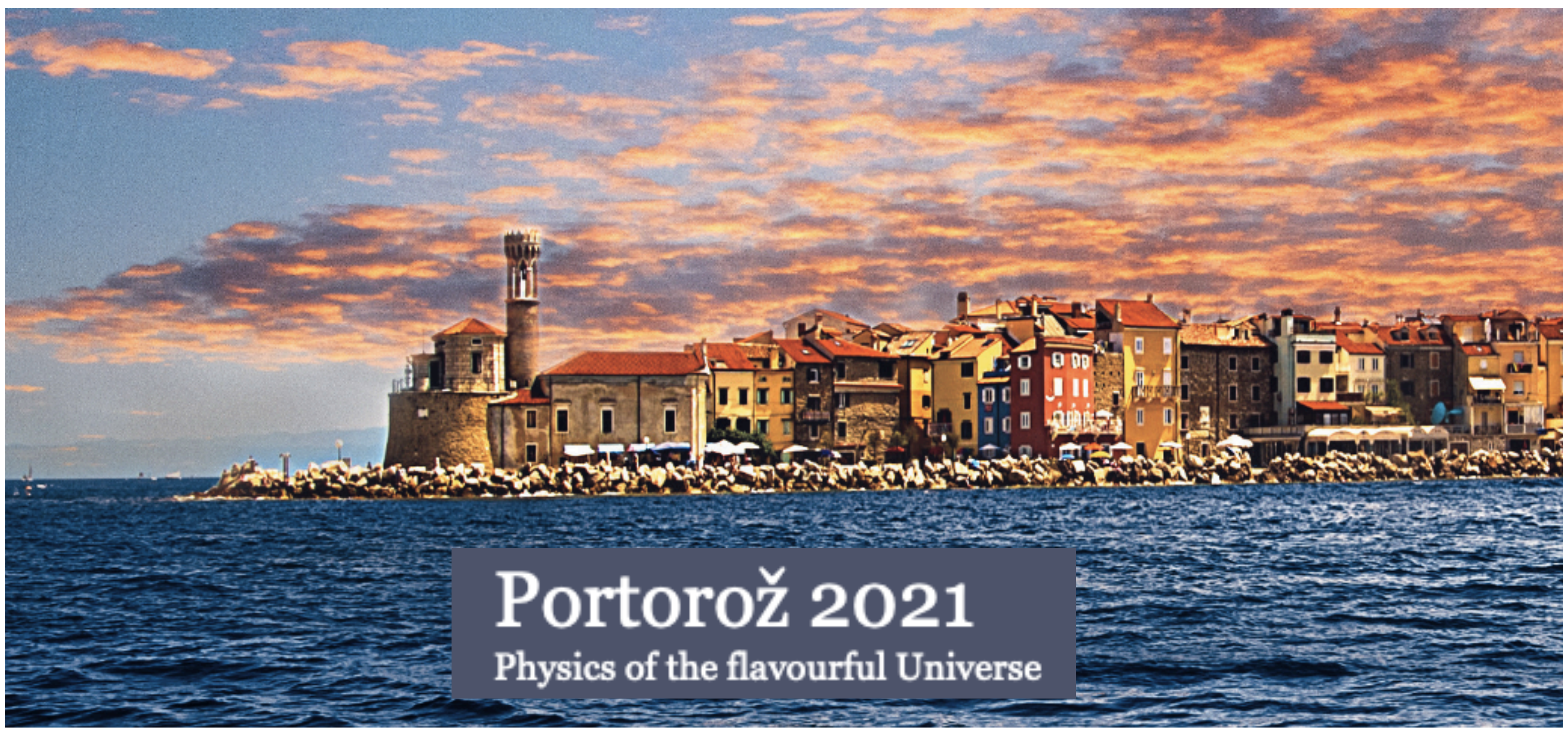
Leptoquarks and LFUV in B-decays

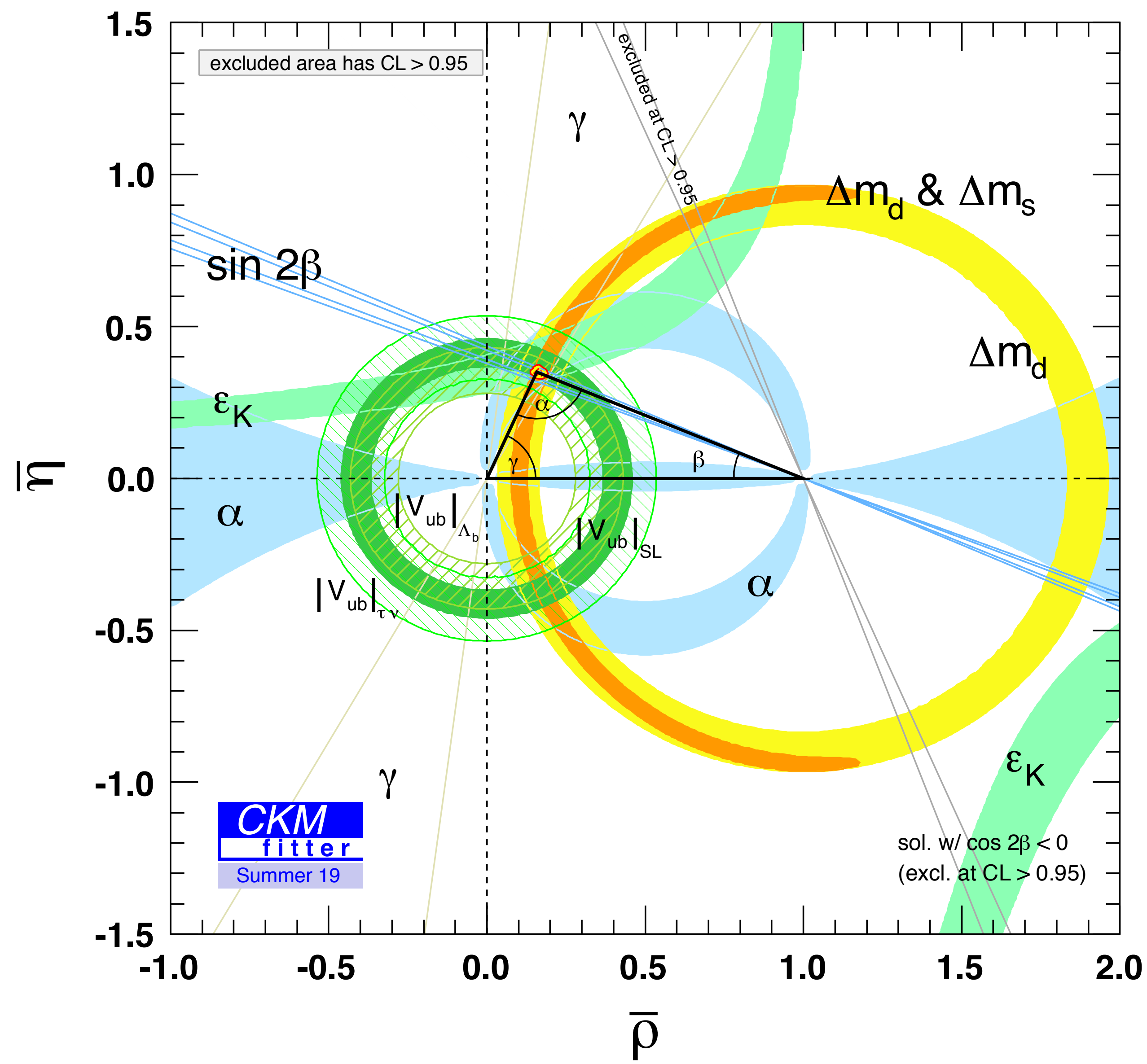
Damir Bečirević

Pôle Théorie, IJCLab
CNRS et Université Paris-Saclay

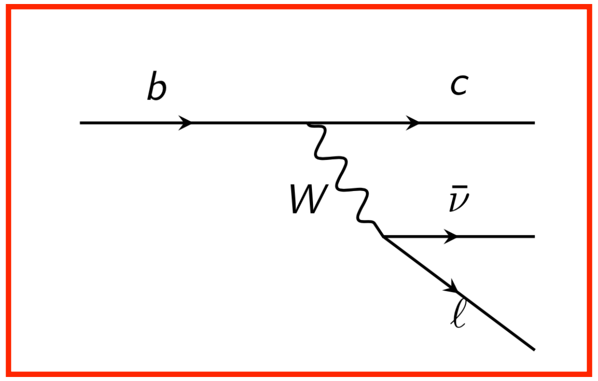


based on works done with A. Angelescu, I. Doršner, S. Fajfer, D. Faroughy, F. Jaffredo, N. Košnik, O. Sumensari

CKM-ology

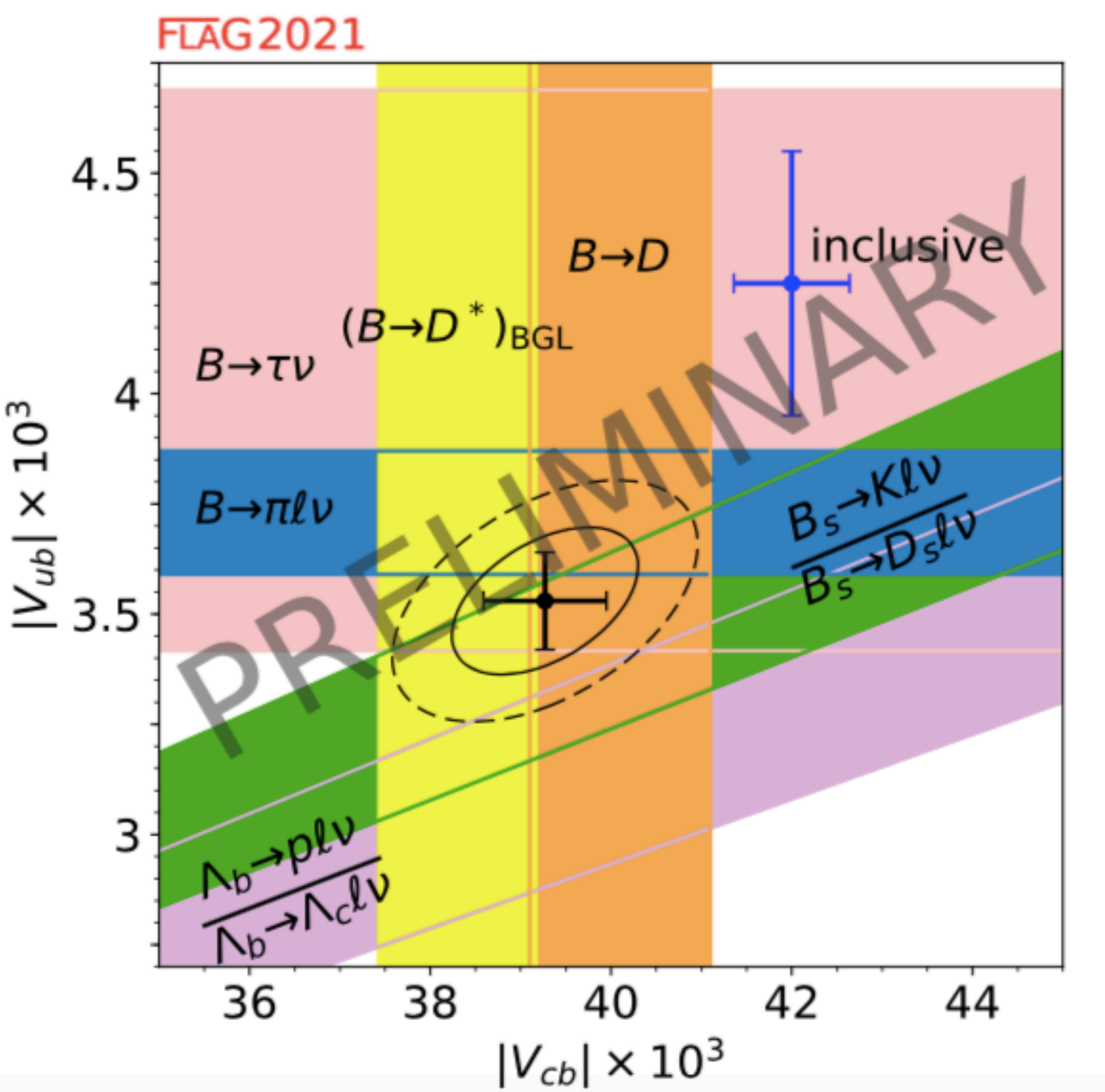


✘ Still open: inclusive v exclusive V_{ub} and V_{cb}?
Is V_{ud} well controlled? V_{us} keeps coming back (EM)…



CKM-ology - Small flavor 'anomaly'

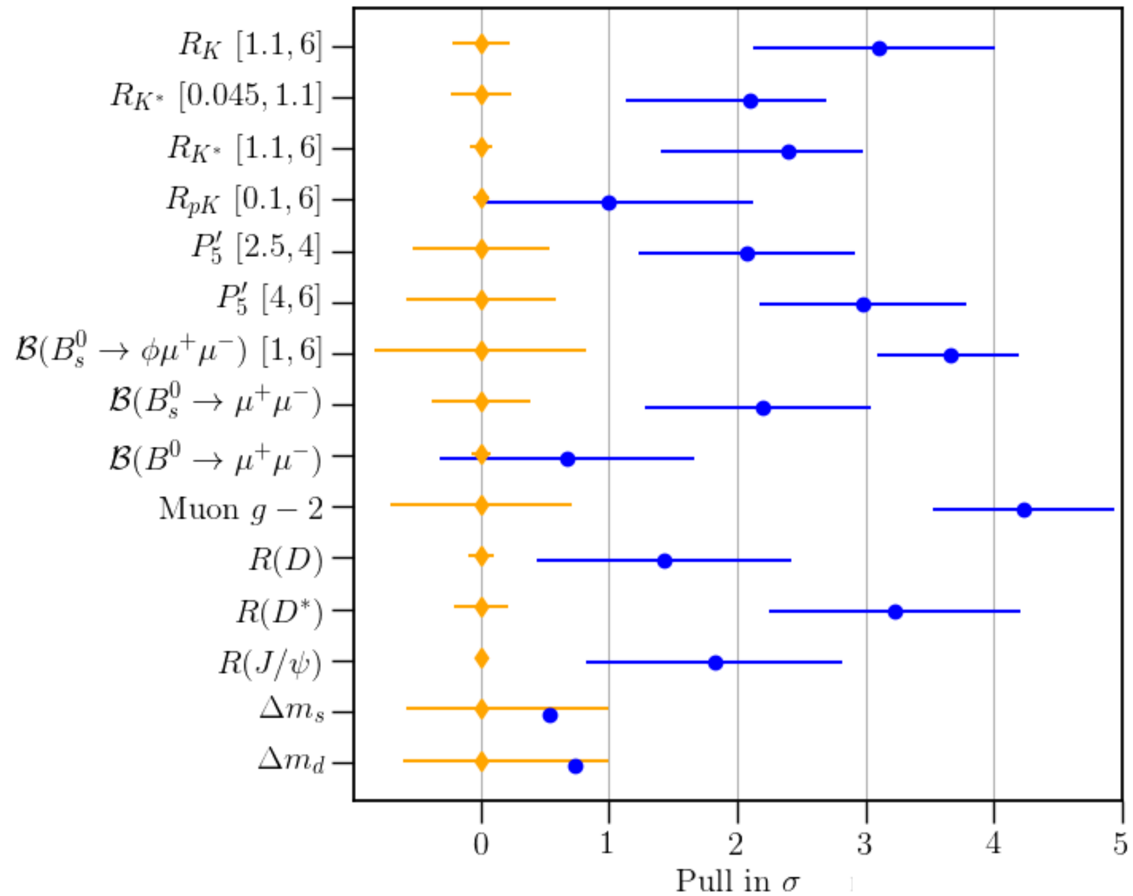
- ✘ Still open: inclusive v exclusive V_{ub} and V_{cb}?

