Theoretical status of the Flavor Anomalies

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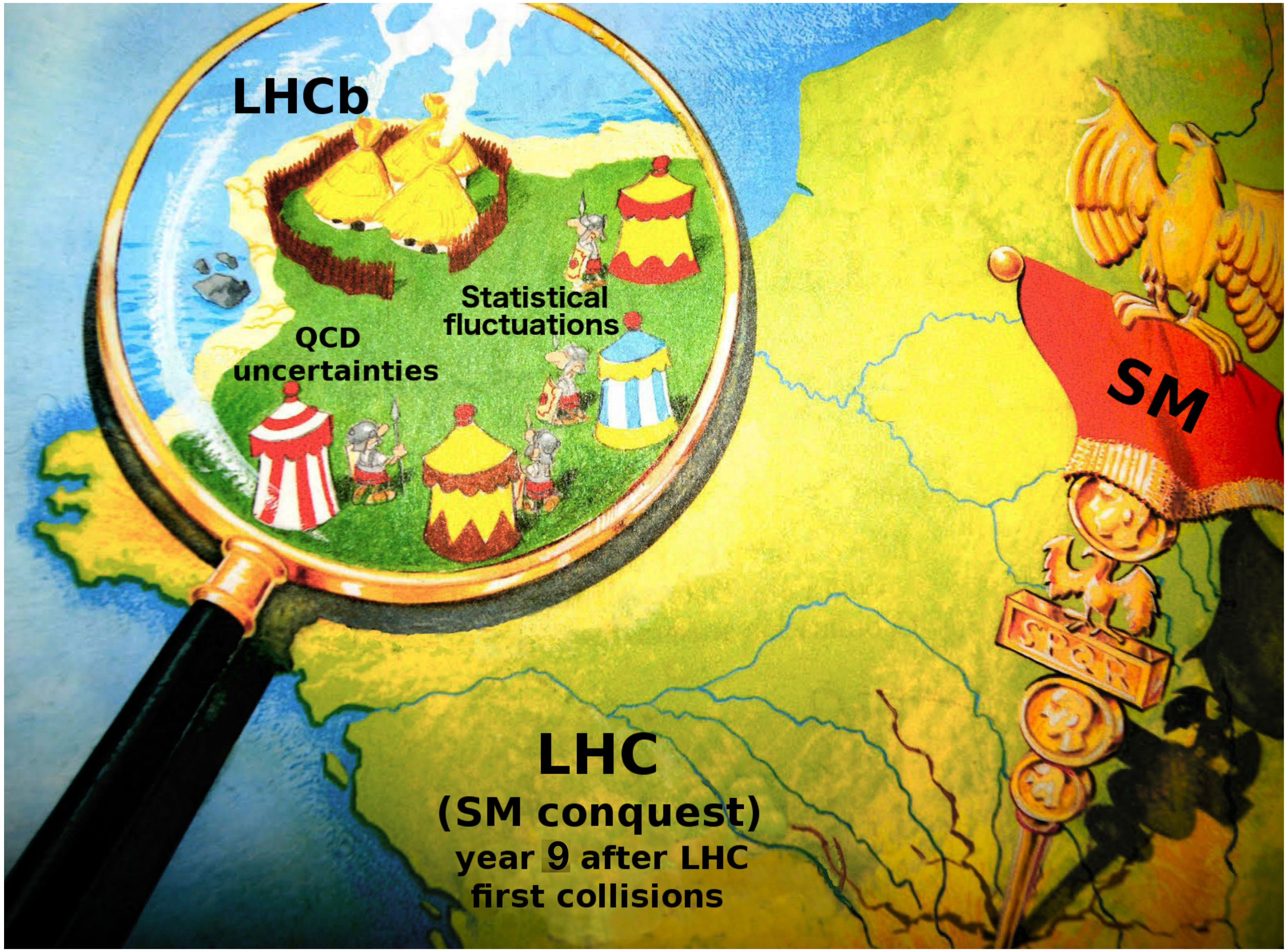
Based on **arXiv:1712.01368**, **arXiv:1805.09328, arXiv:1808.00942,** and ongoing work

DISCRETE 2018, 6th Symposium on Prospects in the Physics of Discrete Symmetries

The LHC landscape

The year is 9 after the LHC first collisions. Experimental data is entirely SM-like. Well, not entirely! The LHCb Collaboration still holds out against the SM. And life is not easy for the SM there...

