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# B anomalies and SM flavor hierarchies

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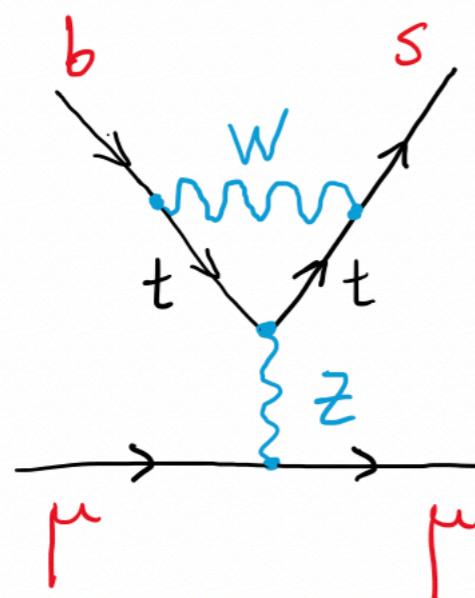
Rare semileptonic B Decays: Theory and Experiment ( $b \rightarrow s\ell\ell$  2019)

# The B-physics anomalies

Hints of Lepton Flavour Universality Violation in semileptonic B decays

$$b \rightarrow s \ell^+ \ell^-$$

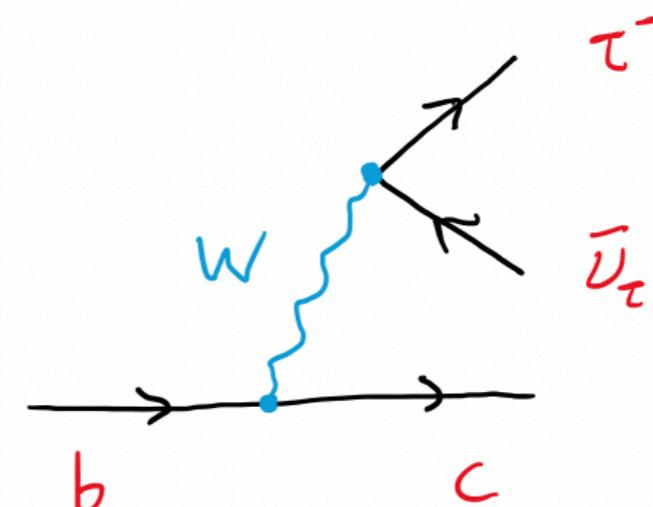
$\mu/e$  universality



$\sim 4\sigma$

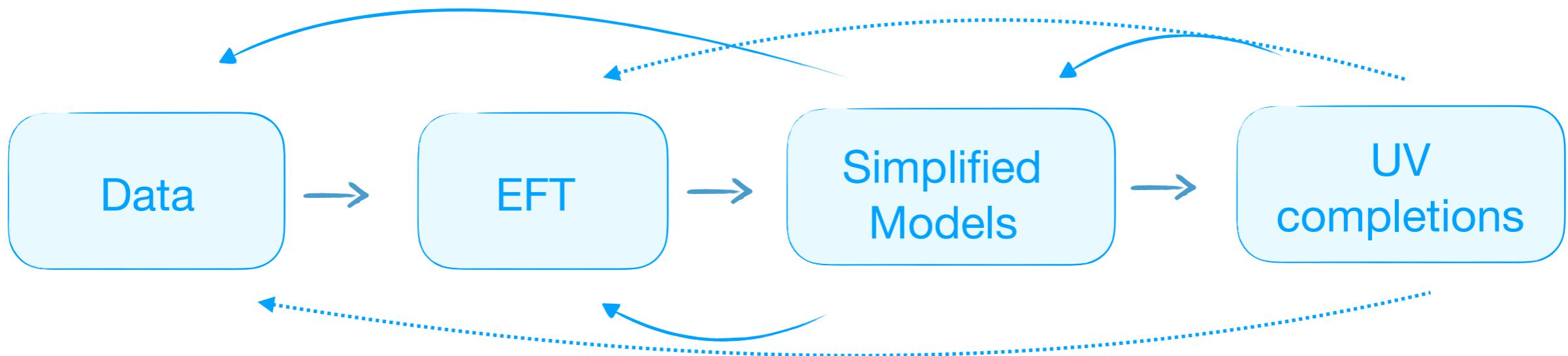
$$b \rightarrow c \tau \nu$$

$\tau/\mu, e$  universality



$\sim 3\sigma$

# The general approach

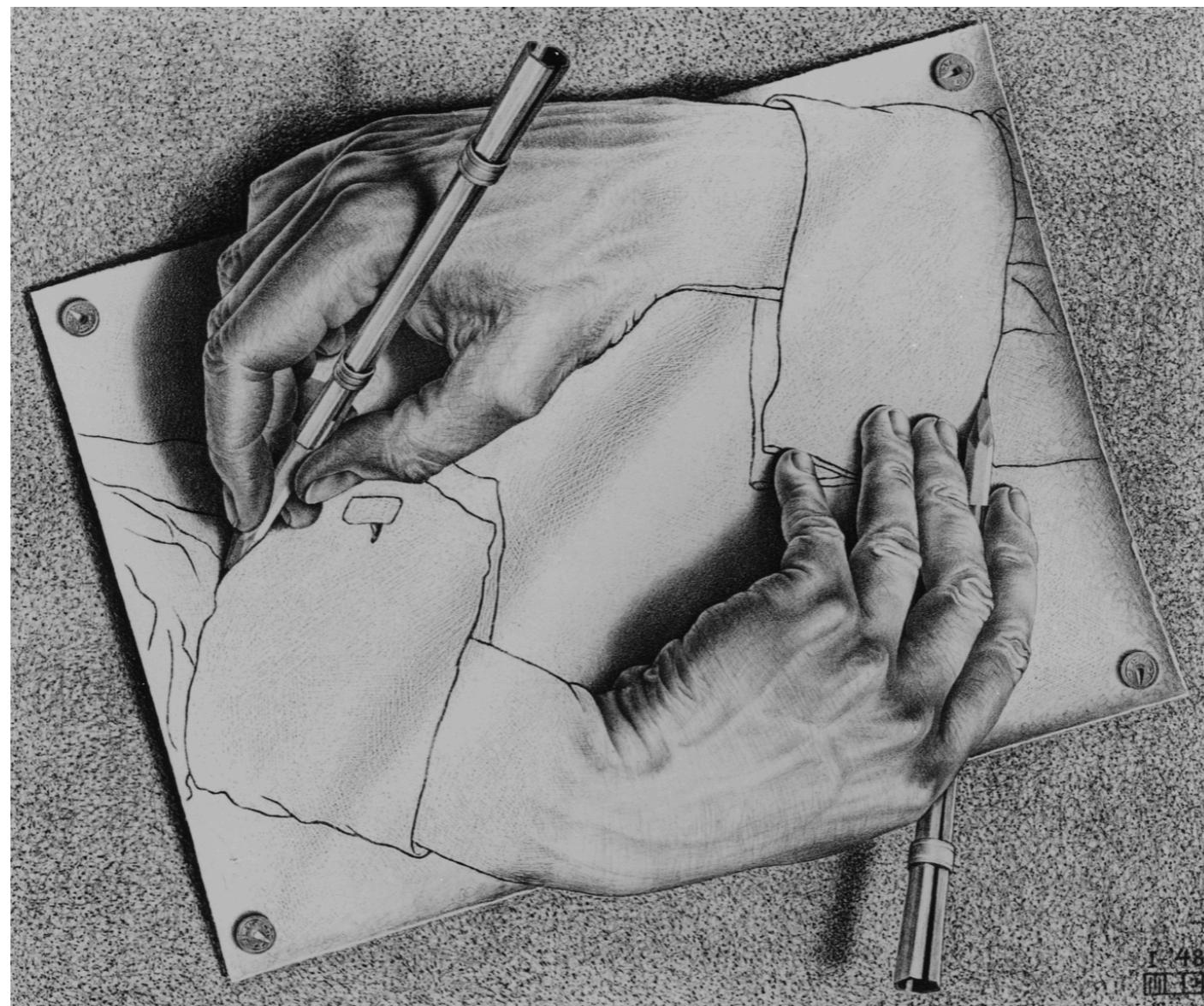


- ★ Analyze the **data** and compare to the SM
- ★ Find an **EFT** solution and investigate correlation with other observables
- ★ Implement **simplified dynamical models**, correlations with even more observables
- ★ Find “reasonable” **UV completions**, correlations with yet more observables

These steps are **complementary** and not unidirectional...

Lots of work has been done in the last years!

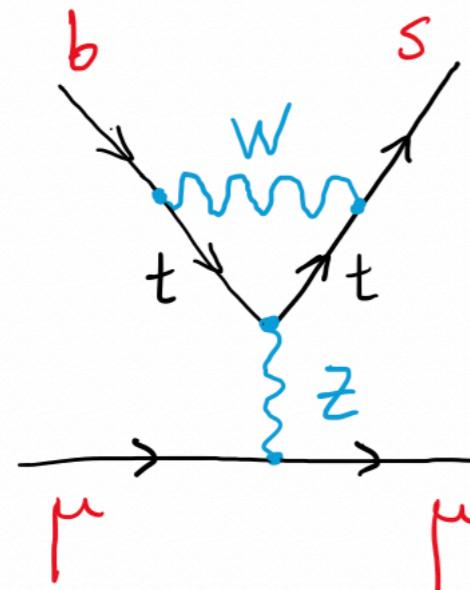
## From data to simplified models



# Towards a combined explanation of the anomalies

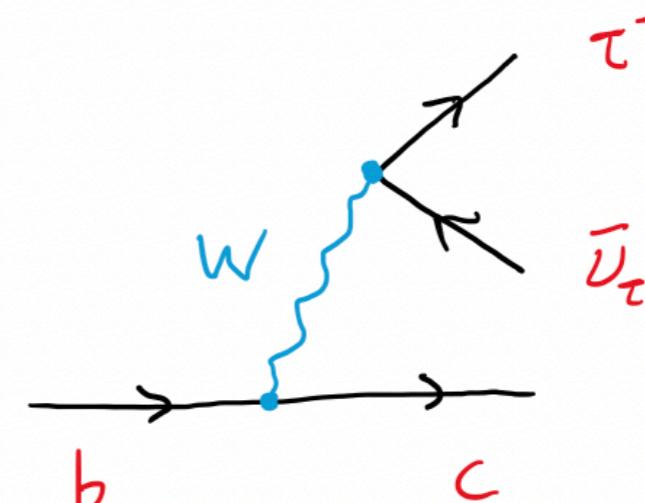
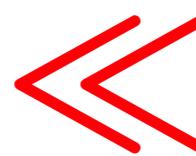
Taken together, these are a significant set of deviations from the SM

→ It is worth looking for a **combined explanation** in terms of New Physics!



$$3_Q \rightarrow 2_Q 2_L 2_L$$

~20% of a SM **loop** effect



$$3_Q \rightarrow 2_Q 3_L 3_L$$

~15% of a SM **tree-level** effect

The only source of **lepton flavor universality violation** in the SM (Yukawas) follows a similar trend:  $y_e \ll y_\mu \ll y_\tau \dots$  Are these anomalies connected to them?

