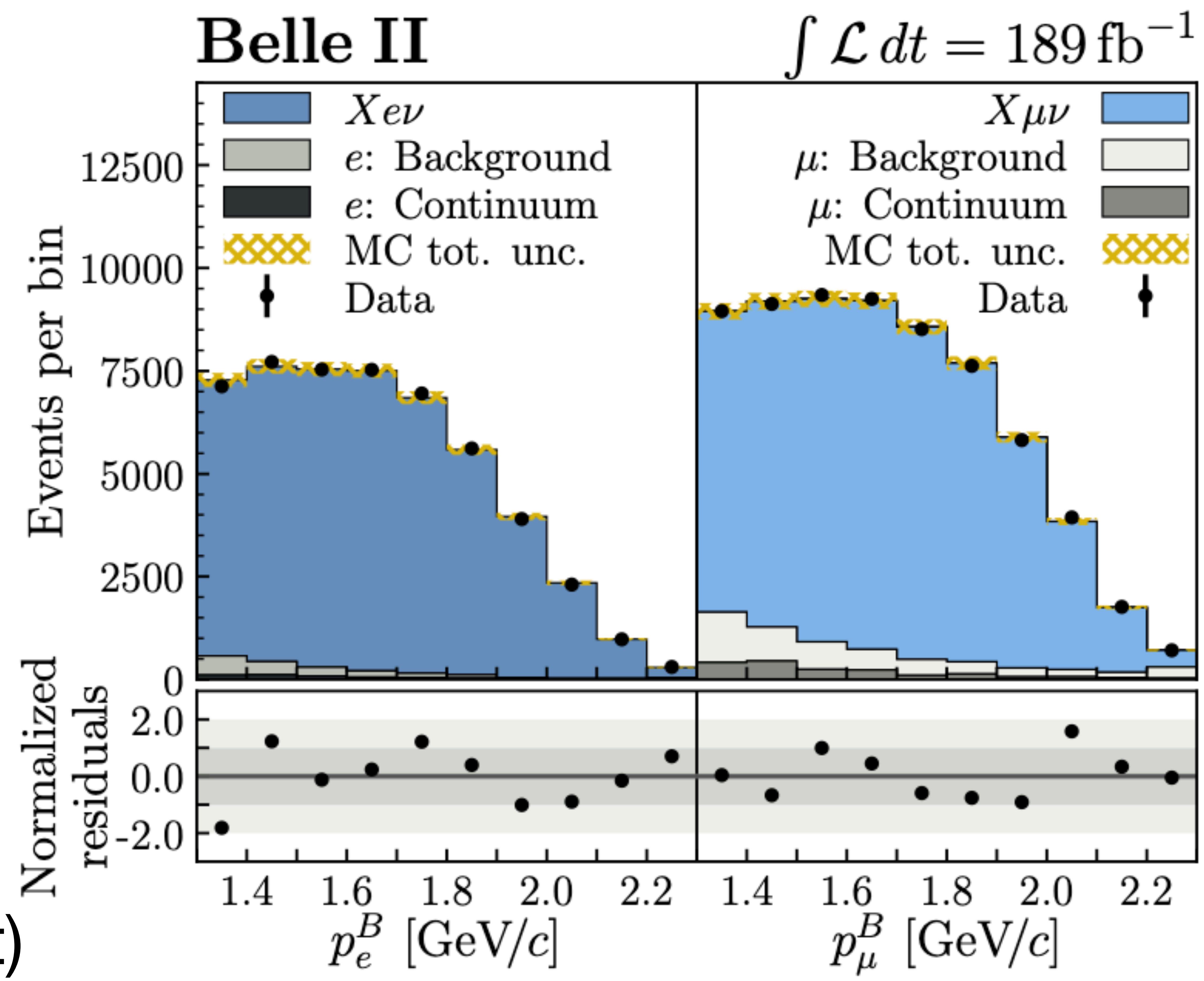
Light-lepton universality tests

- First $R(X_{e/\mu})$ measurement
  $R(X_{e/\mu})$ = 1.007 ± 0.009 (stat) ± 0.019 (syst)

- Most precise BF based LFU test of e-μ universality with semileptonic B decays to date
- Consistent with SM value by 1.2σ
  $R(X_{e/\mu})_{SM}$ = 1.006 ± 0.001 JHEP 11 (2022) 007
- Compatible with exclusive Belle (711 fb^{-1}) measurements PRD 100, 052007 (2019)
  $R(D^*_{e/\mu})$ = 1.01 ± 0.01 (stat) ± 0.03 (syst)
  $R(D^*_{e/\mu})$ = 0.993 ± 0.023 (stat) ± 0.023 (syst)
  PRD 108, 012002(2023)

PRL 131, 051804 (2023)

Signal channel ($B^0\bar{B}^0/B^+B^-$)



- LFU confirmed for light leptons with high precision

First $R_{\tau/\ell}(D^*)$ result from Belle II

- Belle II first result for $R(D^*)$ @ 189 fb^{-1}
  - Hadronic tag with FEI
  - Leptonic τ decays

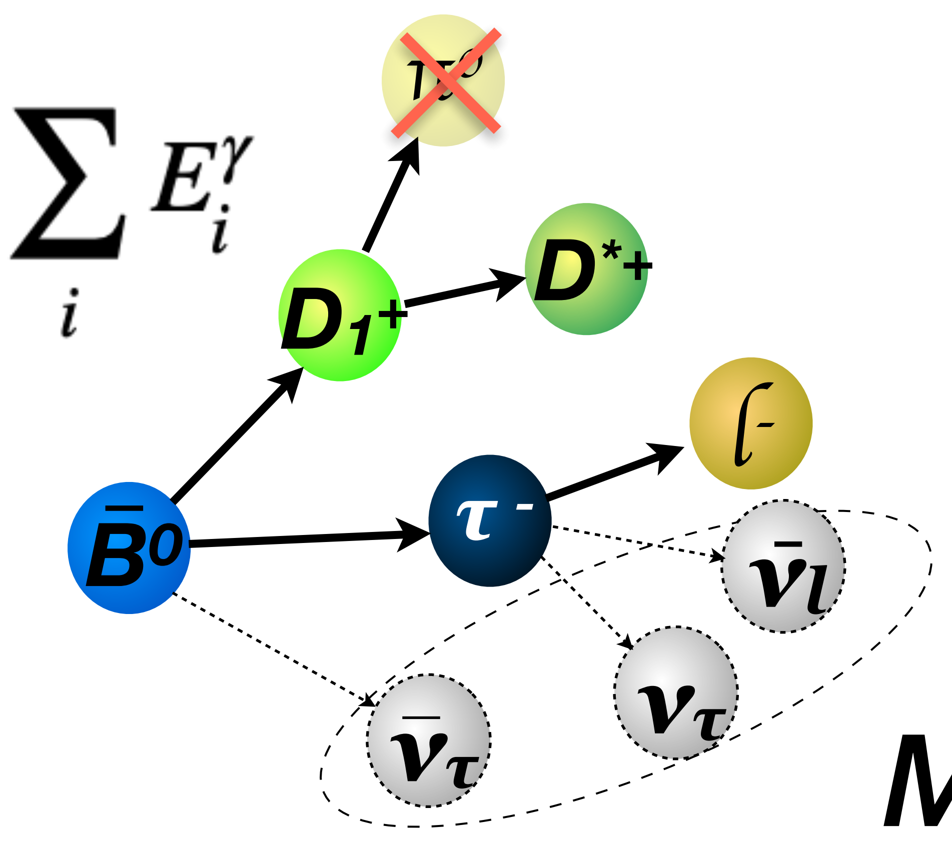
$R(D^*_{\tau/\ell}) = 0.262\ ^{+0.041}_{-0.039}\ (\mathrm{stat})\ ^{+0.035}_{-0.032}\ (\mathrm{syst})$

Source	Uncertainty
Statistical uncertainty	+15.4% -14.6%
E_{ECL} PDF shape	+9.1% -8.3%
MC statistics	±7.5%
$B \to D^{**} l \nu$ modeling	+4.8% -3.5%

- Consistent with
  SM: 0.254 ± 0.005,
  HFLAV24: 0.287 ± 0.012
- SM vs. experimental average deviation: 3.2σ → 3.3σ

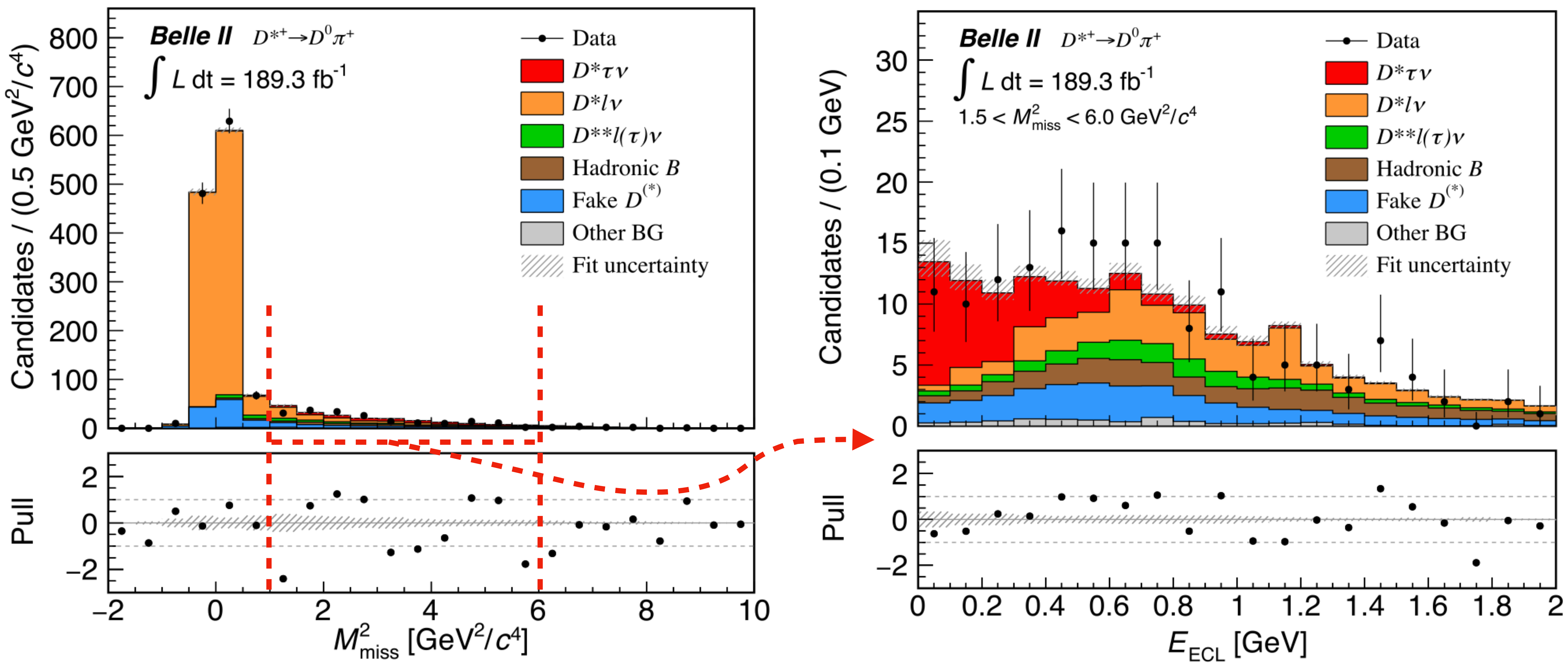
PRD 110 072020 (2024)

$$E_{\mathrm{ECL}} = \sum_i E_i^{\gamma}$$



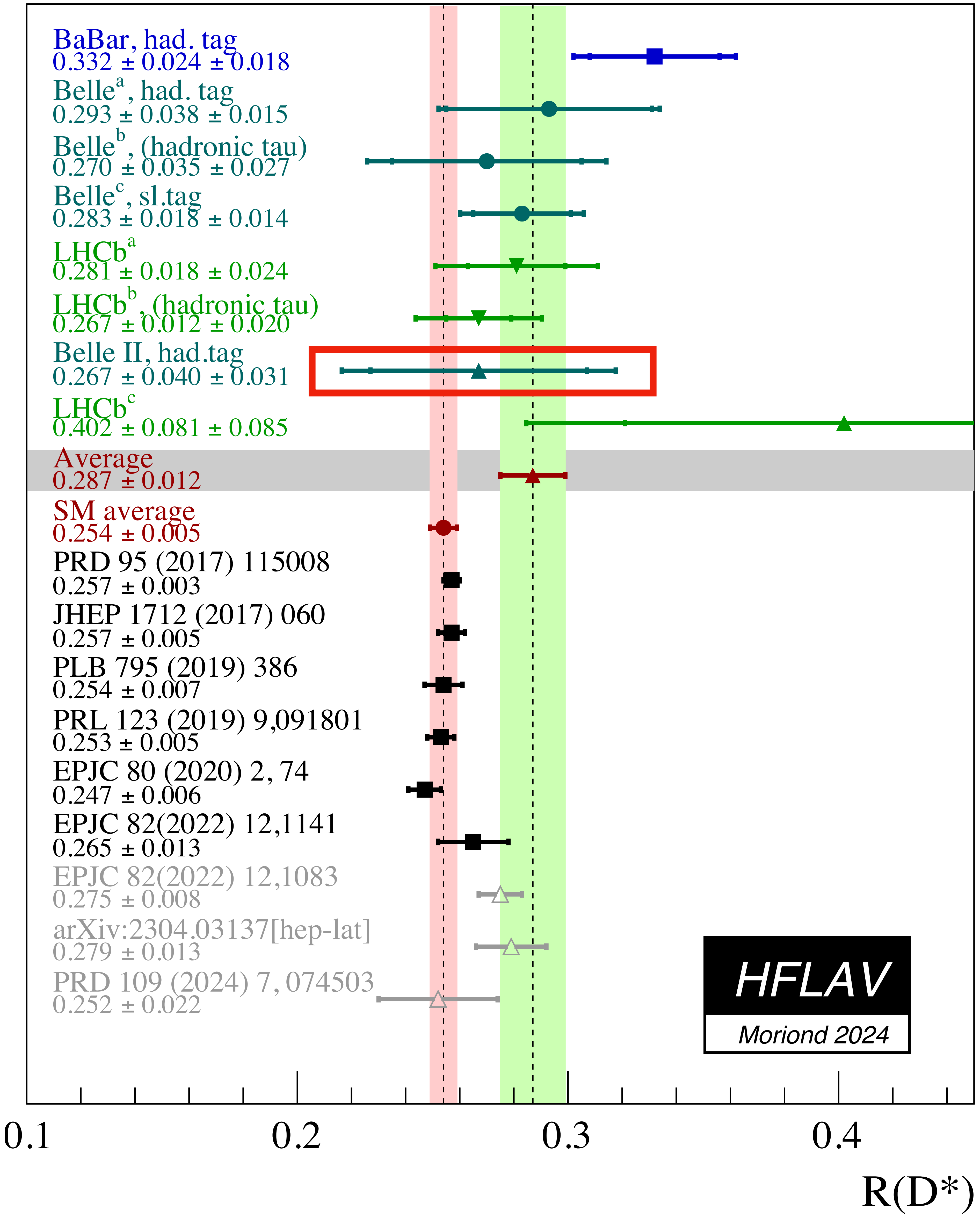
M^2_{miss}

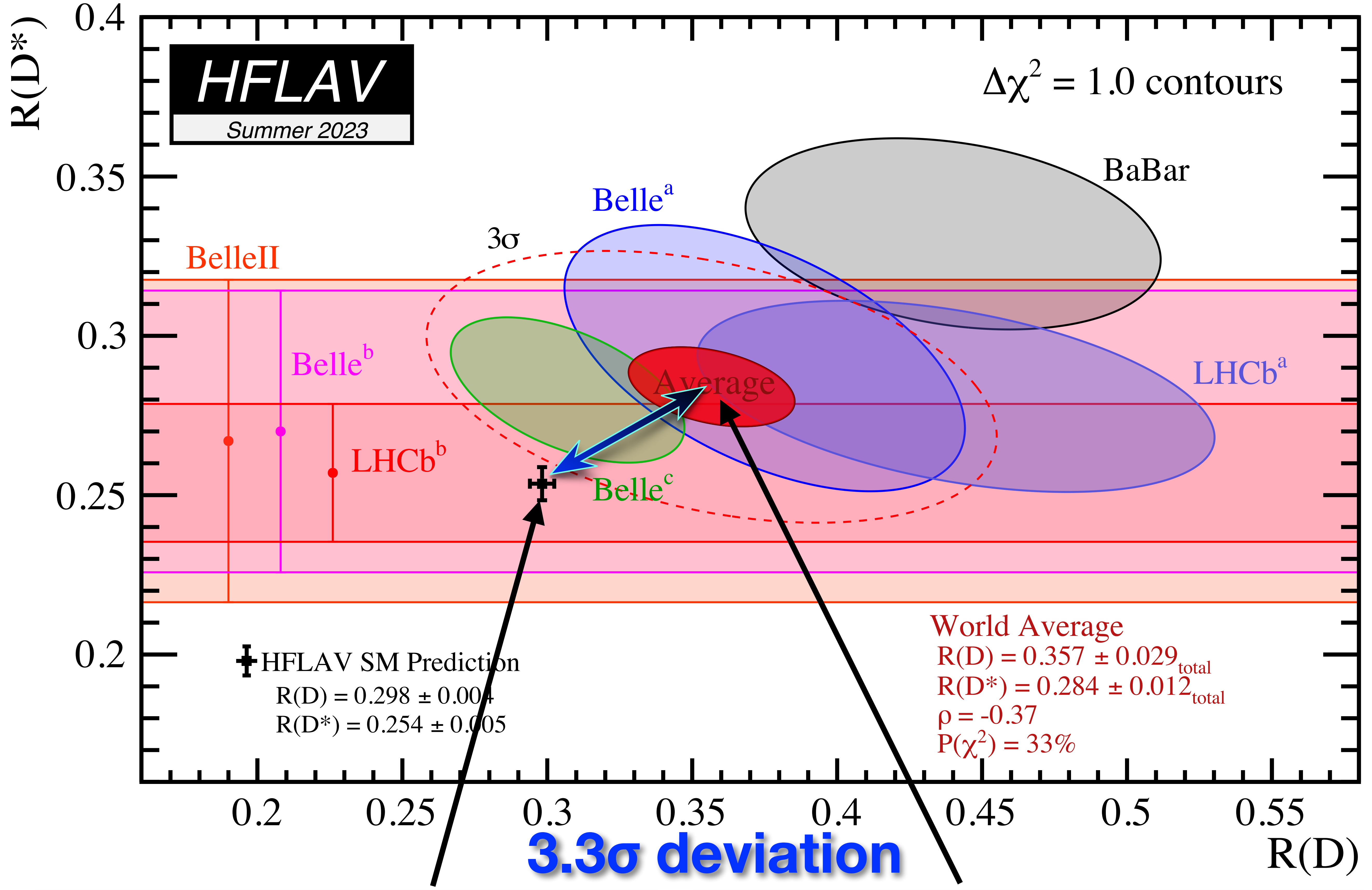
$$M^2_{\mathrm{miss}} = (p_{\mathrm{beam}} - p_{\mathrm{Btag}} - p_{D^{(*)}} - p_\ell)^2$$



“*B* anomaly” in semileptonic decays

- Similarly sensitivity as Belle 15’ result @ 711 fb^{-1} with only 189 fb^{-1}





Standard Model prediction

Experimental average results

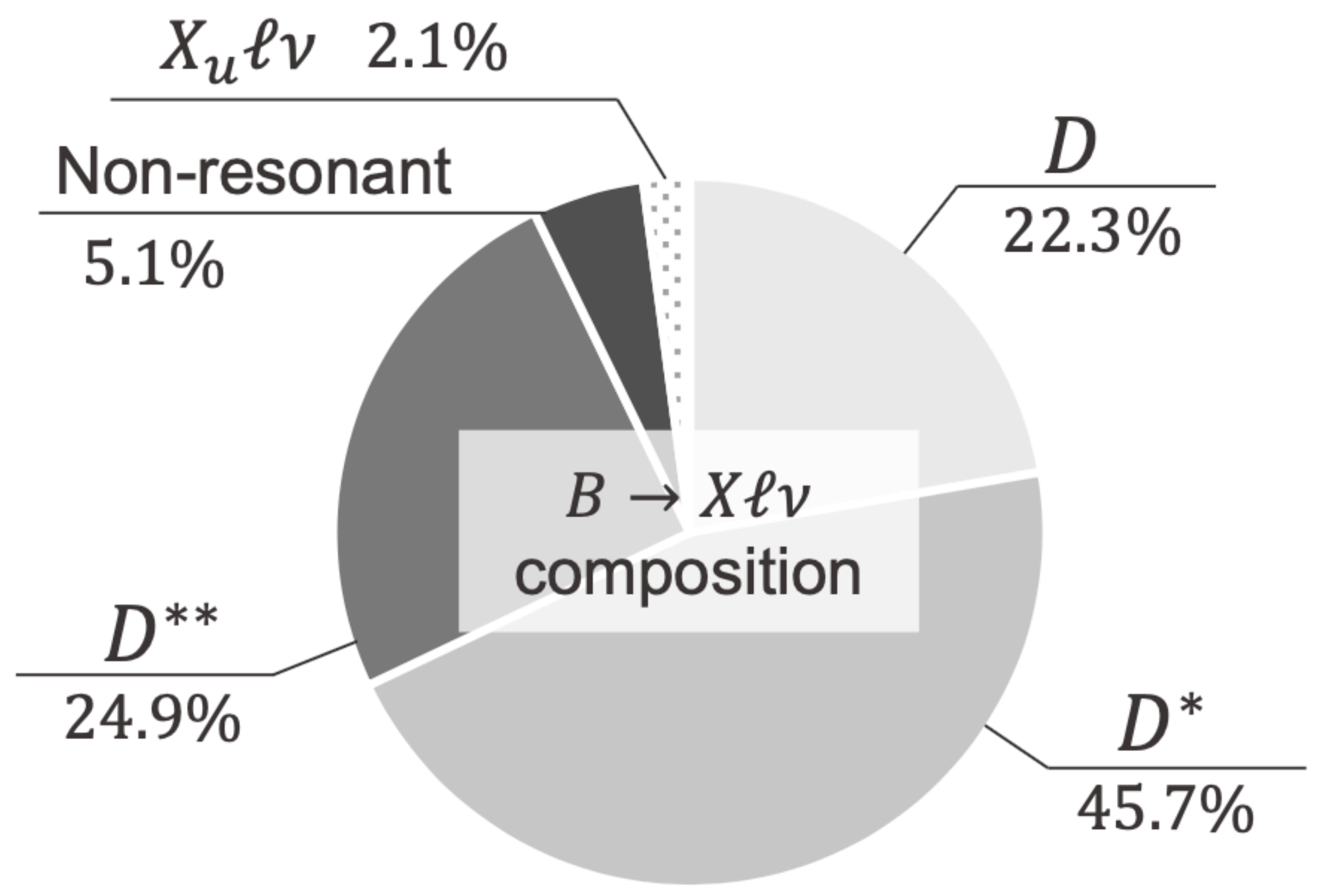
LFU test by $R_{\tau/\ell}(X)$ measurement