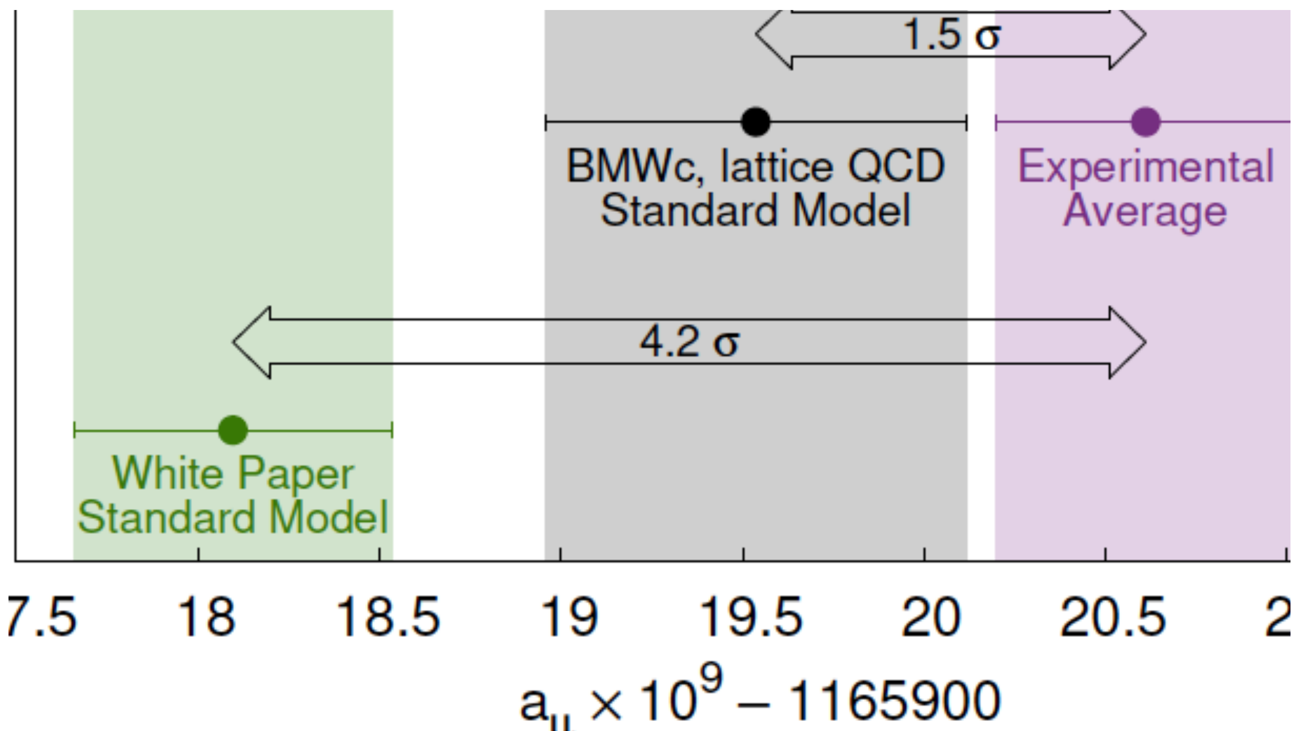


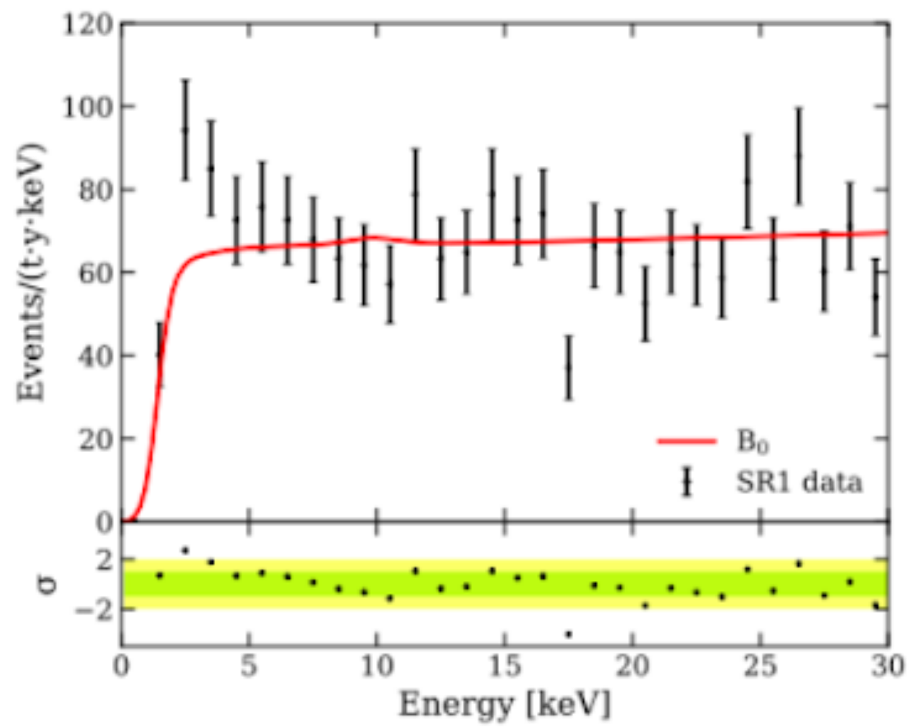
- ✘ Belle II (excl + incl), LHCb (excl)
- ✘ QCD on very fine lattices
  B → D and B → D* at *w=1*
- ✘ *New:* B → D* at *non-zero recoil*

cf. updates at http://flag.unibe.ch

More Flavor Anomalies







LFUV

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}_{\ell\in(e,\mu)} \qquad \& \qquad R^{\rm exp}_{D^{(*)}} > R^{\rm SM}_{D^{(*)}}$$

$$R_{K^{(*)}} = \left.\frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}\right|_{q^2\in[q^2_{\rm min},q^2_{\rm max}]} \qquad \& \qquad R^{\rm exp}_{K^{(*)}} < R^{\rm SM}_{K^{(*)}}$$

$$R^{\rm exp}_{D^{(*)}} > R^{\rm SM}_{D^{(*)}} \quad \Rightarrow \quad \Lambda_{\rm NP} \lesssim 3 \text{ TeV}$$

$$R^{\rm exp}_{K^{(*)}} < R^{\rm SM}_{K^{(*)}} \quad \Rightarrow \quad \Lambda_{\rm NP} \lesssim 30 \text{ TeV}$$

LFUV

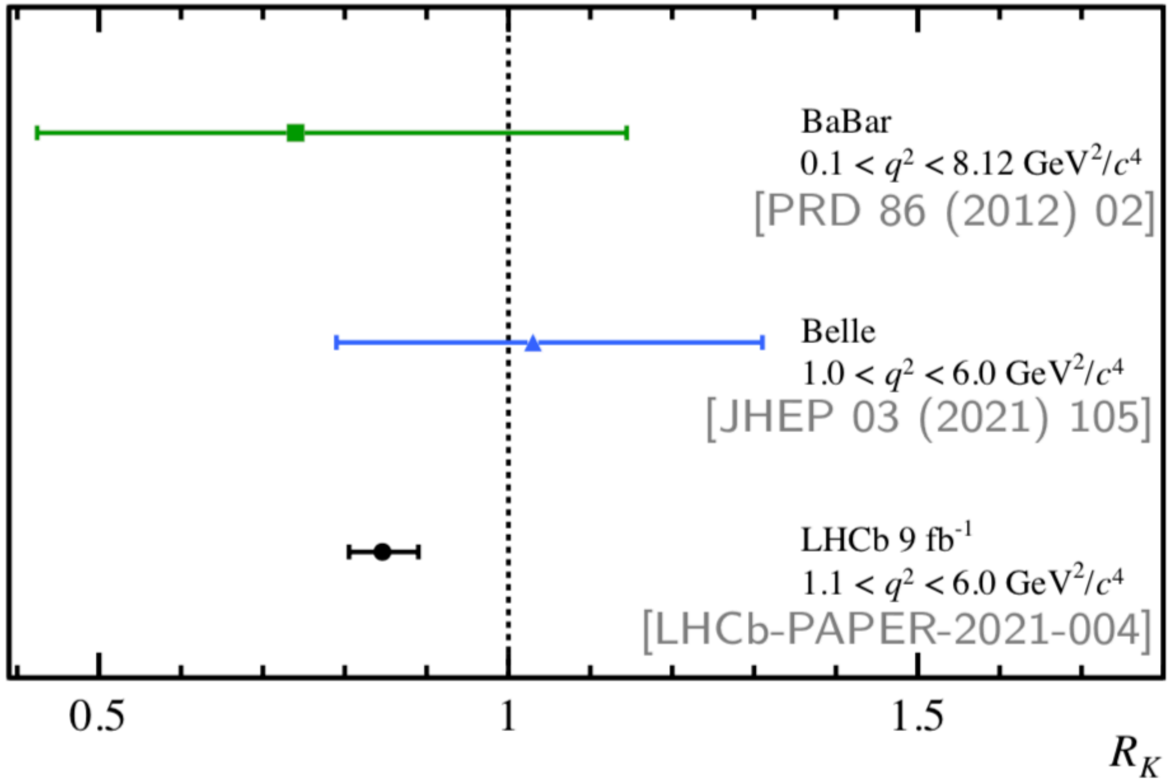
$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}_{\ell\in(e,\mu)} \quad \& \quad R^{\rm exp}_{D^{(*)}} > R^{\rm SM}_{D^{(*)}}$$

$$R_{K^{(*)}} = \left.\frac{\mathcal{B}(B \to K^{(*)}\mu\mu)}{\mathcal{B}(B \to K^{(*)}ee)}\right|_{q^2\in[q^2_{\rm min},q^2_{\rm max}]} \quad \& \quad R^{\rm exp}_{K^{(*)}} < R^{\rm SM}_{K^{(*)}}$$

- CKM factor cancels
- Bulk of hadronic uncertainties cancel
- $\langle D|\bar{c}\Gamma b|B\rangle$ computed in LQCD for several q^2's
- $\langle D^*|\bar{c}\Gamma b|B\rangle$ NEW computed on the lattice
- $R_{K^{(*)}}$: $q^2 \in [1,6]\,\mathrm{GeV}^2$ to stay away from $\bar{c}c$ resonances
- When no LQCD result, use models (LCSR) but say so!
- Control electromagnetism

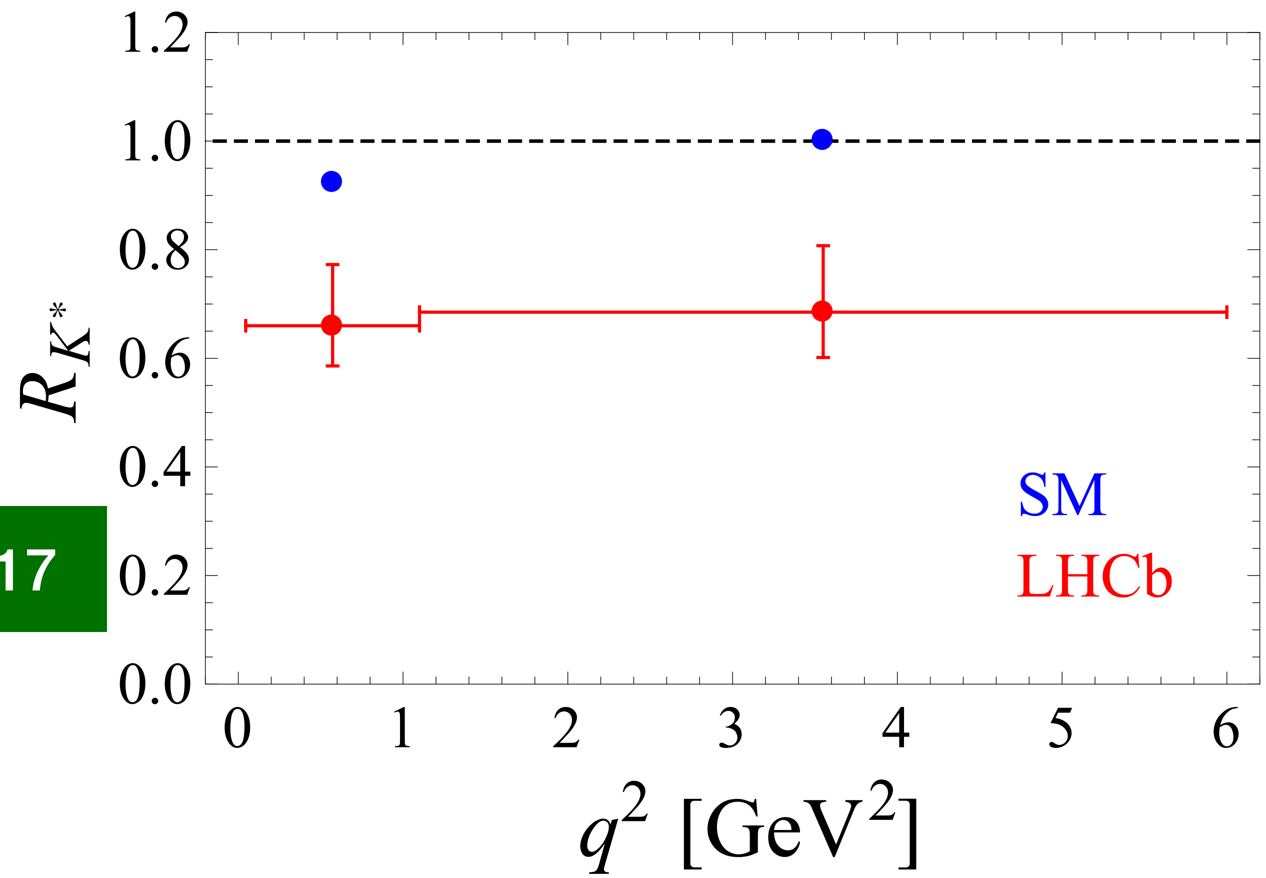
EXP - Moriond EW 2021

2021



$$R_K^{[1.1,6]} = 0.847(42)^{\text{LHCb}} \quad \text{vs} \quad R_K^{[1,6]} = 1.00(1)^{\text{SM}}$$