# The SM flavor puzzle

$$\mathcal{L}_{\text{SM}} = \mathcal{L}_{\text{Gauge}} + \mathcal{L}_{\text{Higgs}} + \mathcal{L}_{\text{Yuk}}$$

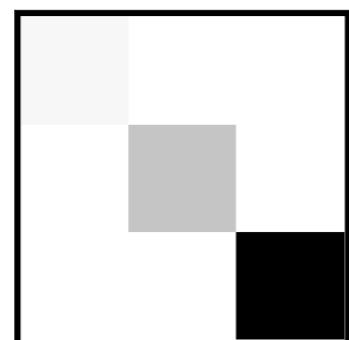
4+2 parameters  
(flavor universal)



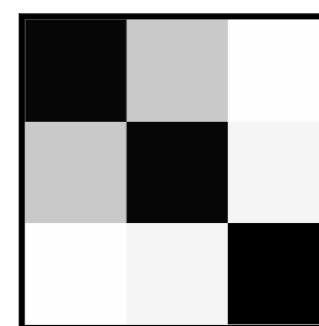
The SM Yukawa sector is characterized by 13 parameters (with massless neutrinos)  
[3 lepton masses + 6 quark masses + 3+1 CKM parameters]

... whose values do not look at all accidental

$$M_{u,d,e} \sim$$



$$V_{\text{CKM}} \sim$$



# The SM flavor puzzle and $U(2)^5$ symmetry

The SM Yukawas

$$M_{u,d,e} \sim \begin{pmatrix} & & \\ & & \\ & & \end{pmatrix}$$

$$V_{\text{CKM}} \sim \begin{pmatrix} & & \\ & & \\ & & \end{pmatrix}$$

$$\psi = (\psi_1 \ \psi_2 \ \psi_3)$$

respect an approximate  $U(2)^5 \equiv U(2)_q \times U(2)_\ell \times U(2)_u \times U(2)_d \times U(2)_e$  symmetry  
minimally broken by 5 spurions

[Barbieri et al. 1105.2296]

$$Y_{u,d,e} = y_{t,b,\tau} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix} U(2)_{q,\ell}$$

$$U(2)_{u,d,e}$$

**Unbroken symmetry**

$$Y_{u,d,e} = y_{t,b,\tau} \begin{pmatrix} \Delta_{u,d,e} & V_{q,\ell} \\ 0 & 1 \end{pmatrix}$$

$$|V_q| \sim V_{cb}$$

$$|\Delta_{u,d,e}| \sim y_{c,s,\mu}$$

**Minimally broken symmetry**

# A NP hint to the flavor puzzle?

The  $B$  anomalies show a similar structure to the one of the Yukawas, hinting to a possible common source. The aim of this talk is to exploit this fact by assuming that:

- ★ These anomalies are a true manifestation of NP
  - TeV scale NP (because of  $R(D^{(*)})$ )
  - Maximally coupled to 3rd gen., with gradually smaller effects in light families
  
- ★ The NP behind the anomalies is connected to the SM Yukawa structure
  - NP Lagrangian respects the same  $U(2)^5$  symmetry, broken only by  $V_{q,\ell}$
  - The “natural” size of these spurions is  $|V_\ell|, |V_q| = O(10^{-1})$

# SMEFT + $U(2)^5$ symmetry

$$\mathcal{L}_{\text{SMEFT}} \supset \mathcal{L}_{\text{SM}} - \frac{1}{v^2} \sum_{k,n} C_k^{[ij\alpha\beta]} \mathcal{O}_k^{[ij\alpha\beta]} + \text{h.c.}$$

Many dimension-six SMEFT operators contribute to semileptonic B decays

$$\begin{aligned} \mathcal{O}_{\ell q}^{(1)} &= (\bar{\ell}_L^\alpha \gamma^\mu \ell_L^\beta)(\bar{q}_L^i \gamma_\mu q_L^j), & \mathcal{O}_{ed} &= (\bar{e}_R^\alpha \gamma^\mu e_R^\beta)(\bar{d}_R^i \gamma_\mu d_R^j), \\ \mathcal{O}_{\ell q}^{(3)} &= (\bar{\ell}_L^\alpha \gamma^\mu \tau^I \ell_L^\beta)(\bar{q}_L^i \gamma_\mu \tau^I q_L^j), & \mathcal{O}_{\ell edq} &= (\bar{\ell}_L^\alpha e_R^\beta)(\bar{d}_R^i q_L^j), \\ \mathcal{O}_{\ell d} &= (\bar{\ell}_L^\alpha \gamma^\mu \ell_L^\beta)(\bar{d}_R^i \gamma_\mu d_R^j), & \mathcal{O}_{\ell equ}^{(1)} &= (\bar{\ell}_L^{a,\alpha} e_R^\beta) \epsilon_{ab} (\bar{q}_L^{a,i} u_R^j), \\ \mathcal{O}_{qe} &= (\bar{q}_L^i \gamma^\mu q_L^j)(\bar{e}_R^\alpha \gamma_\mu e_R^\beta), & \mathcal{O}_{\ell equ}^{(3)} &= (\bar{\ell}_L^{a,\alpha} \sigma_{\mu\nu} e_R^\beta) \epsilon_{ab} (\bar{q}_L^{b,i} \sigma^{\mu\nu} u_R^j), \end{aligned}$$

# SMEFT + $U(2)^5$ symmetry

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$$\cancel{\mathcal{O}_{ed}} = (\bar{e}_R^\alpha \gamma^\mu e_R^\beta)(\bar{d}_R^i \gamma_\mu d_R^j),$$

$$\mathcal{O}_{\ell q}^{(3)} = (\bar{\ell}_L^\alpha \gamma^\mu \tau^I \ell_L^\beta)(\bar{q}_L^i \gamma_\mu \tau^I q_L^j),$$

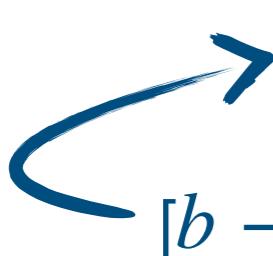
$$\mathcal{O}_{\ell edq} = (\bar{\ell}_L^\alpha e_R^\beta)(\bar{d}_R^i q_L^j),$$

$$\cancel{\mathcal{O}_{\ell d}} = (\bar{\ell}_L^\alpha \gamma^\mu \ell_L^\beta)(\bar{d}_R^i \gamma_\mu d_R^j),$$

$$\cancel{\mathcal{O}_{equ}^{(1)}} = (\bar{\ell}_L^{a,\alpha} e_R^\beta) \epsilon_{ab} (\bar{q}_L^{a,i} u_R^j),$$

$$\cancel{\mathcal{O}_{qe}} = (\bar{q}_L^i \gamma^\mu q_L^j)(\bar{e}_R^\alpha \gamma_\mu e_R^\beta),$$

$$\cancel{\mathcal{O}_{equ}^{(3)}} = (\bar{\ell}_L^{a,\alpha} \sigma_{\mu\nu} e_R^\beta) \epsilon_{ab} (\bar{q}_L^{b,i} \sigma^{\mu\nu} u_R^j),$$

 [ $b \rightarrow s\tau\tau$  only]



Right-handed light-fermion operators are  $U(2)^5$ -suppressed

... but only few yield sizable effects if we impose a minimally broken  $U(2)^5$  symmetry

★ The relation  $C_{\ell q}^{(1)} \approx C_{\ell q}^{(3)}$  needs to be enforced to avoid exp. constraints from  $b \rightarrow s\nu_{(\tau)}\nu_{(\tau)}$

# SMEFT + $U(2)^5$ symmetry

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Many dimension-six SMEFT operators contribute to semileptonic B decays

$\mathcal{O}_{\ell q}^{(1)} = (\bar{\ell}_L^\alpha \gamma^\mu \ell_L^\beta)(\bar{q}_L^i \gamma_\mu q_L^j),$	$\cancel{\mathcal{O}_{ed}} = (\bar{e}_R^\alpha \gamma^\mu e_R^\beta)(\bar{d}_R^i \gamma_\mu d_R^j),$
$\mathcal{O}_{\ell q}^{(3)} = (\bar{\ell}_L^\alpha \gamma^\mu \tau^I \ell_L^\beta)(\bar{q}_L^i \gamma_\mu \tau^I q_L^j),$	$\mathcal{O}_{\ell edq} = (\bar{\ell}_L^\alpha e_R^\beta)(\bar{d}_R^i q_L^j),$
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$\cancel{\mathcal{O}_{qe}} = (\bar{q}_L^i \gamma^\mu q_L^j)(\bar{e}_R^\alpha \gamma_\mu e_R^\beta),$	$\cancel{\mathcal{O}_{equ}^{(3)}} = (\bar{\ell}_L^{a,\alpha} \sigma_{\mu\nu} e_R^\beta) \epsilon_{ab} (\bar{q}_L^{b,i} \sigma^{\mu\nu} u_R^j),$

- ★ The relation  $C_{\ell q}^{(1)} \approx C_{\ell q}^{(3)}$  needs to be enforced to avoid exp. constraints from  $b \rightarrow s\nu_{(\tau)}\nu_{(\tau)}$
- ★ The  $U_1 \sim (\mathbf{3}, \mathbf{1})_{2/3}$  vector leptoquark is the **only single mediator** that matches this structure, with  $C_{\ell q}^{(1)} = C_{\ell q}^{(3)}$  and  $C_{qe} = 0$

# EFT flavor structure

$$\mathcal{L}_{\text{EFT}} \supset \mathcal{L}_{\text{SM}} - \frac{1}{v^2} \left[ C_V \Lambda_V^{[ij\alpha\beta]} \left( \mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)} \right)^{[ij\alpha\beta]} + \left( 2 C_S \Lambda_S^{[ij\alpha\beta]} \mathcal{O}_{\ell edq}^{[ij\alpha\beta]} + \text{h.c.} \right) \right]$$

NP parameters:  $C_V, C_S$  [NP strength]  $\Lambda_V = \Gamma_L^\dagger \times \Gamma_L, \Lambda_S = \Gamma_L^\dagger \times \Gamma_R$  [Flavor structure]

At lowest order in the spurion ( $V_{q,\ell}$ ) expansion

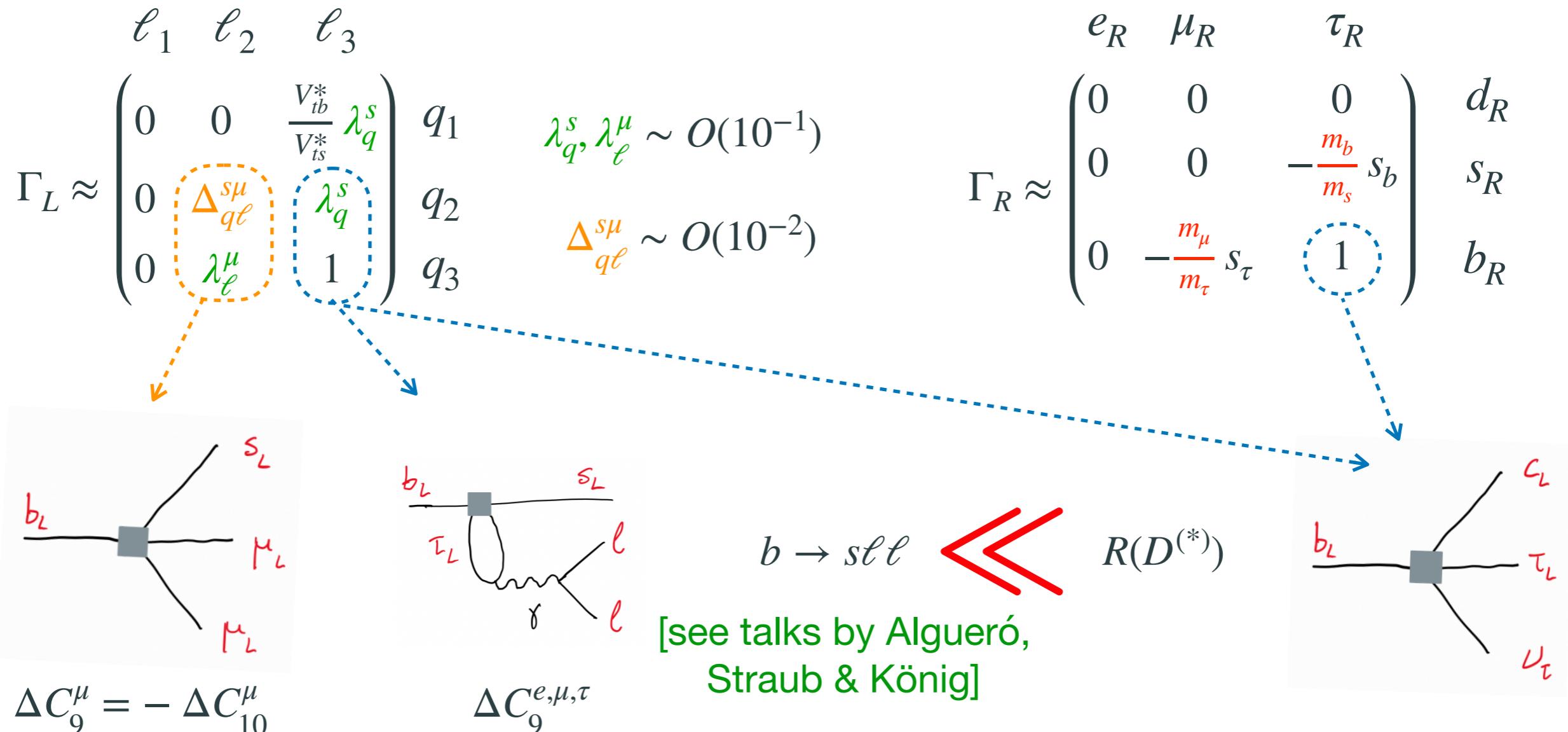
$$\Gamma_L \approx \begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \\ 0 & 0 & \frac{V_{tb}^*}{V_{ts}^*} \lambda_q^s \\ 0 & \Delta_{q\ell}^{s\mu} & \lambda_q^s \\ 0 & \lambda_\ell^\mu & 1 \end{pmatrix} \begin{matrix} q_1 \\ q_2 \\ q_3 \end{matrix} \quad \begin{aligned} \lambda_q^s, \lambda_\ell^\mu &\sim O(10^{-1}) \\ \Delta_{q\ell}^{s\mu} &\sim O(10^{-2}) \end{aligned}$$

$$\Gamma_R \approx \begin{pmatrix} e_R & \mu_R & \tau_R \\ 0 & 0 & 0 \\ 0 & 0 & -\frac{m_b}{m_s} s_b \\ 0 & -\frac{m_\mu}{m_\tau} s_\tau & 1 \end{pmatrix} \begin{matrix} d_R \\ s_R \\ b_R \end{matrix}$$