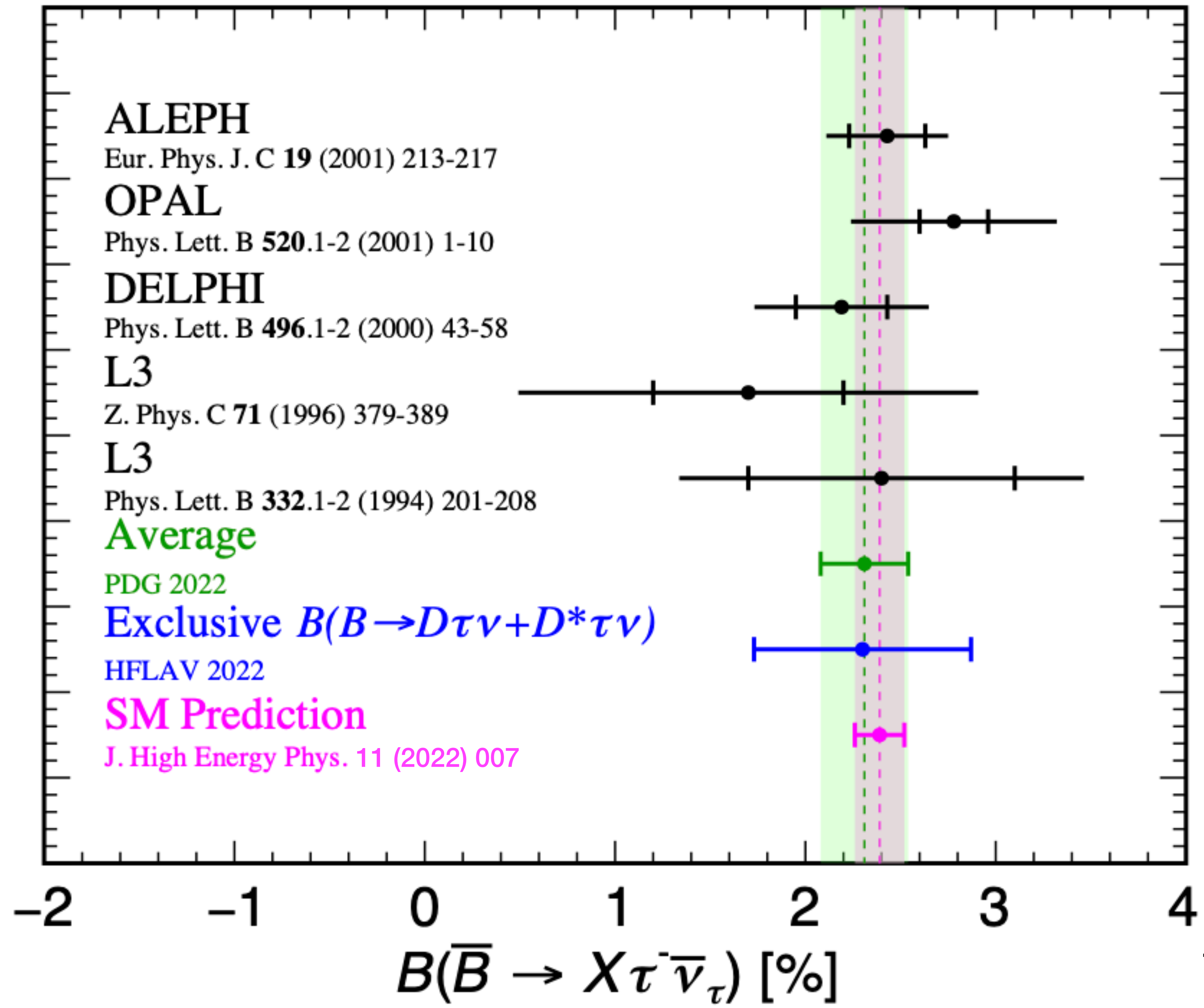
- Breakdown of $B \to Xl\nu$ branching fractions
  - ~ 2/3 overlap with D and D^*
    - ~ 3/4 D decay to ν, K_L^0, $n\pi$ …
  - ~ 1/3 contribution from D^{**} and nonresonant X_c
- Multiple LEP experiments measured Br($B \to X\tau\nu$)
  - Br($B \to X\tau\nu$) are completely saturated by D/D^* BFs
  - ➡ An update measurement is needed

- $R(X)$ is critical cross-check of $R(D^{(*)})$, largest contribution from $R(D^{(*)})$, a partially complementary test of LFU

$$R(X_{\tau/\ell}) = \frac{Br(\bar{B} \to X\tau^-\bar{\nu}_\tau)}{Br(\bar{B} \to X\ell^-\bar{\nu}_\ell)}$$

- $R(X)$ has never been measured





Results of $R_{\tau/\ell}(X)$ for LFU test

- Main systematics
  - Adjustment to MC (form factor, D and B branching factions)
  - Sample size in sideband for reweighting
- First Belle II preliminary $R_{\tau/\ell}(X)$ result

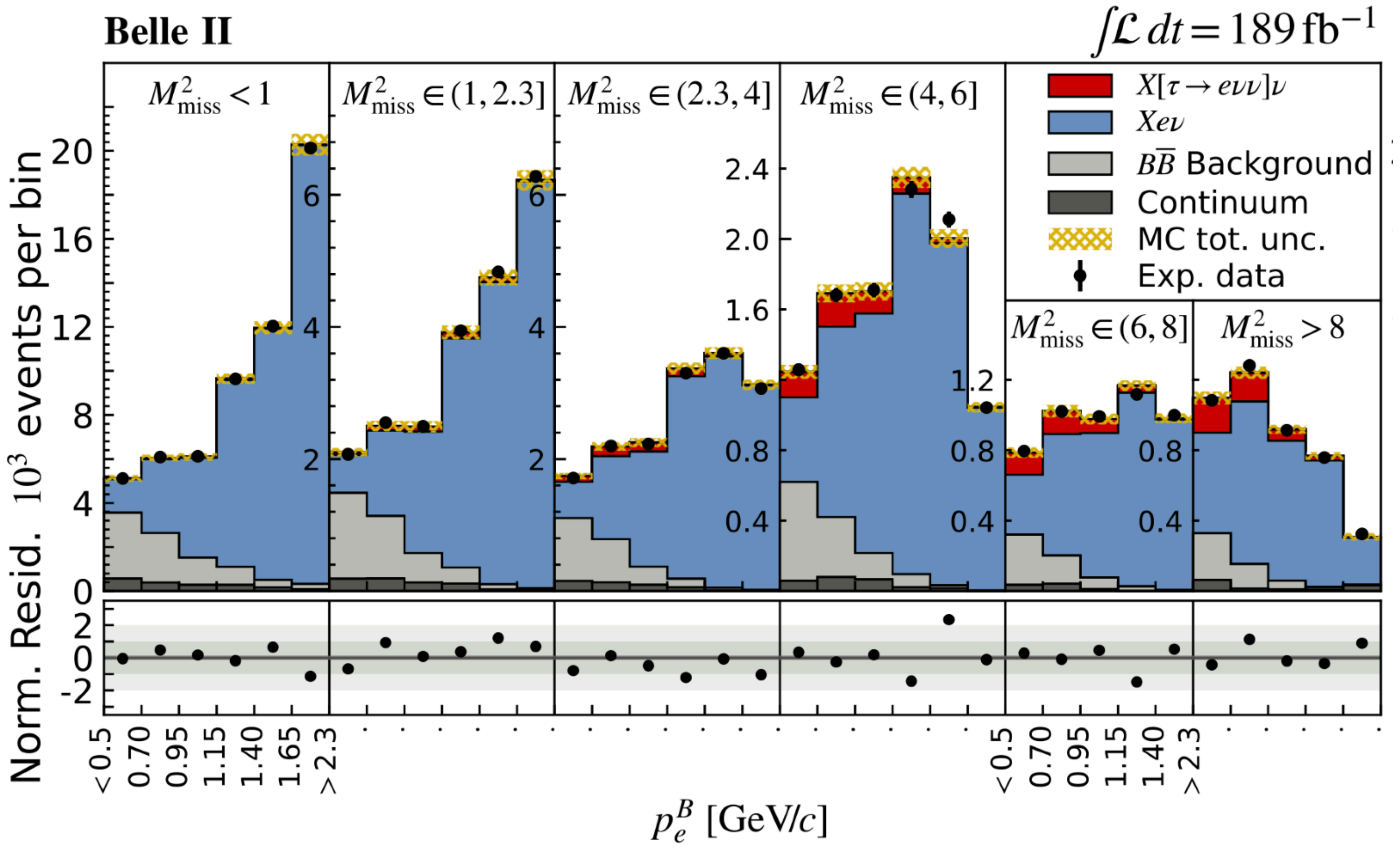
$R_{\tau/\ell}(X) = 0.228 \pm 0.016\ (\text{stat}) \pm 0.036\ (\text{syst})$

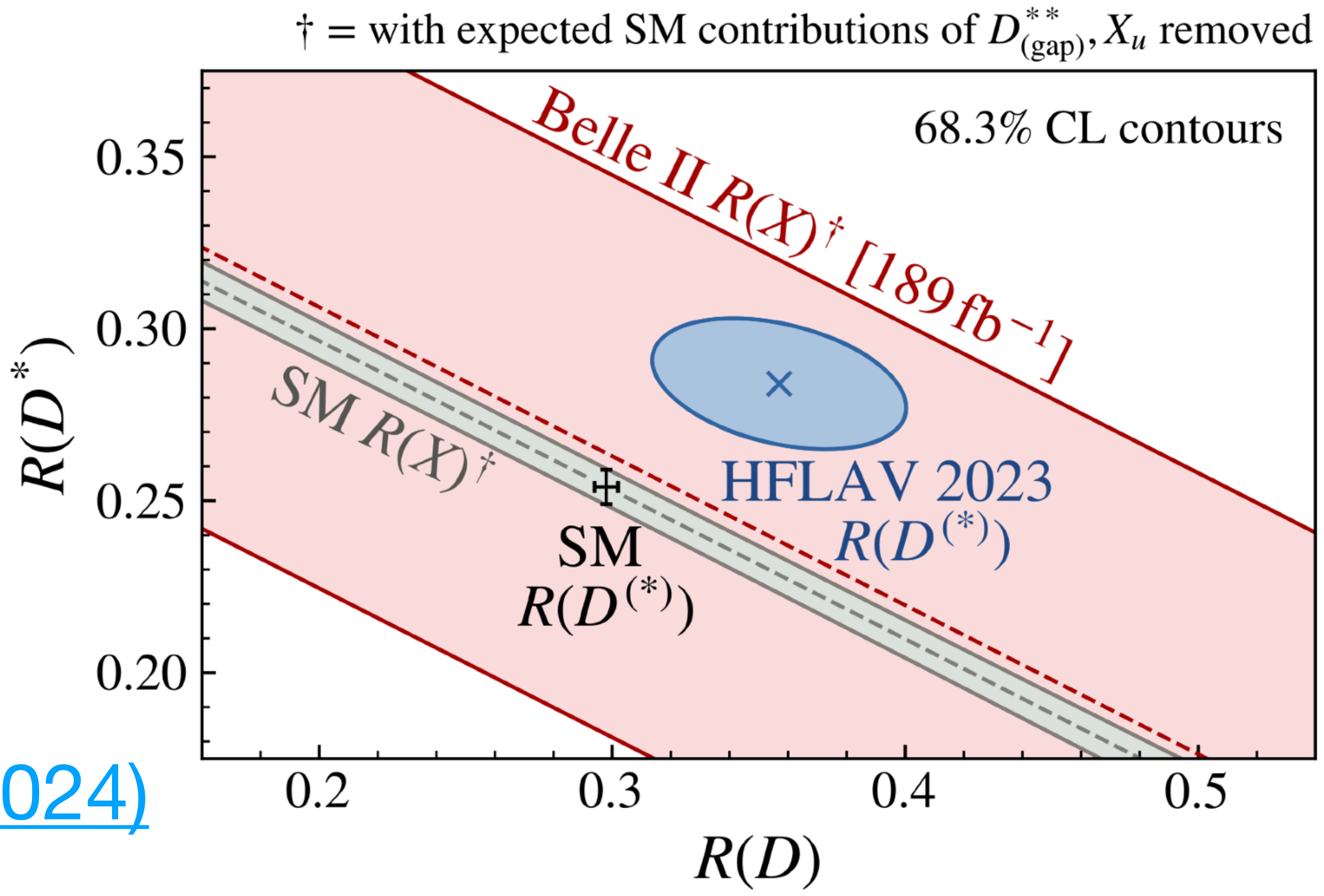
$R_{\tau/e}(X) = 0.232 \pm 0.020\ (\text{stat}) \pm 0.037\ (\text{syst})$

$R_{\tau/\mu}(X) = 0.222 \pm 0.027\ (\text{stat}) \pm 0.050\ (\text{syst})$

- Consistent with rough SM expectation

$R_{\tau/l}(X)_{\text{SM}} \approx 0.222$



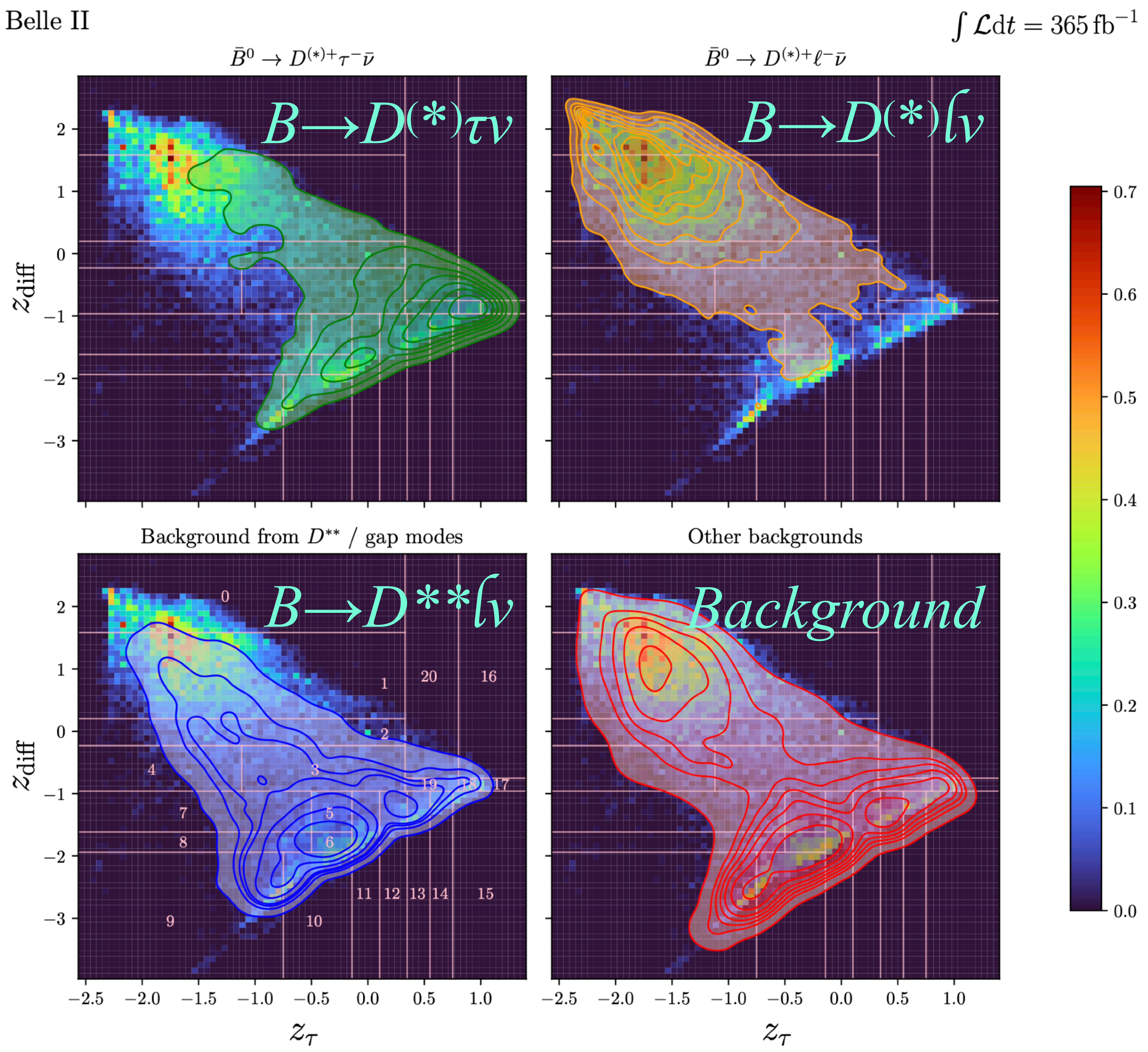


PRL 132 211804 (2024)

$R_{\tau/\ell}(D^{(*)+})$ with semileptonic tag *Preliminary*

- Belle II data @ 365 fb^{-1}
- Semileptonic tag: $B \to D^{(*)} l \nu$
  - 26 *D* decays
- Signal reconstruction: only B^0, leptonic tau decays
  - 13 *D* decays

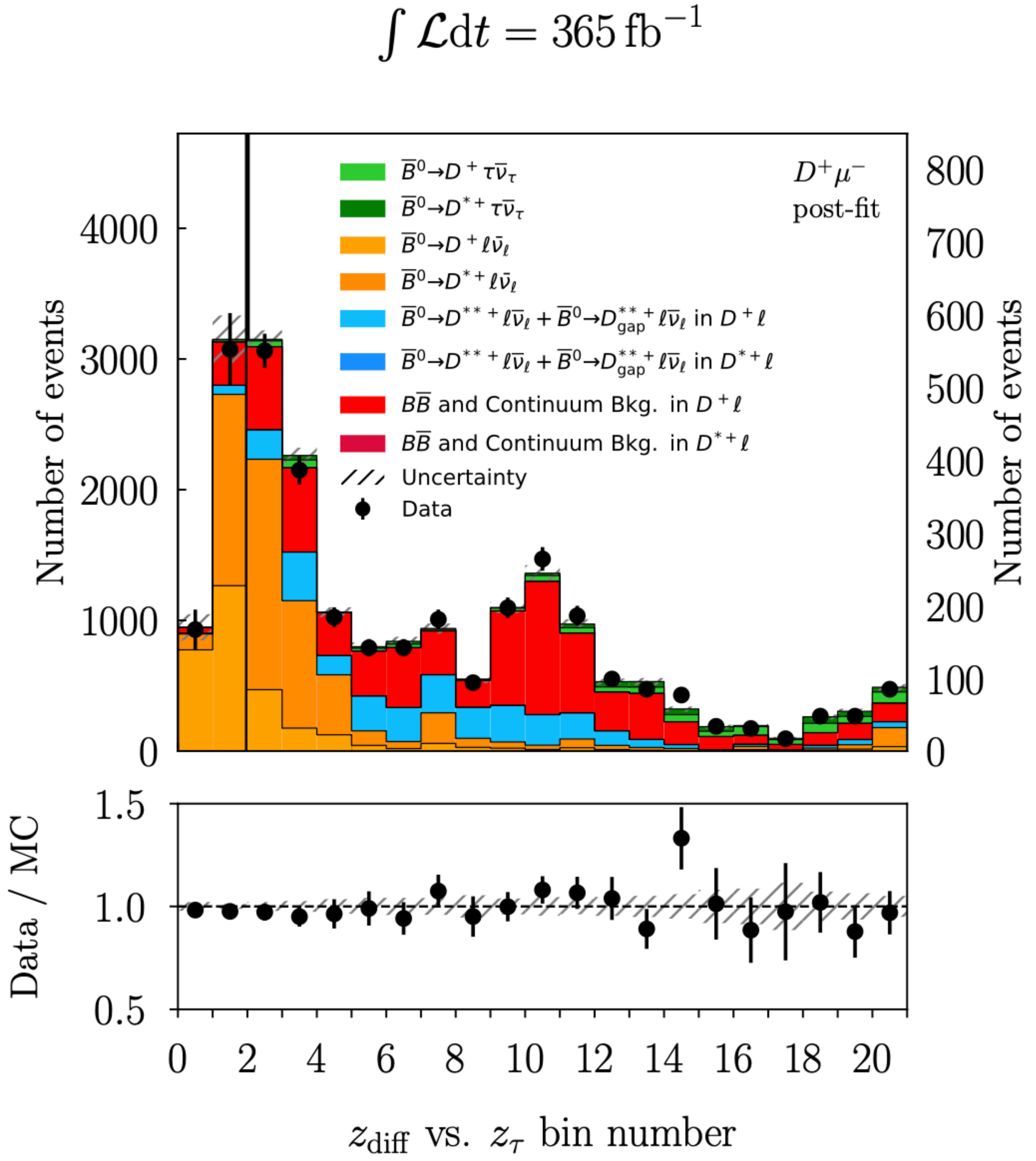
- A BDT trained to separate events in 3 classes
  - Semitauonic signal events z_τ
  - Semileptonic normalization evnets z_ℓ
  - Background z_{bkg}
- Extract signal in a 2D binned template fit
  - z_τ vs. $z_{diff}(z_\ell - z_{bkg})$