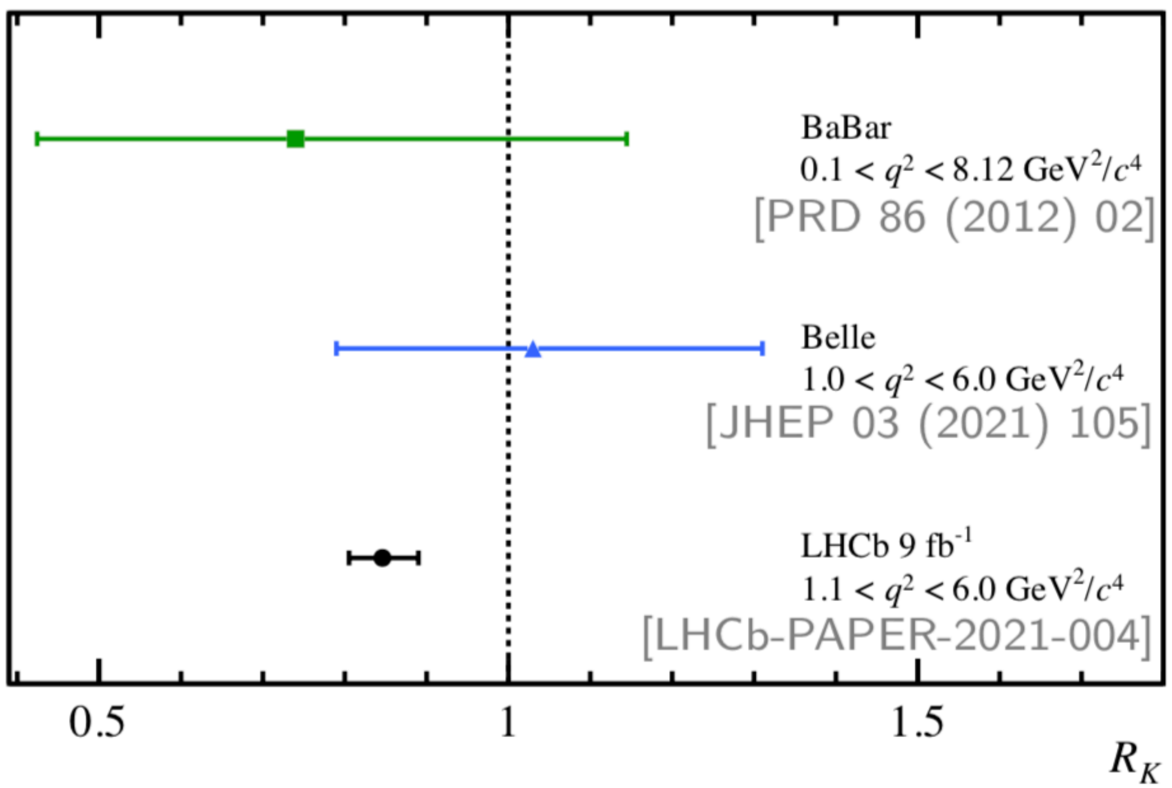
2017

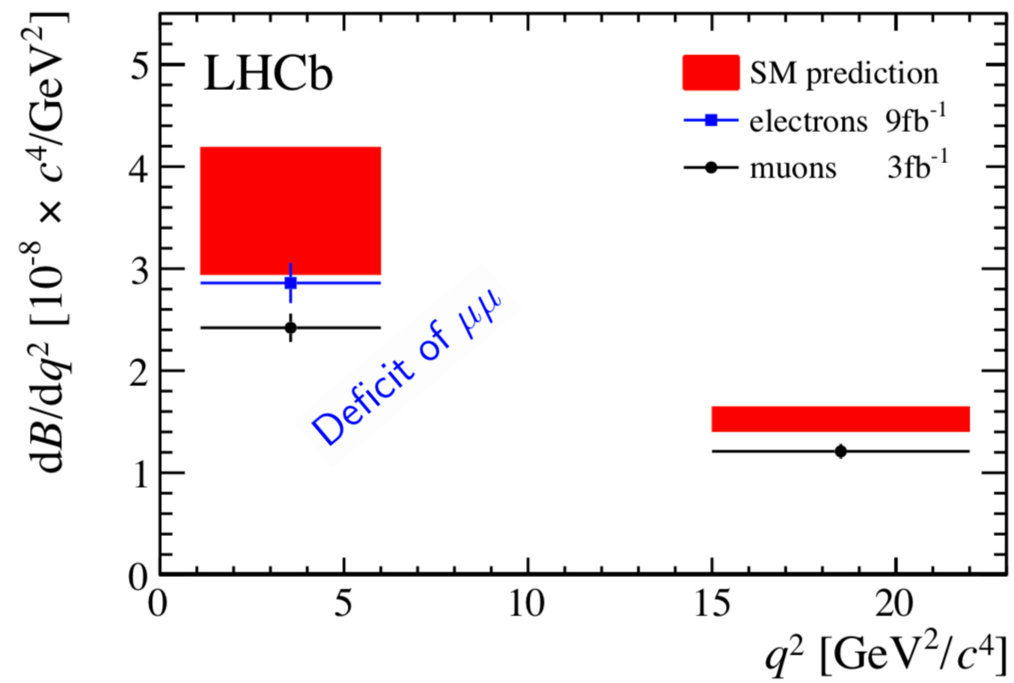


$$R_{K^*}^{[1.1,6]} = 0.71(10)^{\text{LHCb}} \quad \text{vs} \quad R_{K^*}^{[1,6]} = 1.00(1)^{\text{SM}}$$

EXP - Moriond EW 2021

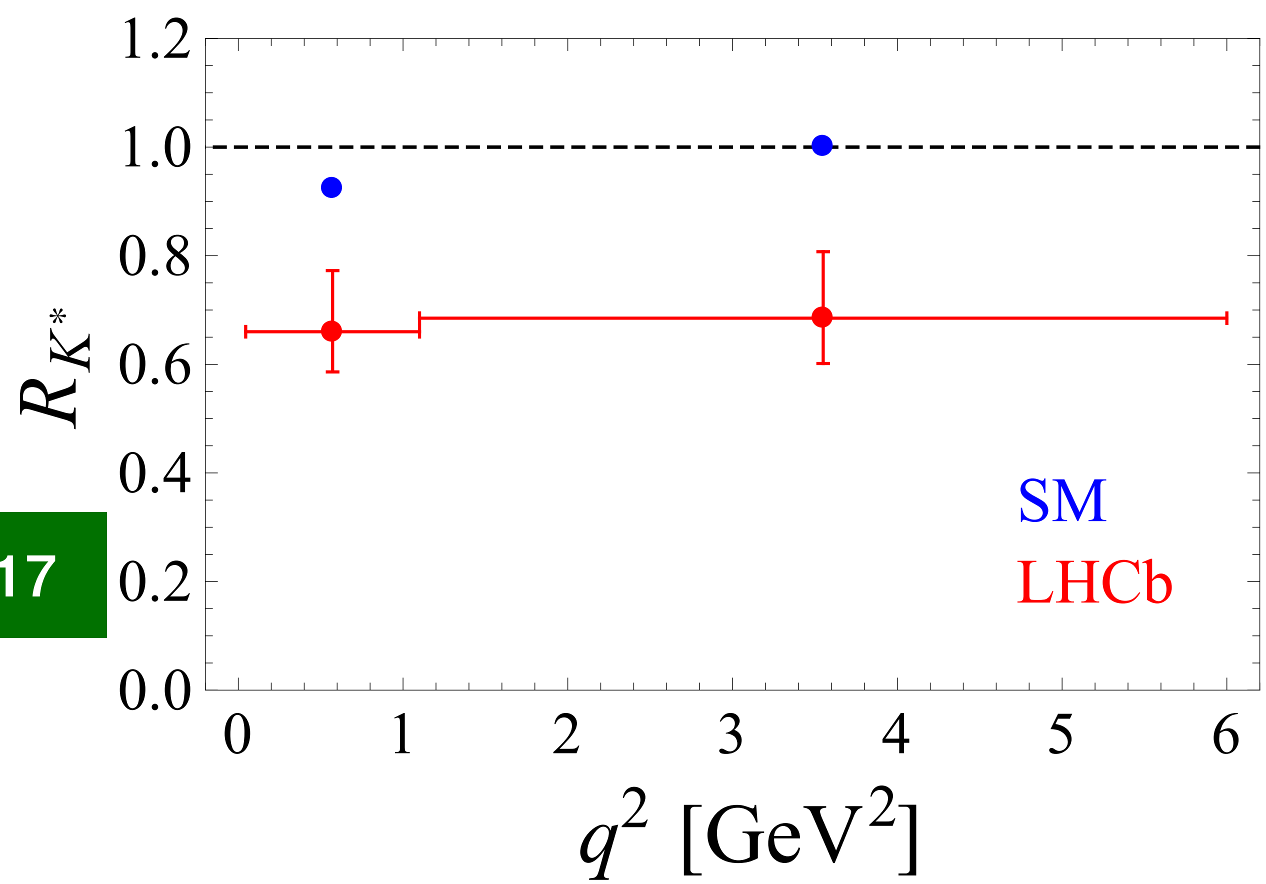
2021





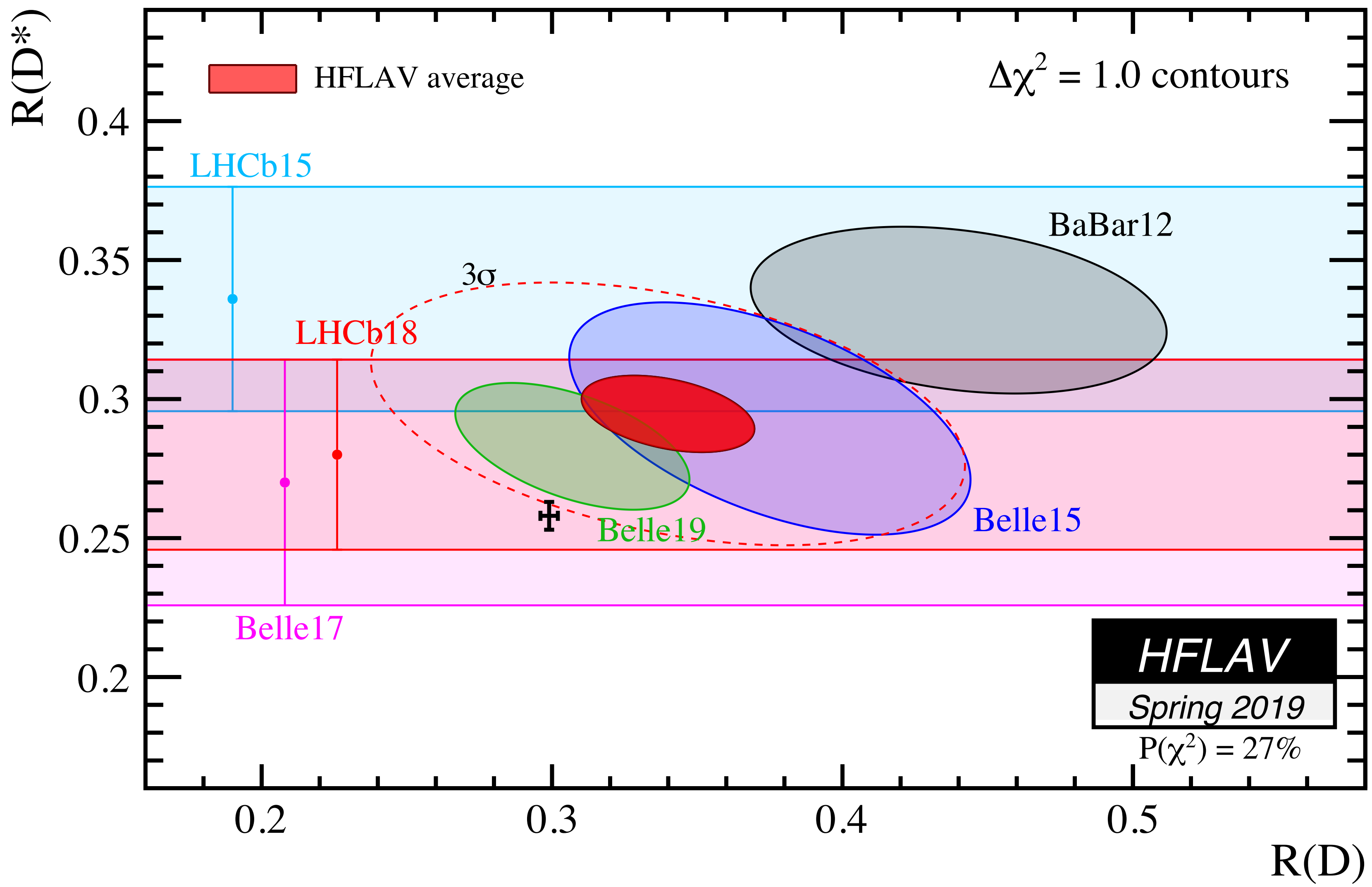
$$R_K^{[1.1,6]} = 0.847(42)^{\text{LHCb}} \quad \text{vs} \quad R_K^{[1,6]} = 1.00(1)^{\text{SM}}$$

2017



$$R_{K^*}^{[1.1,6]} = 0.71(10)^{\text{LHCb}} \quad \text{vs} \quad R_{K^*}^{[1,6]} = 1.00(1)^{\text{SM}}$$

EXP - Moriond 2019



$$\text{Exp}: \quad R_D = 0.340 \pm 0.030\,, \quad R_{D^*} = 0.295 \pm 0.014$$

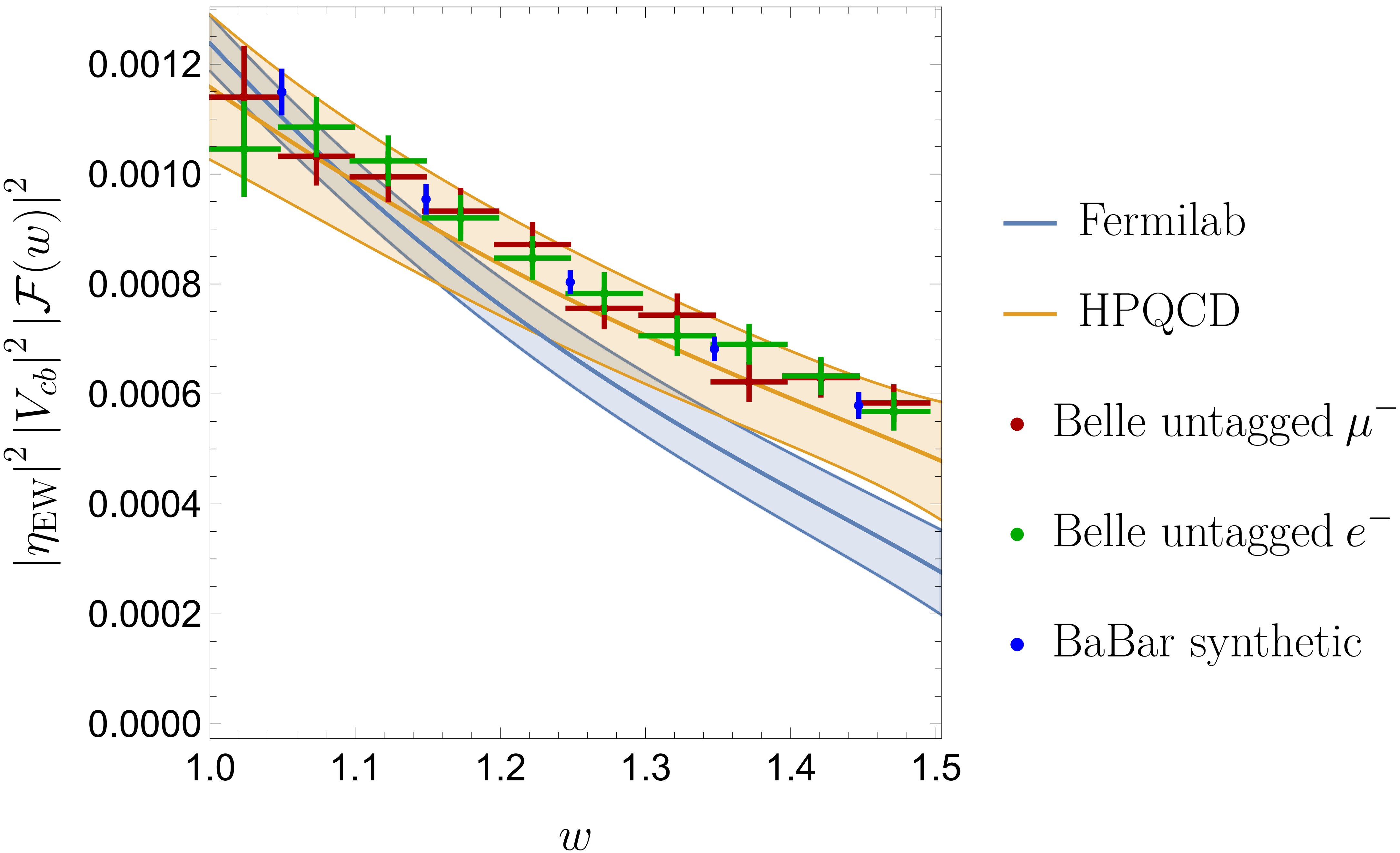
$$\text{SM}: \quad R_D^{\text{SM}} = 0.293 \pm 0.008\,, \quad R_{D^*}^{\text{SM}} = 0.257 \pm 0.003$$

Note to our exp colleagues:

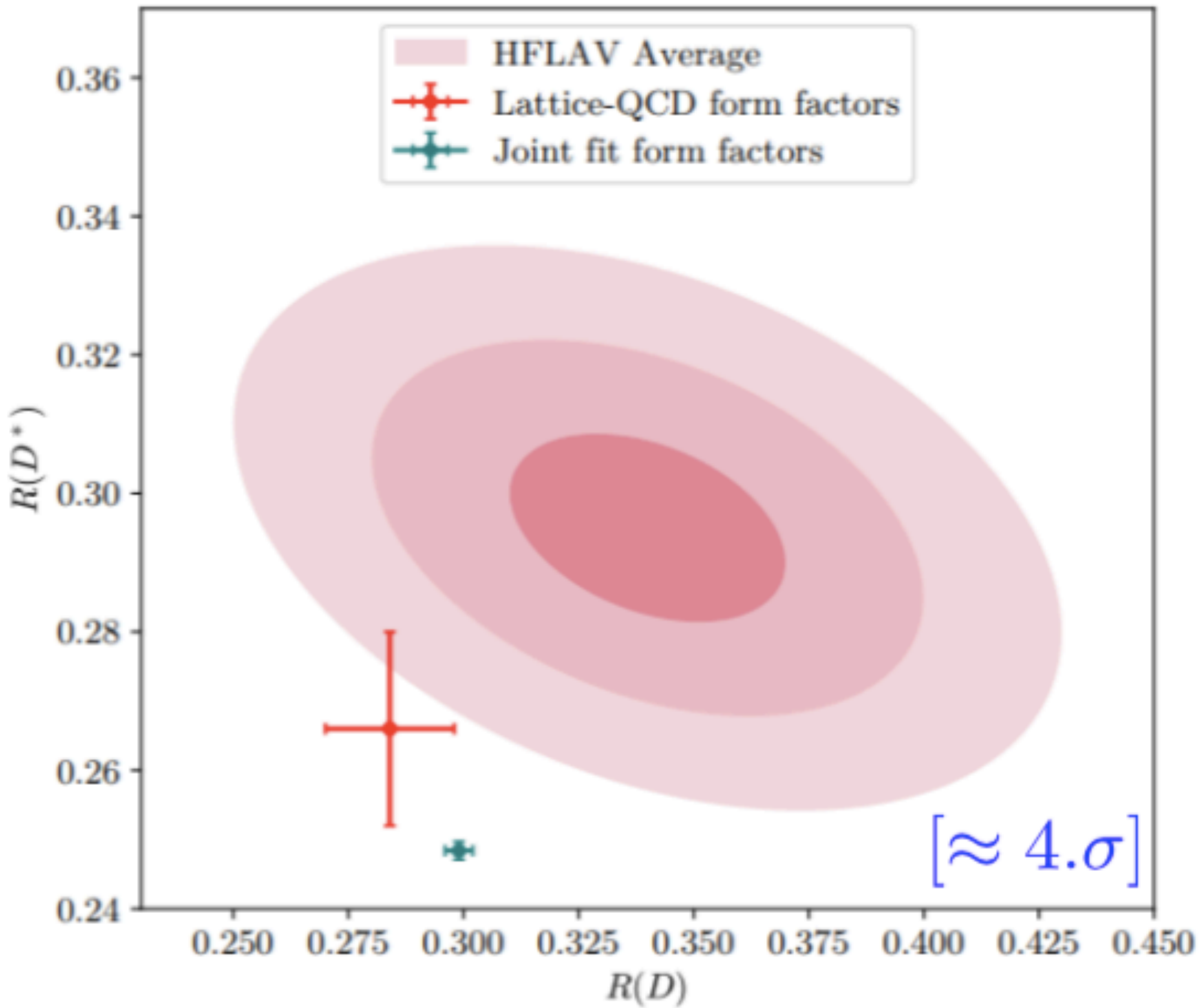
Can we please have $\widetilde{R}_{D^{(*)}} = \dfrac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu})}{\int_{m_\tau^2}^{q^2_{\max}} dq^2 \left[\dfrac{d\mathcal{B}(B \to D^{(*)}\ell\bar{\nu})}{dq^2}\right]}$?

Warning!

$$\frac{d\mathcal{B}(B \to D^*\ell\bar{\nu})}{dq^2} = \frac{1}{2m_B m_{D^*}} \frac{d\mathcal{B}(B \to D^*\ell\bar{\nu})}{dw} \propto |V_{cb}|^2 |\mathcal{F}(w)|^2$$



Warning!



Fermilab/MILC result - 2021

EFT - exclusive $b \to c\ell\nu$

$$\mathcal{L}_{\text{eff}} = -2\sqrt{2} G_F V_{cb} \Big[(1 + g_{V_L})(\bar{c}_L \gamma_\mu b_L)(\bar{\ell}_L \gamma^\mu \nu_L) + g_{V_R} (\bar{c}_R \gamma_\mu b_R)(\bar{\ell}_L \gamma^\mu \nu_L) + g_{S_R} (\bar{c}_L b_R)(\bar{\ell}_R \nu_L) + g_{S_L} (\bar{c}_R b_L)(\bar{\ell}_R \nu_L) + g_T (\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\ell}_R \sigma^{\mu\nu} \nu_L) \Big] + \text{h.c.}$$

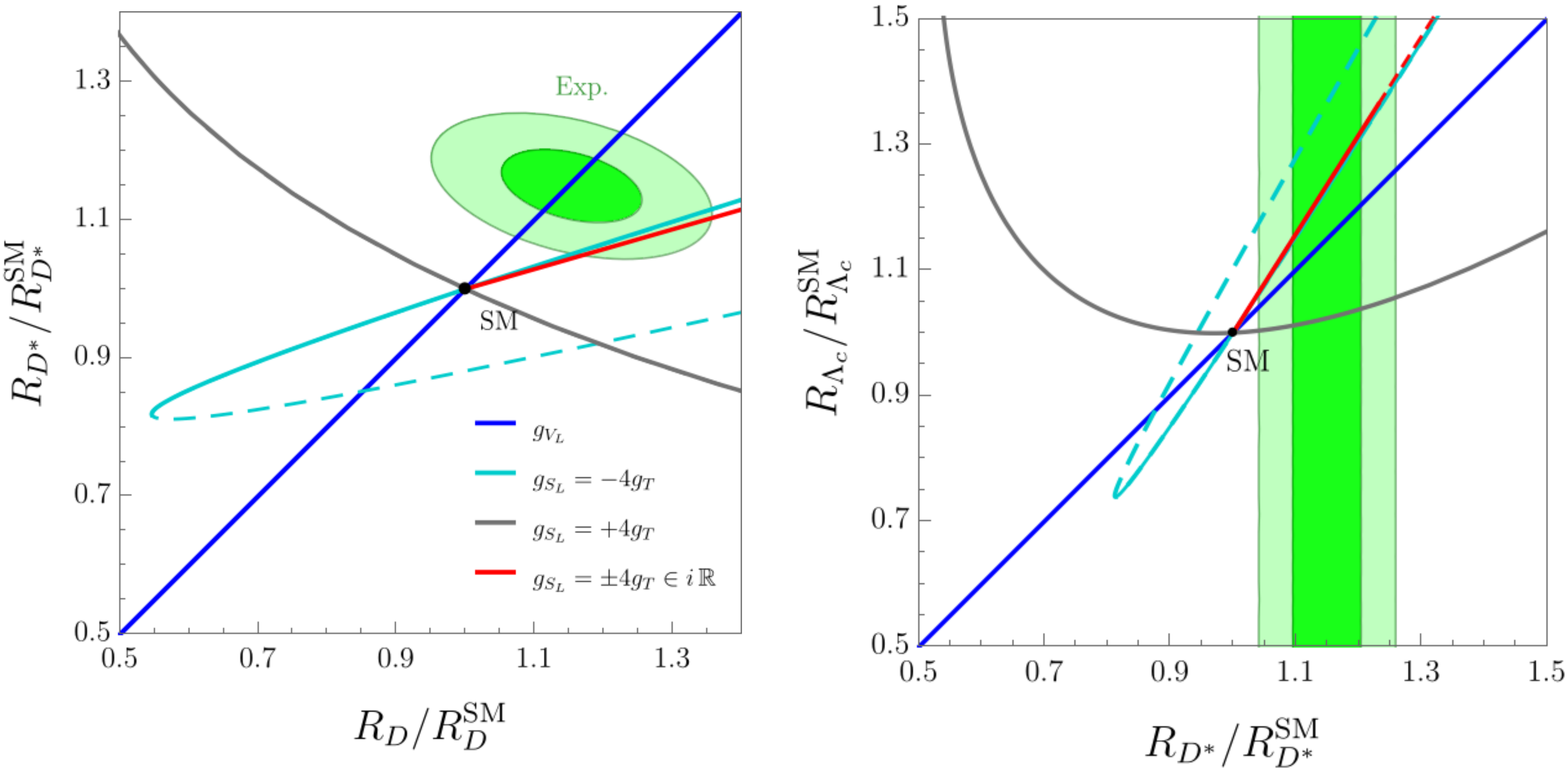
- $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariance:

  $\Rightarrow$ g_{V_R} is LFU at dimension 6 ($W \bar{c}_R b_R$ vertex).

  $\Rightarrow$ Four coefficients left: g_{V_L}, g_{S_L}, g_{S_R} and g_T.

EFT - exclusive $b \to c\ell\nu$

$$\mathcal{L}_{\rm eff} = -2\sqrt{2}G_F V_{cb}\Big[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{V_R}(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{S_R}(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$



EFT - exclusive $b \to c\ell\nu$

$$\mathcal{L}_{\rm eff} = -2\sqrt{2}G_F V_{cb}\Big[(1+g_{V_L})(\bar{c}_L\gamma_\mu b_L)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{V_R}(\bar{c}_R\gamma_\mu b_R)(\bar{\ell}_L\gamma^\mu\nu_L) + g_{S_R}(\bar{c}_L b_R)(\bar{\ell}_R\nu_L) + g_{S_L}(\bar{c}_R b_L)(\bar{\ell}_R\nu_L) + g_T(\bar{c}_R\sigma_{\mu\nu}b_L)(\bar{\ell}_R\sigma^{\mu\nu}\nu_L)\Big] + \text{h.c.}$$

$g_{V_L}(m_b)$	0.07 ± 0.02	$0.02/1$	✔
$g_{S_R}(m_b)$	-0.31 ± 0.05	$5.3/1$	✘
$g_{S_L}(m_b)$	0.12 ± 0.06	$8.8/1$	✘
$g_T(m_b)$	-0.03 ± 0.01	$3.1/1$	✔
$g_{S_L} = +4g_T \in \mathbb{R}$	-0.03 ± 0.07	$12.5/1$	✘
$g_{S_L} = -4g_T \in \mathbb{R}$	0.16 ± 0.05	$2.0/1$	✔
$g_{S_L} = \pm 4g_T \in i\,\mathbb{R}$	0.48 ± 0.08	$2.4/1$	✔

$$\chi^2_{\rm SM} = 12.7$$

EFT - exclusive $b \to c\ell\nu$

$g_{V_L}(m_b)$	0.07 ± 0.02	$0.02/1$	✔
$g_{S_R}(m_b)$	-0.31 ± 0.05	$5.3/1$	✘
$g_{S_L}(m_b)$	0.12 ± 0.06	$8.8/1$	✘
$g_T(m_b)$	-0.03 ± 0.01	$3.1/1$	✔
$g_{S_L} = +4g_T \in \mathbb{R}$	-0.03 ± 0.07	$12.5/1$	✘
$g_{S_L} = -4g_T \in \mathbb{R}$	0.16 ± 0.05	$2.0/1$	✔
$g_{S_L} = \pm 4g_T \in i\,\mathbb{R}$	0.48 ± 0.08	$2.4/1$	✔

Main worry remain the hadronic uncertainties in the D^* case:
No clear LQCD info regarding the shapes of FFs
Keep also in mind the SD part of the soft photon problem is missing

EFT - exclusive $b \to c \ell \nu$

Model	$g_{\text{eff}}^{b\to c\tau\bar{\nu}}(\mu = m_\Delta)$	$R_{D^{(*)}}$
$S_1 = (\bar{3}, 1, 1/3)$	$g_{V_L},\ g_{S_L} = -4\, g_T$	✓
$R_2 = (3, 2, 7/6)$	$g_{S_L} = 4\, g_T$	✓
$S_3 = (\bar{3}, 3, 1/3)$	g_{V_L}	✗
…	…	…
$U_1 = (3, 1, 2/3)$	$g_{V_L},\ g_{S_R}$	✓
$U_3 = (3, 3, 2/3)$	g_{V_L}	✗
…	…	…

$g_{V_L}(m_b)$	0.07 ± 0.02	$0.02/1$	✔
	± 0.05	$5.3/1$	✘
	± 0.06	$8.8/1$	✘
	± 0.01	$3.1/1$	✔
	± 0.07	$12.5/1$	✘
$g_{S_L} = -4 g_T \in \mathbb{R}$	0.16 ± 0.05	$2.0/1$	✔
$g_{S_L} = \pm 4 g_T \in i\,\mathbb{R}$	0.48 ± 0.08	$2.4/1$	✔

Main worry remain the hadronic uncertainties in the $D*$ case:
No clear LQCD info regarding the shapes of FFs
Keep also in mind the SD part of the soft photon problem is missing

EFT - exclusive $b \to s\ell\ell$

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[\sum_{i=1}^{6} C_i(\mu)\mathcal{O}_i(\mu) + \sum_{i=7,8,9,10,P,S,\ldots} \Big(C_i(\mu)\mathcal{O}_i + C_i'(\mu)\mathcal{O}_i' \Big) \right] + \text{h.c.}$$

$$\mathcal{O}_9^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu \ell) \qquad \mathcal{O}_{10}^{(\prime)} = (\bar{s}\gamma_\mu P_{L(R)} b)(\bar{\ell}\gamma^\mu\gamma^5 \ell)$$

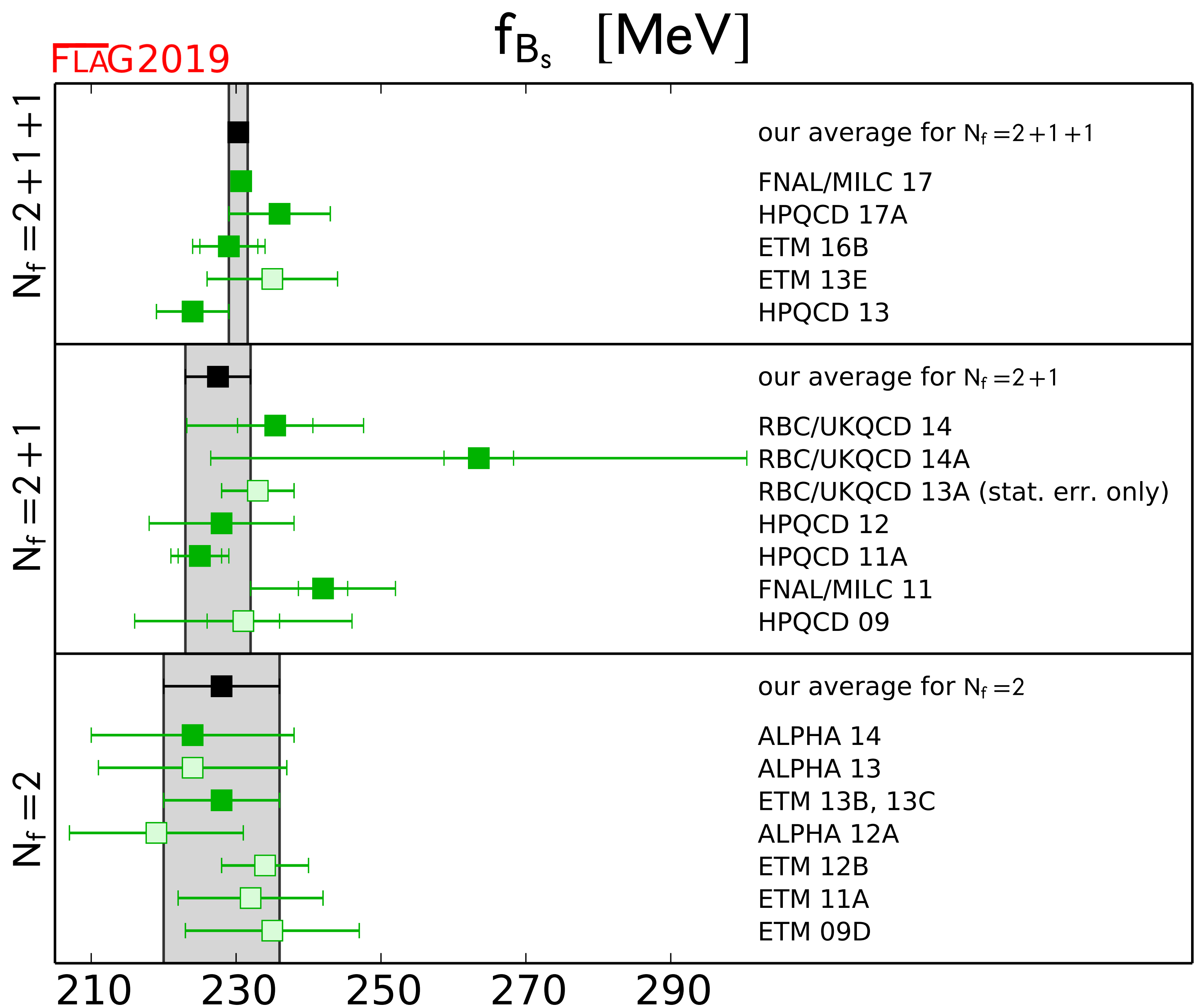
$$\mathcal{O}_S^{(\prime)} = (\bar{s} P_{R(L)} b)(\bar{\ell}\ell) \qquad \mathcal{O}_P^{(\prime)} = (\bar{s} P_{R(L)} b)(\bar{\ell}\gamma_5 \ell)$$