# EFT flavor structure

$$\mathcal{L}_{\text{EFT}} \supset \mathcal{L}_{\text{SM}} - \frac{1}{v^2} \left[ C_V \Lambda_V^{[ij\alpha\beta]} (\mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)})^{[ij\alpha\beta]} + (2 C_S \Lambda_S^{[ij\alpha\beta]} \mathcal{O}_{\ell edq}^{[ij\alpha\beta]} + \text{h.c.}) \right]$$

NP parameters:  $C_V, C_S$  [NP strength]  $\Lambda_V = \Gamma_L^\dagger \times \Gamma_L, \Lambda_S = \Gamma_L^\dagger \times \Gamma_R$  [Flavor structure]



# $U(2)^5$ predictions

$$\mathcal{L}_{\text{EFT}} \supset \mathcal{L}_{\text{SM}} - \frac{1}{v^2} \left[ C_V \Lambda_V^{[ij\alpha\beta]} \left( \mathcal{O}_{\ell q}^{(1)} + \mathcal{O}_{\ell q}^{(3)} \right)^{[ij\alpha\beta]} + \left( 2 C_S \Lambda_S^{[ij\alpha\beta]} \mathcal{O}_{\ell edq}^{[ij\alpha\beta]} + \text{h.c.} \right) \right]$$

NP parameters:  $C_V, C_S$  [NP strength]  $\Lambda_V = \Gamma_L^\dagger \times \Gamma_L, \Lambda_S = \Gamma_L^\dagger \times \Gamma_R$  [Flavor structure]

$$\Gamma_L \approx \begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \\ 0 & 0 & \frac{V_{tb}^*}{V_{ts}^*} \lambda_q^s \\ 0 & \Delta_{q\ell}^{s\mu} & \lambda_q^s \\ 0 & \lambda_\ell^\mu & 1 \end{pmatrix} \begin{matrix} q_1 \\ q_2 \\ q_3 \end{matrix} \quad \begin{matrix} \lambda_q^s, \lambda_\ell^\mu \sim O(10^{-1}) \\ \Delta_{q\ell}^{s\mu} \sim O(10^{-2}) \end{matrix}$$

$$\Gamma_R \approx \begin{pmatrix} e_R & \mu_R & \tau_R \\ 0 & 0 & 0 \\ 0 & 0 & -\frac{m_b}{m_s} s_b \\ 0 & -\frac{m_\mu}{m_\tau} s_\tau & 1 \end{pmatrix} \begin{matrix} d_R \\ s_R \\ b_R \end{matrix}$$

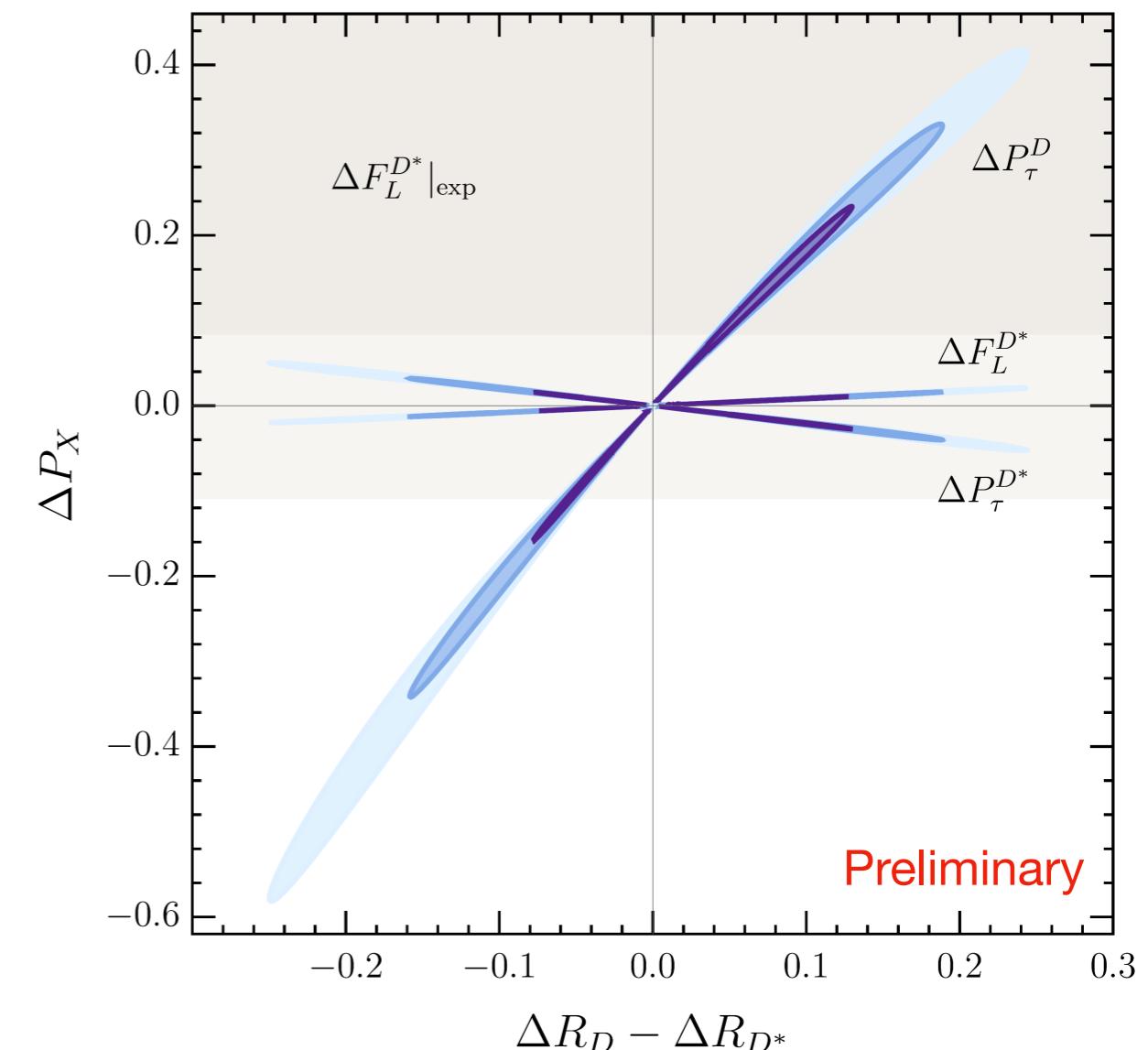
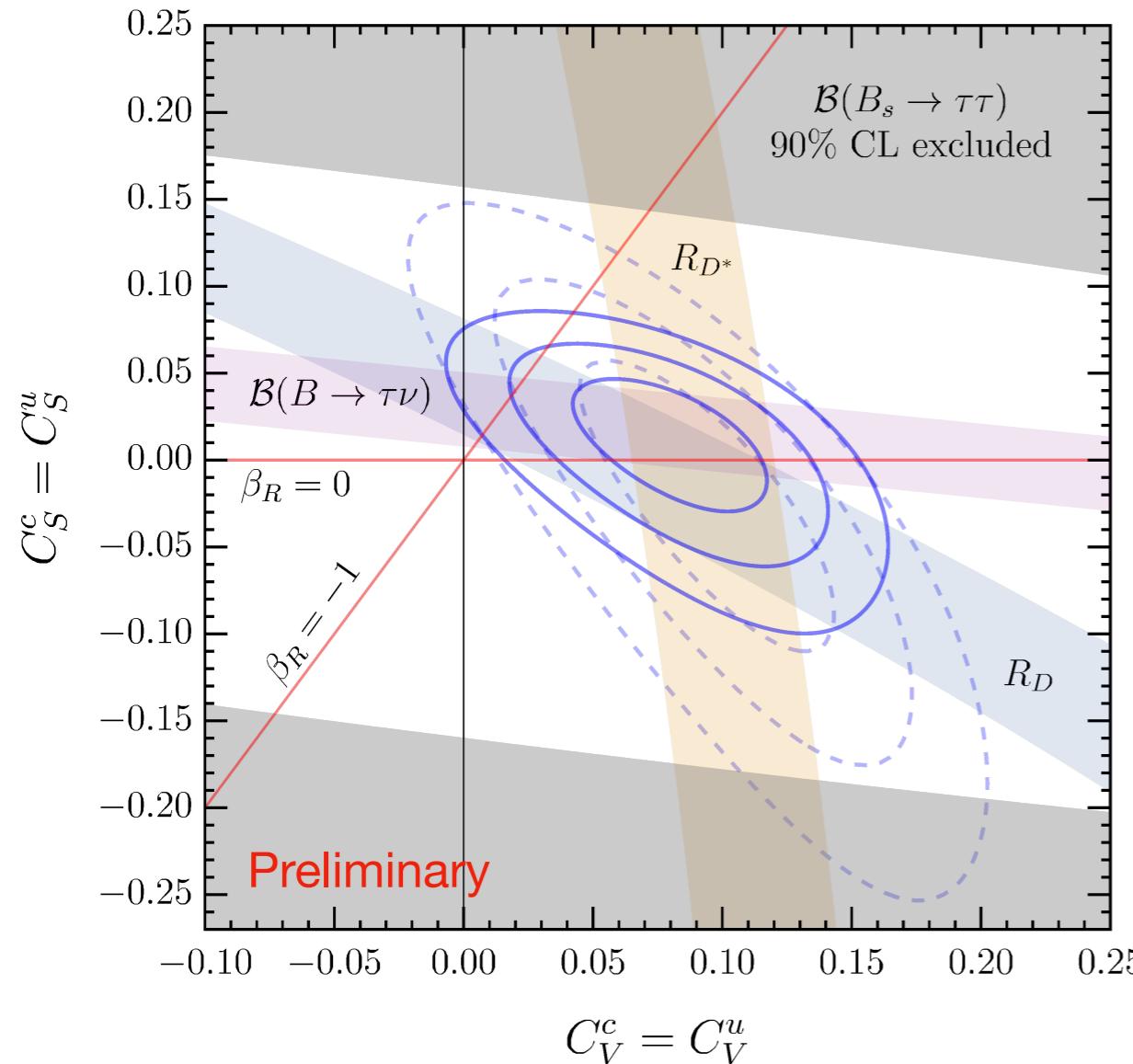
Predictions:

$$\frac{b \rightarrow s\ell\ell}{b \rightarrow d\ell\ell} = \frac{b \rightarrow s\ell\ell}{b \rightarrow d\ell\ell} \Bigg|_{\text{SM}}$$

$$\frac{b \rightarrow c\ell\nu}{b \rightarrow u\ell\nu} = \frac{b \rightarrow c\ell\nu}{b \rightarrow u\ell\nu} \Bigg|_{\text{SM}}$$