Results of $R_{\tau/\ell}(D^{(*)+})$

Preliminary

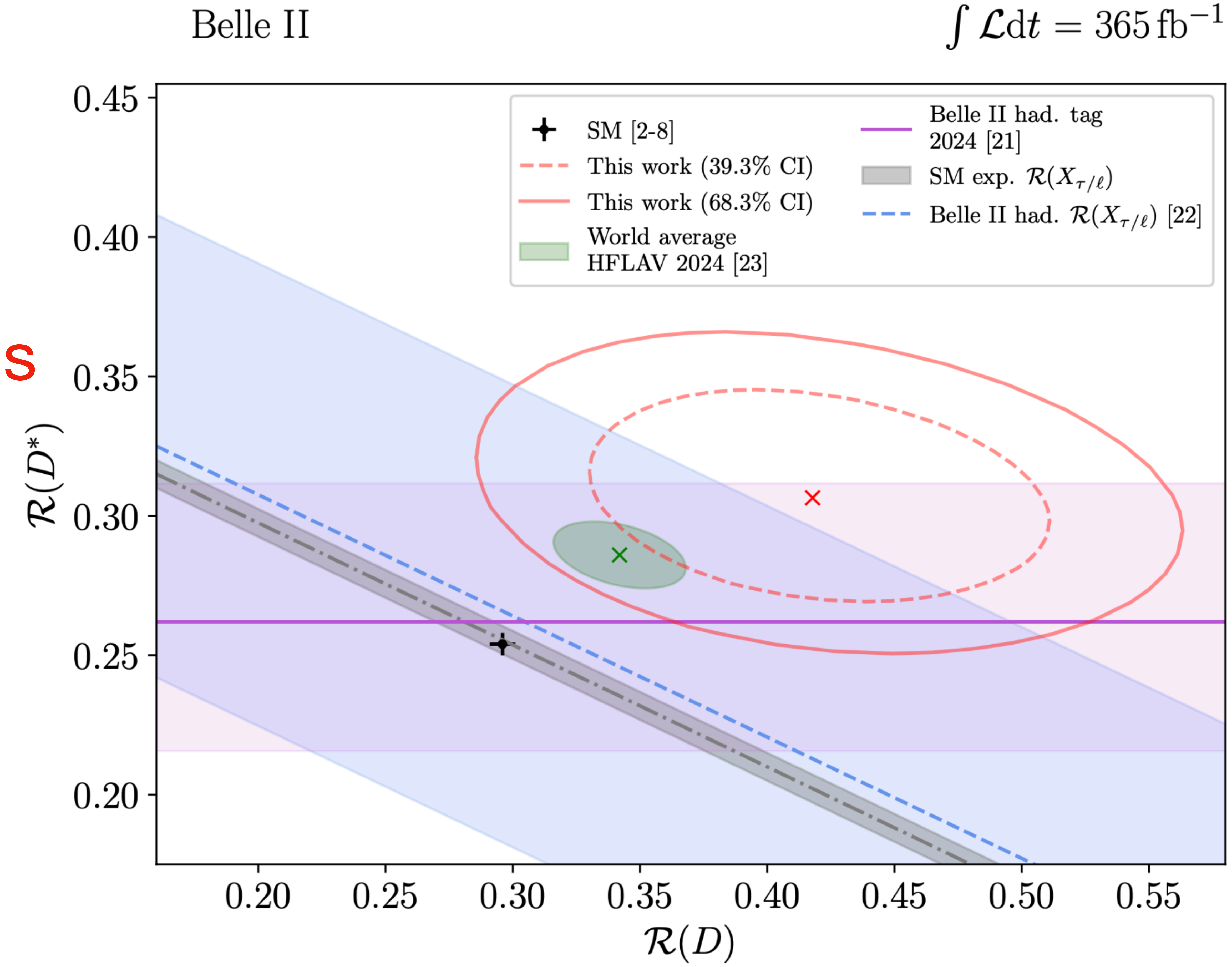
- Main systematics
  - The finite size of the simulated samples
  - The lepton ID efficiency and fake rate corrections



- First Belle II $R(D^{(*)})$ result with semilep. tag

$R_{\tau/\ell}(D^+) = 0.418 \pm 0.074\ (\mathrm{stat}) \pm 0.051\ (\mathrm{syst})$

$R_{\tau/\ell}(D^{*+}) = 0.316 \pm 0.034\ (\mathrm{stat}) \pm 0.018\ (\mathrm{syst})$



New Physics Scenarios with Effective Field Theory

- New physics contribution to $R(D^{(*)})$ are tested with Wilson operators

$$\mathcal{H}_{\text{eff}} = \frac{4G_F}{\sqrt{2}} V_{cb}[(1 + C_{V_L})\mathcal{O}_{V_L} + C_{V_R}\mathcal{O}_{V_R} + C_{S_L}\mathcal{O}_{S_L} + C_{S_R}\mathcal{O}_{S_R} + C_T\mathcal{O}_T]$$

$\mathcal{O}_{V_L}$, $\mathcal{O}_{V_R}$: Left-, right-handed vector operators
$\mathcal{O}_{S_L}$, $\mathcal{O}_{S_R}$: Left-, right-handed scalar operators
$\mathcal{O}_T$: Tensor vector operators

C_X: Willson coefficient for a X operator

Refer to: PRD 110, 075005 (2024)

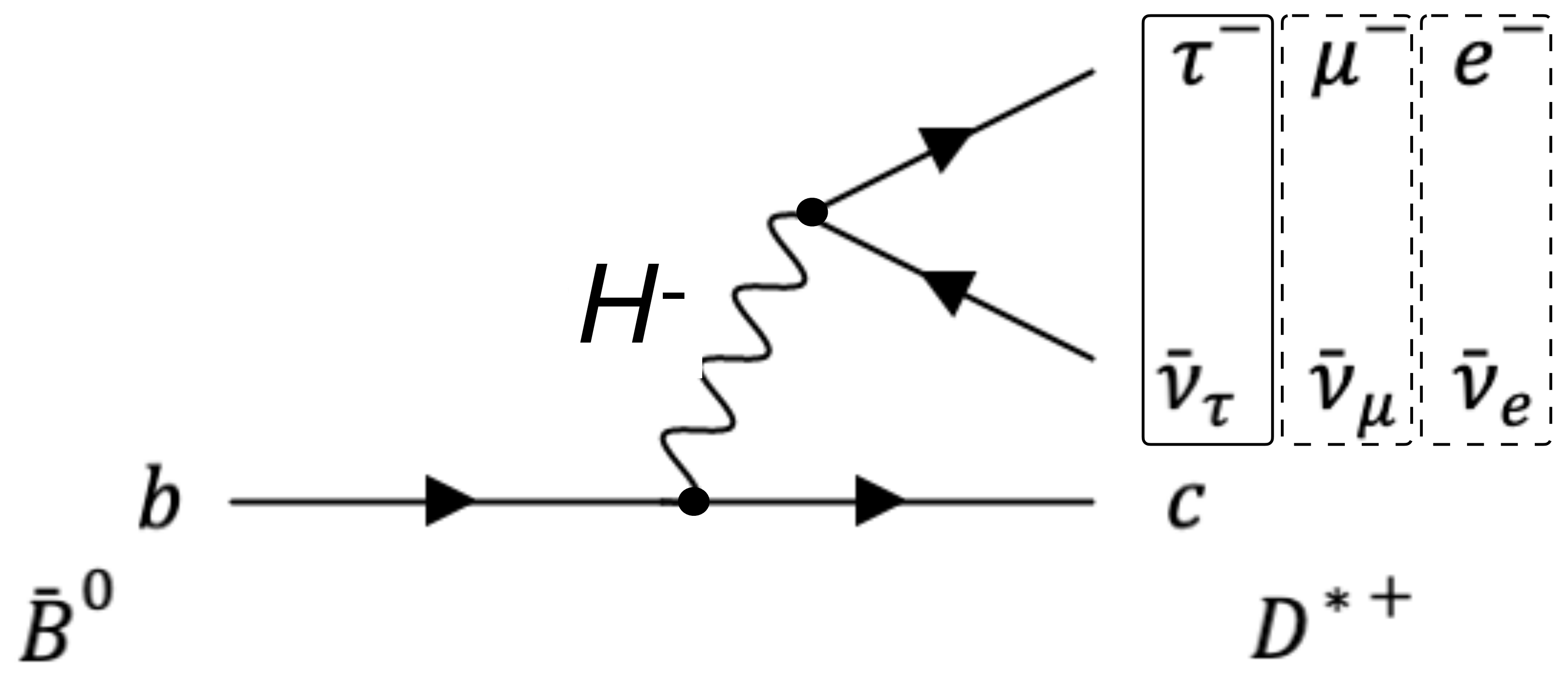
$$\frac{R_{D^*}}{R_{D^*}^{\text{SM}}} = |1 + C_{V_L}|^2 + |C_{V_R}|^2 + 0.04|C_{S_L} - C_{S_R}|^2 + 16.0|C_T|^2$$
$$- 1.83\text{Re}[(1 + C_{V_L})C_{V_R}^*] - 0.11\text{Re}[(1 + C_{V_L} - C_{V_R})(C_{S_L}^* - C_{S_R}^*)]$$
$$- 5.17\text{Re}[(1 + C_{V_L})C_T^*] + 6.60\text{Re}[C_{V_R}C_T^*],$$

- Exp. average to constrain Wilson coefficients

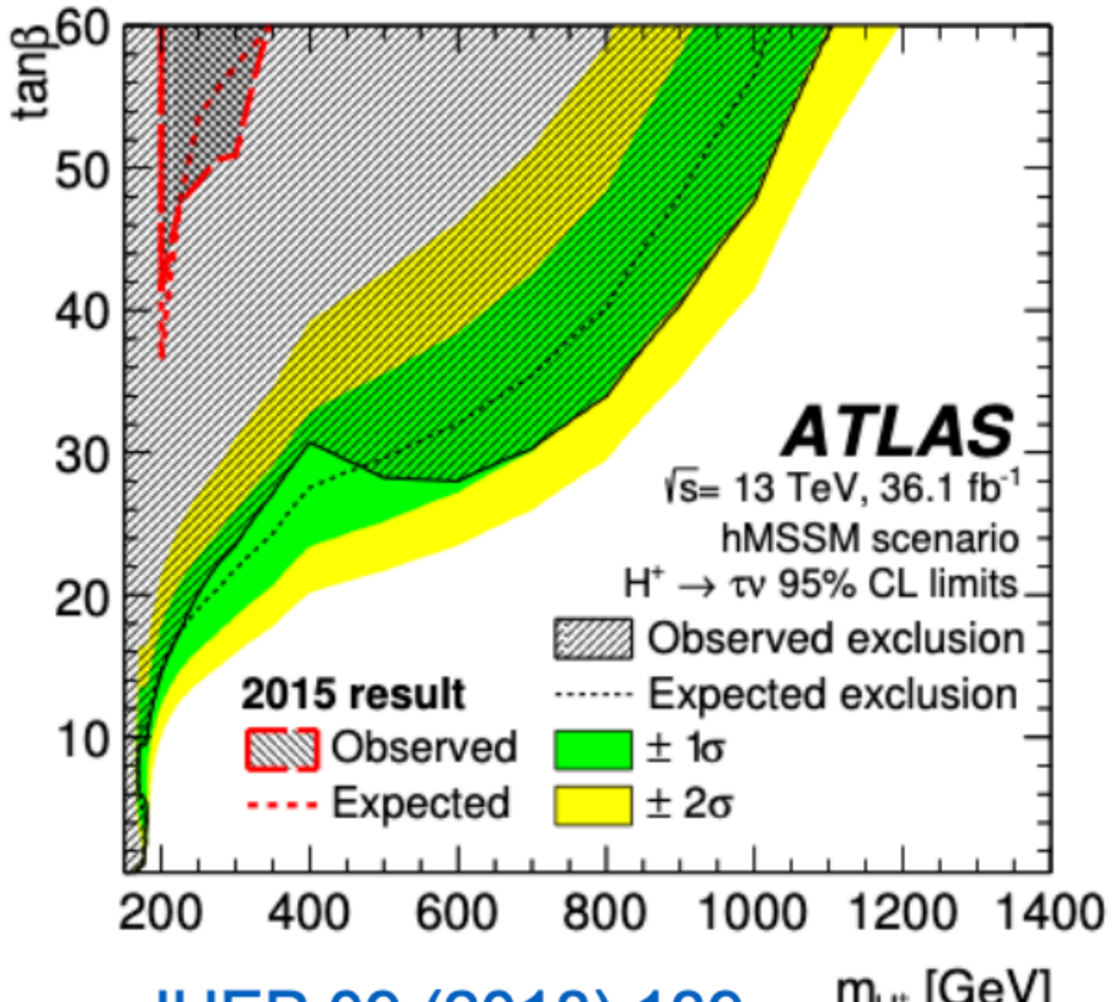
	$R(D)$	$R(D^*)$
Exp. average	0.356 ± 0.029	0.284 ± 0.013
SM	0.298 ± 0.004	0.254 ± 0.005

Constraint on charged Higgs scenario

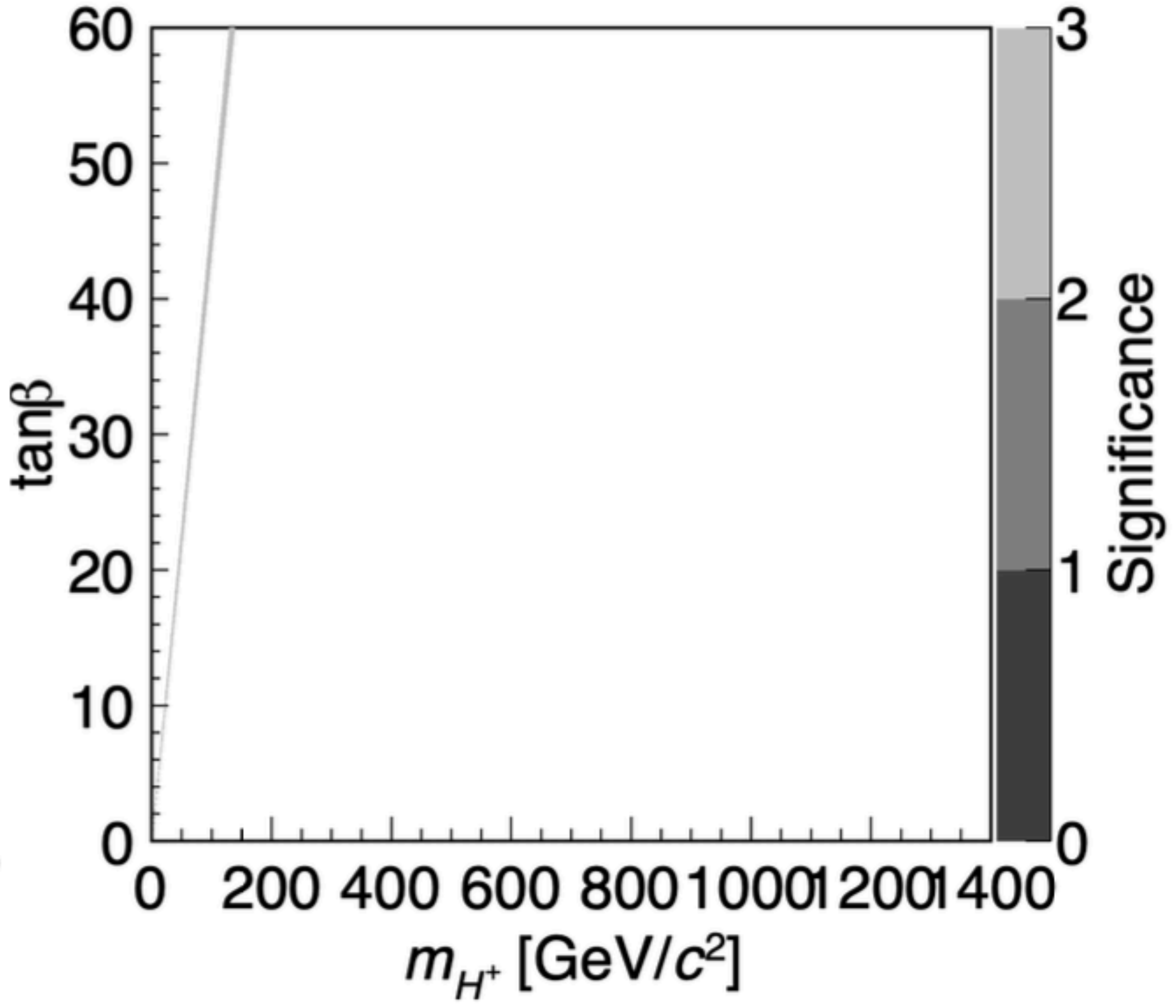
Model	Coefficients
2HDM (type-II) Phys. Rev. D 87, 034028	$\begin{cases} C_{S_L} = -m_b m_\tau(\mu_b)\dfrac{\tan^2\beta}{m_{H^+}^2} \\ C_{S_R} = -m_c(\mu_b) m_\tau(\mu_b)\dfrac{1}{m_{H^+}^2} \end{cases}$
General 2HDM	C_{S_L}



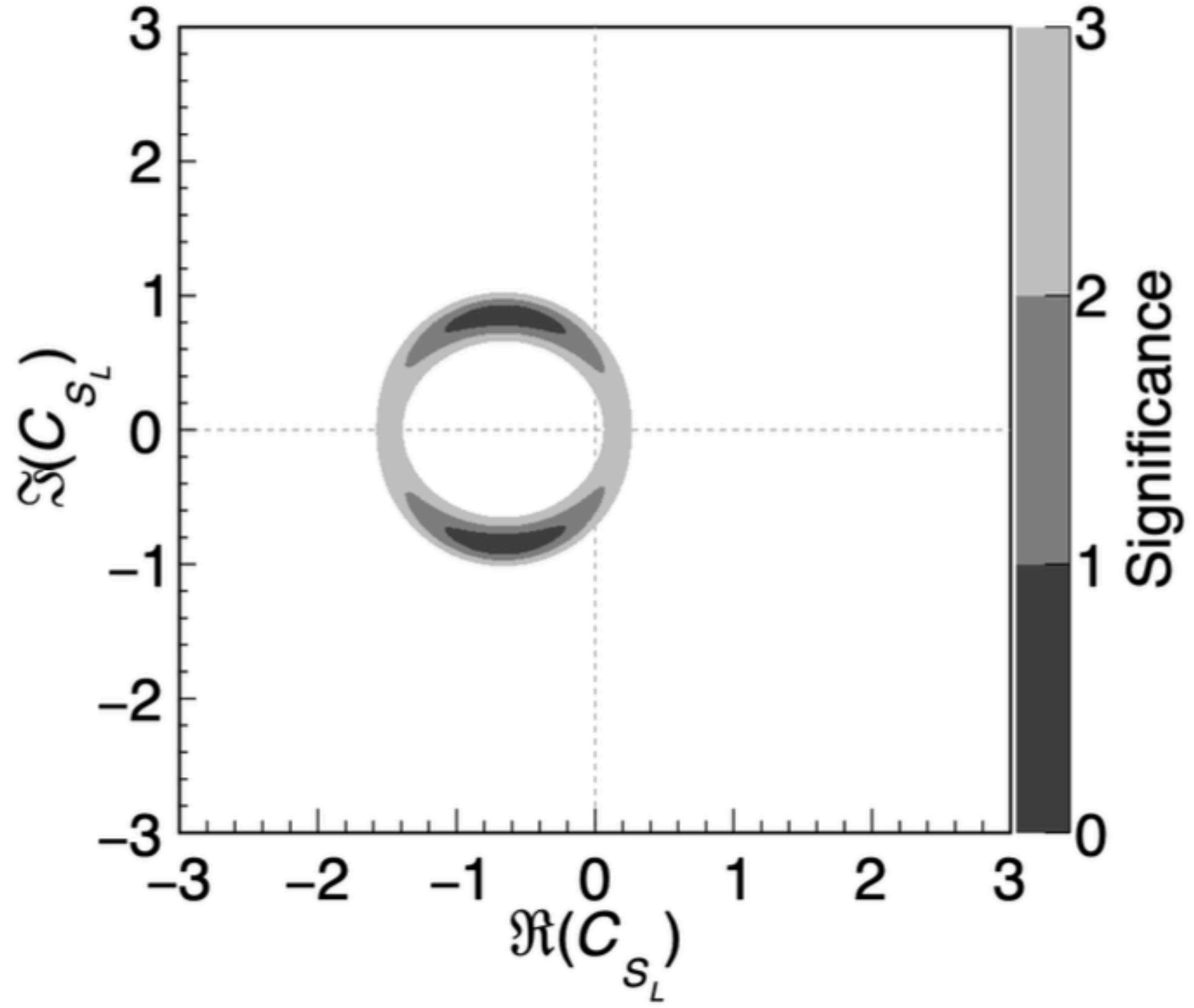
2HDM (type II)