$$\mathcal{O}_7^{(\prime)} = m_b(\bar{s}\sigma_{\mu\nu} P_{R(L)} b) F^{\mu\nu}$$

Exp : $\mathcal{B}(B_s \to \mu\mu) = (2.85 \pm 0.33) \times 10^{-9}$

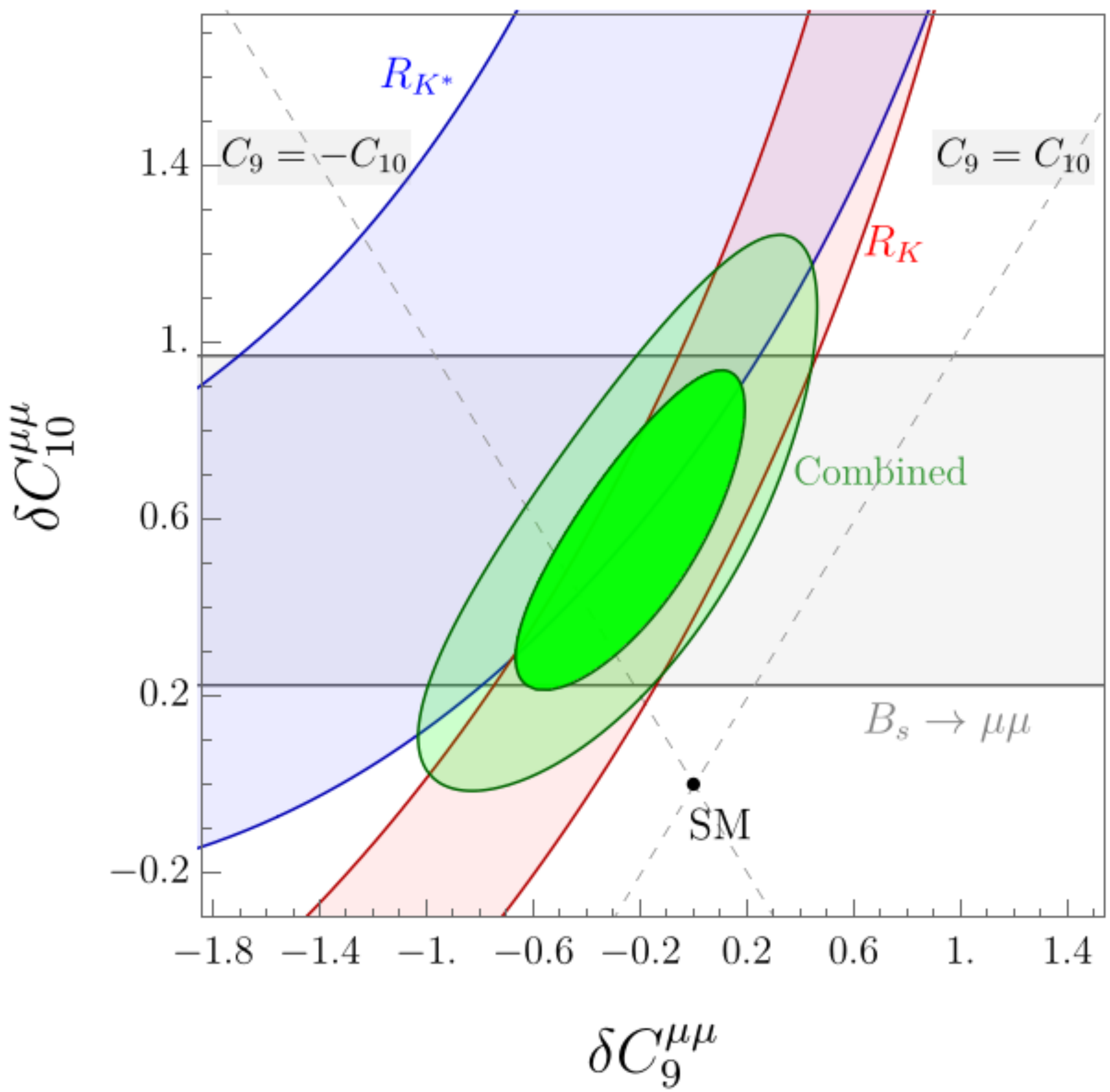
SM : $\mathcal{B}(B_s \to \mu\mu) = (3.66 \pm 0.14) \times 10^{-9}$

$$\langle 0|\bar{s}\gamma^\mu\gamma_5 b|B_s(p)\rangle = i f_{B_s}\, p^\mu$$

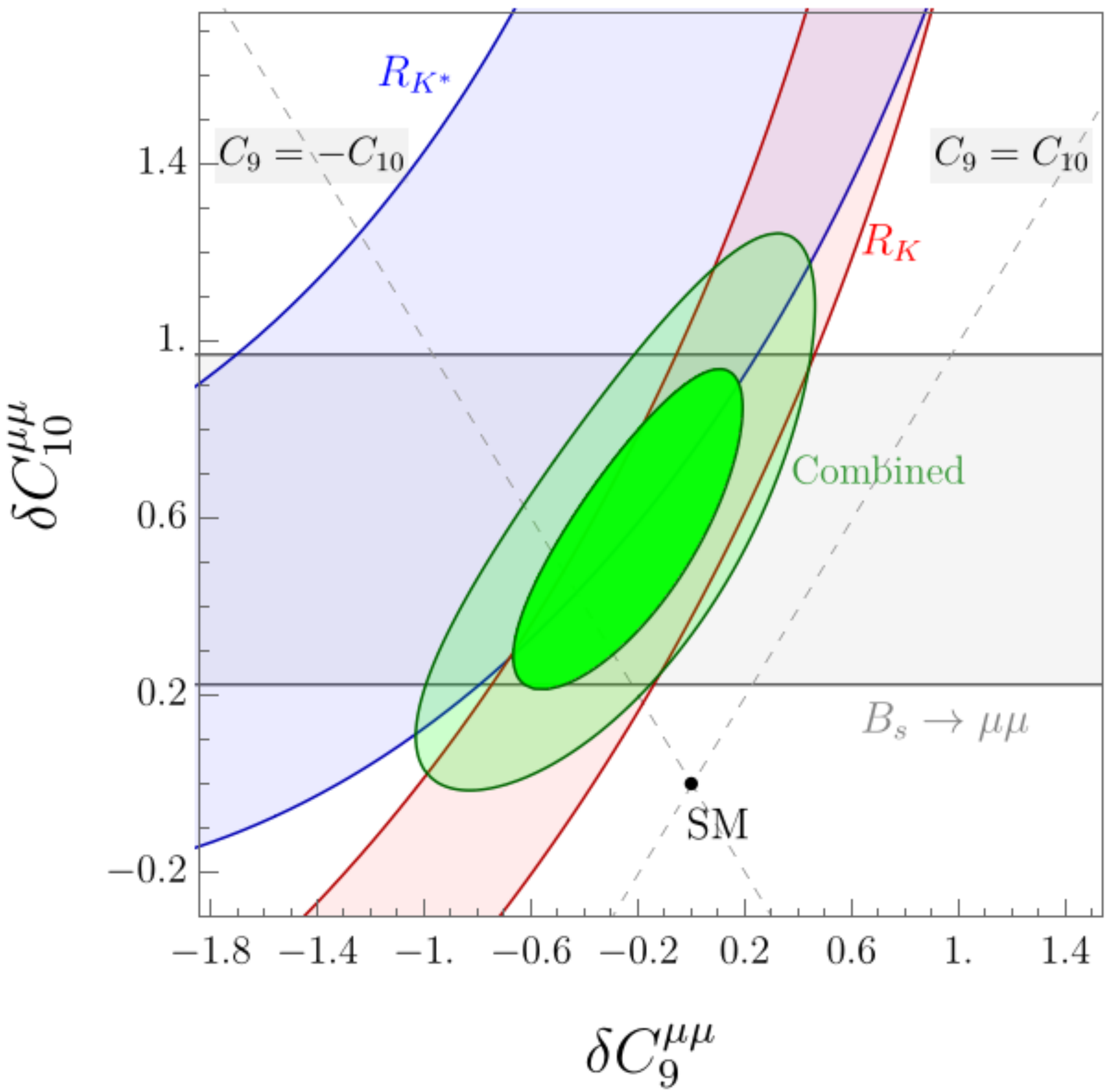


cf. updates at http://flag.unibe.ch

Fit to clean quantities: $\mathcal{B}(B_s \to \mu\mu)$ and $R_{K^{(*)}}$



Fit to clean quantities: $\mathcal{B}(B_s \to \mu\mu)$ and $R_{K^{(*)}}$



- Only vector (axial) coefficients can accommodate data.
- $C'_{9,10}$ disfavored by $R_{K^*}^{\mathrm{exp}} < R_{K^*}^{\mathrm{SM}}$
- $C_9 = -C_{10}$ allowed – consistent with a left-handed $SU(2)_L$ invariant operator!

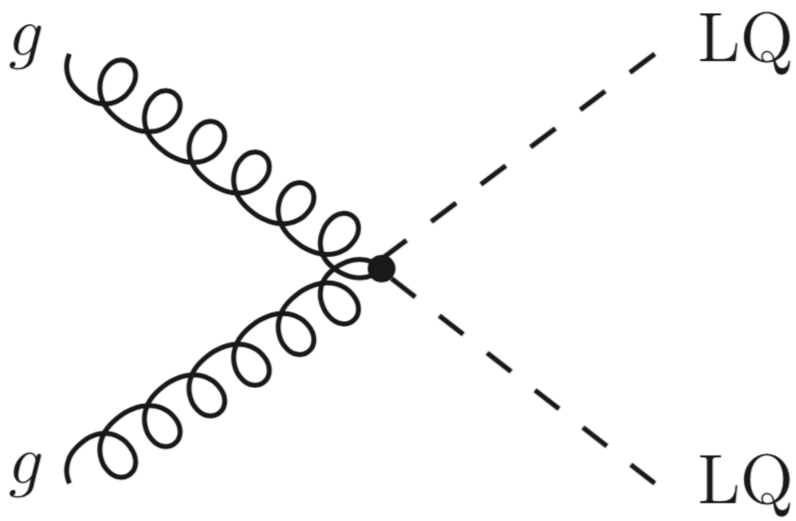
What LQ scenario?

Model	$R_{D^{(*)}}$	$R_{K^{(*)}}$	$R_{D^{(*)}}$ & $R_{K^{(*)}}$
$S_1 = (\bar{3}, 1, 1/3)$	✓	✗	✗
$R_2 = (3, 2, 7/6)$	✓	✓*	✗
$S_3 = (\bar{3}, 3, 1/3)$	✗	✓	✗
$U_1 = (3, 1, 2/3)$	✓	✓	✓
$U_3 = (3, 3, 2/3)$	✗	✓	✗

N.B. U_1 is the only one to accommodate both!

Observable
$b \to s\mu\mu$
$b \to c\tau\nu$
$\mathcal{B}(\tau \to \mu\phi)$
$\mathcal{B}(B \to \tau\nu)$
$\mathcal{B}(D_s \to \mu\nu)$
$\mathcal{B}(D_s \to \tau\nu)$
$r_K^{e/\mu}$
$r_K^{\tau/\mu}$
$R_D^{\mu/e}$

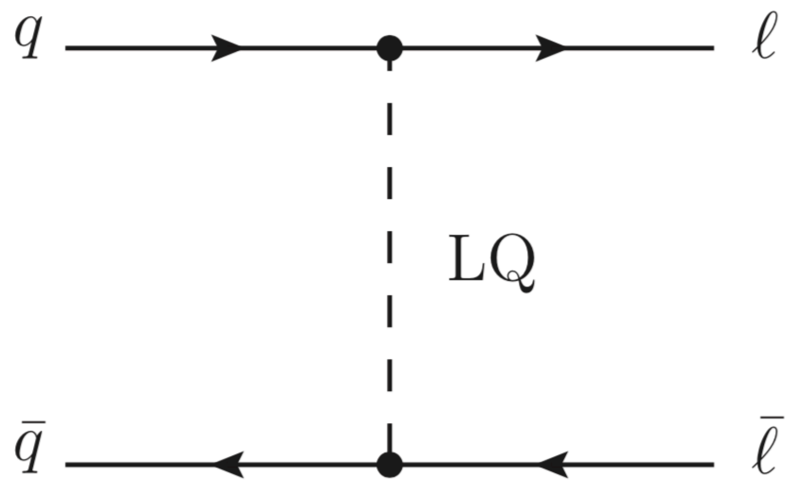
From direct searches
Atlas and CMS 2018-2021

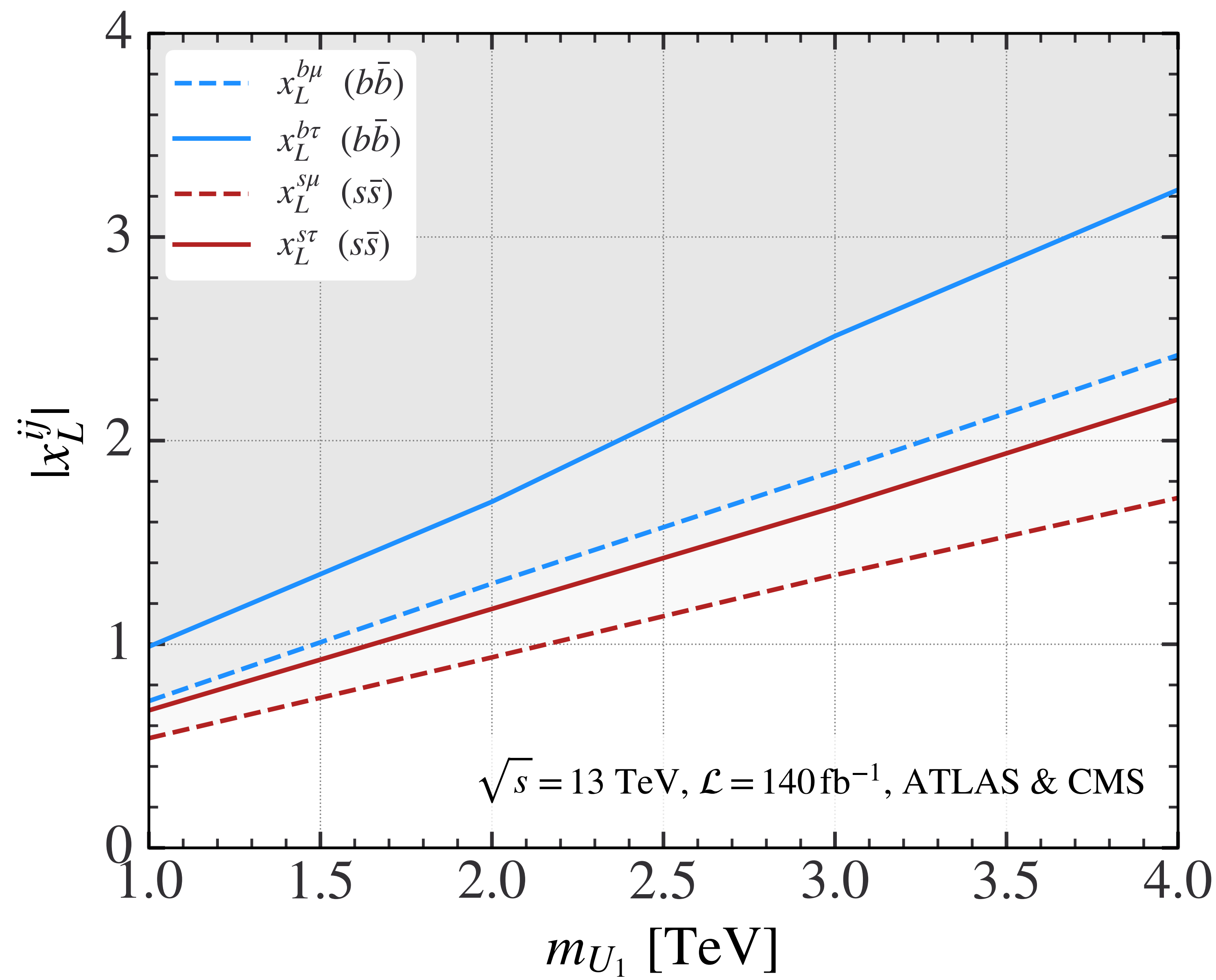


Decays	Scalar LQ limits	Vector LQ limits	$\mathcal{L}_{\text{int}}$
$jj\,\tau\bar{\tau}$	–	–	–
$b\bar{b}\,\tau\bar{\tau}$	1.0 (0.8) TeV	1.5 (1.3) TeV	36 fb^{-1}
$t\bar{t}\,\tau\bar{\tau}$	1.4 (1.2) TeV	2.0 (1.8) TeV	140 fb^{-1}
$jj\,\mu\bar{\mu}$	1.7 (1.4) TeV	2.3 (2.1) TeV	140 fb^{-1}
$b\bar{b}\,\mu\bar{\mu}$	1.7 (1.5) TeV	2.3 (2.1) TeV	140 fb^{-1}
$t\bar{t}\,\mu\bar{\mu}$	1.5 (1.3) TeV	2.0 (1.8) TeV	140 fb^{-1}
$jj\,\nu\bar{\nu}$	1.0 (0.6) TeV	1.8 (1.5) TeV	36 fb^{-1}
$b\bar{b}\,\nu\bar{\nu}$	1.1 (0.8) TeV	1.8 (1.5) TeV	36 fb^{-1}
$t\bar{t}\,\nu\bar{\nu}$	1.2 (0.9) TeV	1.8 (1.6) TeV	140 fb^{-1}

N.B. QCD corrections now available - should be included in the future studies!