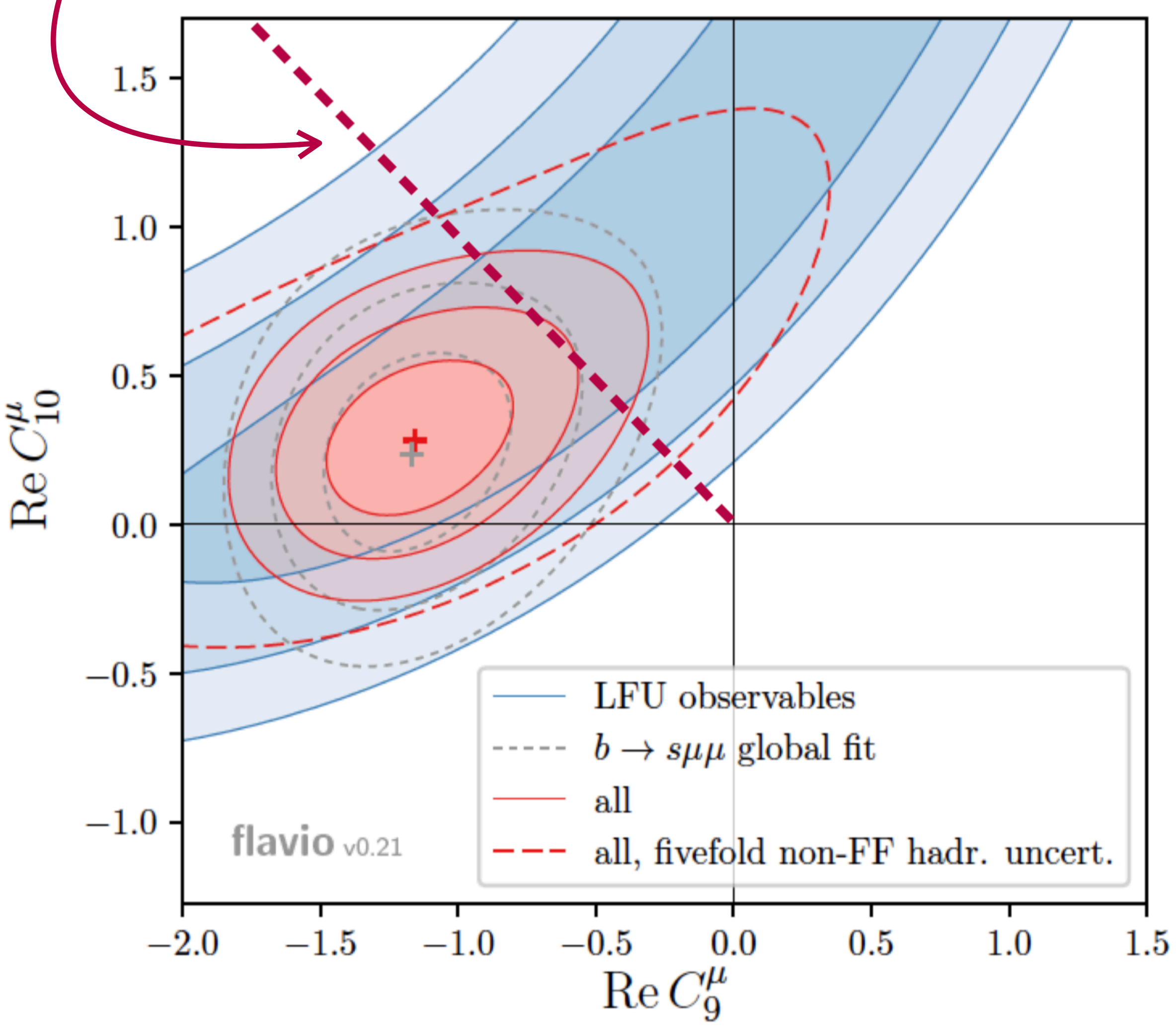


The $b \to s\ell\ell$ anomalies

See Annarita Buonaura's talk
for an experimental insight!