JHEP 09 (2018) 139



General 2HDM



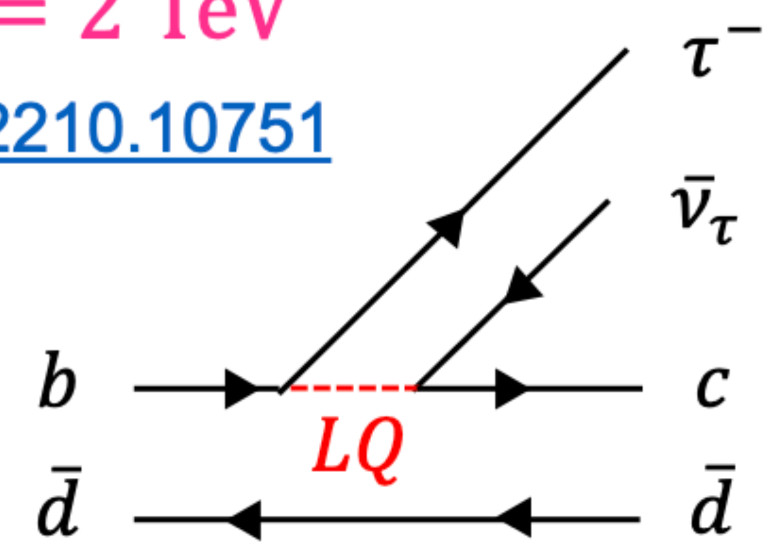
- Charged Higgs in 2HDM (type II) is disfavored
- General 2HDM still survives

Constraint on leptoquark scenario

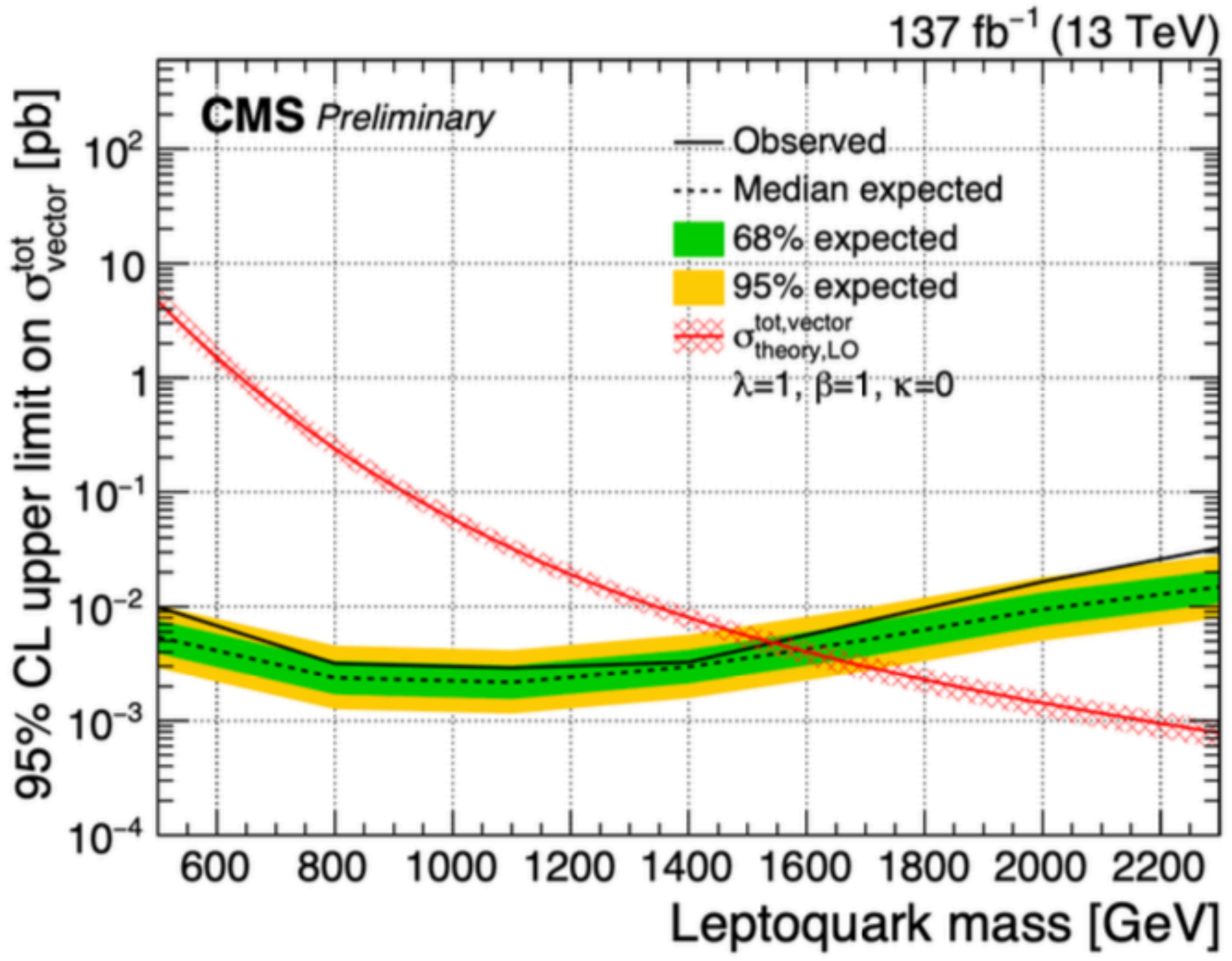
Model	Coefficients	
	$\Lambda_{LQ} = M_{LQ}$	$\mu_b = m_b$
$SU(2)_L$-singlet vector U_1^{μ}	C_{V_L}, C_{S_R}	C_{V_L}, C_{S_R}
$SU(2)_L$-singlet scalar S_1	C_{V_L}, $C_{S_L} = -4C_T$	C_{V_L}, $C_{S_L} = -8.7C_T$
$SU(2)_L$-doublet vector R_2	C_{V_R}, $C_{S_L} = +4C_T$	C_{V_R}, $C_{S_L} = +8.2C_T$

$M_{LQ} = 2$ TeV

arXiv:2210.10751

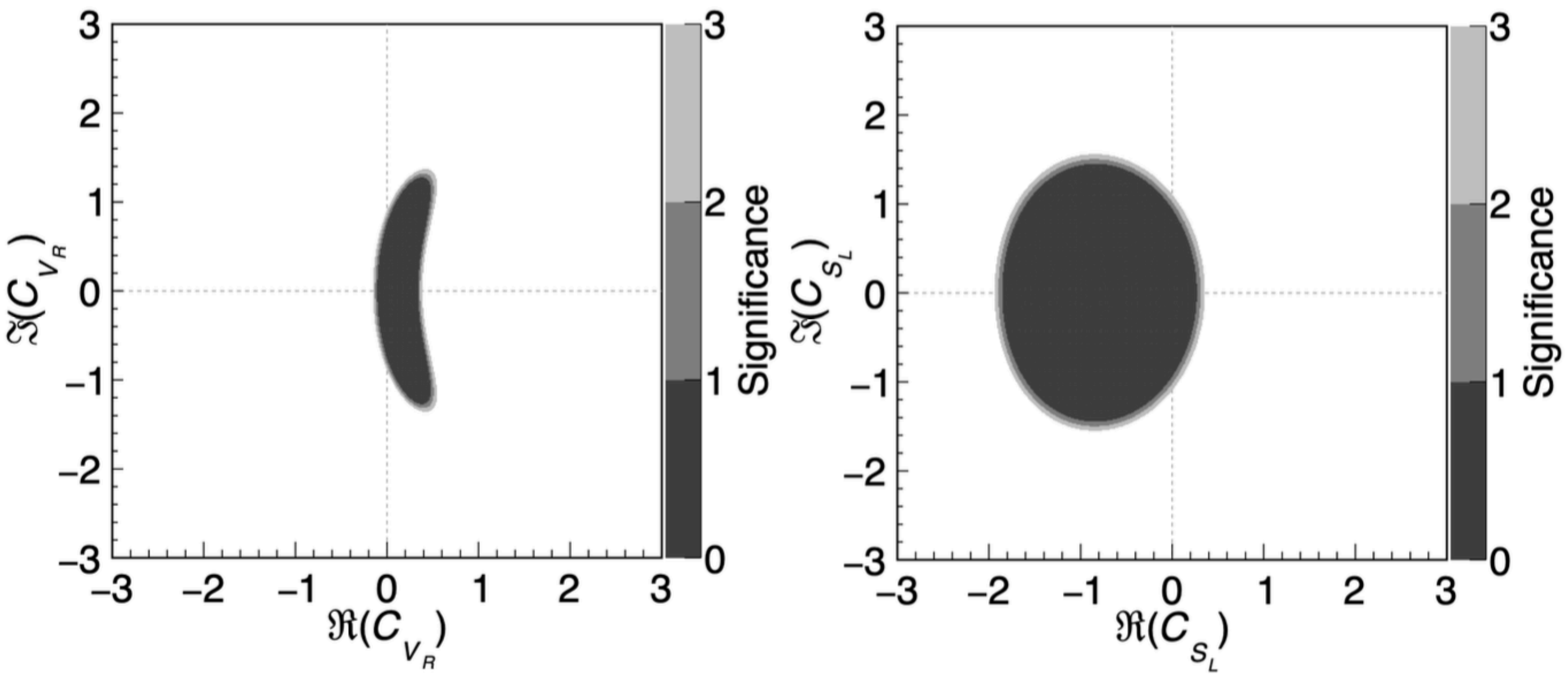


Vector leptoquark model



JHEP 05 (2024) 311

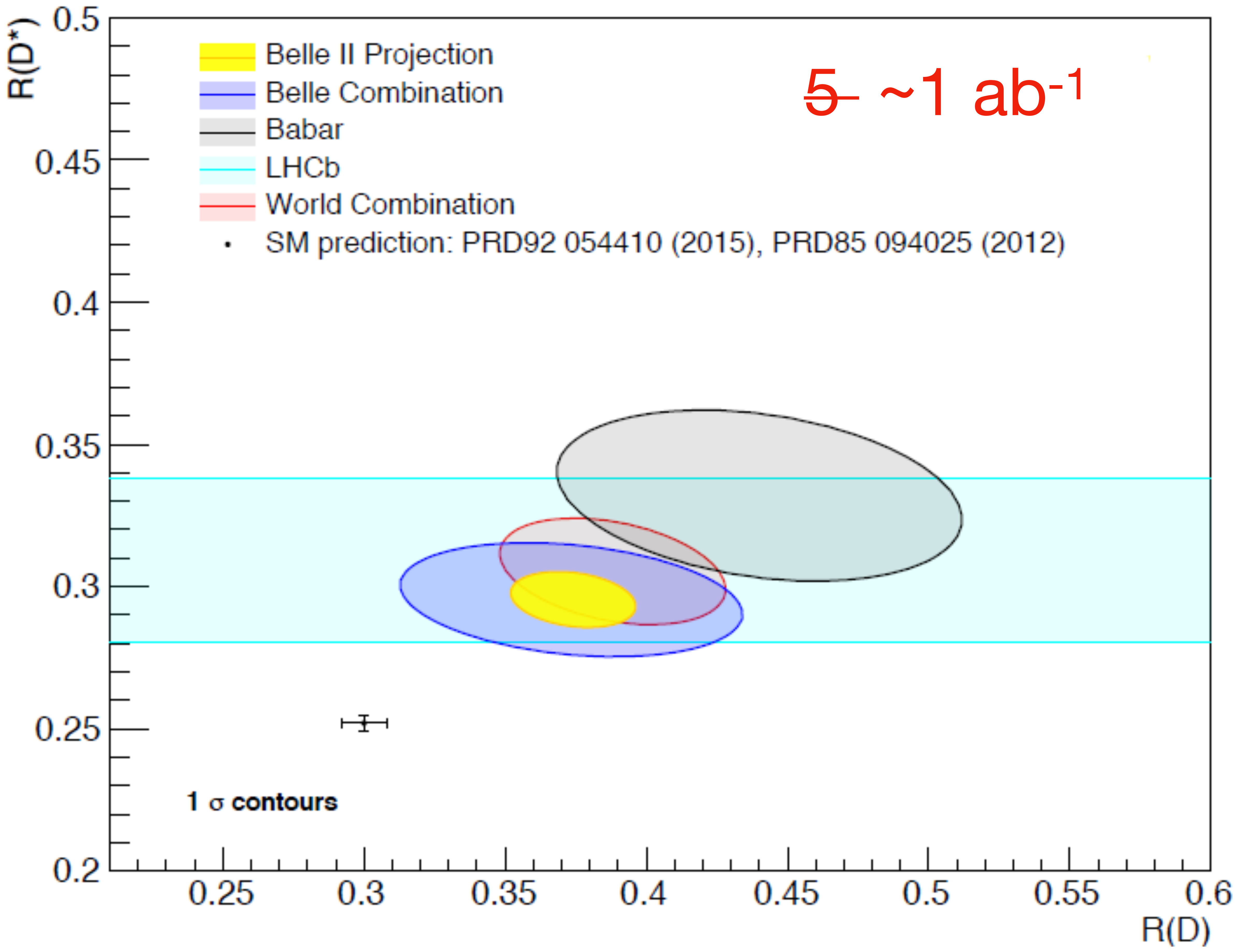
Leptoquark model (R_2 type)



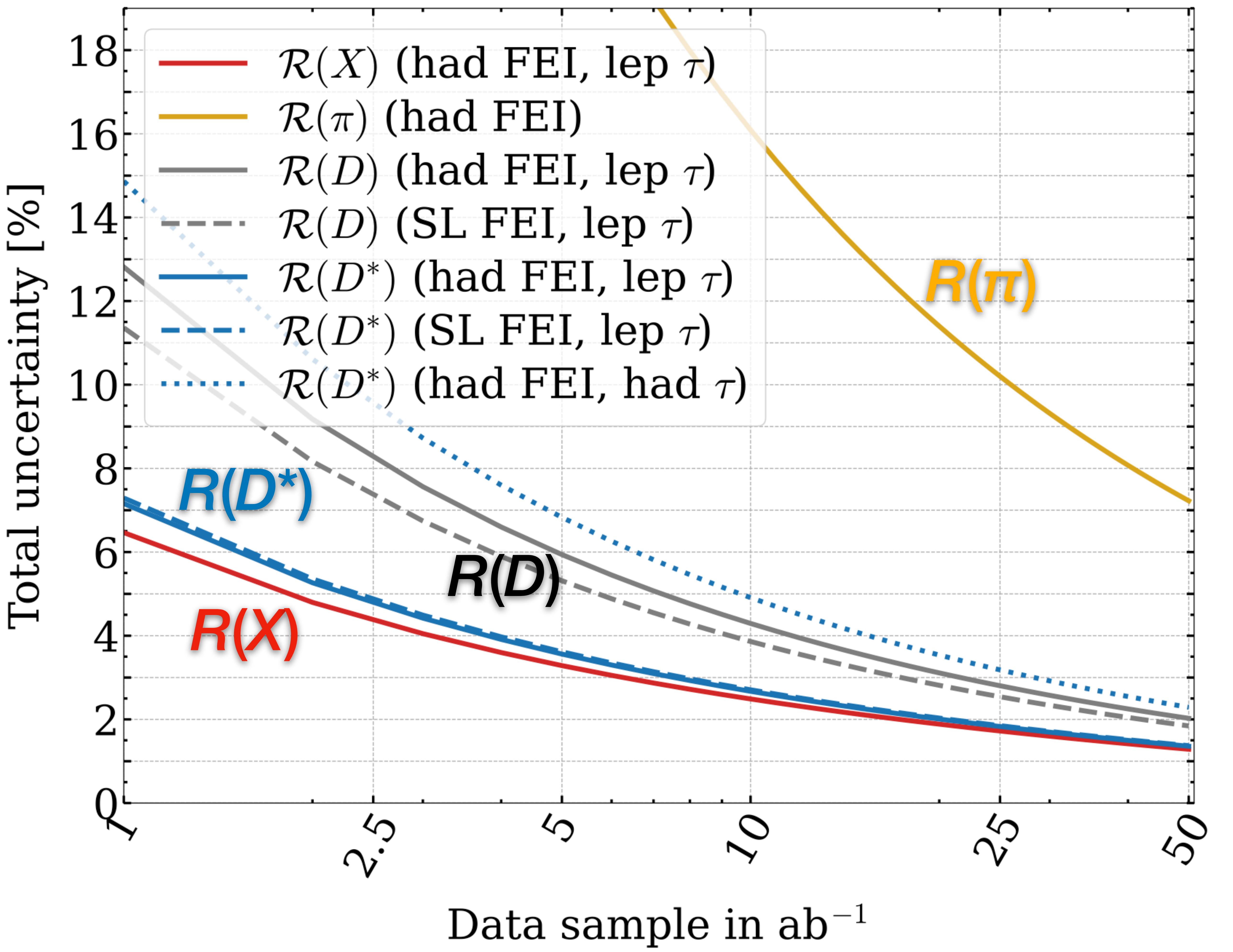
- All three models have favored regions within 1σ $R(D^{(*)})$ exp. average
- $R(D^{(*)})$ can be explained with three leptoquark models of 2 TeV

Expected sensitivity of LFU test at Belle II

The Belle II Physics Book, PTEP 2019, 123C01



arXiv:2207.06307



Summary and prospects

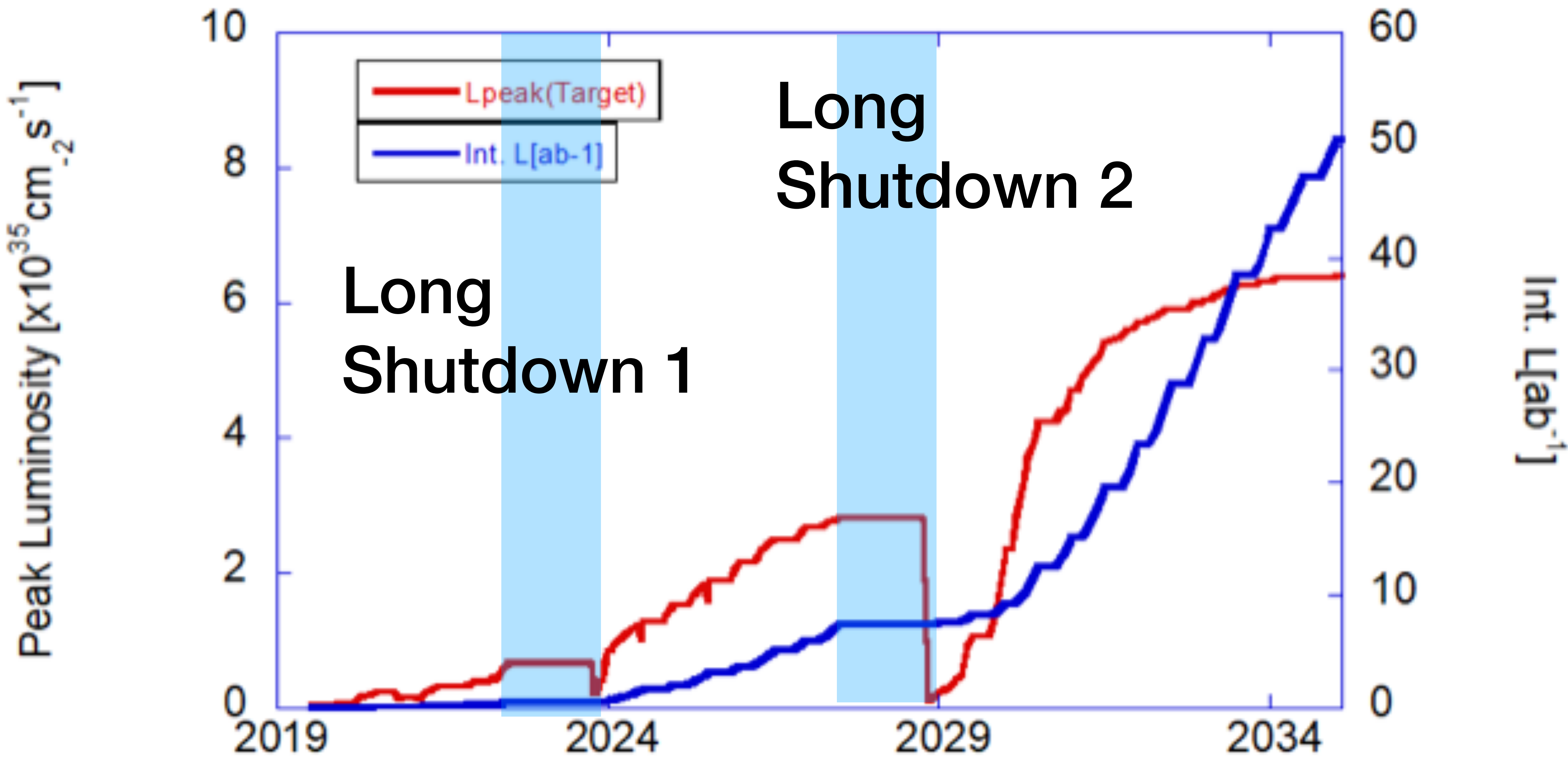
- $R(D^{(*)})$ shows 3.3σ deviation between experimental average value and standard model prediction
  - Hint of Lepton Flavor Universality Violation
- Belle II performed new tests of LFU
  - 189 fb^{-1} data

    $R_{\tau/\ell}(D^*) = 0.267\ ^{+0.041}_{-0.039}\ \text{(stat)}\ ^{+0.028}_{-0.033}\ \text{(syst)}$

    $R_{\tau/\ell}(X) = 0.228 \pm 0.016\ \text{(stat)} \pm 0.036\ \text{(syst)}$
  - 365 fb^{-1} data

    $R_{\tau/\ell}(D^+) = 0.418 \pm 0.074\ \text{(stat)} \pm 0.051\ \text{(syst)}$

    $R_{\tau/\ell}(D^{*+}) = 0.316 \pm 0.034\ \text{(stat)} \pm 0.018\ \text{(syst)}$
- $R(D^{(*)})$ results with hadronic tag @ 365 fb^{-1} coming soon, stay tuned !!!