From dilepton spectra at high p_T Atlas and CMS 2018-2020

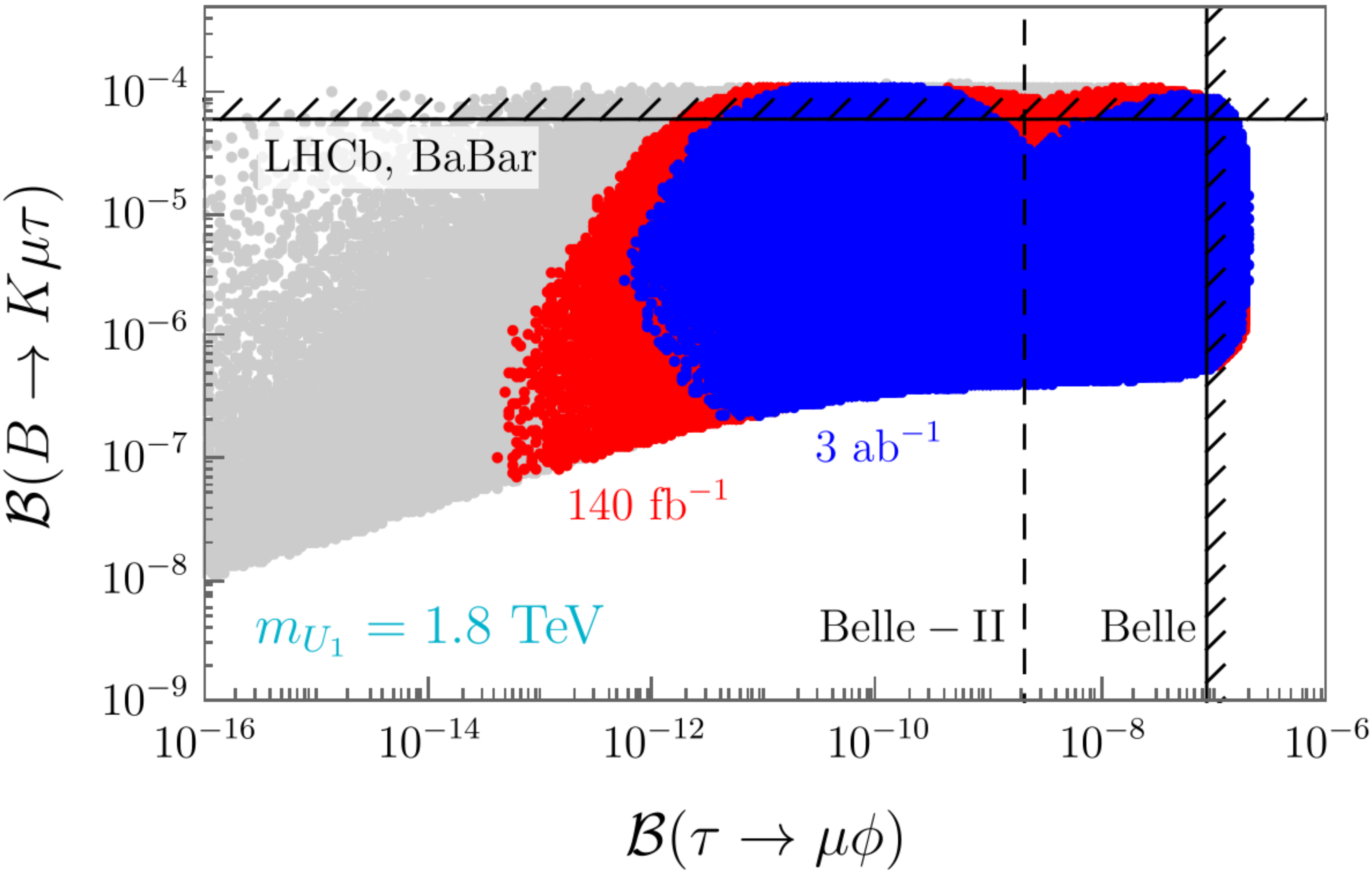




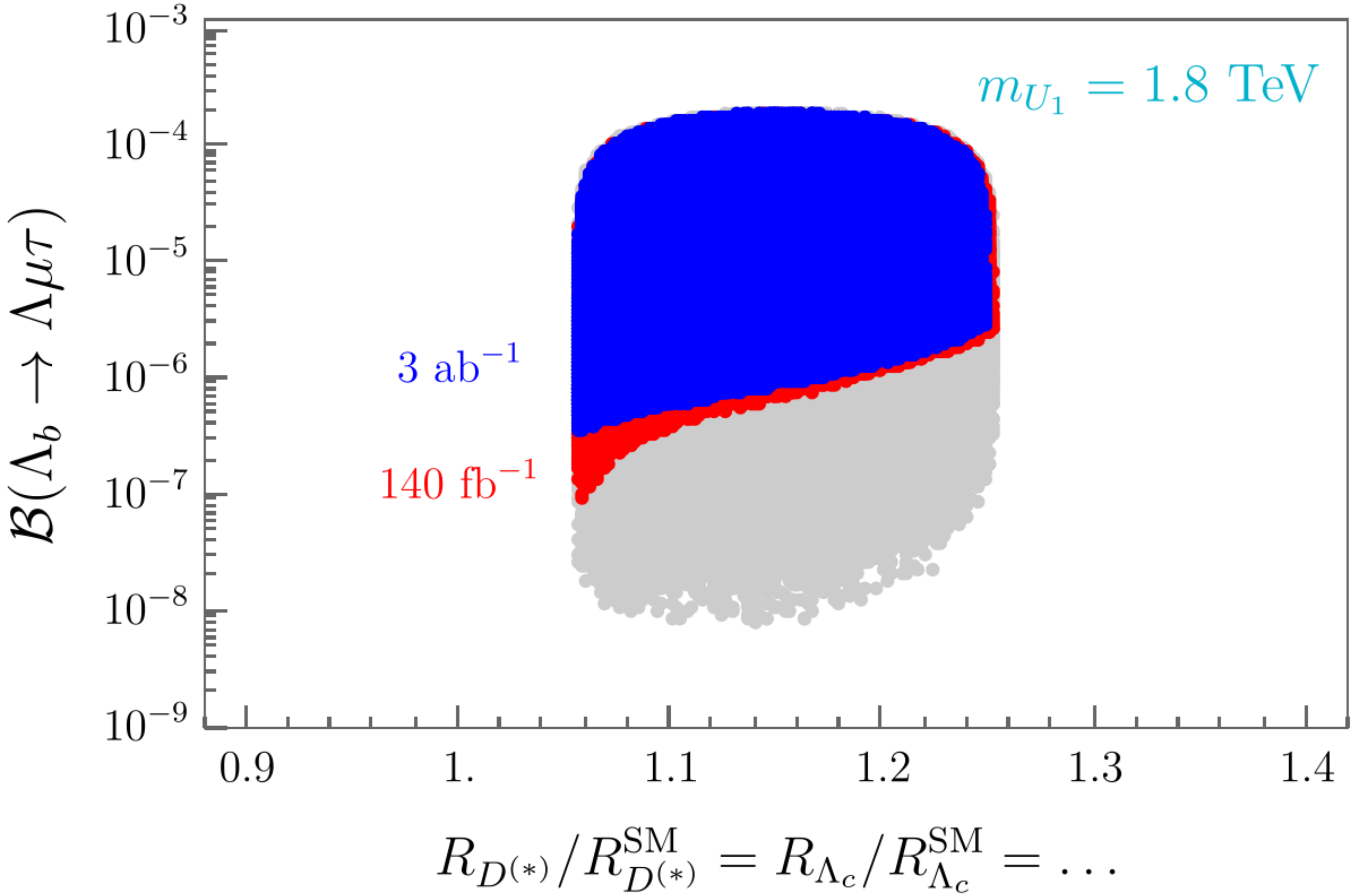
Example U1

$$\mathcal{L}_{U_1} = x_L^{ij}\,\overline{Q}_i\gamma_\mu L_j\,U_1^\mu + x_R^{ij}\,\overline{d}_{R_i}\gamma_\mu \ell_{Rj} U_1^\mu + \text{h.c.}$$

LFV predictions



LFV predictions



- Way to go 1: Combine two scalar LQs [S_1 with S_3, or R_2 with S_3]
- Way to go 2: Vector LQ (U_1)
  Non-renormalizable and thus requires UV-completion which can be an opportunity to tackle the hierarchy problem!

Concerning R2

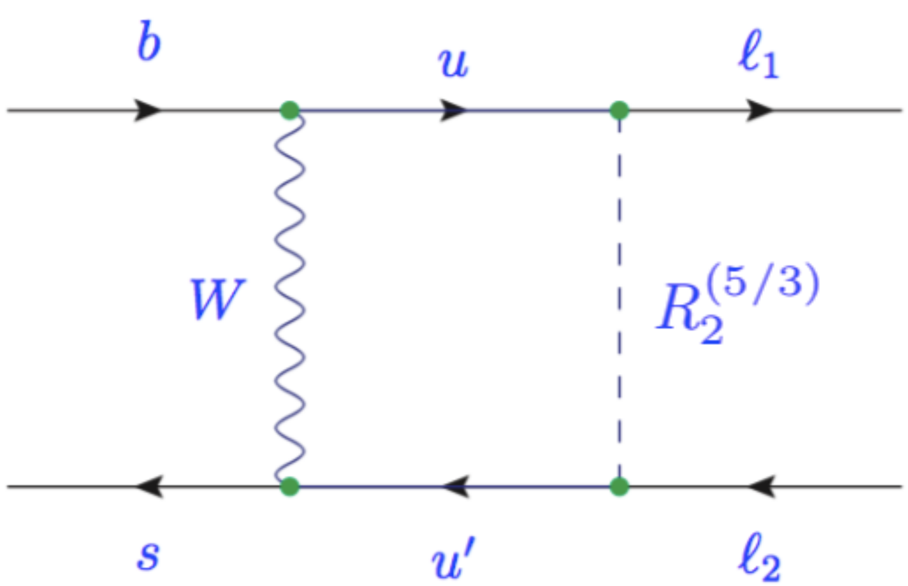
Model	$R_{D^{(*)}}$	$R_{K^{(*)}}$	$R_{D^{(*)}}$ & $R_{K^{(*)}}$
$S_1 = (\bar{3}, 1, 1/3)$	✓	✗	✗
$R_2 = (3, 2, 7/6)$	✓	✓*	✗
$S_3 = (\bar{3}, 3, 1/3)$	✗	✓	✗
$U_1 = (3, 1, 2/3)$	✓	✓	✓
$U_3 = (3, 3, 2/3)$	✗	✓	✗

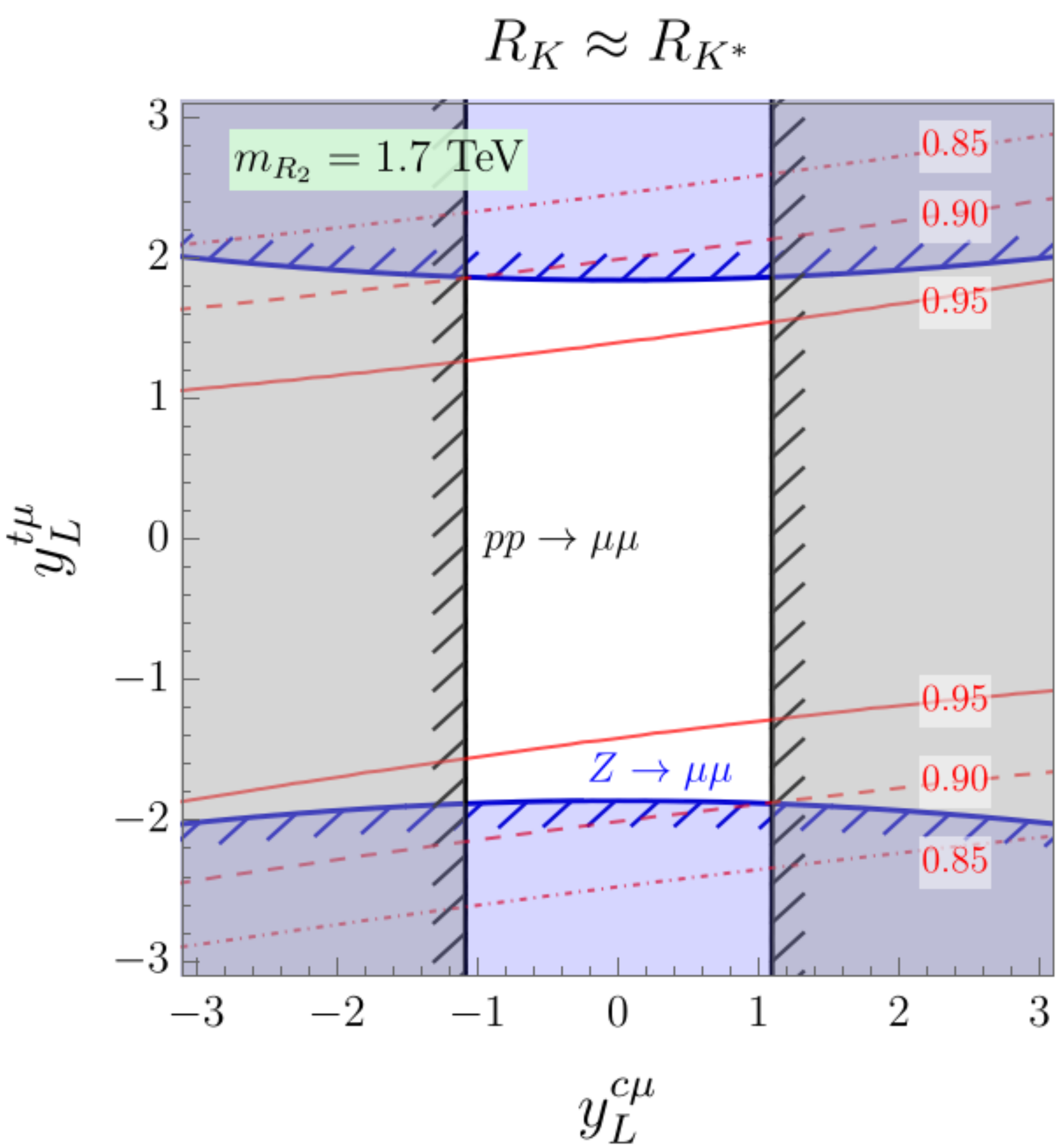
$$\mathcal{L}_{R_2} = y_R^{ij}\,\overline{Q}_i \ell_{Rj}\,R_2 - y_L^{ij}\,\overline{u}_{Ri} R_2 i\tau_2 L_j + \text{h.c.}$$

$$C_9^{kl} = C_{10}^{kl} \overset{\text{tree}}{=} -\frac{\pi v^2}{2V_{tb}V_{ts}^*\alpha_{\text{em}}}\frac{y_R^{sl}\left(y_R^{bk}\right)^*}{m_{R_2}^2}$$

$$C_9^{kl} = -C_{10}^{kl} \overset{\text{loop}}{=} \sum_{u,u'\in\{u,c,t\}} \frac{V_{ub}V_{u's}^*}{V_{tb}V_{ts}^*} y_L^{u'k}\left(y_L^{ul}\right)^* \mathcal{F}(x_u, x_{u'})$$

$$y_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & y_L^{c\mu} & 0 \\ 0 & y_L^{t\mu} & 0 \end{pmatrix}, \qquad y_R = 0$$