# Testing the NP helicity structure in $b \rightarrow c\tau\nu$

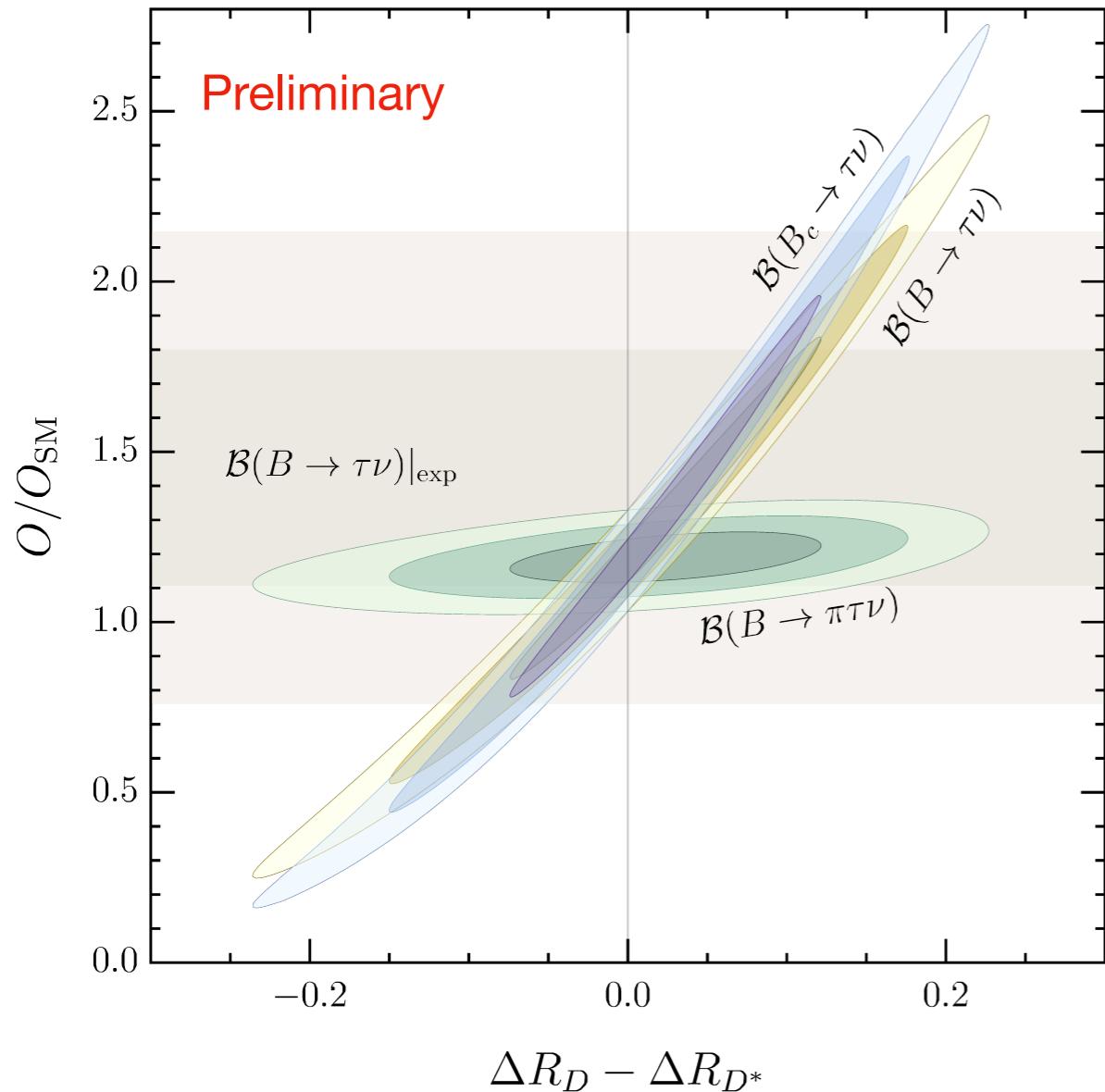
[JFM, Isidori, Pagès, Yamamoto, to appear]



$$C_{V,S}^c = C_{V,S}^u = C_{V,S} \left( 1 + \frac{V_{tb}^*}{V_{ts}^*} \lambda_q^\ell \right)$$

$$\Delta R_D - \Delta R_{D^*} \approx 2.4 C_S^c$$

# Predictions in other CC $B_{(c)}$ decays



$U(2)^5$  predictions:

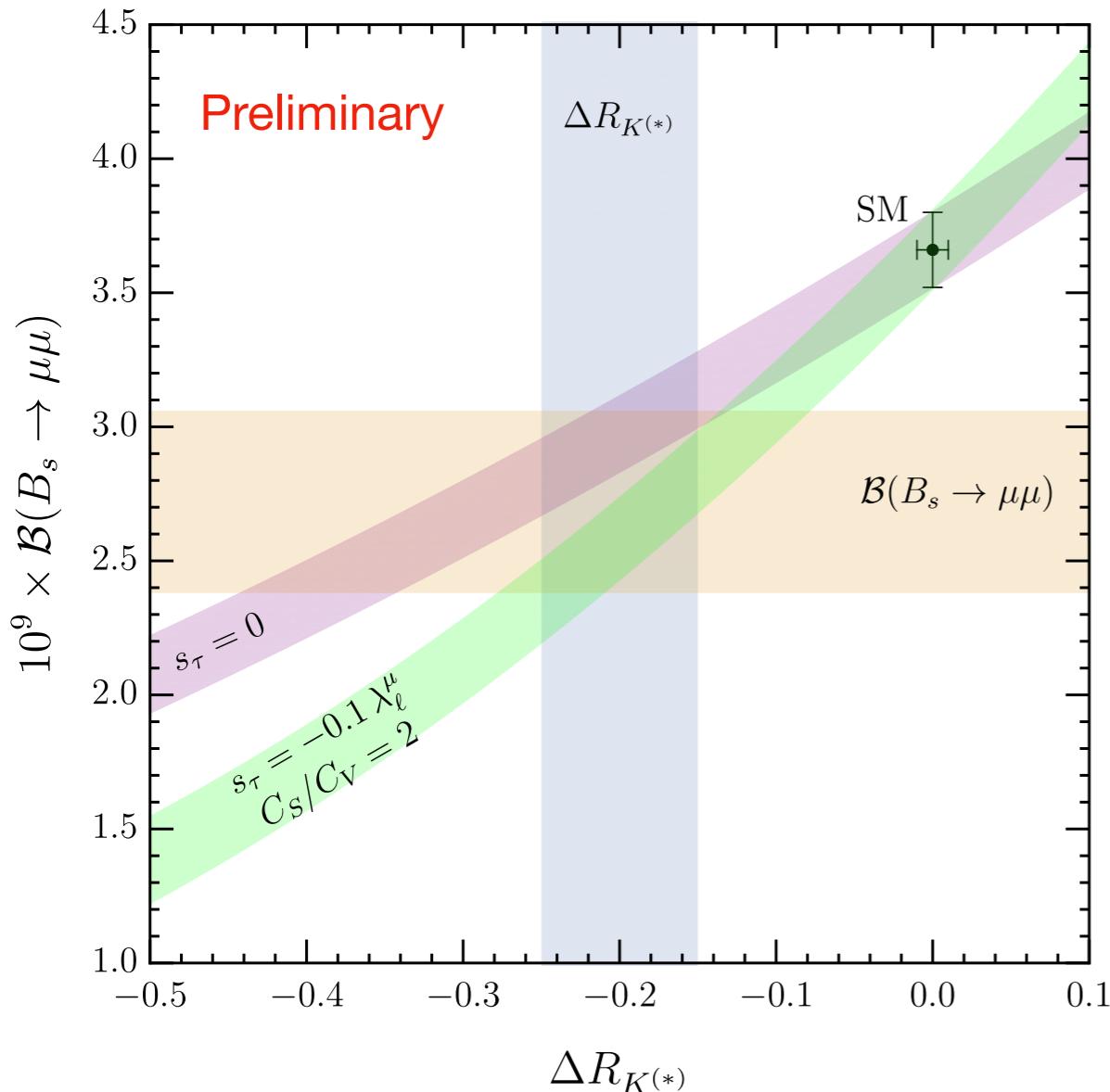
$$\frac{R_\pi}{R_\pi^{\text{SM}}} \approx 0.75 \frac{R_D}{R_D^{\text{SM}}} + 0.25 \frac{R_{D^*}}{R_{D^*}^{\text{SM}}}$$

$$\frac{\mathcal{B}(\bar{B}_u \rightarrow \tau\bar{\nu})}{\mathcal{B}(\bar{B}_u \rightarrow \tau\bar{\nu})_{\text{SM}}} \approx \frac{\mathcal{B}(\bar{B}_c \rightarrow \tau\bar{\nu})}{\mathcal{B}(\bar{B}_c \rightarrow \tau\bar{\nu})_{\text{SM}}}$$

N.B.:  $R_\pi \equiv \frac{\mathcal{B}(B \rightarrow \pi\tau\nu)}{\mathcal{B}(B \rightarrow \pi\ell\nu)}$

[JFM, Isidori, Pagès, Yamamoto, to appear]

# Predictions in NC $B_{(s)}$ decays



$$\frac{\mathcal{B}(B_s \rightarrow \mu\mu)}{\mathcal{B}(B_s \rightarrow \mu\mu)_{\text{SM}}} \approx 1 - \frac{\Delta R_{K^{(*)}}}{0.24 C_{10}^{\text{SM}}} \left( 1 - 3.2 \frac{s_\tau}{\lambda_\ell^\mu} \frac{C_S}{C_V} \right)$$

$U(2)^5$  prediction ( $b \rightarrow s$  vs  $b \rightarrow d$ ):

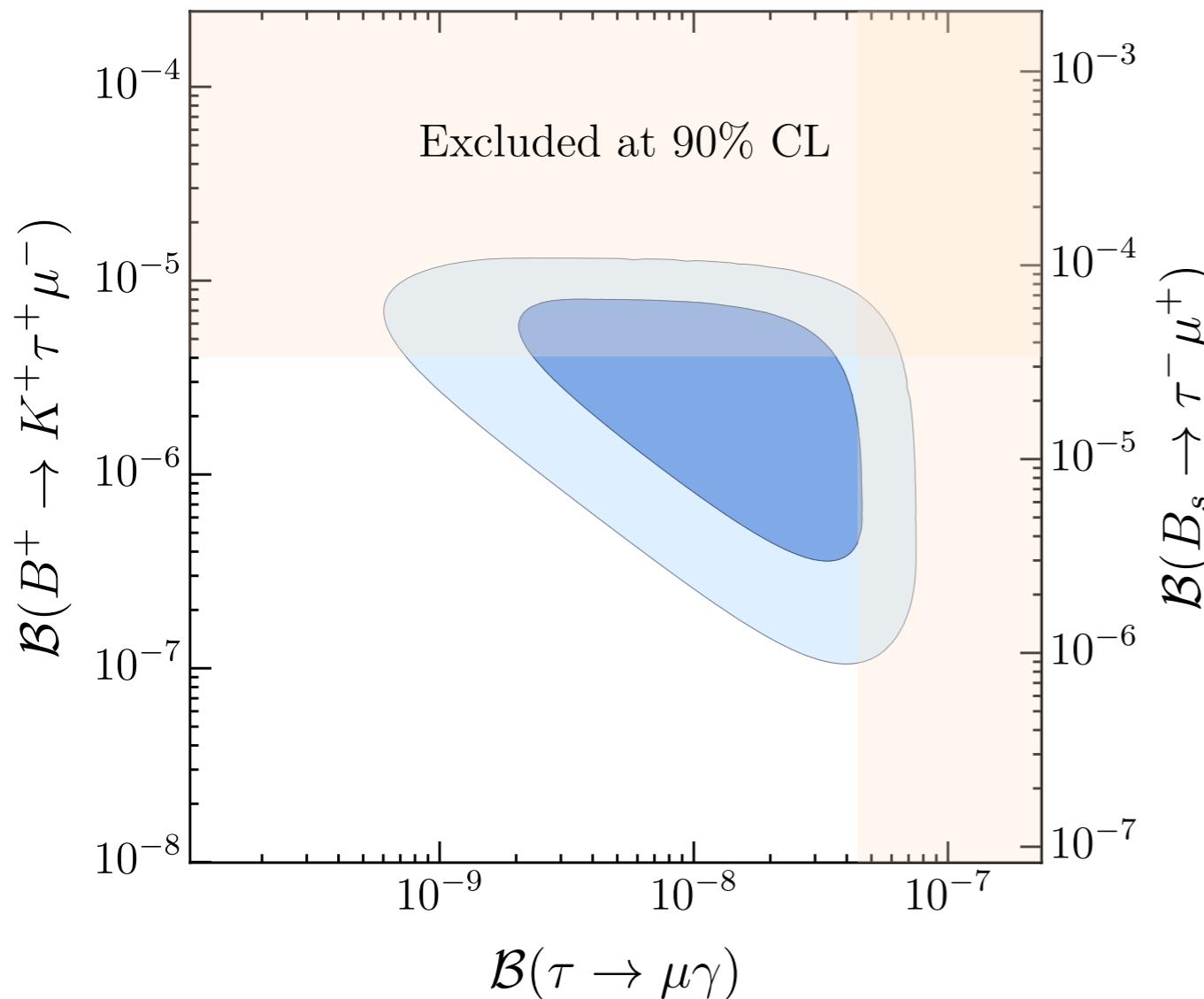
$$R_K \approx R_{K^*} \approx \frac{\mathcal{B}(B \rightarrow \pi \mu \bar{\mu})_{[\Delta q^2_{\text{pert}}]}}{\mathcal{B}(B \rightarrow \pi e \bar{e})_{[\Delta q^2_{\text{pert}}]}}$$

$$\frac{\mathcal{B}(B_s \rightarrow \mu\mu)}{\mathcal{B}(B_s \rightarrow \mu\mu)_{\text{SM}}} \approx \frac{\mathcal{B}(B_d \rightarrow \mu\mu)}{\mathcal{B}(B_d \rightarrow \mu\mu)_{\text{SM}}}$$

[JFM, Isidori, Pagès, Yamamoto, to appear]

# LFV in $\tau \rightarrow \mu$ transitions

Taking  $C_S/C_V = 2$



[Cornella, JFM, Isidori, 1903.11517]