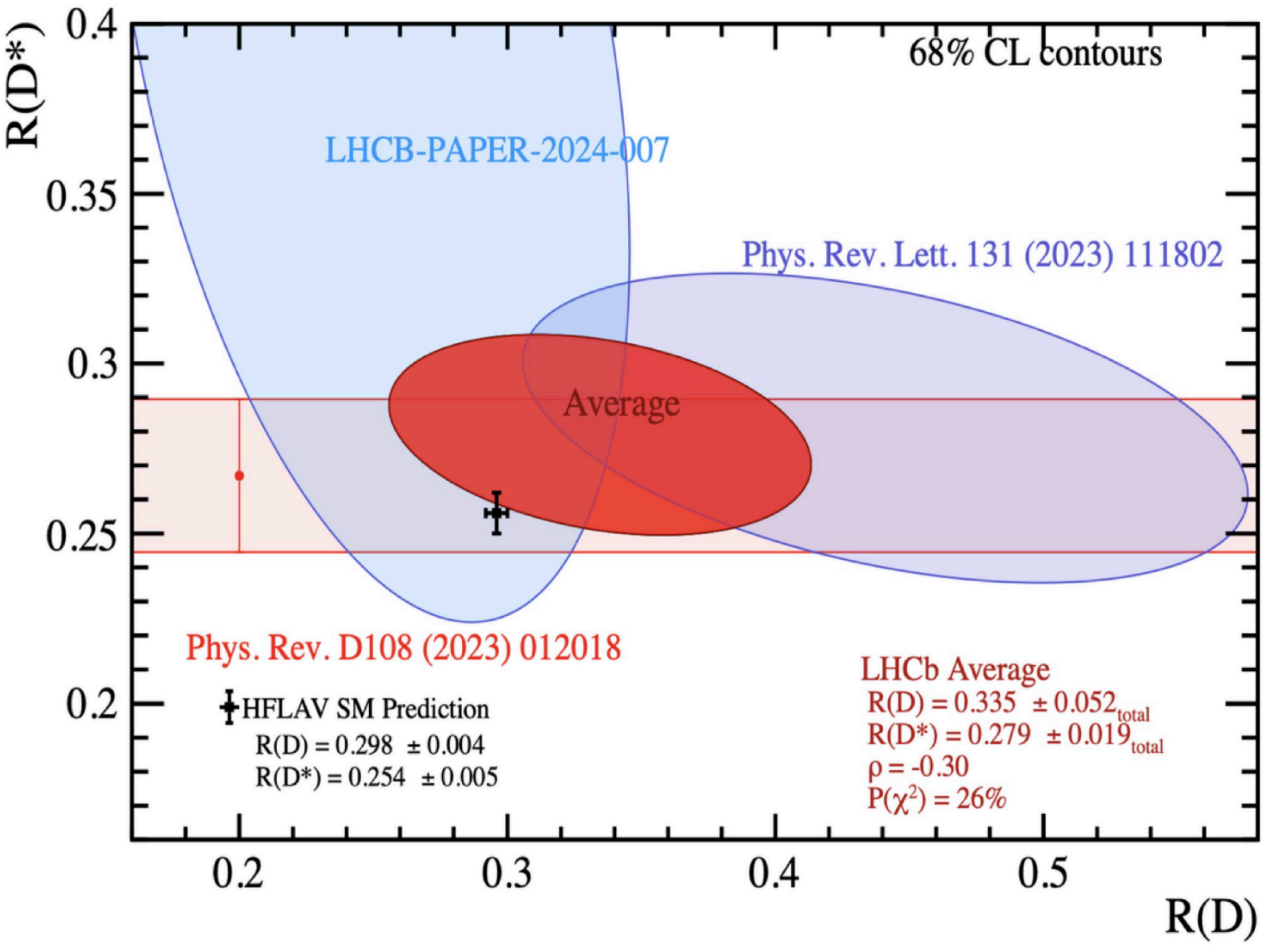
Backup

LFU in D_s decays

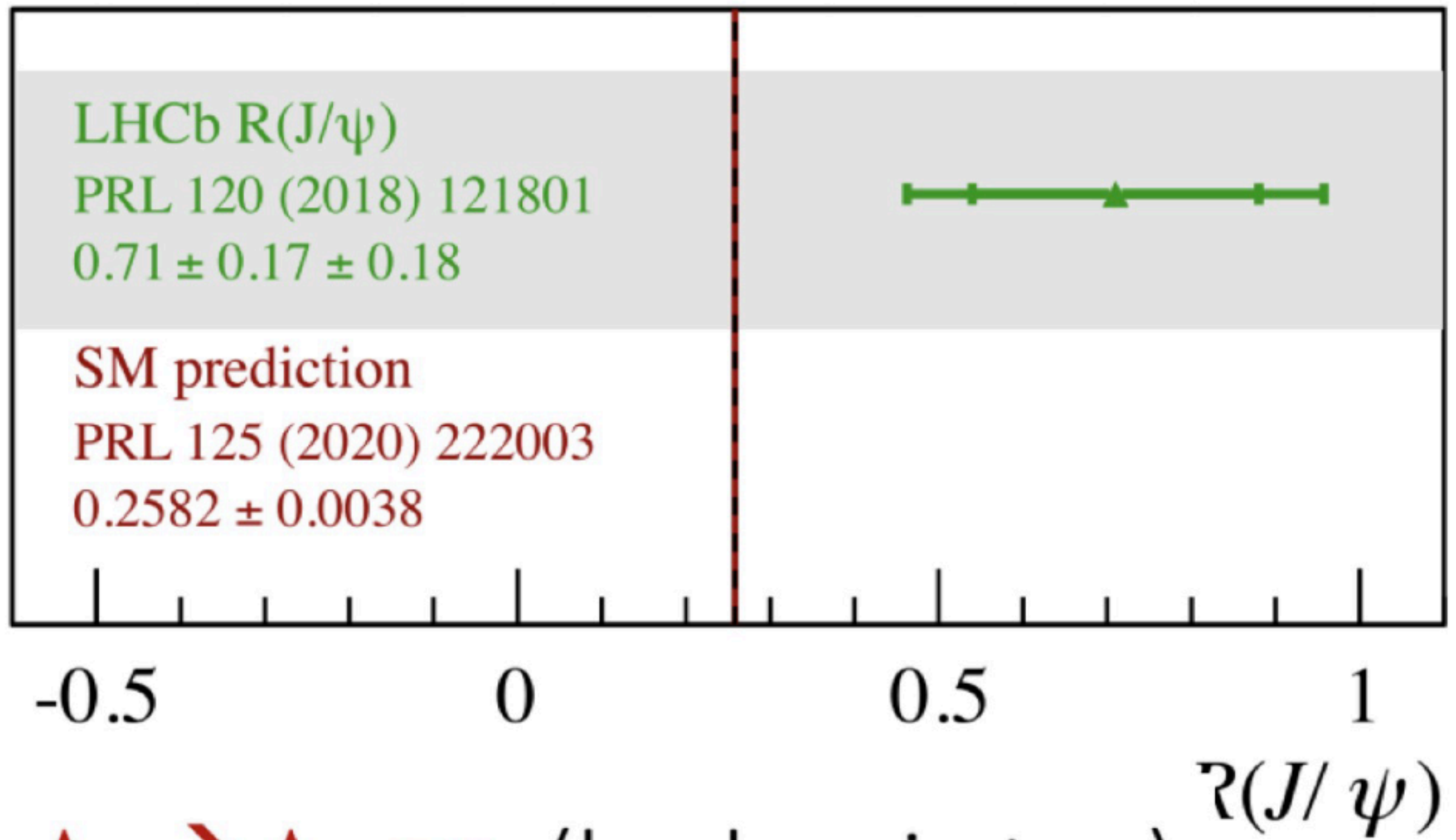
BESIII PRD108(2023)11200, μν (5.29±0.11±0.09) × 10^{-3}

$$R_{\tau/\mu} = \frac{\mathcal{B}[D_s^+ \to \tau^+ \nu]}{\mathcal{B}[D_s^+ \to \mu^+ \nu]} = 10.05 \pm 0.35$$ consistent with the SM prediction 9.75

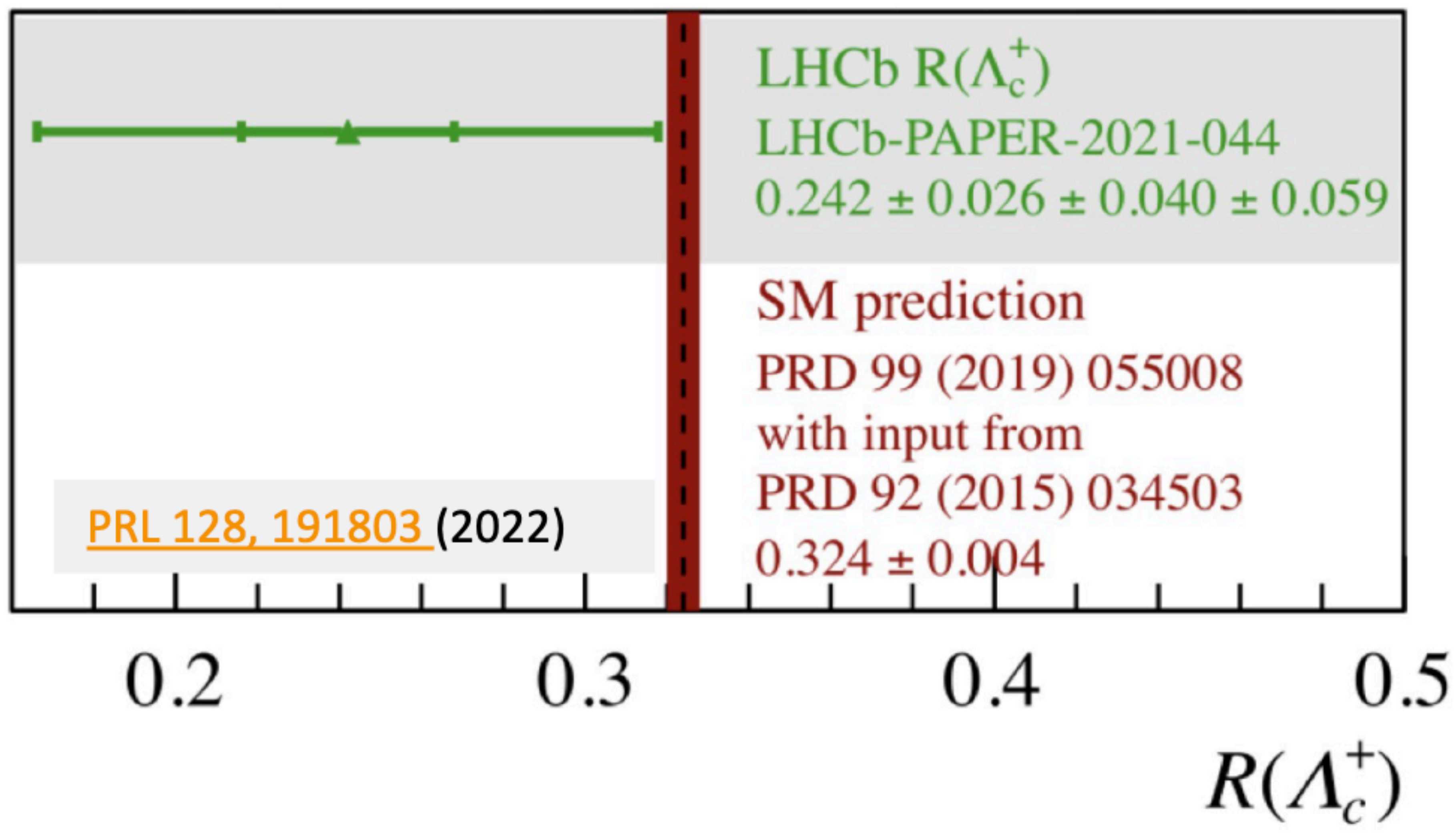
Recent LHCb measurements



$B_c \to J/\psi\, \tau\nu$ (muonic tau)



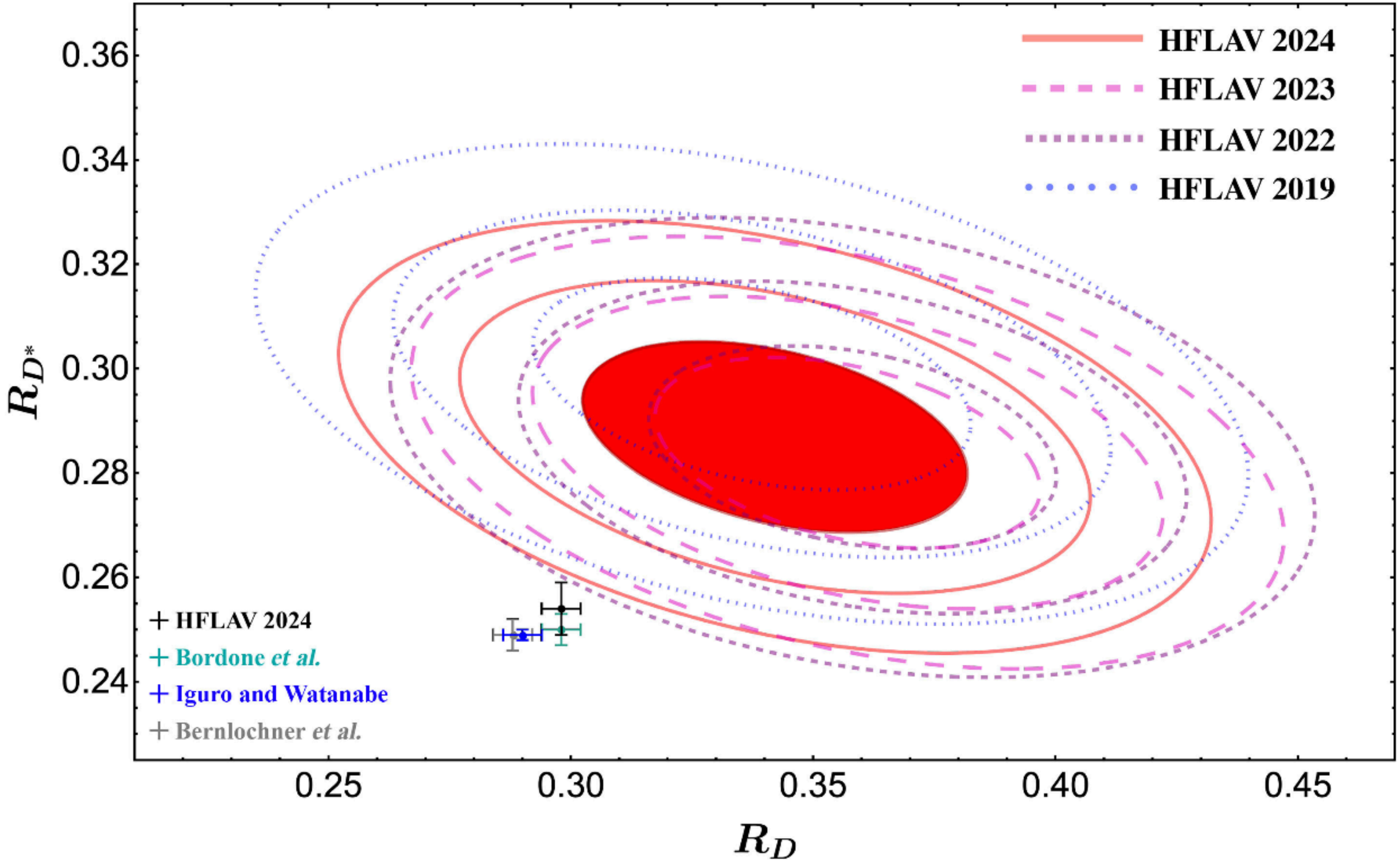
$\Lambda_b \to \Lambda_c\, \tau\nu$ (hadronic tau)



M.Rotondo, FPCP 2024

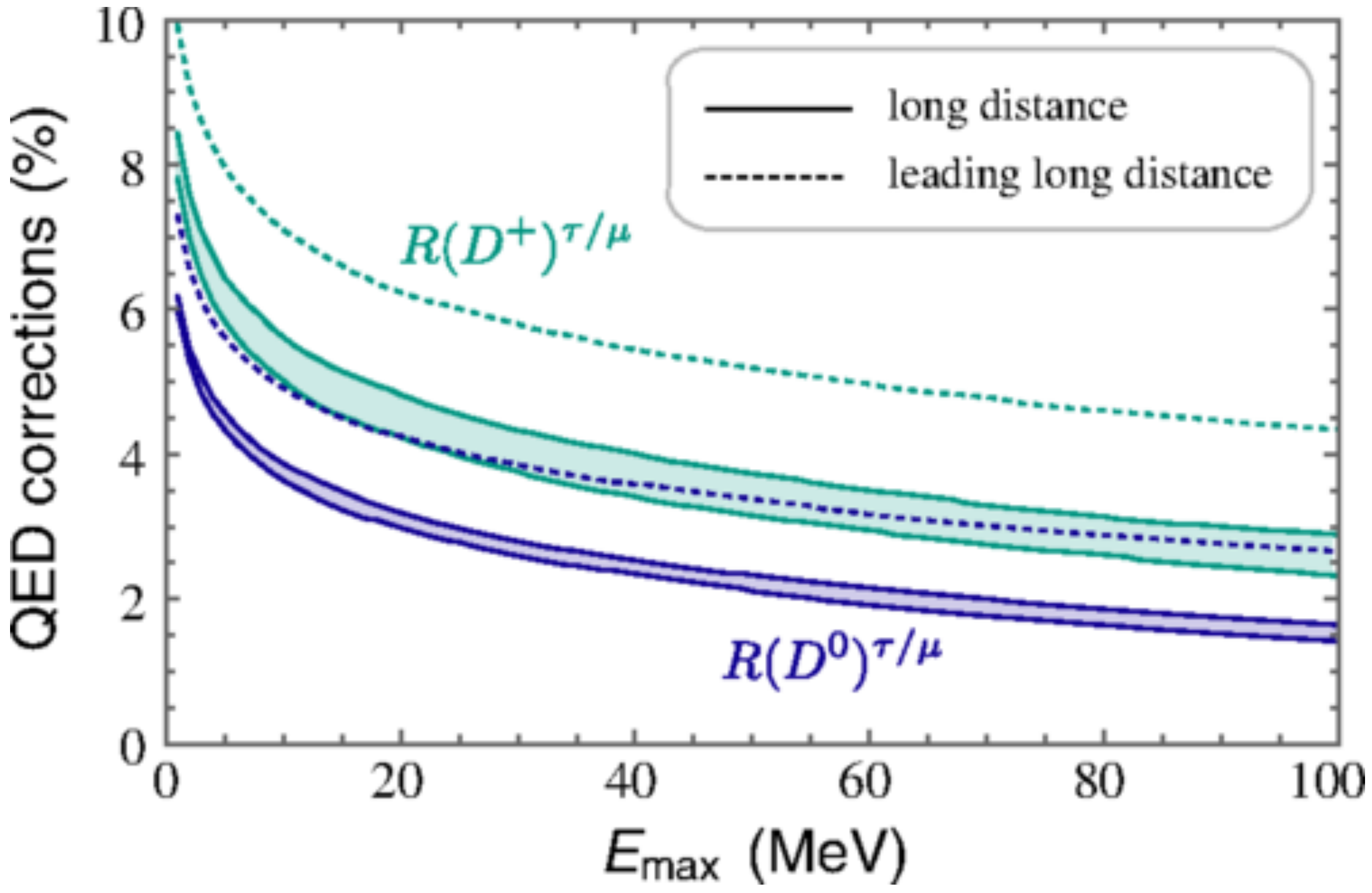
"*B* anomaly" in semileptonic decays

PRD 110, 075005 (2024)



LFUV in SM

- LFU is broken in Yukawa interaction
  - Difference in kinematics and Higgs coupling due to different lepton masses
    - Charged lepton mass changes kinematics and modifies form factors in the hadronization
- QED corrections depend on lepton velocity (τ vs. ℓ (e, μ))
  - Long-distance QED correction could violate the lepton flavor universality