S_3 & R_2 Model

- In flavor basis

$$\mathcal{L} \supset y_R^{ij}\, \bar{Q}_i \ell_{Rj} R_2 + y_L^{ij}\, \bar{u}_{Ri} L_j \widetilde{R}_2^\dagger + y^{ij}\, \bar{Q}_i^C i\tau_2 (\tau_k S_3^k) L_j + \text{h.c.}$$

$$R_2 = (3, 2, 7/6),\ S_3 = (\bar{3}, 3, 1/3)$$

- In mass-eigenstates basis

$$\begin{aligned}\mathcal{L} \supset\ & (V_{\text{CKM}}\, y_R\, E_R^\dagger)^{ij}\, \bar{u}'_{Li} \ell'_{Rj} R_2^{(5/3)} + (y_R\, E_R^\dagger)^{ij}\, \bar{d}'_{Li} \ell'_{Rj} R_2^{(2/3)} \\ & + (U_R\, y_L\, U_{\text{PMNS}})^{ij}\, \bar{u}'_{Ri} \nu'_{Lj} R_2^{(2/3)} - (U_R\, y_L)^{ij}\, \bar{u}'_{Ri} \ell'_{Lj} R_2^{(5/3)} \\ & - (y\, U_{\text{PMNS}})^{ij}\, \bar{d}'^C_{Li} \nu'_{Lj} S_3^{(1/3)} - \sqrt{2}\, y^{ij}\, \bar{d}'^C_{Li} \ell'_{Lj} S_3^{(4/3)} \\ & + \sqrt{2} (V^*_{\text{CKM}}\, y\, U_{\text{PMNS}})_{ij}\, \bar{u}'^C_{Li} \nu'_{Lj} S_3^{(-2/3)} - (V^*_{\text{CKM}}\, y)_{ij}\, \bar{u}'^C_{Li} \ell'_{Lj} S_3^{(1/3)} + \text{h.c.}\end{aligned}$$

Embedding to SU(5) GUT feasible

and assume

$$\underline{y_R = y_R^T \qquad y = -y_L}$$

$$y_R\, E_R^\dagger = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y_R^{b\tau} \end{pmatrix},\quad U_R\, y_L = \begin{pmatrix} 0 & 0 & 0 \\ 0 & y_L^{c\mu} & y_L^{c\tau} \\ 0 & 0 & 0 \end{pmatrix},\quad U_R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{pmatrix}$$

Parameters: m_{R_2}, m_{S_3}, $y_R^{b\tau}$, $y_L^{c\mu}$, $y_L^{c\tau}$ and θ

Effective Lagrangian at $\mu \approx m_{\rm LQ}$:

- $b \to c\tau\bar{\nu}$: **NB**. $\Lambda_{\rm NP}/g_{\rm NP} \approx 1$ TeV

$$\propto \frac{y_L^{c\tau}\, y_R^{b\tau\,*}}{m_{R_2}^2}\left[(\bar{c}_R b_L)(\bar{\tau}_R \nu_L) + \frac{1}{4}(\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\tau}_R \sigma^{\mu\nu} \nu_L)\right] + \dots$$

- $b \to s\mu\mu$: **NB**. $\Lambda_{\rm NP}/g_{\rm NP} \approx 30$ TeV

$$\propto \sin 2\theta \, \frac{|y_L^{c\mu}|^2}{m_{S_3}^2}\, (\bar{s}_L \gamma^\mu b_L)(\bar{\mu}_L \gamma_\mu \mu_L)$$

- Δm_{B_s}:

$$\propto \sin^2 2\theta \, \frac{\left[\left(y_L^{c\mu}\right)^2 + \left(y_L^{c\tau}\right)^2\right]^2}{m_{S_3}^2} (\bar{s}_L \gamma^\mu b_L)^2$$

$\Rightarrow$ Suppression mechanism of $b \to s\mu\mu$ wrt $b \to c\tau\bar{\nu}$ for small $\sin 2\theta$.

$\Rightarrow$ Phenomenology suggests $\theta \approx \pi/2$ and $y_R^{b\tau}$ complex

Effective Lagrangian at $\mu \approx m_{\rm LQ}$:

- $b \to c\tau\bar{\nu}$: **NB**. $\Lambda_{\rm NP}/g_{\rm NP} \approx 1$ TeV

$$\propto \frac{y_L^{c\tau} y_R^{b\tau\,*}}{m_{R_2}^2} \left[(\bar{c}_R b_L)(\bar{\tau}_R \nu_L) + \frac{1}{4}(\bar{c}_R \sigma_{\mu\nu} b_L)(\bar{\tau}_R \sigma^{\mu\nu} \nu_L) \right] + \ldots$$

- $b \to s\mu\mu$: **NB**. $\Lambda_{\rm NP}/g_{\rm NP} \approx 30$ TeV

$$\propto \sin 2\theta \, \frac{|y_L^{c\mu}|^2}{m_{S_3}^2} (\bar{s}_L \gamma^\mu b_L)(\bar{\mu}_L \gamma_\mu \mu_L)$$

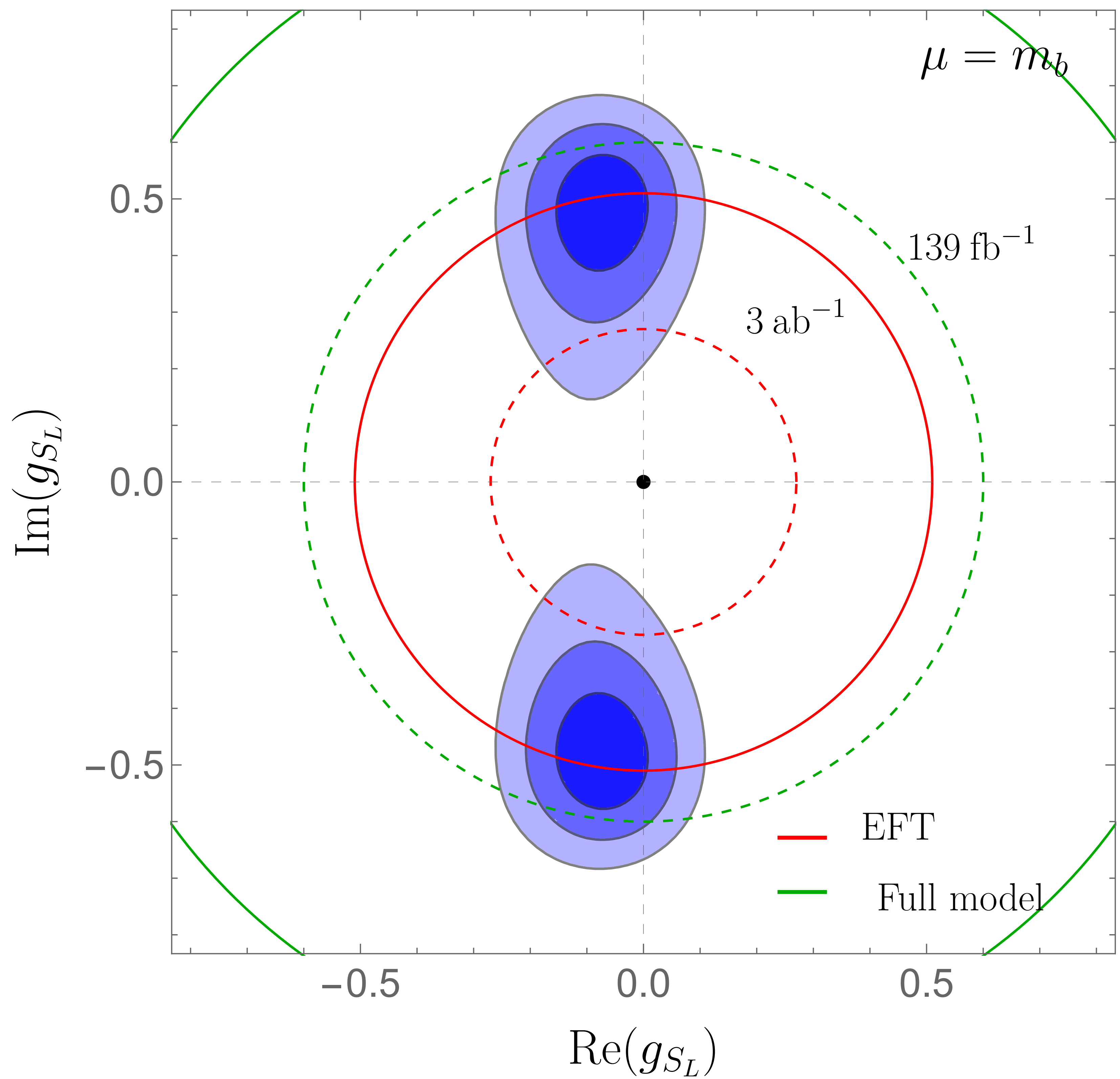
- Δm_{B_s}:

$$\propto \sin^2 2\theta \, \frac{\left[\left(y_L^{c\mu}\right)^2 + \left(y_L^{c\tau}\right)^2 \right]^2}{m_{S_3}^2} (\bar{s}_L \gamma^\mu b_L)^2$$

$\Rightarrow$ Suppression mechanism of $b \to s\mu\mu$ wrt $b \to c\tau\bar{\nu}$ for small $\sin 2\theta$.

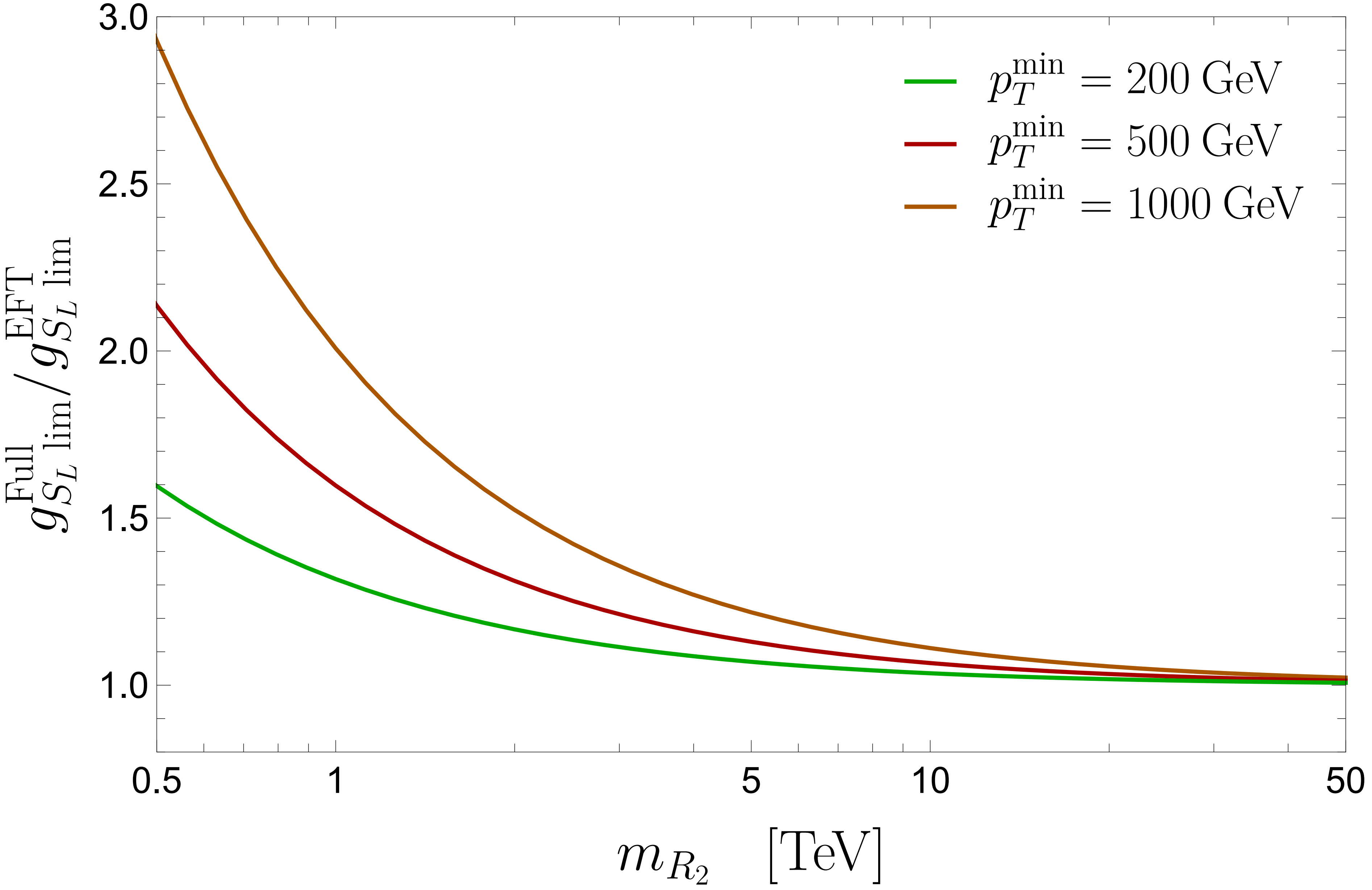
$\Rightarrow$ Phenomenology suggests $\theta \approx \pi/2$ and $y_R^{b\tau}$ complex