$\tau\mu$ -LFV offers a great probe of the helicity structure

→ possible strong enhancement of  $B_s \rightarrow \tau\mu$ ,  $B \rightarrow K\tau\mu$ ,  $\tau \rightarrow \mu\gamma$  for sizable  $C_S$

$$\mathcal{B}(\tau \rightarrow \mu\gamma) \sim 10^{-9}$$

$$\mathcal{B}(B \rightarrow K\tau\mu) \sim 10^{-6}$$

$$\mathcal{B}(B_s \rightarrow \tau^+ \mu^-) \sim 10^{-5}$$

★ Recent LHCb measurement

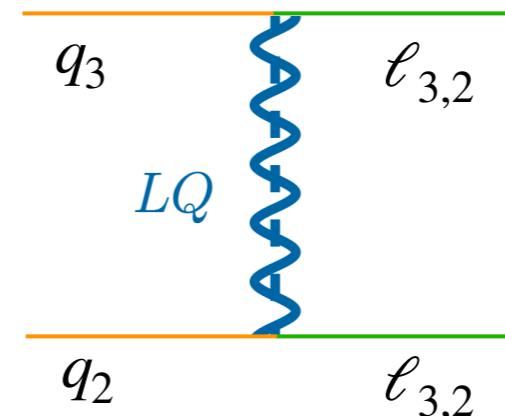
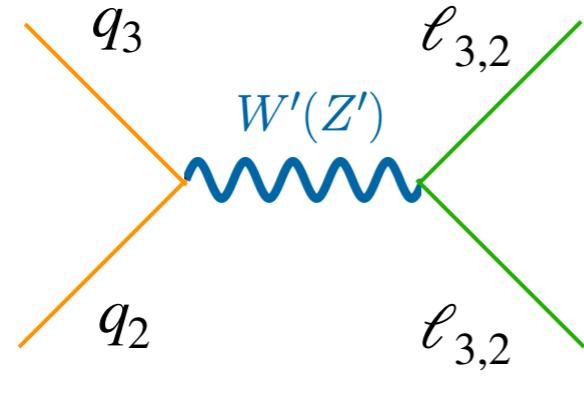
$$\mathcal{B}(B_s \rightarrow \tau\mu) < 3.4 \times 10^{-5}$$

[LHCb, 1905.06614]

# From EFT to simplified models



# Which mediator?



Only few possibilities are available

★ **Minimal  $W'/Z'$  models** in tension with high- $p_T$  data ( $p p \rightarrow \tau \tau$  tails)

[Faroughy et al. 1609.07138]

$W' +$  light  $\nu_R$  in better shape but still in tension with  $p p \rightarrow \tau \nu$  tails

[Greljo et al. 1811.07920]

★ **Leptoquarks** (scalars or vectors) are the best candidates so far

✓ no 4-lepton (LFV, LFUV) or 4-quark processes ( $\Delta F = 2$ ) at tree level

# The main suspects

[see talk by Pere Arnan]

Model	$R_{K(*)}$	$R_{D(*)}$	$R_{K(*)} \& R_{D(*)}$
$S_1 = (3, 1)_{-1/3}$	✗	✓	✗
$R_2 = (3, 2)_{7/6}$	✗	✓	✗
$\tilde{R}_2 = (3, 2)_{1/6}$	✗	✗	✗
$S_3 = (3, 3)_{-1/3}$	✓	✗	✗
$U_1 = (3, 1)_{2/3}$	✓	✓	✓
$U_3 = (3, 3)_{2/3}$	✓	✗	✗

[Angelescu, Bećirević, Faroughy, Sumensary, 1808.08179]

Three viable options in the market:

★  $U_1 + \text{UV completion}$

[di Luzio, Greljo, Nardecchia 1708.08450;  
Calibbi, Crivellin, Li 1709.00692;  
Bordone, Cornella, JF, Isidori 1712.01368;  
Barbieri, Tesi, 1712.06844...]

★  $S_1 + S_3$

[Crivellin, Muller, Ota 1703.09226;  
Buttazzo et al. 1706.07808;  
Marzocca 1803.10972]

★  $S_3 + R_2$

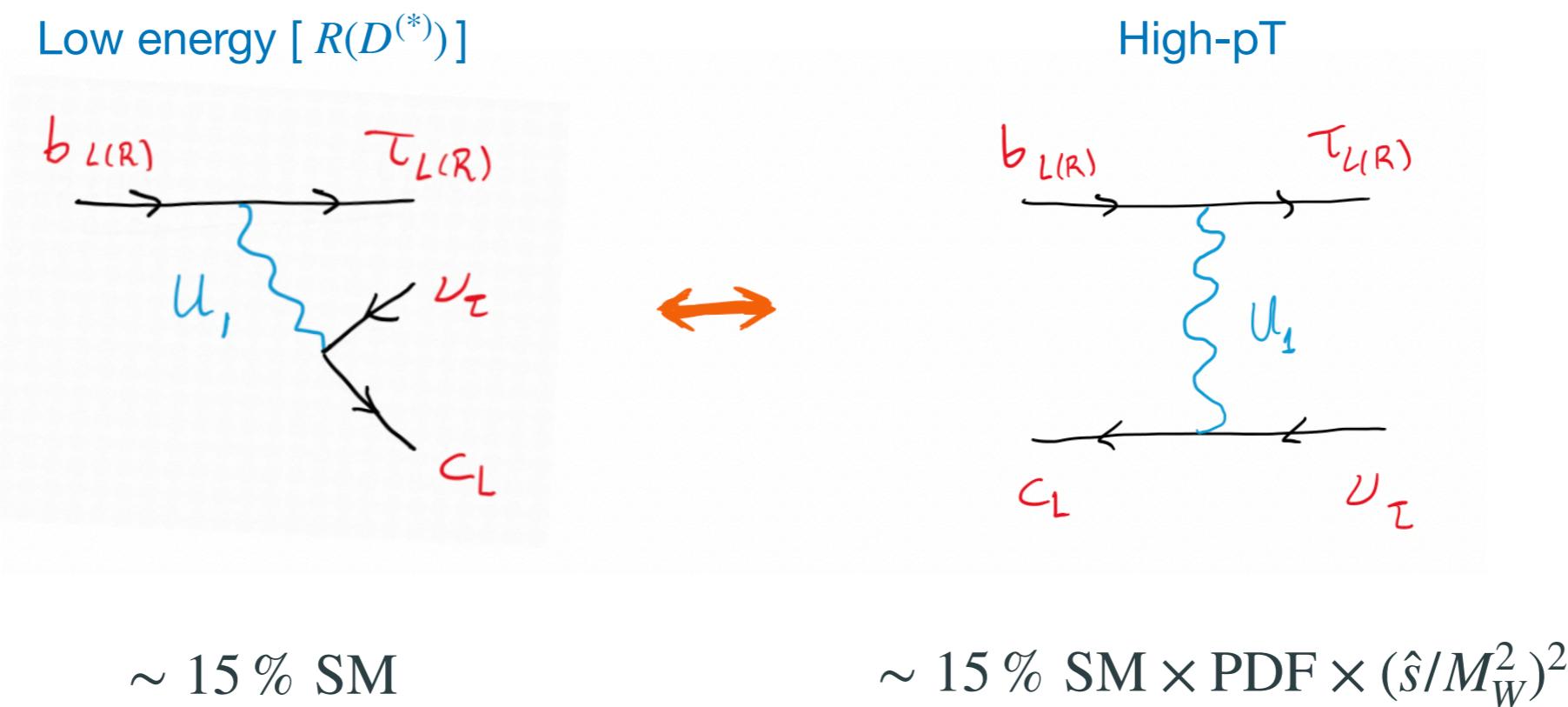
[Bećirević et al., 1806.05689]

The vector leptoquark ( $U_1$ ) brings some interesting features into the game

- ✓ No tree-level  $b \rightarrow s\nu\nu$
- ✓ The  $U_1$  nicely matches the SMEFT+ $U(2)^5$  structure (SM flavor puzzle)

# Hunting the vector leptoquark at high-pT

This mediator is a clear target for the high-pT program at LHC!

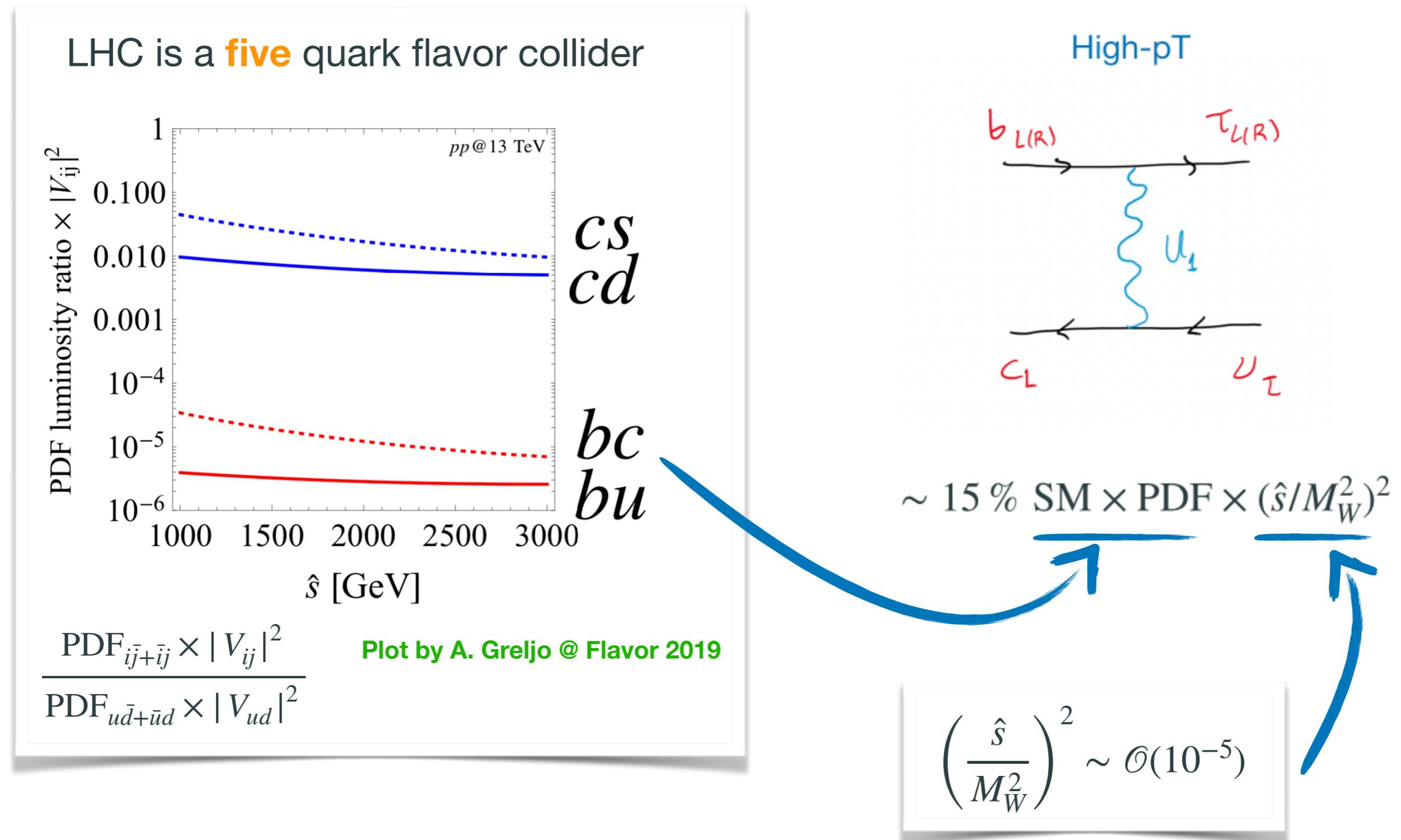


Generic characteristics of the new state:

- ★ Masses **around the TeV scale** [2-6 TeV] (hard to reach via direct (pair) production)
- ★ Flavor non-universal, with much **stronger couplings to 3rd generation**