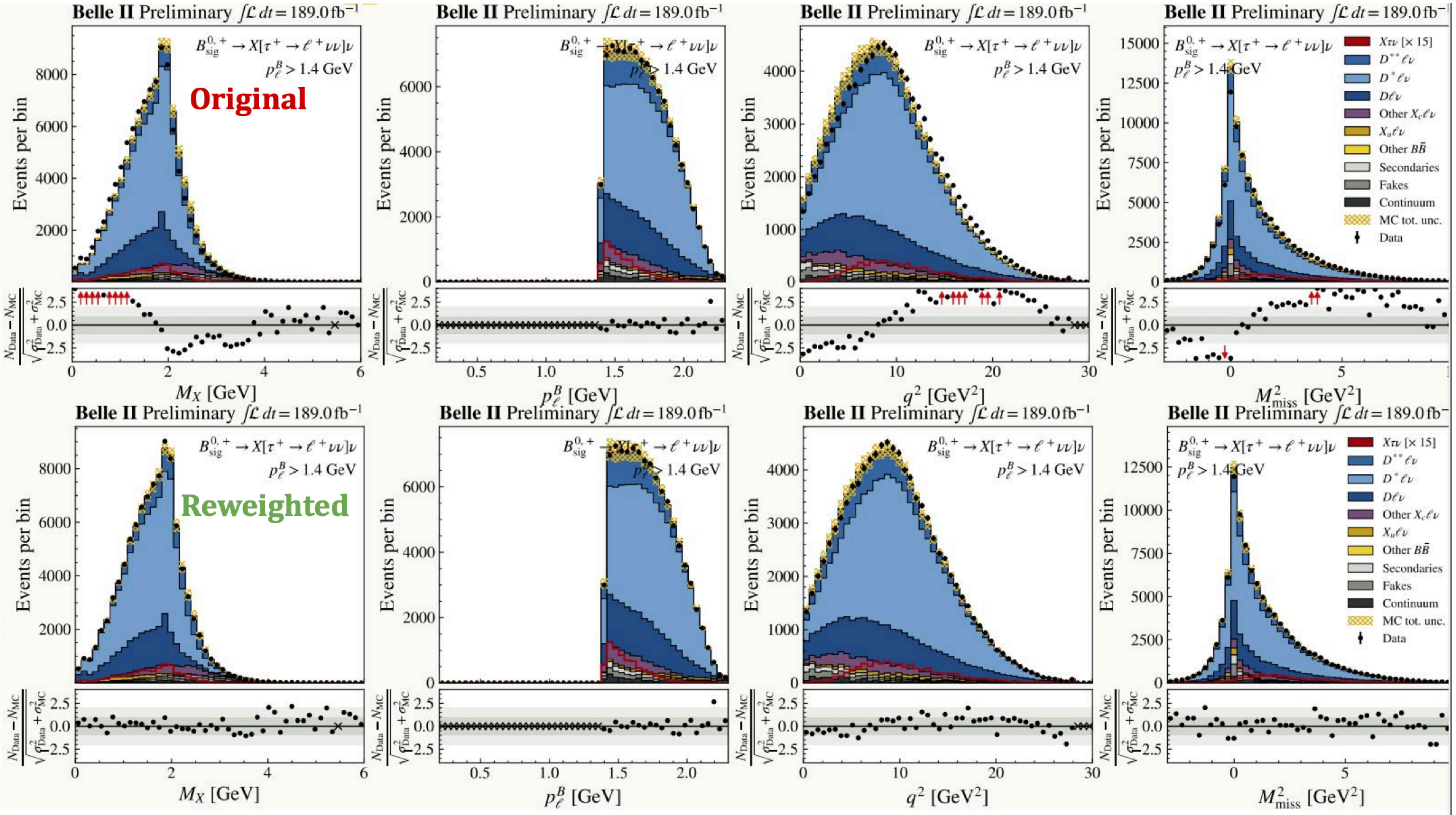
PRL. 120, 261804 (2018)

M_X reweighting

Reliable

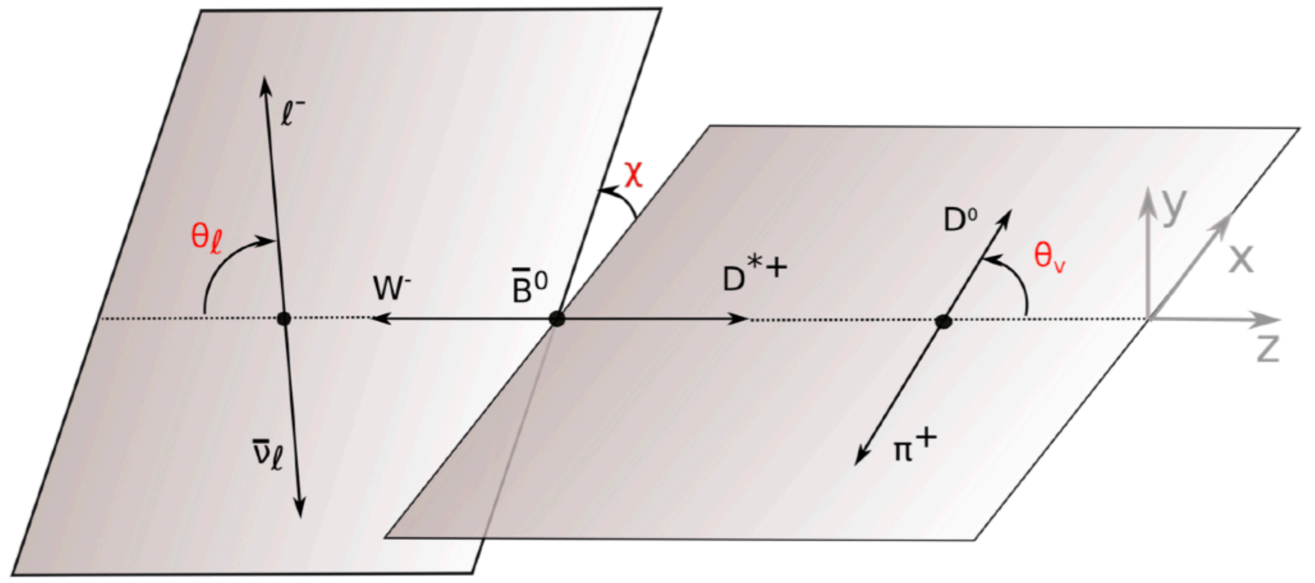
Henrik Junkerkalefeld

$$M_X{}^2 = \begin{pmatrix} E_X \\ \vec{p}_X \end{pmatrix}^2 \qquad q^2 = \left[\begin{pmatrix} E_{\mathrm{CMS}}/2 \\ -\vec{p}_{B_{\mathrm{tag}}} \end{pmatrix} - \begin{pmatrix} E_X \\ \vec{p}_X \end{pmatrix} \right]^2 \qquad m^2_{\mathrm{miss}} = \left[\begin{pmatrix} E_{\mathrm{CMS}} \\ \vec{p}_{\mathrm{CMS}} \end{pmatrix} - \begin{pmatrix} E_{\mathrm{CMS}}/2 \\ -\vec{p}_{B_{\mathrm{tag}}} \end{pmatrix} - \begin{pmatrix} E_\ell \\ \vec{p}_\ell \end{pmatrix} - \begin{pmatrix} E_X \\ \vec{p}_X \end{pmatrix} \right]^2$$



LFU tests in $B \to D^* l \nu$ angular asymmetries

- Measure angular asymmetries separately for $D^* e\nu$ and $D^* \mu\nu$ final states; their differences are sensitive to LFU violation
- Belle II measures A_{FB}, S_3, S_5, S_7, S_9 (defined in PRD 107,015011) as a function of w, with $x = \cos\theta_l$ for $A_x(w)$, other choices for S_3-S_9

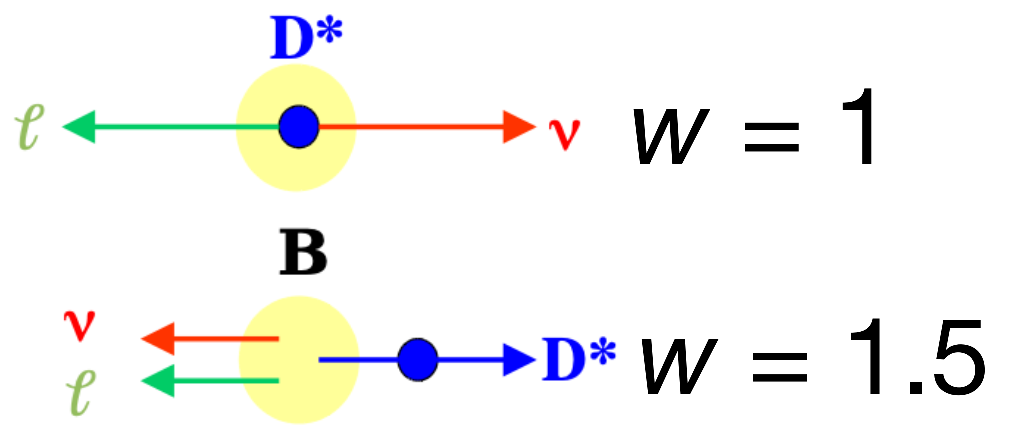


$$\mathcal{A}_x(w) \equiv \left(\frac{d\Gamma}{dw}\right)^{-1}\left[\int_0^1 - \int_{-1}^0\right] dx \frac{d^2\Gamma}{dw\,dx} \qquad \mathcal{A}_x(w) = \frac{N_x^+(w) - N_x^-(w)}{N_x^+(w) + N_x^-(w)}$$

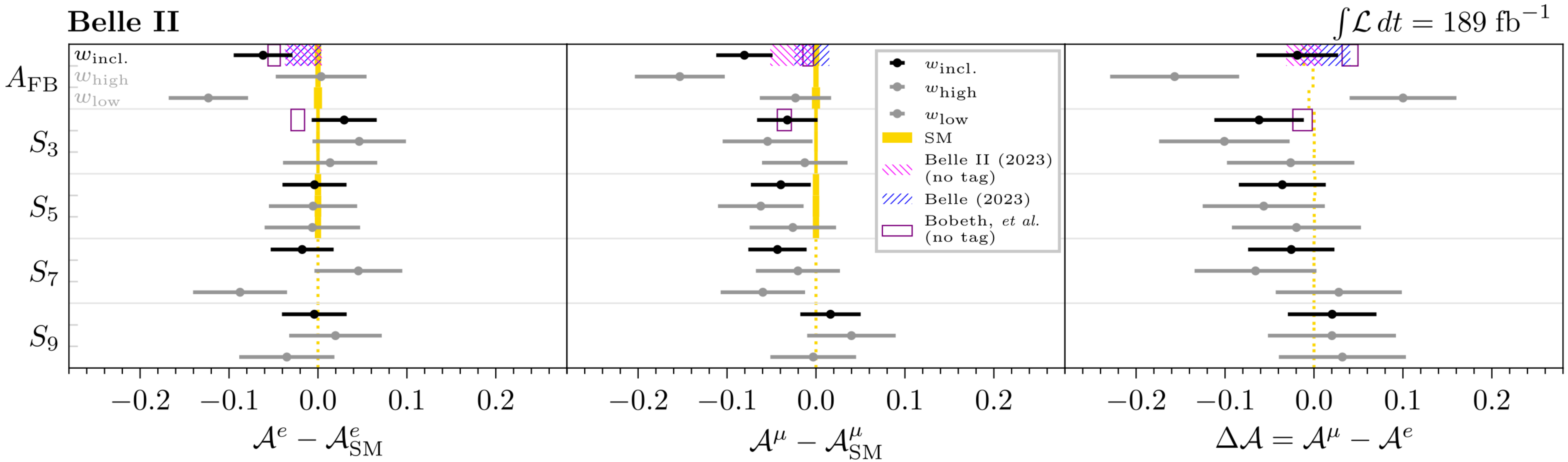
$$w \equiv \frac{m_{B^0}^2 + m_{D^*}^2 - q^2}{2 m_B m_{D^*}}$$

- The differences are expected to be small in SM

$$\Delta\mathcal{A}_x(w) \equiv \mathcal{A}_x^\mu(w) - \mathcal{A}_x^e(w)$$



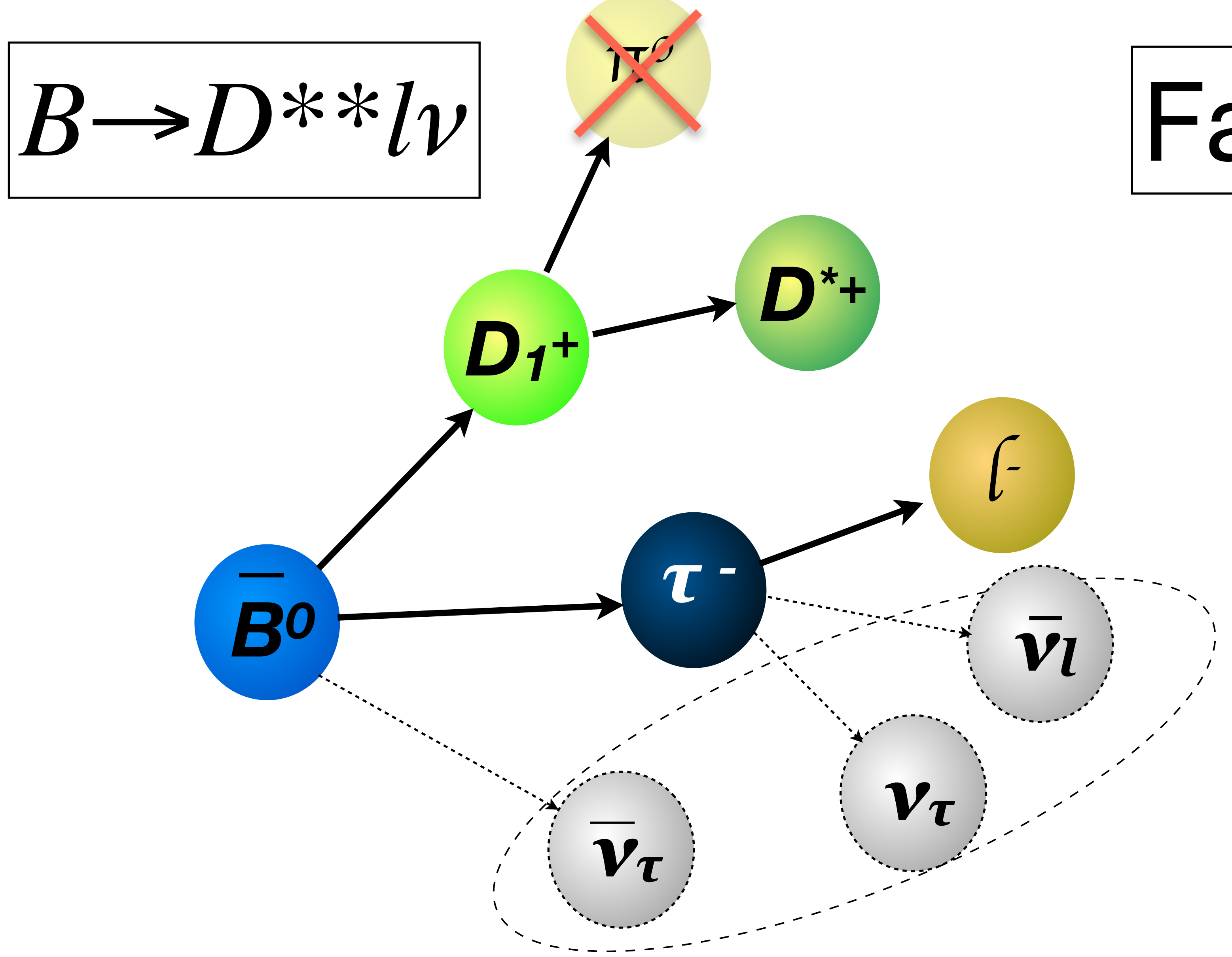
- All asymmetry consistent with SM, the measurements are statistics limited

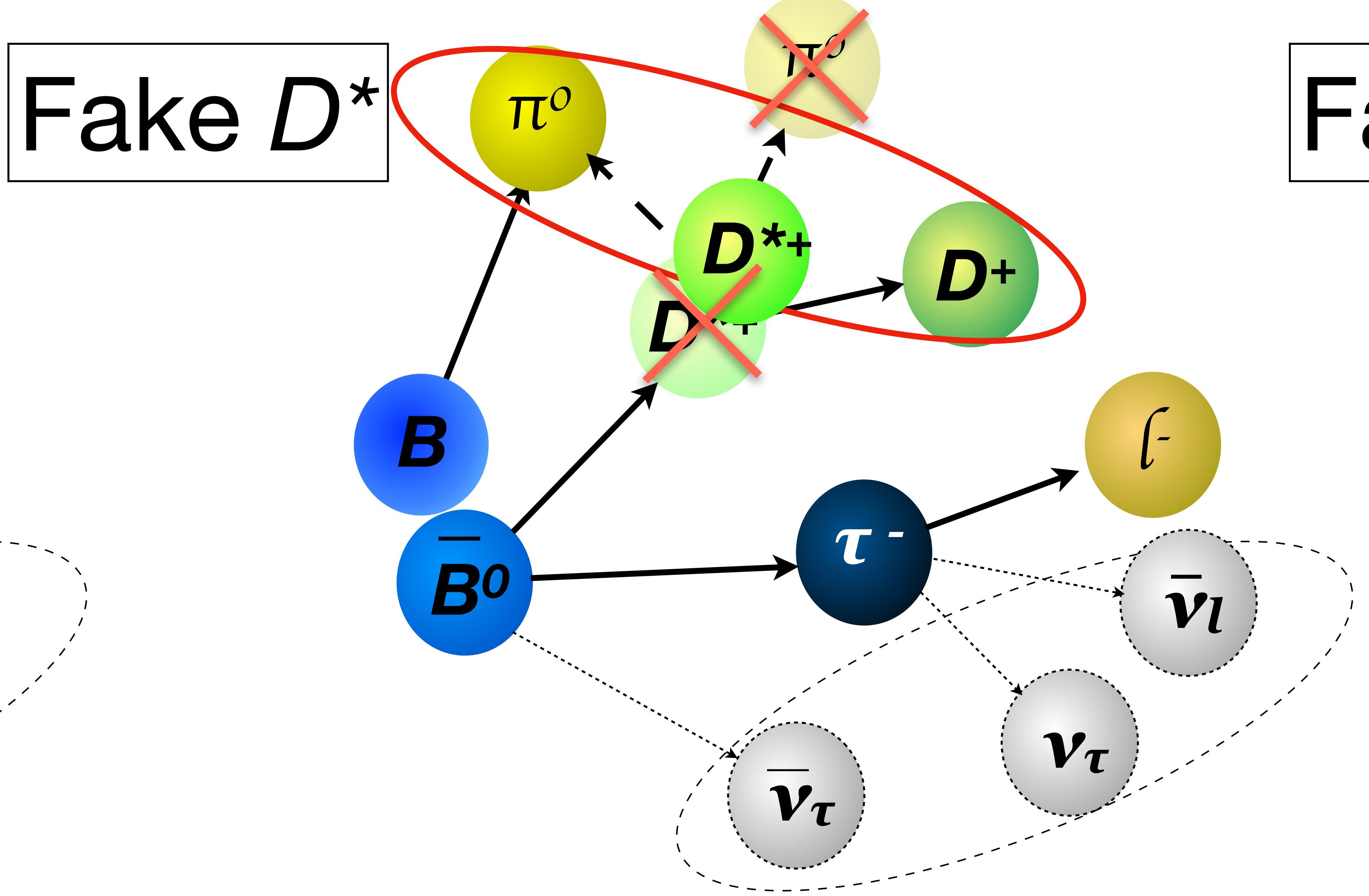


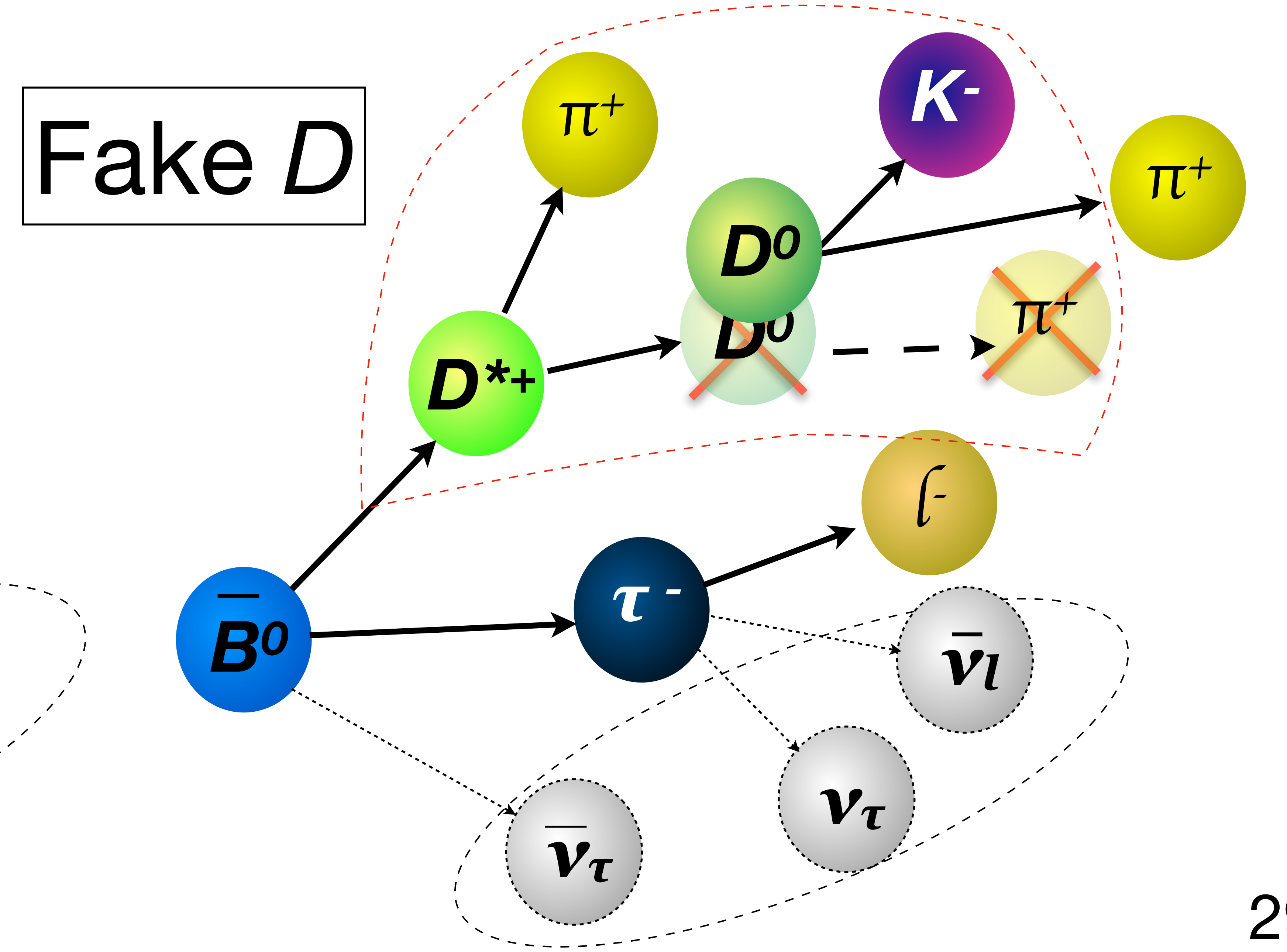
Dominant backgrounds

- Fraction of survived *B* candidates in each category after event selections are estimated based on Belle II MC simulation