Bounds derived from $pp \to \tau\nu$ at high p_T not useful

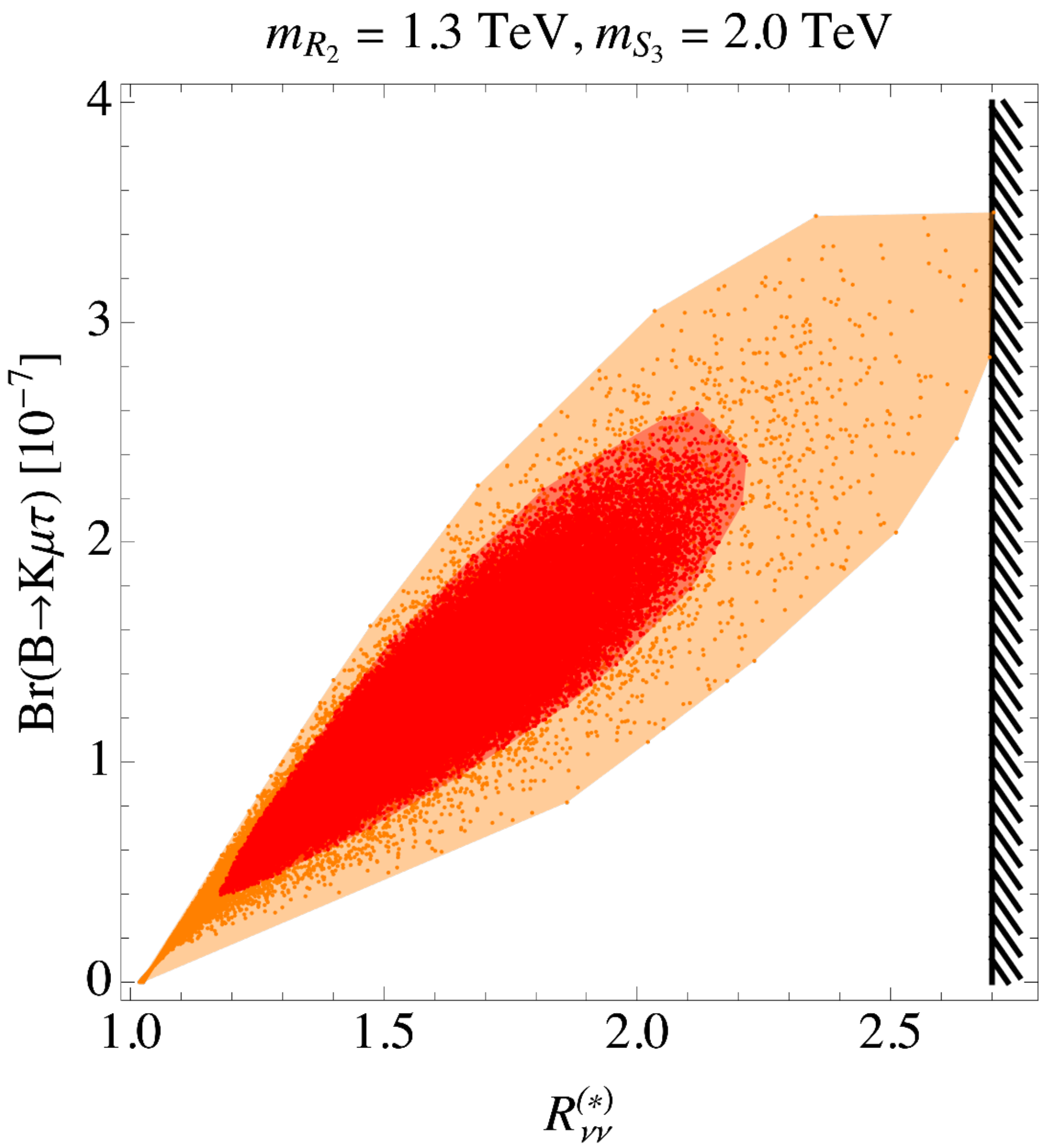


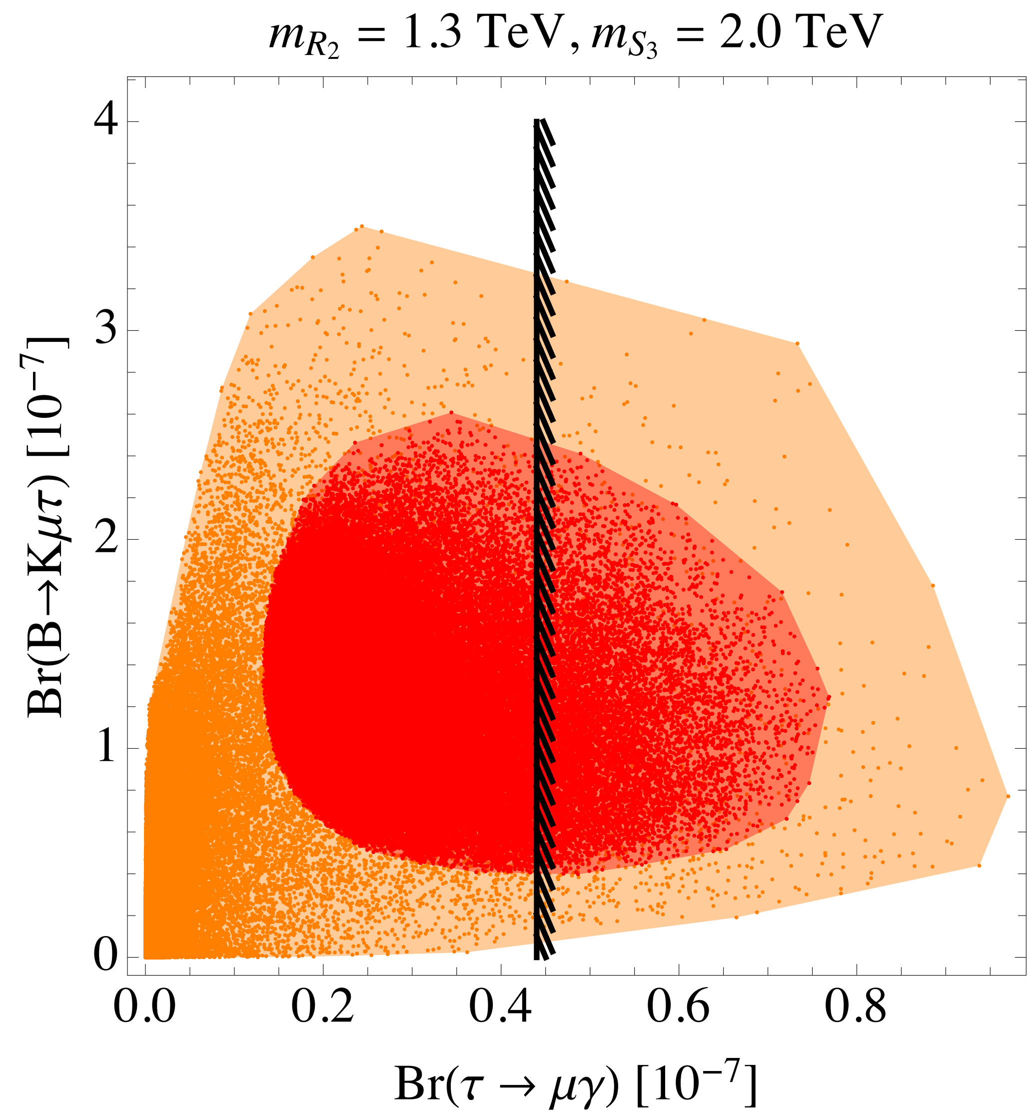
NB: New ATLAS data

Note also…


3.0
2.5
2.0
1.5
1.0
0.5
1
5
10
50
$p_T^{\rm min} = 200$ GeV
$p_T^{\rm min} = 500$ GeV
$p_T^{\rm min} = 1000$ GeV
$g^{\rm Full}_{S_L\,{\rm lim}}/g^{\rm EFT}_{S_L\,{\rm lim}}$
m_{R_2} [TeV]

Pheno Interesting, eg.



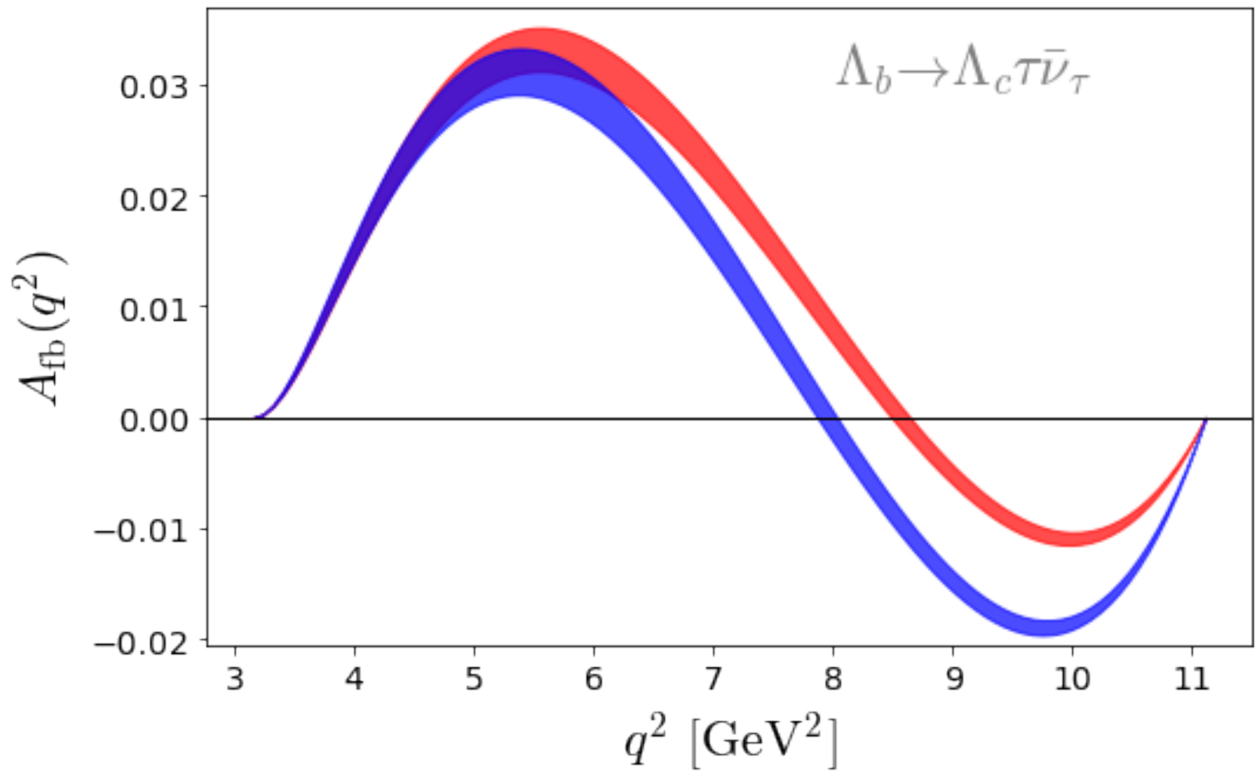


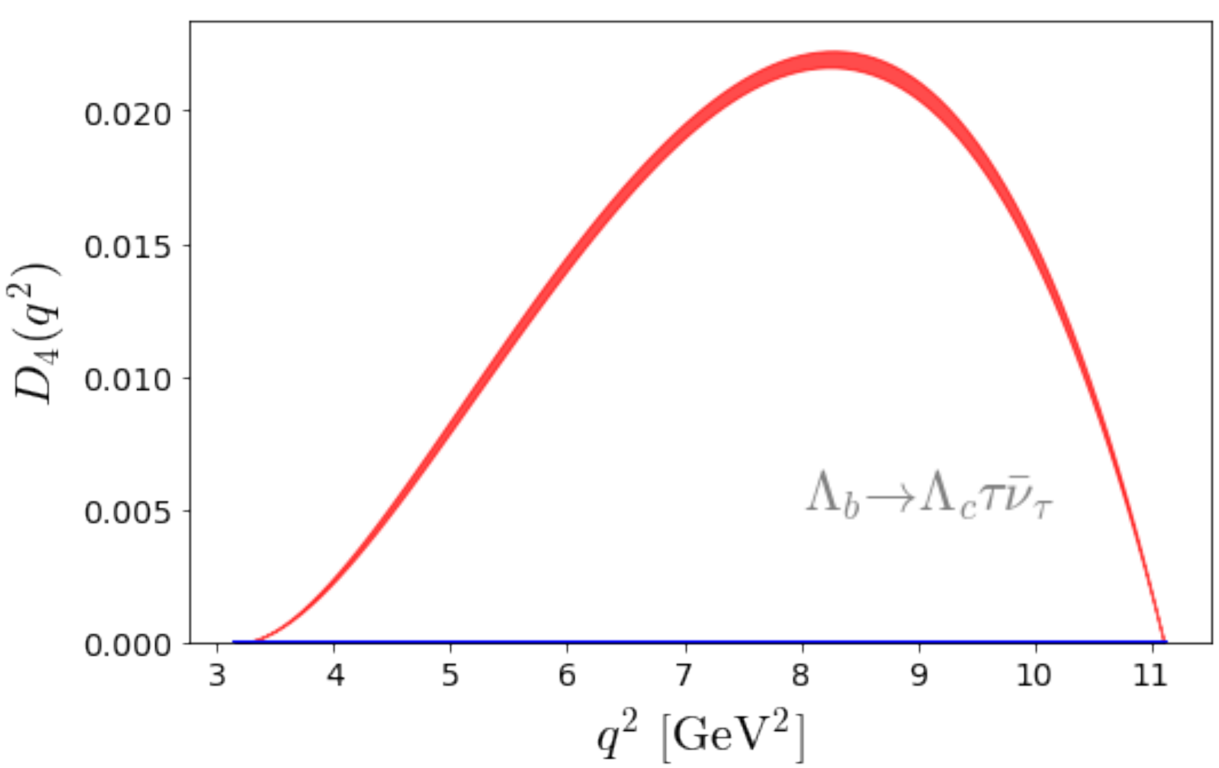
$$R_{\nu\nu}^{(*)} = \frac{\mathcal{B}(B \to K^{(*)}\nu\nu)}{\mathcal{B}(B \to K^{(*)}\nu\nu)^{\rm SM}}$$

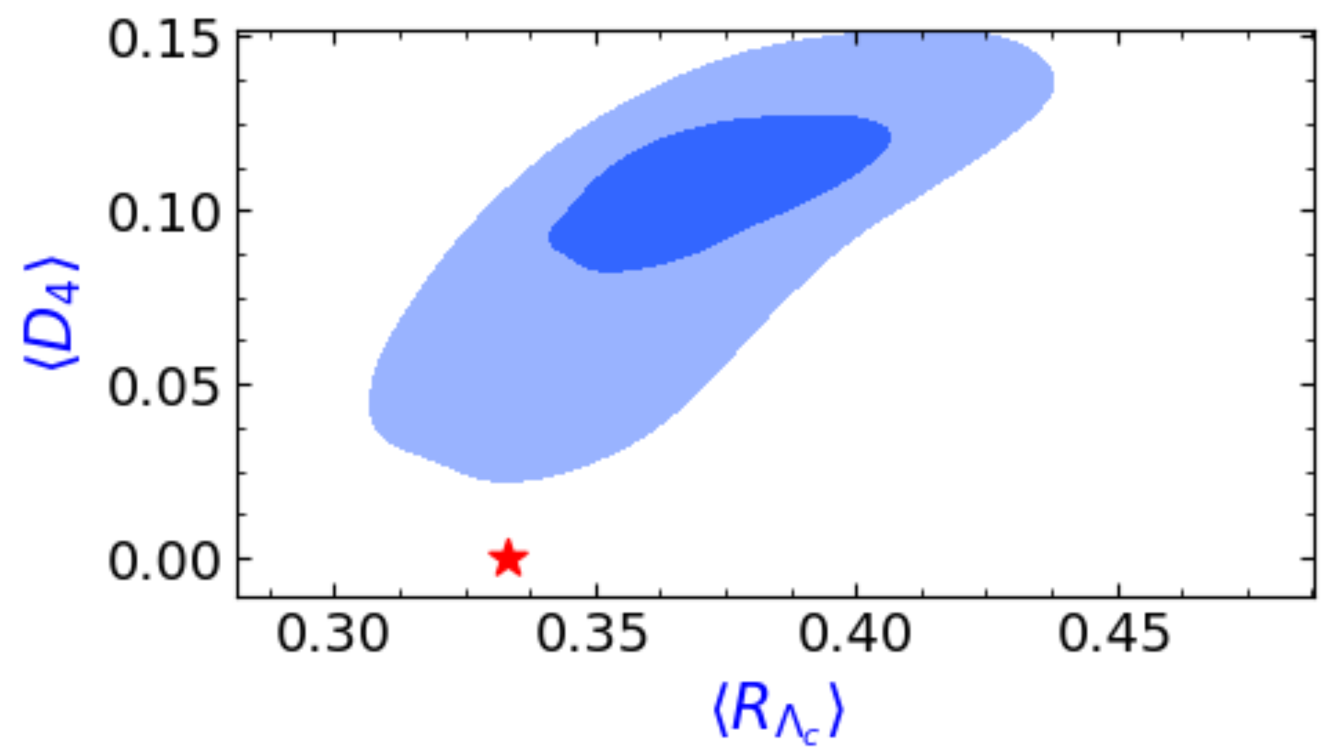
Discriminating power of the angular distribution

Eg. baryons

$$\frac{d^4\mathcal{B}}{dq^2 d\cos\theta_\tau d\cos\theta d\phi} = A_1 + A_2\cos\theta$$
$$+ (B_1 + B_2\cos\theta)\cos\theta_\tau + (C_1 + C_2\cos\theta)\cos^2\theta_\tau$$
$$+ (D_3\sin\theta\cos\phi + D_4\sin\theta\sin\phi)\sin\theta_\tau$$
$$+ (E_3\sin\theta\cos\phi + E_4\sin\theta\sin\phi)\sin\theta_\tau\cos\theta_\tau$$







Summary and Perspectives

- As of now, indications of LFUV in B decays are surviving experimental scrutiny
- New LHCb data on $\mathcal{B}(B_s \to \mu\mu)$ and R_K corroborate the picture that the plausible scenarios describing deficit of $b \to s\mu\mu$ verify $\delta C_9 \neq 0$, and $\delta C_9 = -\delta C_{10} < 0$ in particular
- Several options for describing the surplus of $b \to c\tau\nu$
- Experimental opportunities in angular observables relevant to $B \to D^{(*)}\ell\nu$ and $\Lambda_b \to \Lambda_c\ell\nu$
- Please be careful when dealing with hadronic uncertainties!
- Combining EFT, direct searches, and bounds from high p_T dilepton spectra at LHC help rule out some minimalistic leptoquark scenarios
- Way to go 1: Vector LQ despite non-renormalizability [UV completion, potential proliferation of parameters or assumptions]
- Way to go 2: Combine 2 scalar LQs: S_3 with S_1 or S_3 with R_2
- References given in arXiv: 2012.09872, 2103.12504, a few papers to come, as well as the speakers at this meeting.