# Hunting the vector leptoquark at high-pT

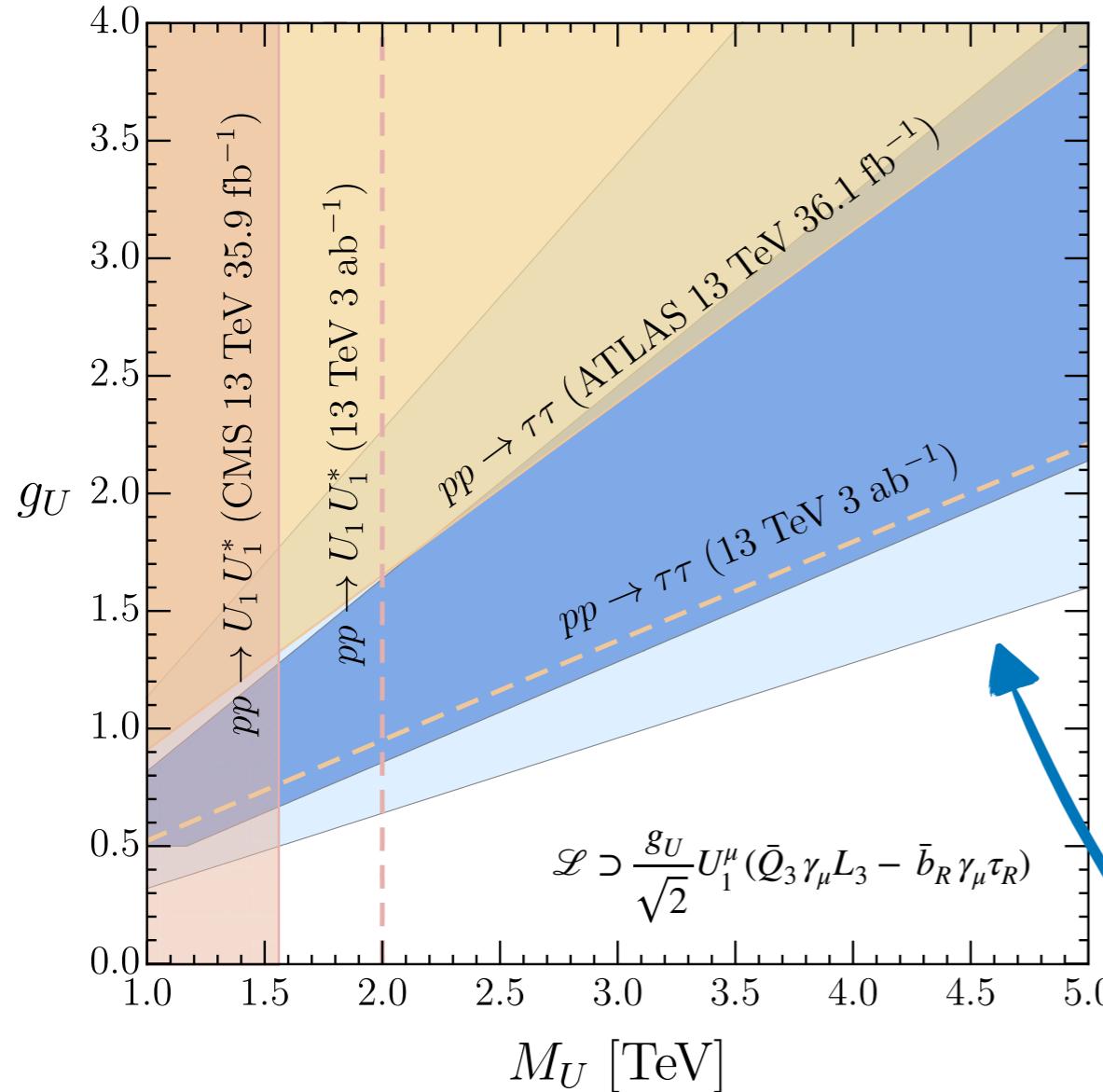
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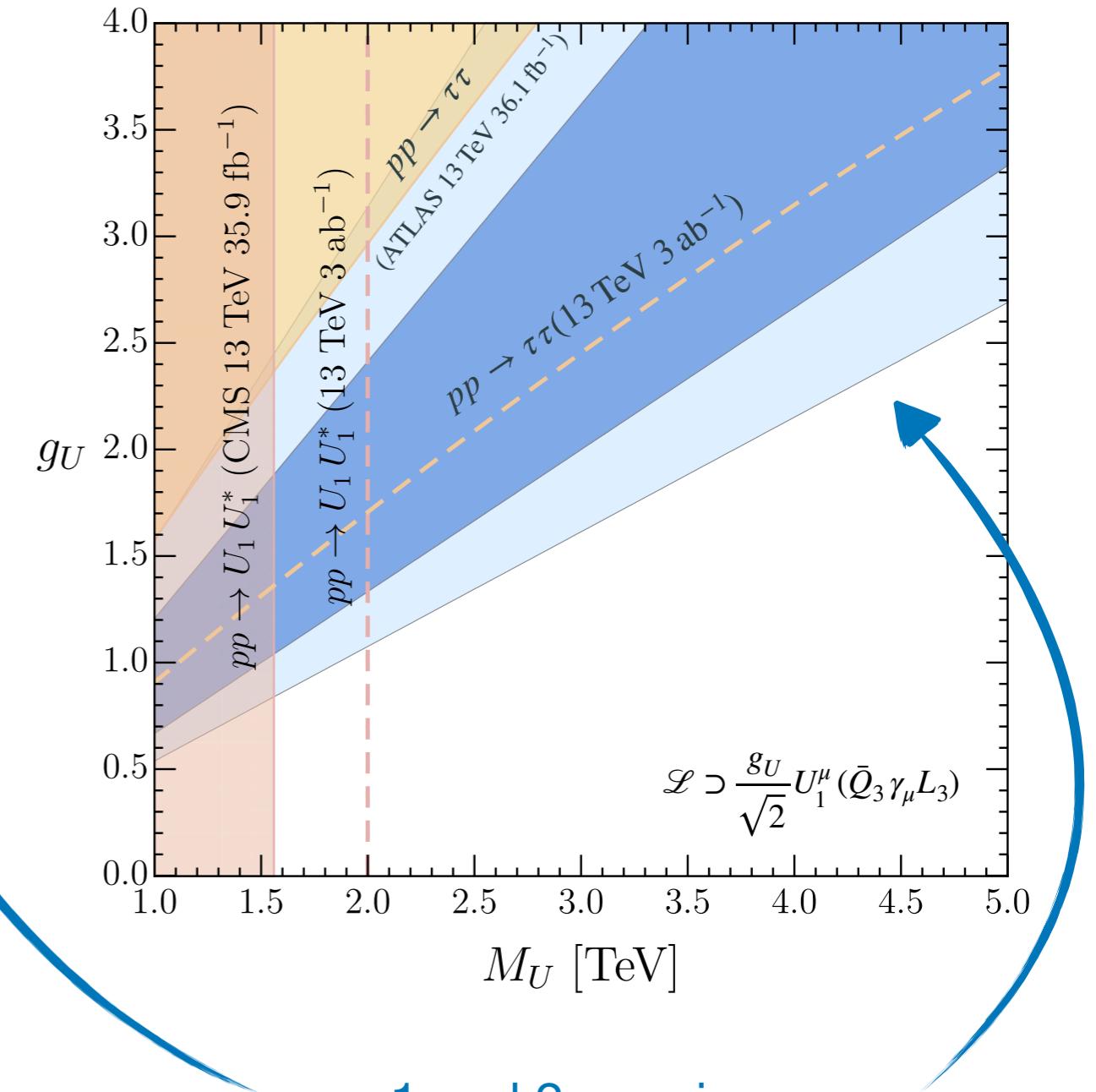
# High-pT + Low energy

[High-pT bounds from Baker, JFM, Isidori, König, 1901.10480]

LH + RH



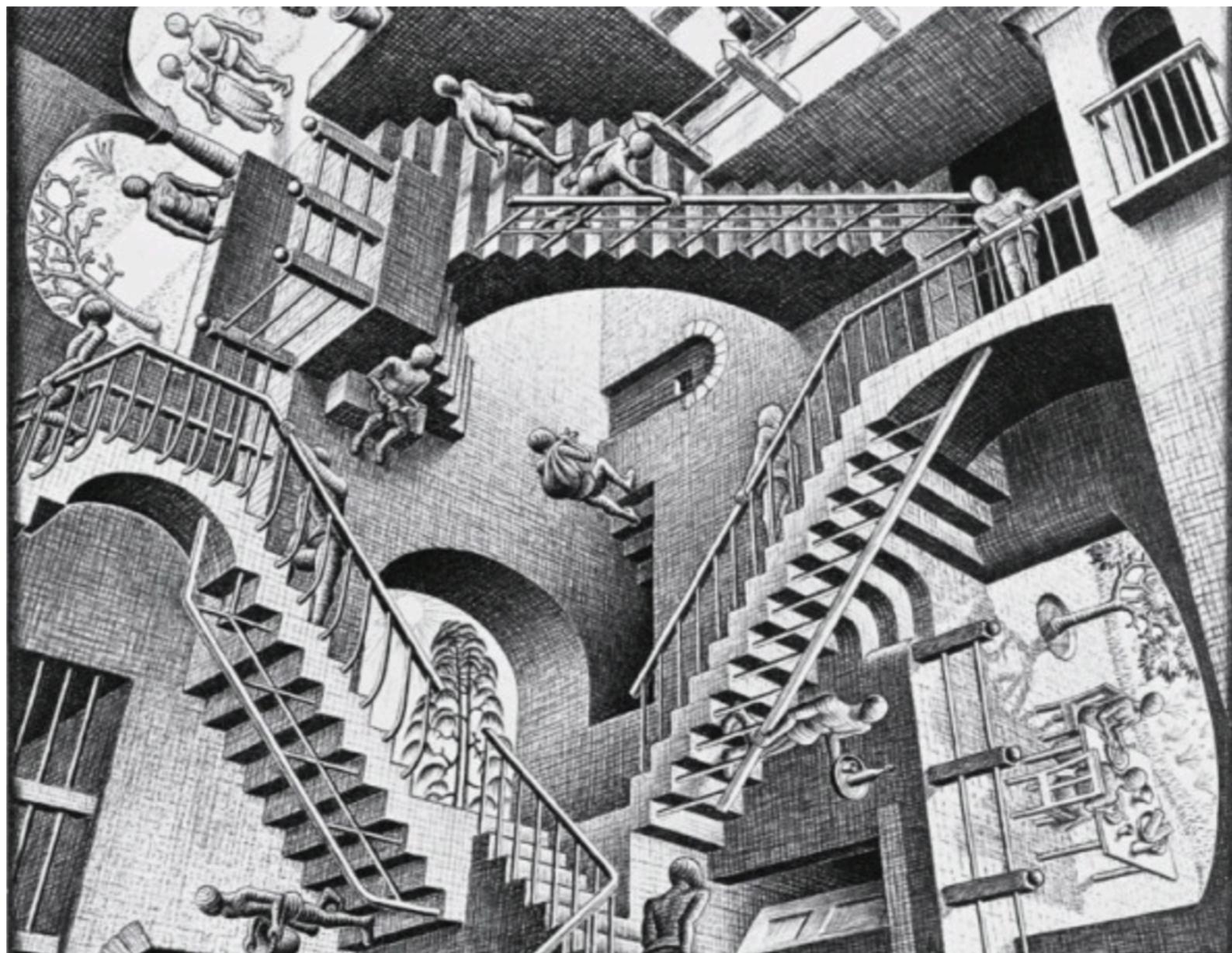
LH only



[Cornella, JFM, Isidori, 1903.11517]

(\*) N.B.: Assuming  $\beta_{s\tau} < 0.25$

## Beyond the simplified picture



# Towards a UV-complete $U_1$ model

The vector-leptoquark solution points to Pati-Salam unification

$$\text{PS} \equiv \mathbf{SU}(4) \times \mathbf{SU}(2)_L \times \mathbf{SU}(2)_R$$

Pati, Salam, Phys. Rev. D10 (1974) 275

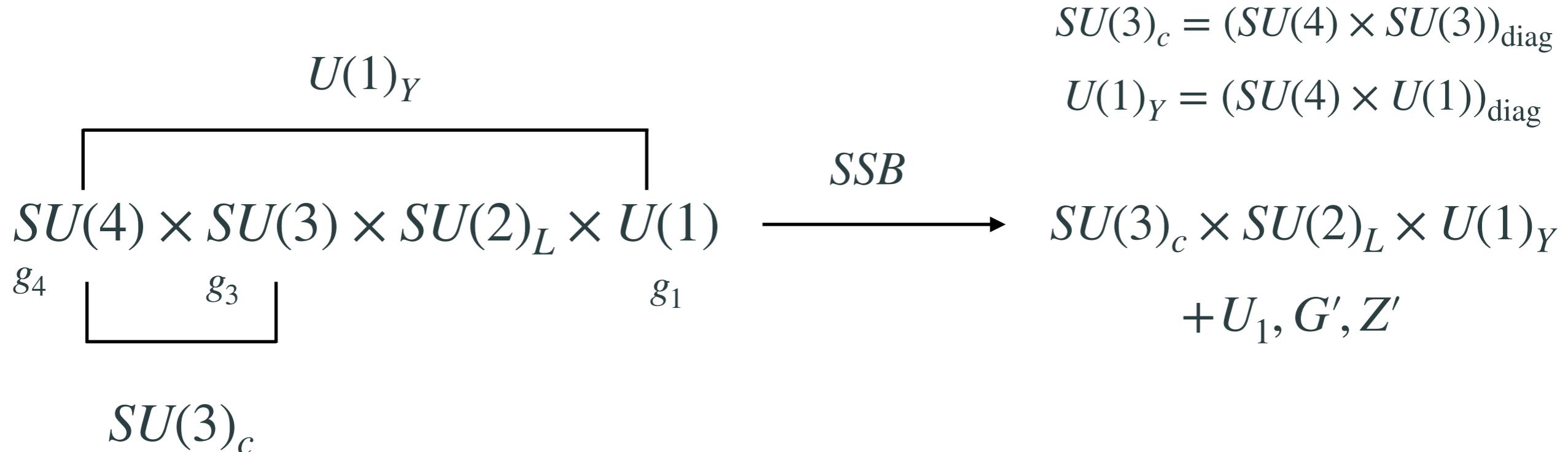
$$\Psi_{L,R} = \begin{pmatrix} Q_{L,R}^1 \\ Q_{L,R}^2 \\ Q_{L,R}^3 \\ L_{L,R} \end{pmatrix}$$