B condidates	$B \to D^* \tau \nu$	$B \to D^* l \nu$	Background Truth $D^{(*)}$	Background Fake $D^{(*)}$
			$B \to D^{**} l \nu$, $B \to D^{(*)} X$, B^0<->$B^{\pm}$, …	
B^0	2.7%	65.5%	12.5%	19.2%
$B^{\pm}$	1.7%	34.7%	5.9%	57.8%

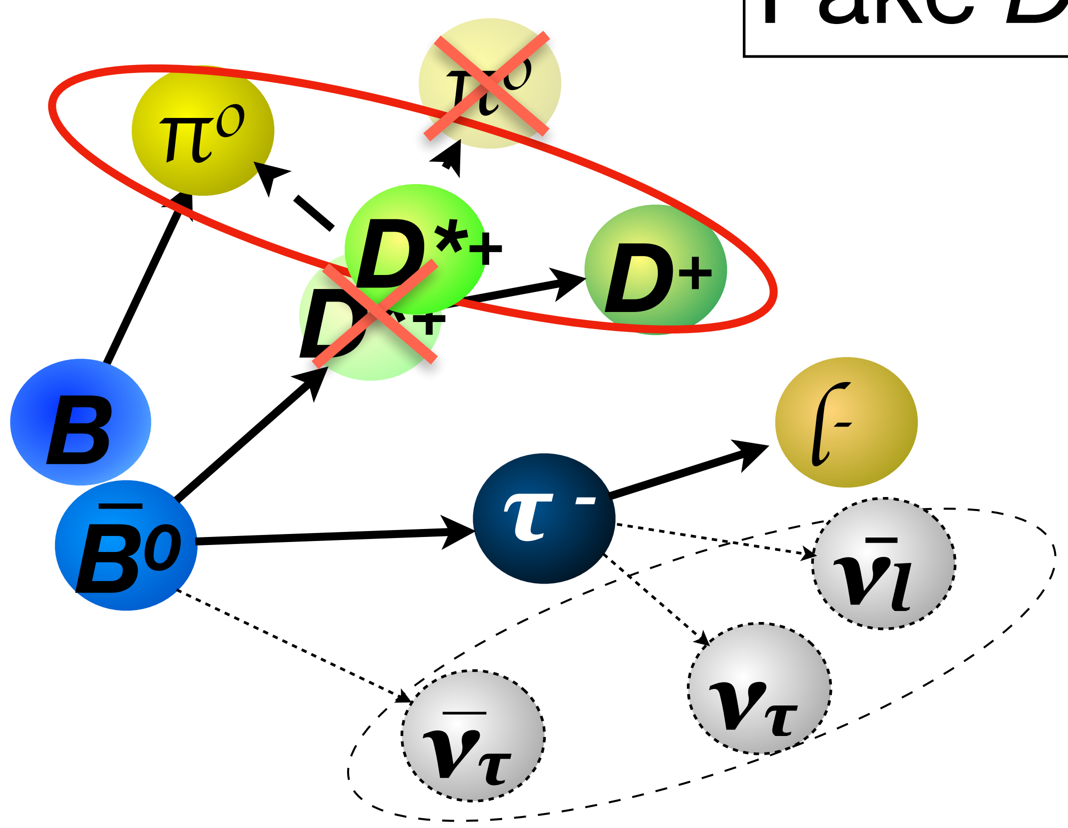


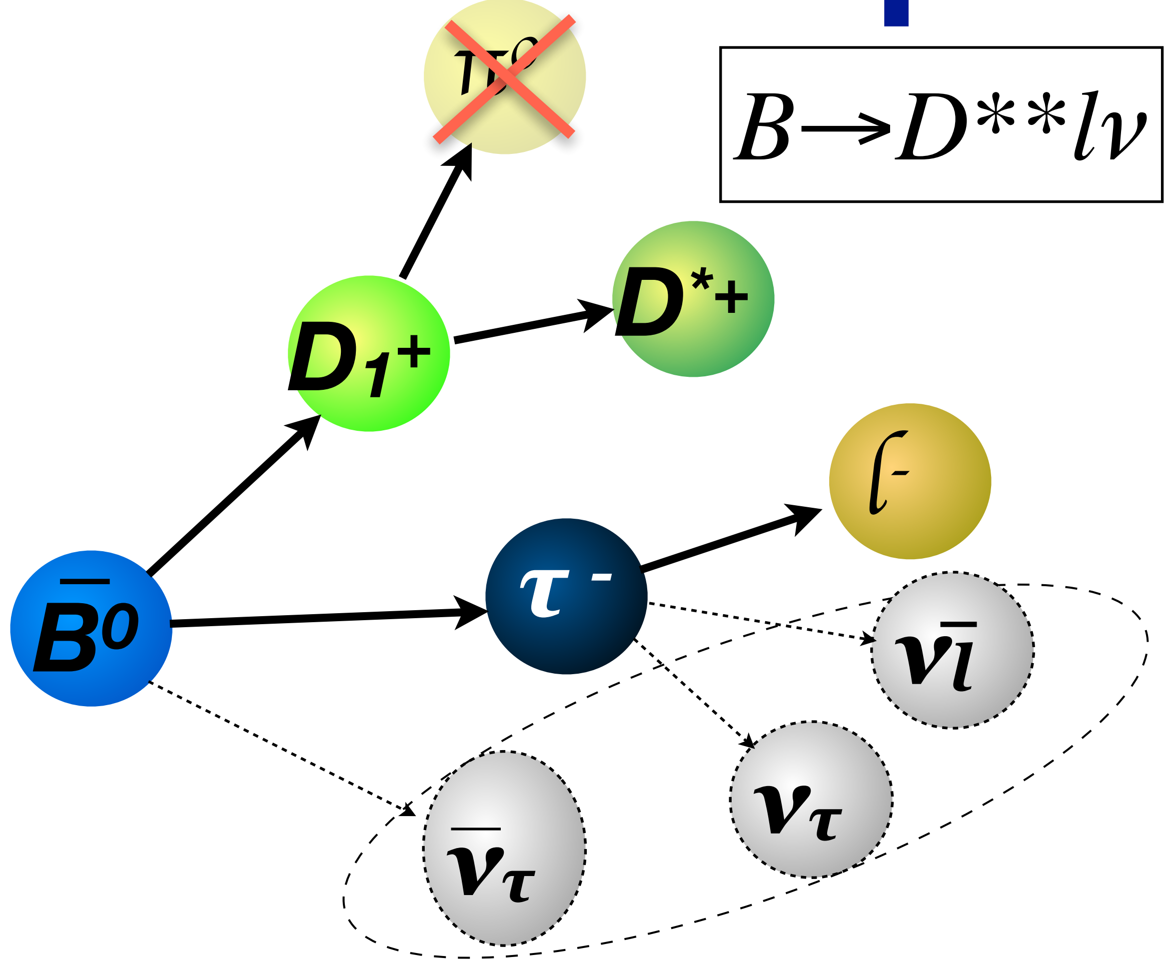


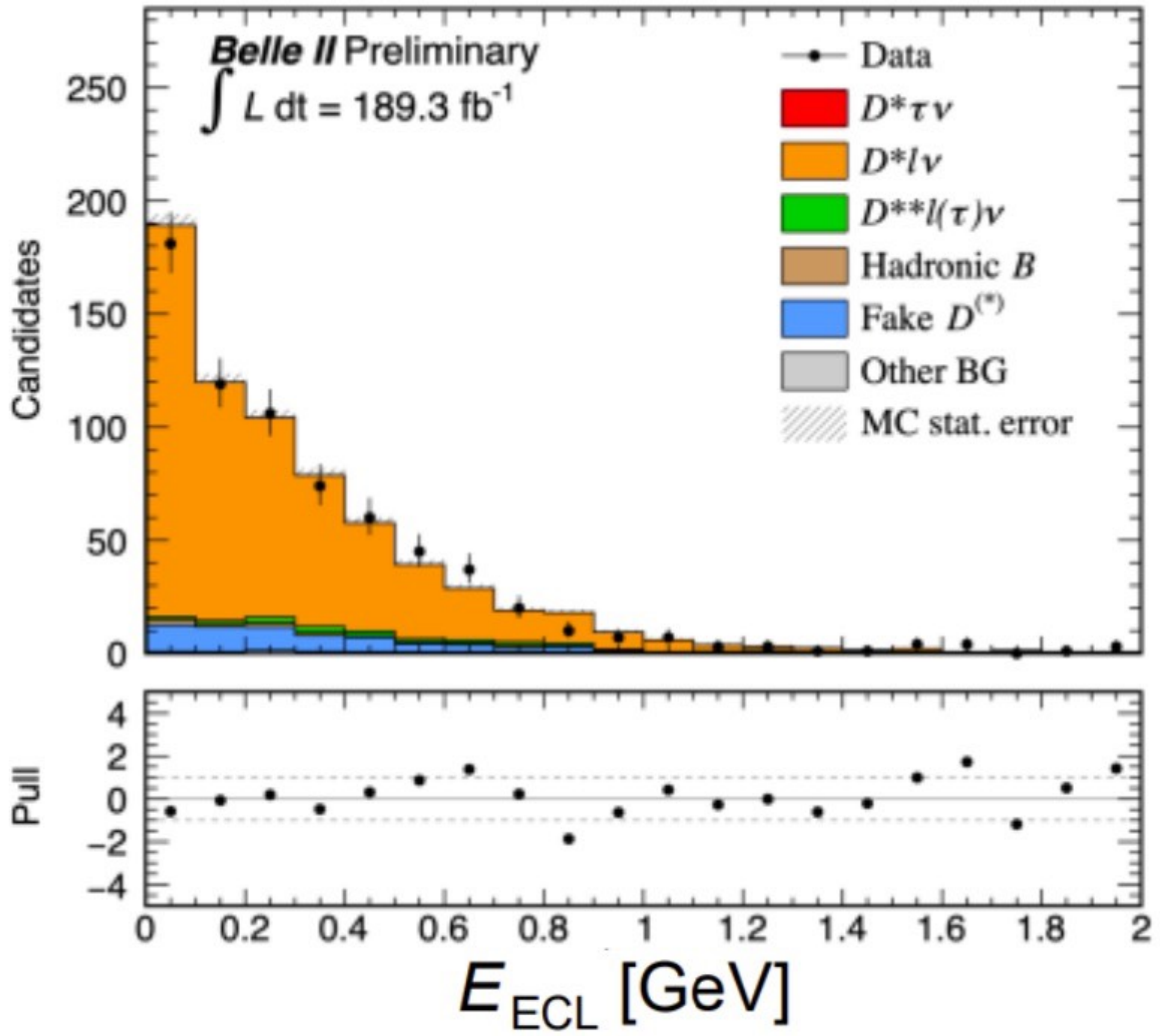


Dominant backgrounds and control samples

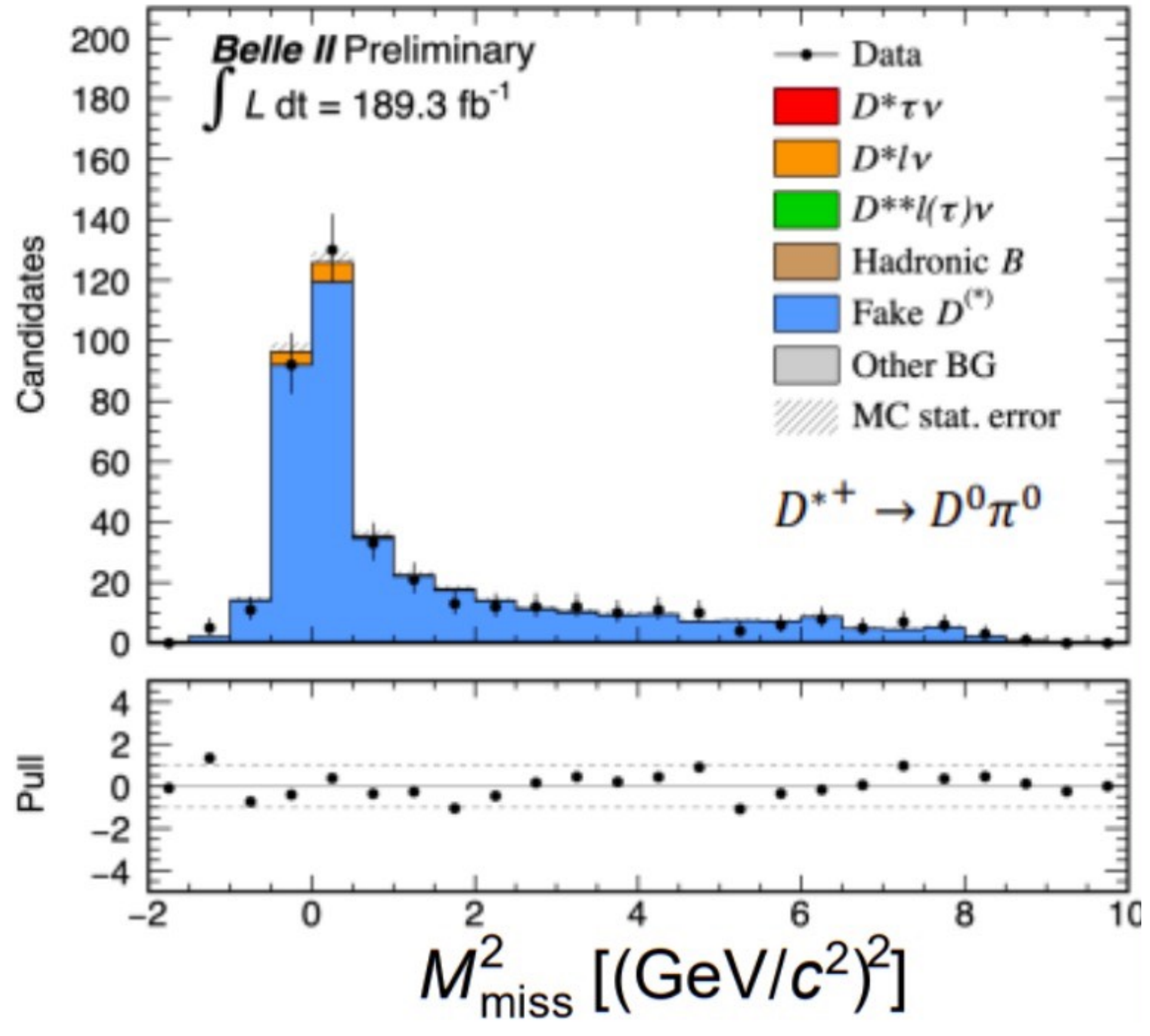
Fake D^*



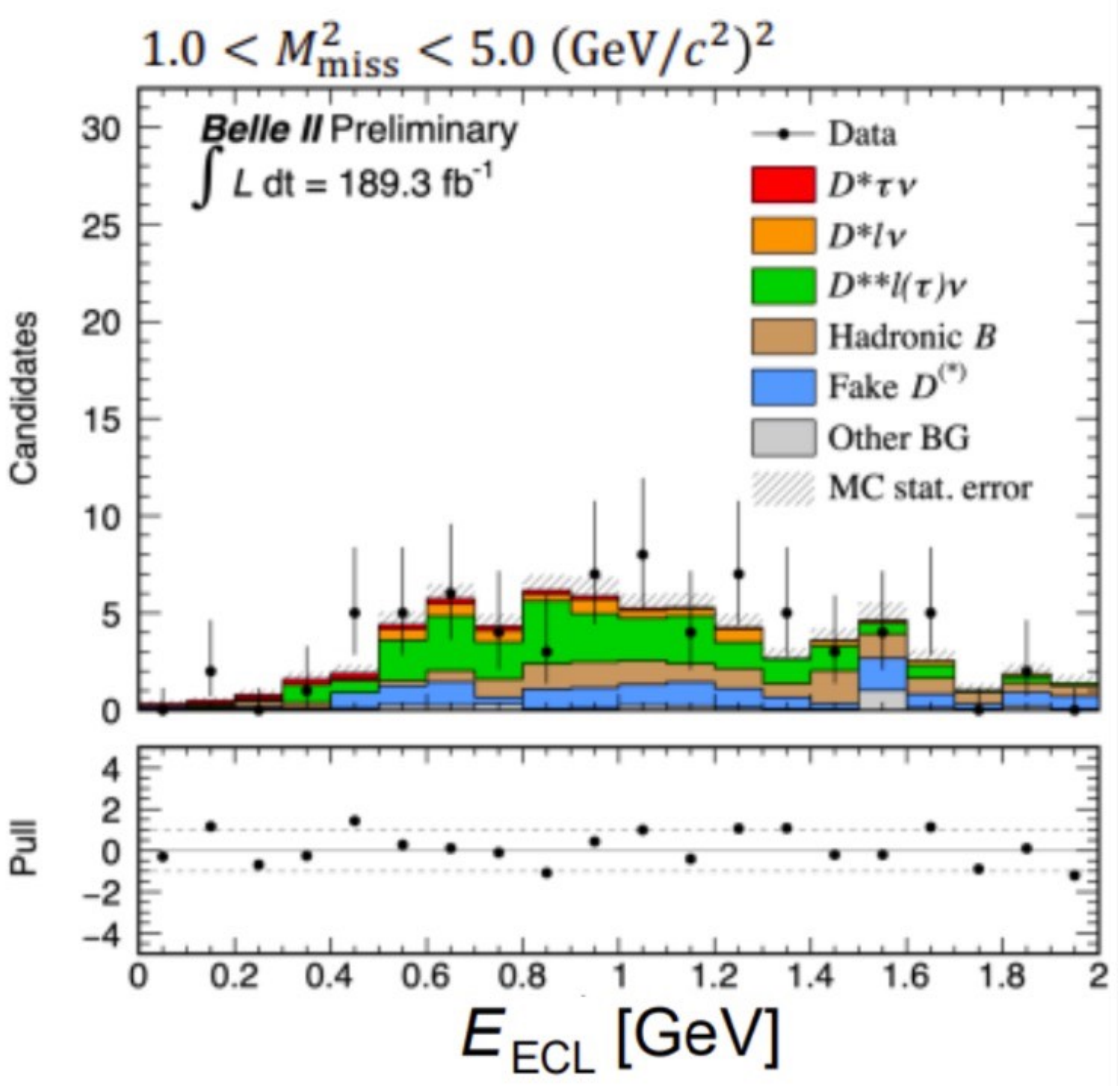




$q^2 < 3.5$ GeV sideband: validate E_{ECL} modeling



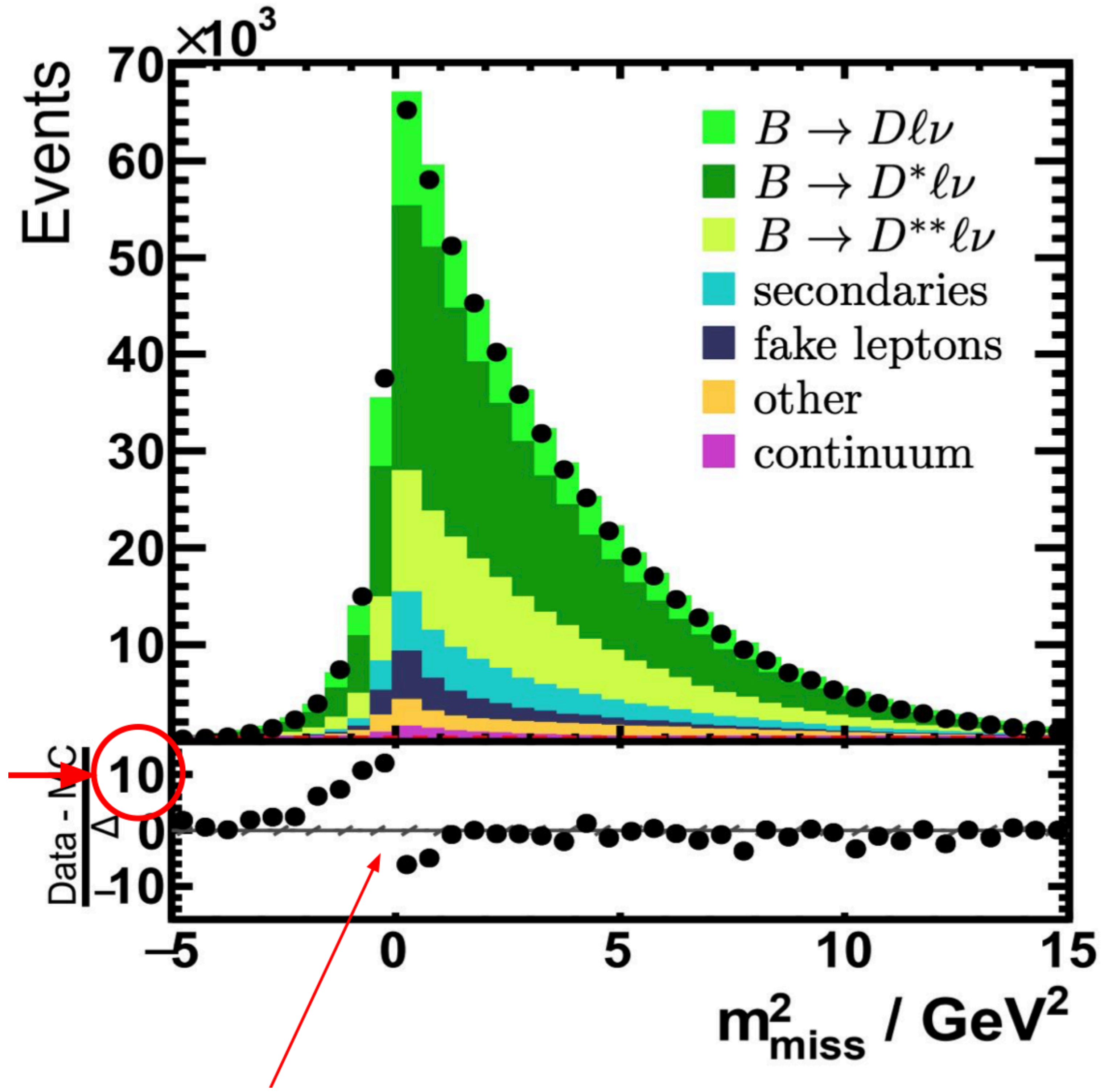
$m(D\pi)$ - $m(D^*)$ sideband: validate fake D^* modeling