Re $C_9^\mu = -$ Re C_{10}^μ (V − A solution)

Altmannshofer, Stangl, Straub '17



$$\mathcal{O}_9^\mu = (\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \mu)$$

$$\mathcal{O}_{10}^\mu = (\bar{s}\gamma_\alpha P_L b)(\bar{\mu}\gamma^\alpha \gamma_5 \mu)$$

Several anomalies observed in $b \to s\ell\ell$ ($\ell = e, \mu$) transitions [$\sim 5\sigma$ from the SM]

★ Various observables involved [$R_K, R_{K^*}, P_5', b \to s\mu\mu$ branching fractions…]

★ "Clean" Lepton Flavor Universality ratios alone give a (combined) 4σ deviation from the SM

$$R(K^{(*)}) = \frac{\mathscr{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathscr{B}(B \to K^{(*)}e^+e^-)}$$

★ Results compatible with no NP in electrons (or subleading effects)

★ Left-handed quark helicity largely favored; situation less clear in the lepton sector

★ Mostly driven by LHCb

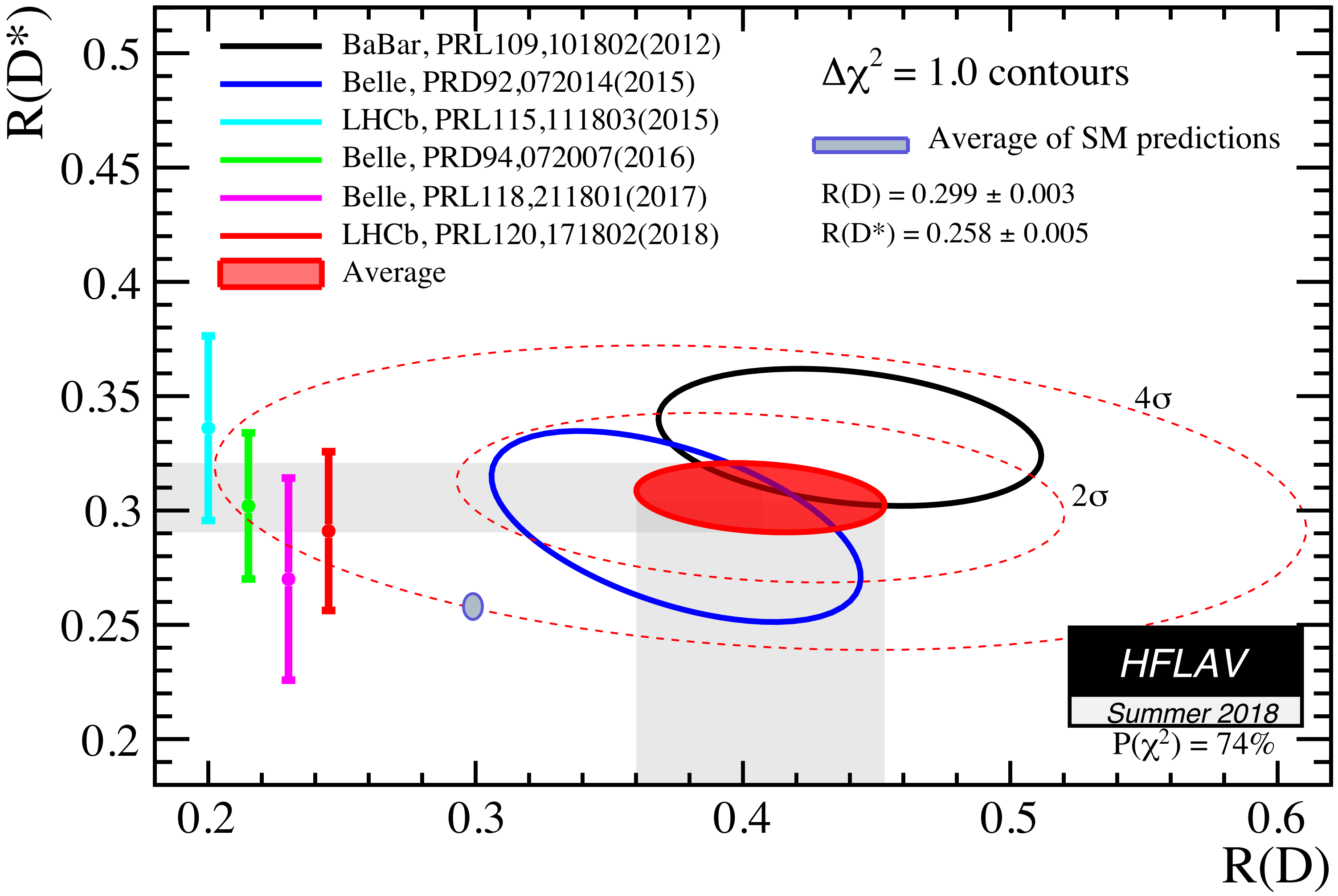
The $R(D^{(*)})$ anomalies

See Annarita Buonaura's talk for an experimental insight!

Experimental measurements disagree by almost 4σ with the SM in $b \to c\tau\nu$ transitions…

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