[Lepton number as the 4th “color”]

- ✓  $\text{SU}(4)$  is the smallest group containing the required vector LQ [ $U_1 \sim (3, 1)_{2/3}$ ]
- ✓ No proton decay (protected by symmetry)
- ✗ The (flavor blind) Pati-Salam model cannot work
  - The bounds from  $K_L \rightarrow \mu e$  and  $D - \bar{D}$  lift the LQ mass to 100 TeV
- ✗ The associated  $Z'$  would be excessively produced at LHC
  - $M_U \sim M_{Z'} \sim \mathcal{O}(\text{TeV})$  &  $\mathcal{O}(g_s)$   $Z'$  couplings to valence quarks

# 4321 model(s)

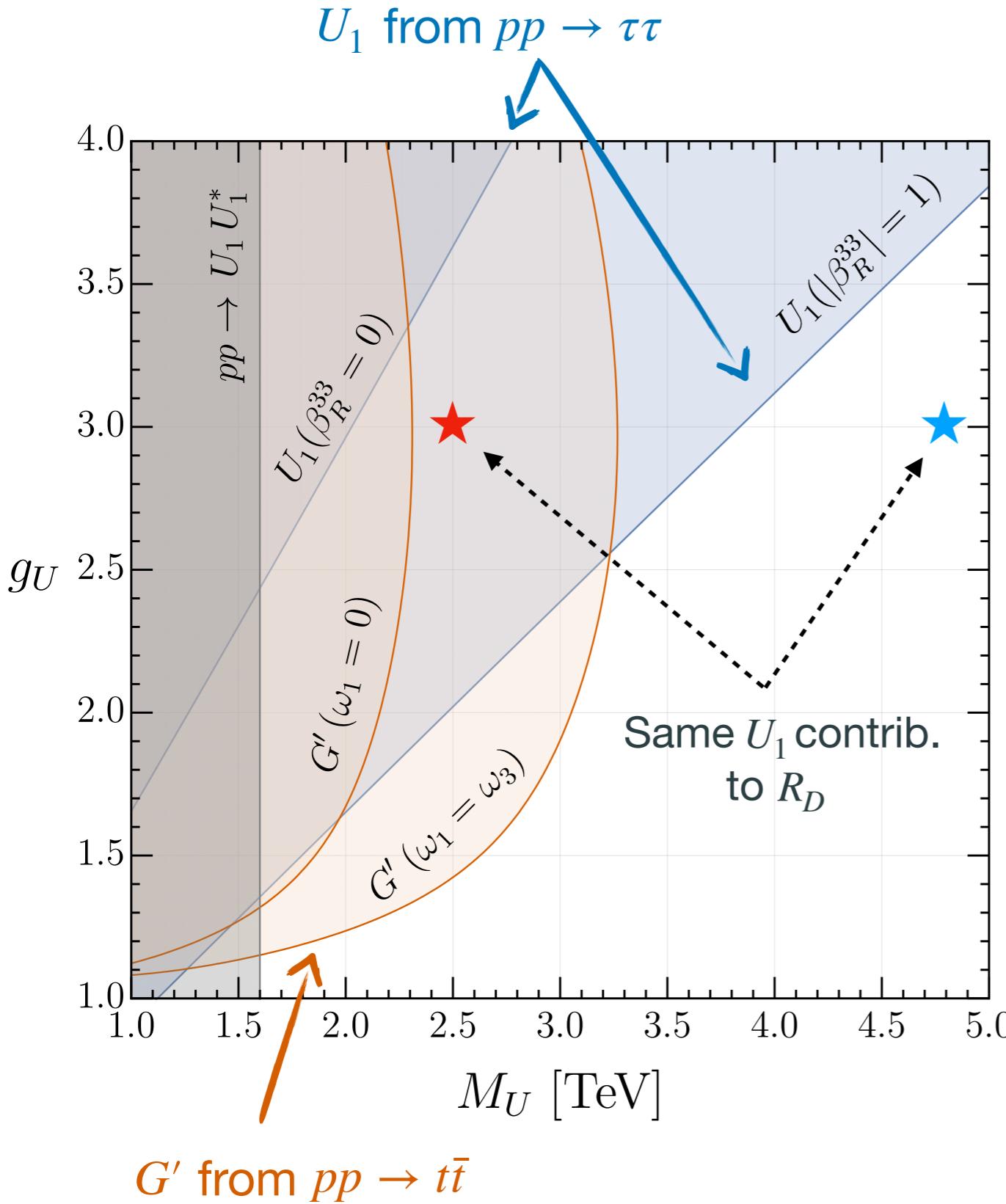
Georgi and Y. Nakai, 1606.05865  
 Diaz, Schmaltz, Zhong 1706.05033  
 di Luzio, Greljo, Nardecchia 1708.08450



Why an additional  $SU(3)$ ?

- ✗ The extra  $SU(3)$  gives a  $G'$  (color-octet), apart from the unavoidable  $Z'$
- ✓ It allows to decorrelate the  $SU(4)$  from the SM color group. In the limit  $g_4 \gg g_{3,1}$
- $\mathcal{O}(g_3/g_4)$  and  $\mathcal{O}(g_1/g_4)$   $G'$  and  $Z'$  couplings to valence quarks

# High-pT interplay with the new vectors



In particular models, the  $U_1$ ,  $G'$  and  $Z'$  masses are related

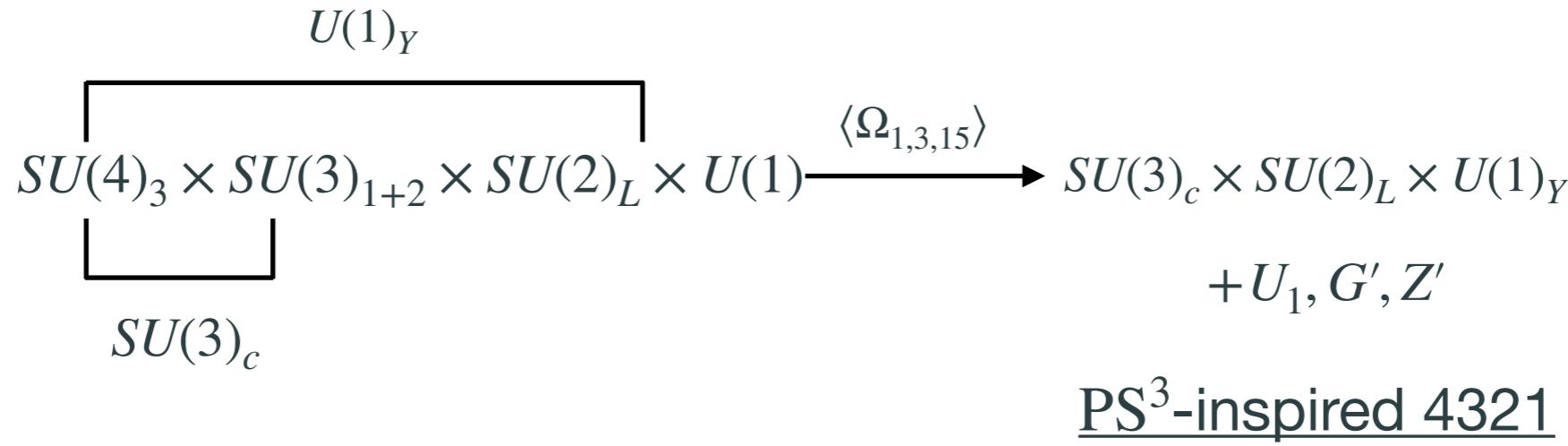
$$M_{G'} = M_U \frac{g_U}{\sqrt{g_U^2 - g_c^2}} \sqrt{\frac{2\omega_3^2}{\omega_1^2 + \omega_3^2}}$$

$\omega_i$  : scalar vevs

$G'$  searches are very important for the pure LH leptoquark... but not so much if RH couplings are also present

$Z'$  searches typically less relevant

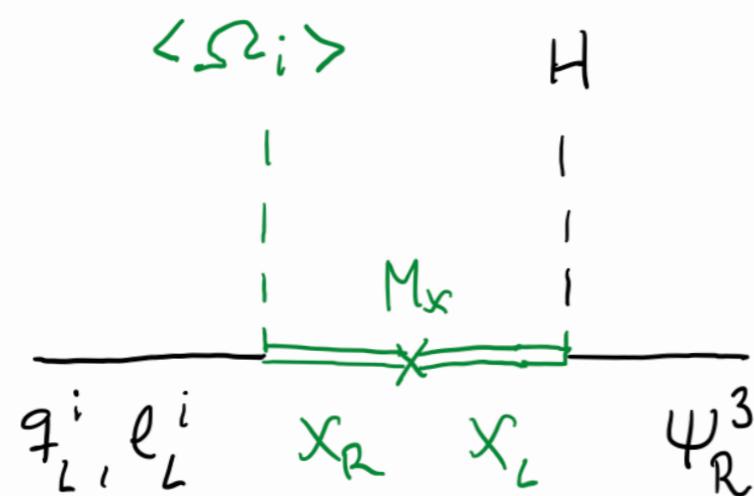
# A 4321 model for the B-anomalies



★ Accidental  $U(2)^5$  symmetry in gauge sector

★ Explicitly broken by the  $\Omega_i$  fields

$$[V_{q,\ell} \sim \langle \Omega_i \rangle / M_\chi]$$



(common source for the  $V_{q,\ell}$  spurions)

Field	$SU(4)$	$SU(3)'$	$SU(2)_L$	$U(1)'$
$q_L'^i$	1	3	2	1/6
$u_R'^i$	1	3	1	2/3
$d_R'^i$	1	3	1	-1/3
$\ell_L'^i$	1	1	2	-1/2
$e_R'^i$	1	1	1	-1
$\psi_L^3$	4	1	2	0
$\psi_{R_{u,d}}^3$	4	1	1	$\pm 1/2$
$\chi_L^i$	4	1	2	0
$\chi_R^i$	4	1	2	0
$H$	1	1	2	1/2
$\Omega_1$	4	1	1	-1/2
$\Omega_3$	4	3	1	1/6
$\Omega_{15}$	15	1	1	0

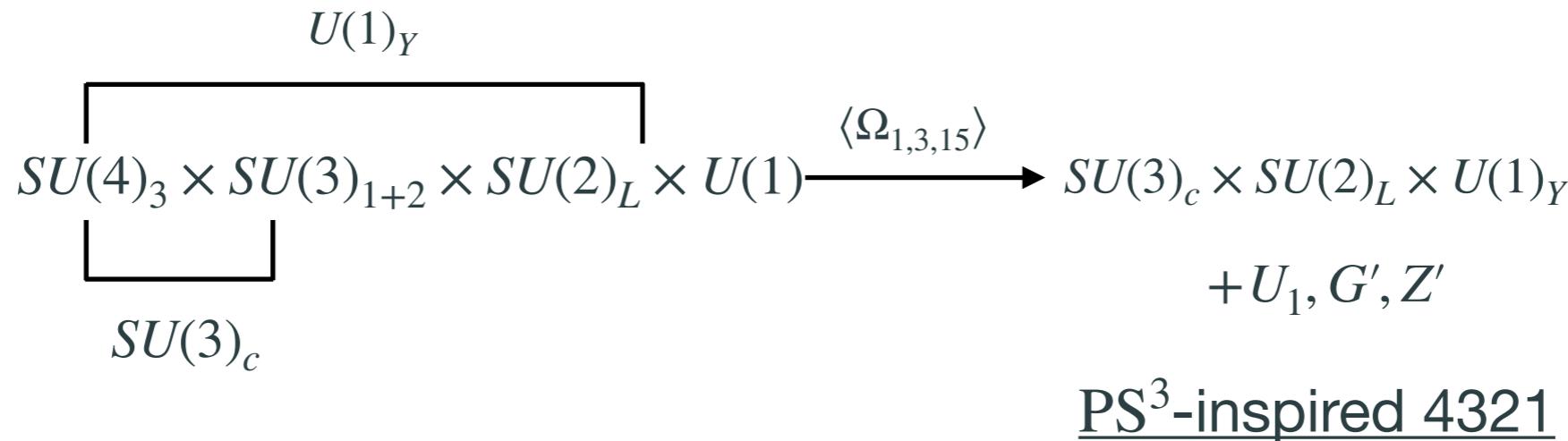
1st & 2nd families

3rd family

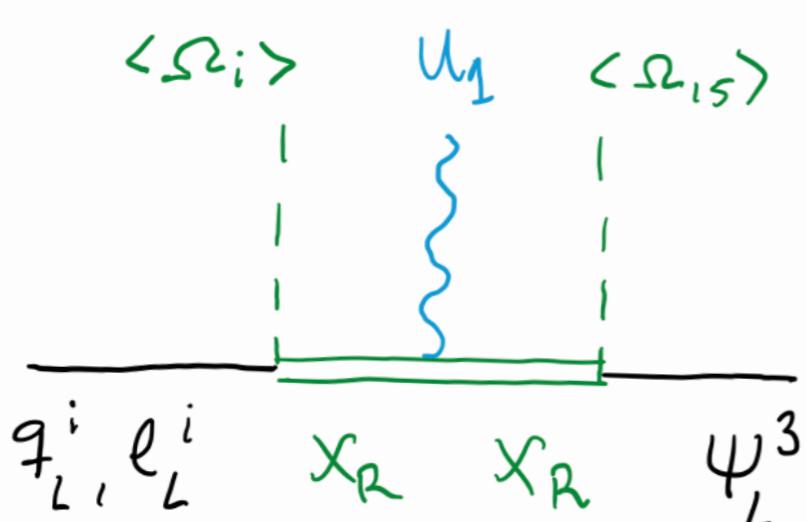
$n_{VL} = 2$

[Bordone, Cornella, JFM, Isidori 1712.01368, 1805.09328;  
Greljo, Stefanek, 1802.04274; Cornella, JFM, Isidori 1903.11517]