Reconstruct $D^*\pi^0 l\nu$ validate D^{**} modeling

$R_{\tau/\ell}(X)$ measurement is difficult

- Belle attempt to understand the Data/MC disagreement
  - Detector effects are far too small
  - Beam backgrounds are far too small
  - The original appears to be somewhere in the physics simulation
- The main issues are:
  - Branching fractions are a big piece of the puzzle (particularly $D \to K_L X$) but cannot solve it entirely
  - The phase-space modeling using in ~40% of D decays is significant/unfixable
  - The PDG inclusive and exclusive BFs cannot be reconciled

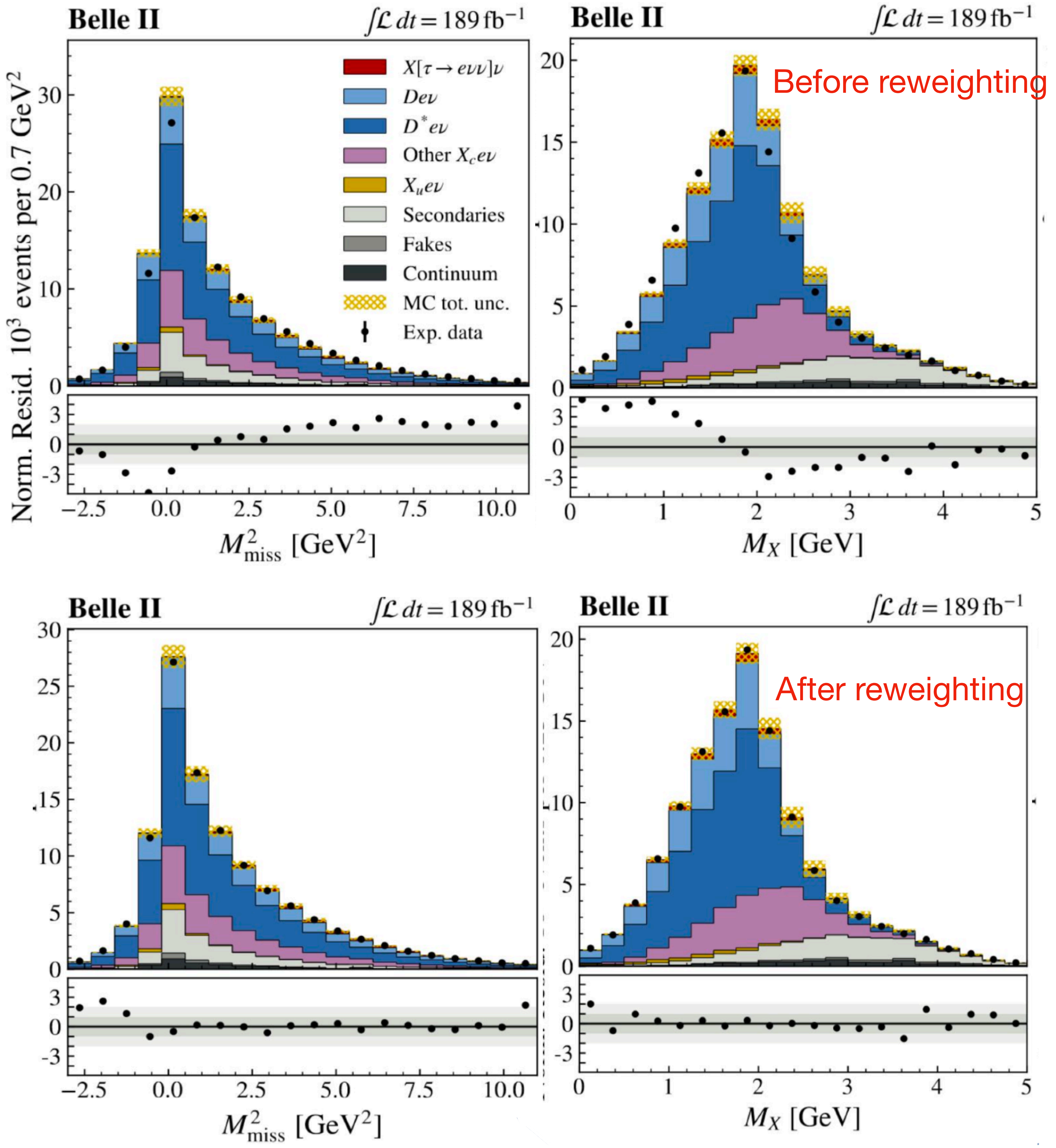


- Fixing the issue at generator level is not feasible
  - Instead, use M_X to reweight our MC

Update the modeling for $R_{\tau/\ell}(X)$ measurement

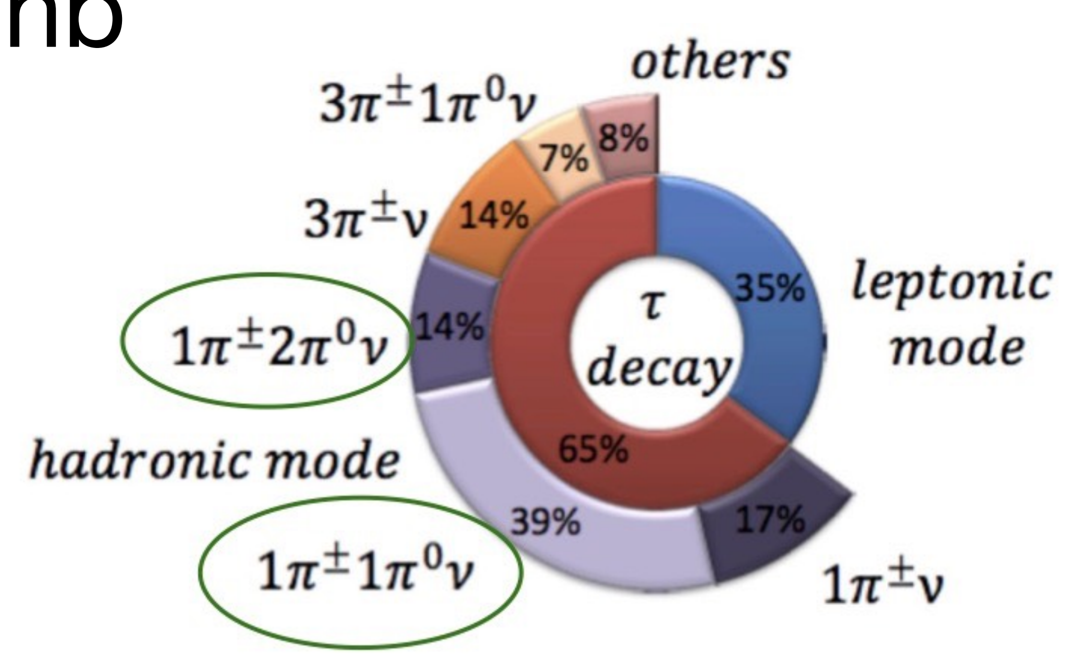
PRL132, 211804

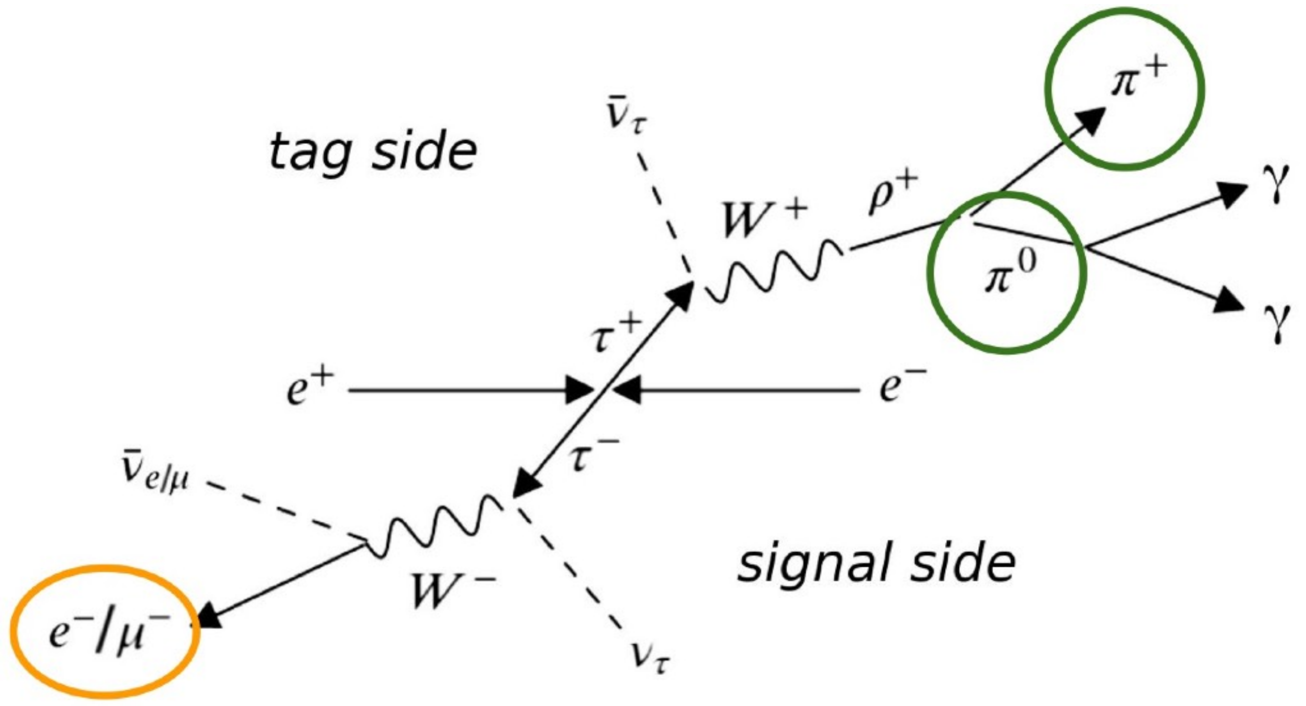
- Approach employed at Belle II: M_X reweighting
  - Events weights from data/MC ratio in M_X distribution, applied to all events
  - q^2, M^2_{miss} can be expressed by reliable parts and M_X part
- Detailed adjustments to MC (FFs, B and D BFs)
- Signal yields are extracted by a binned maximum-likelihood simultaneous fit to lepton momentum at different M^2_{miss} bins



LFU test: τ decays

- Belle II is also a τ factory, σ_τ =0.92 nb <-> σ_B=1.05 nb
  - Produced as τ pairs; tag τ and signal τ
- New analysis: 362 fb^{-1}
  - 1x1 event topology
- Main systematics
  - Particle identification (0.32%)
  - Trigger (0.10%)
- Consistent with the SM at 1.4 σ





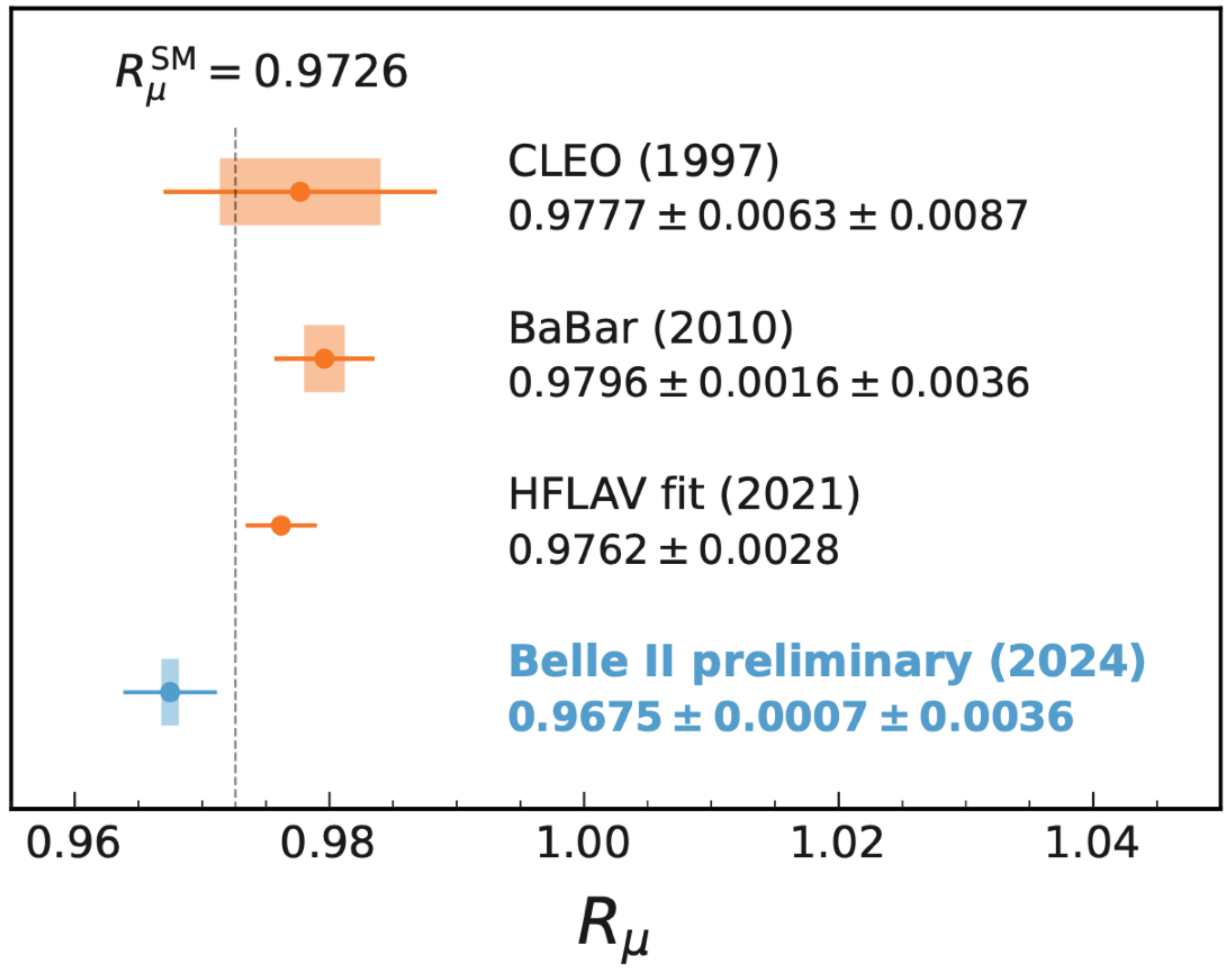
$$R_\mu = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

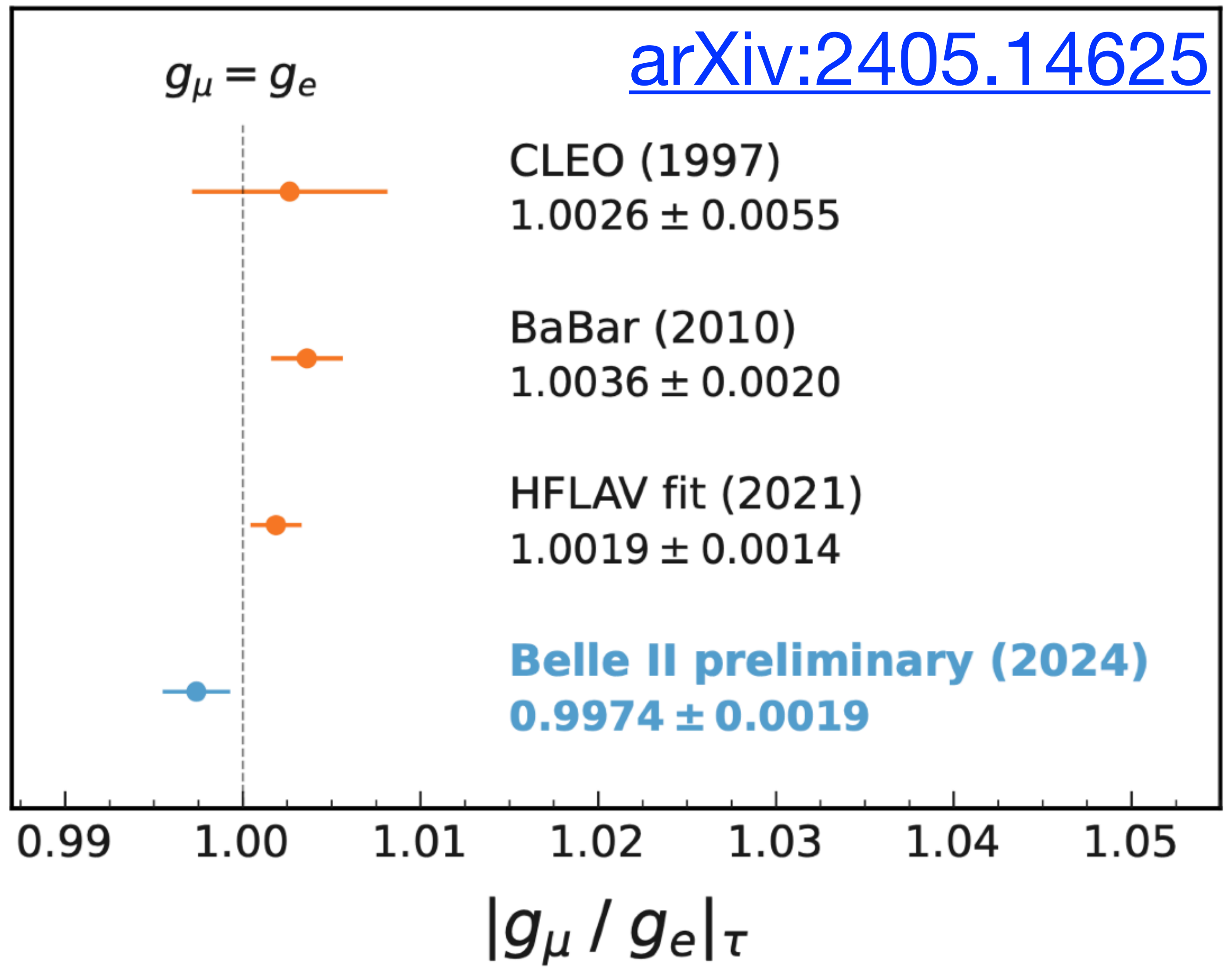
Slightly smaller than 1 in the SM due to e-u mass difference (R_μ^{SM} = 0.9726)

$$\left|\frac{g_\mu}{g_e}\right|_\tau = \sqrt{R_\mu \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)}}$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

1 in the SM





Most precise test of LFU in τ decays

New physics model

TABLE VI. Summary table for the single-mediator NP scenarios in light of the $b \to c\tau\nu$ anomaly. We add implications for the LHC searches and flavor observables in the last two columns, which is useful to identify the NP scenario. In the $V_2^{(1/3)}$ LQ scenario, 2σ for R_{D^*} implies that it can explain the R_{D^*} anomaly within the 2σ range (but not within 1σ).

	Spin	Charge	Operators	R_D	R_{D^*}	LHC	Flavor
$H^\pm$	0	$(\mathbf{1}, \mathbf{2}, 1/2)$	O_{S_L}	✓	✓	$b\tau\nu$	$B_c \to \tau\nu$, $F_L^{D^*}$, $P_\tau^{D^*}$, M_W
S_1	0	$(\bar{\mathbf{3}}, \mathbf{1}, 1/3)$	O_{V_L}, O_{S_L}, O_T	✓	✓	$\tau\tau$	ΔM_s, P_τ^D, $B \to K^{(*)}\nu\nu$
$R_2^{(2/3)}$	0	$(\mathbf{3}, \mathbf{2}, 7/6)$	O_{S_L}, O_T, (O_{V_R})	✓	✓	$b\tau\nu$, $\tau\tau$	$P_\tau^{D^*}$, M_W, $Z \to \tau\tau$, d_N
U_1	1	$(\mathbf{3}, \mathbf{1}, 2/3)$	O_{V_L}, O_{S_R}	✓	✓	$b\tau\nu$, $\tau\tau$	ΔM_s, $R_{K^{(*)}}$, $B_s \to \tau\tau$, d_N
$V_2^{(1/3)}$	1	$(\bar{\mathbf{3}}, \mathbf{2}, 5/6)$	O_{S_R}	✓	2σ	$\tau\tau$	$B_s \to \tau\tau$, $B_u \to \tau\nu$, M_W

PRD 110, 075005 (2024)