# A 4321 model for the B-anomalies



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$e_R'^i$	1	1	1	-1
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$\psi_{R_{u,d}}^3$	4	1	1	±1/2
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1st & 2nd families				
3rd family				
$n_{VL} = 2$				
$H$	1	1	2	1/2
$\Omega_1$	4̄	1	1	-1/2
$\Omega_3$	4̄	3	1	1/6
$\Omega_{15}$	15	1	1	0

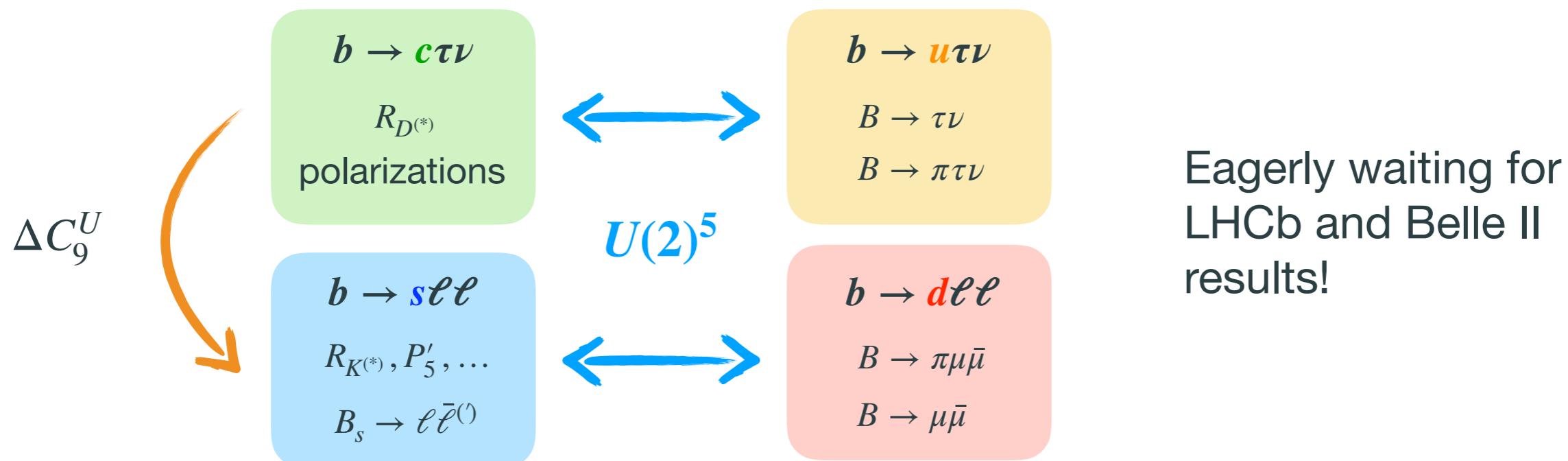
[Bordone, Cornella, JFM, Isidori 1712.01368, 1805.09328;  
Greljo, Stefanek, 1802.04274; Cornella, JFM, Isidori 1903.11517]

# Conclusions

Current data is inconclusive and the overall picture might change but...

... it is possible to find solutions to the flavor anomalies **connected to the SM Yukawa structure (SM flavor puzzle!)**

This connection predicts relations that will be tested experimentally



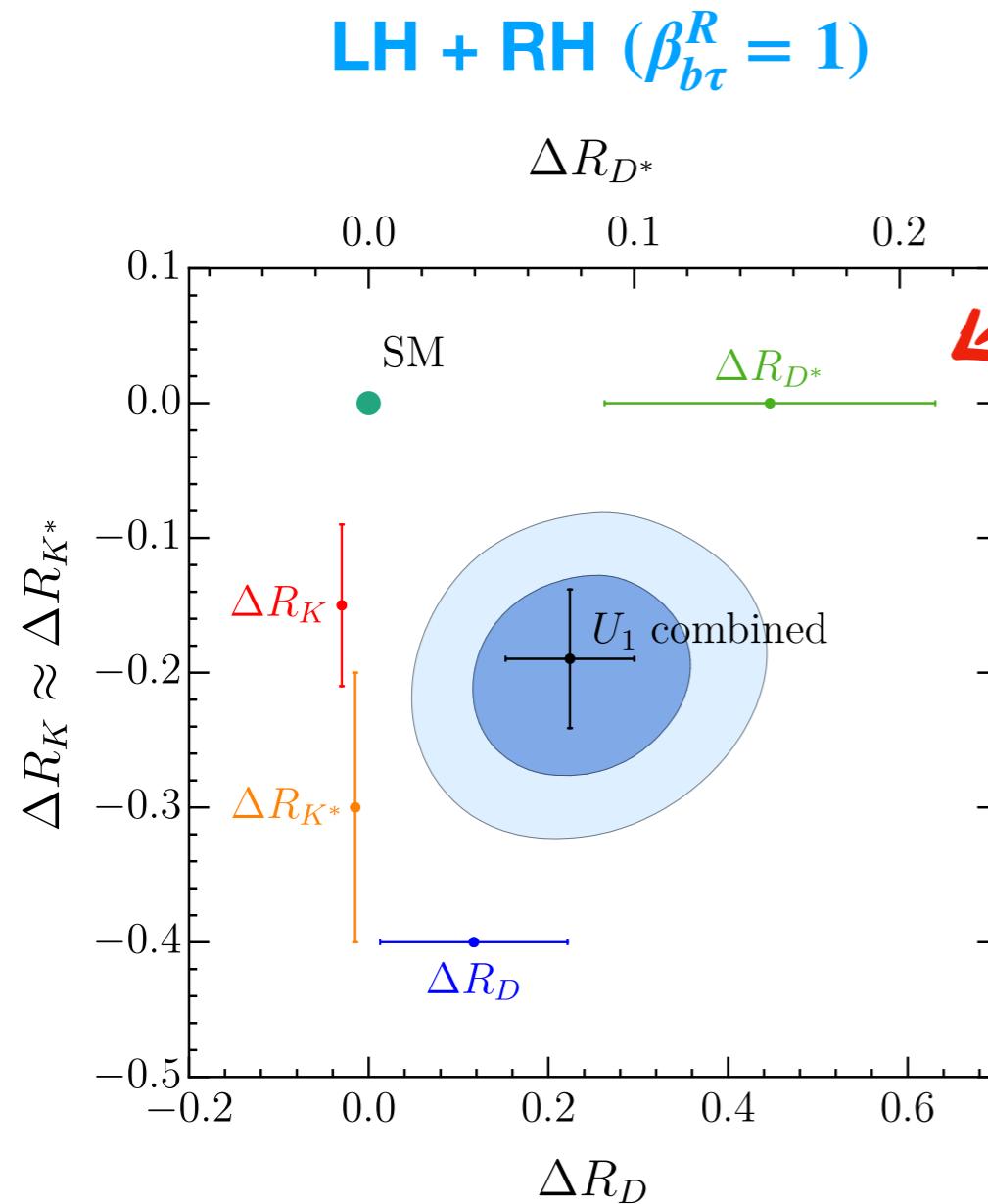
The  $U_1 \sim (3, 1)_{2/3}$  vector leptoquark is an excellent mediator to explain the anomalies

→ Additional mediators and high- $p_T$  signatures ( $G'$ ,  $Z'$ , VL fermions)

**Thank you!**

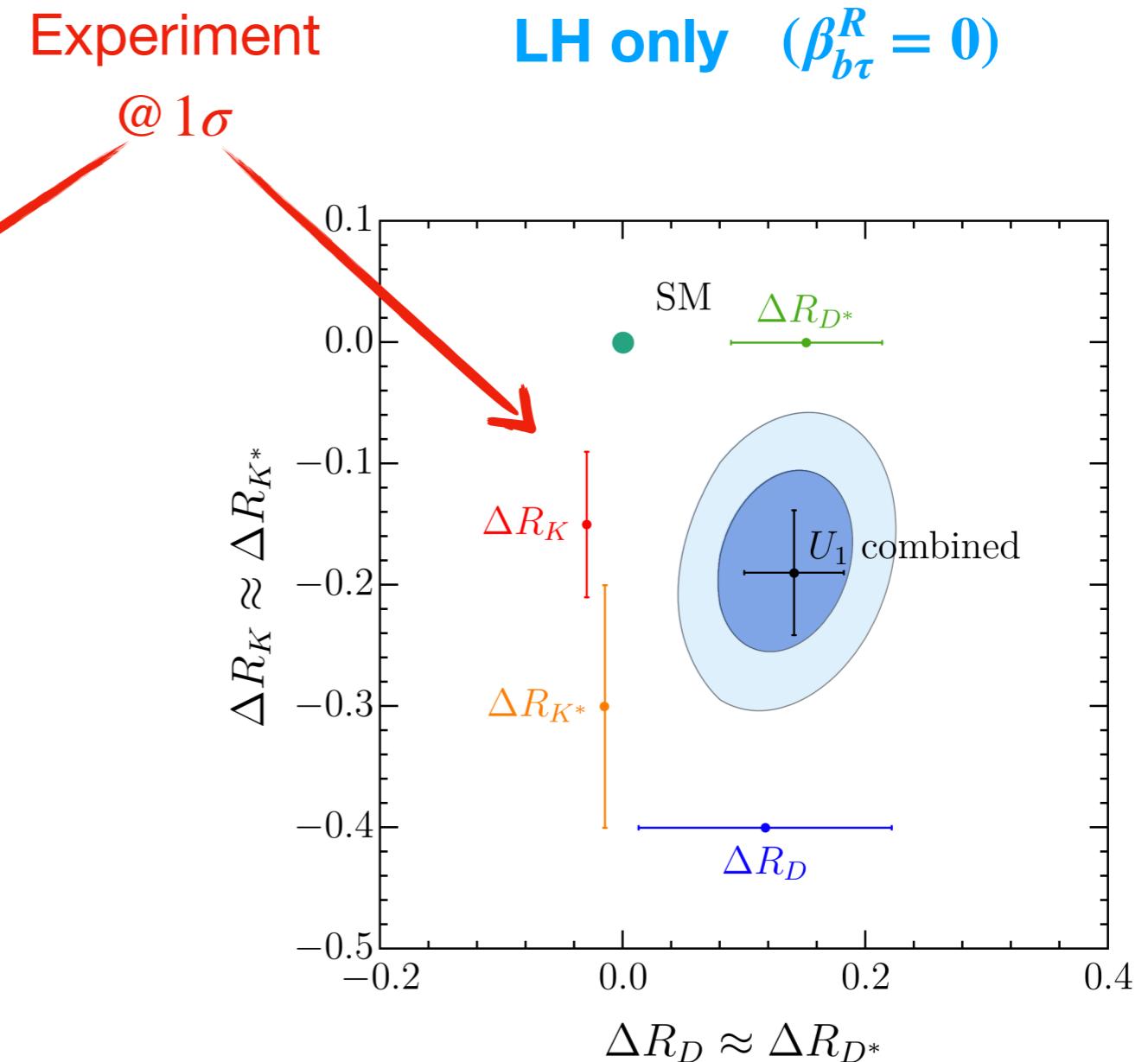
# Low-energy fit results

For both extreme cases, the low-energy fit (in particular to the anomalies) is very good!



**NP scale naturally higher**

(thanks to the scalar contribution)



**Slightly better fit**

(due to the new Belle  $R_{D^{(*)}}$  measurement)