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



Preliminary hints for deviations in $B_c \to J/\psi\tau\nu$: $R(J/\psi) = 0.71 \pm 0.17 \pm 0.18$

[LHCb Collaboration 1711.05623]

What are the anomalies telling us?

See Paulina Rocha's talk for a model for $b \to s\ell\ell$ alone

The B anomalies are possibly the **largest coherent set** of deviations from the SM we have ever seen…

… So let us assume that the anomalies (both!) are genuine hints of NP and that they are both connected. Can we conclude something meaningful?

Intriguingly, they follow a very peculiar structure

$$\boldsymbol{b \to s\ell\ell} \qquad \ll \qquad \boldsymbol{b \to c\tau\nu}$$

$$3_Q \to 2_Q 2_L 2_L \qquad\qquad 3_Q \to 2_Q 3_L 3_L$$

~25% of a SM **loop** effect

~20% of a SM **tree-level** effect

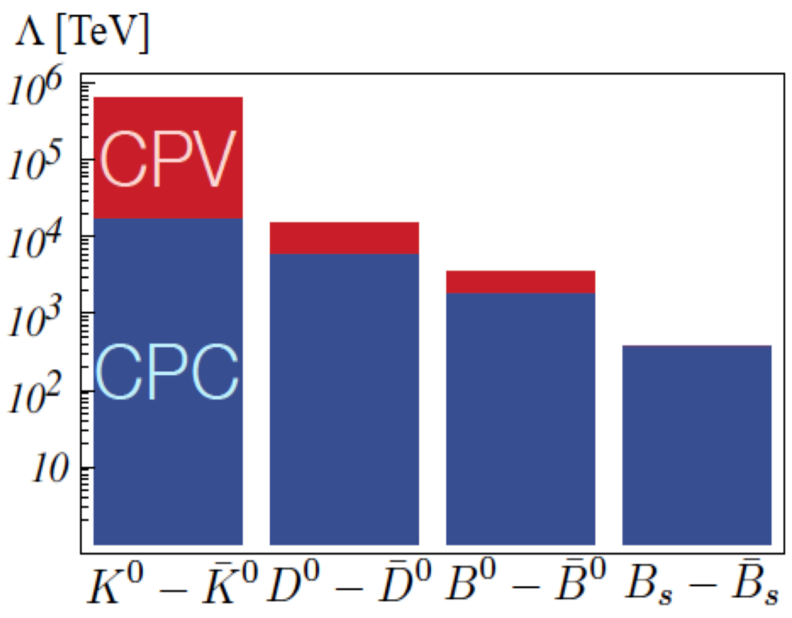
The only source of **Lepton Flavor Universality Violation** in the SM (Yukawas) follow a similar trend: $y_e \ll y_\mu \ll y_\tau$…. Are the anomalies related to them?

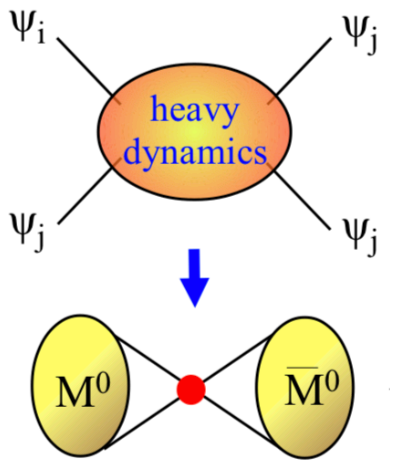
What are the anomalies telling us?

A combined explanation calls for NP:$^{(*)}$

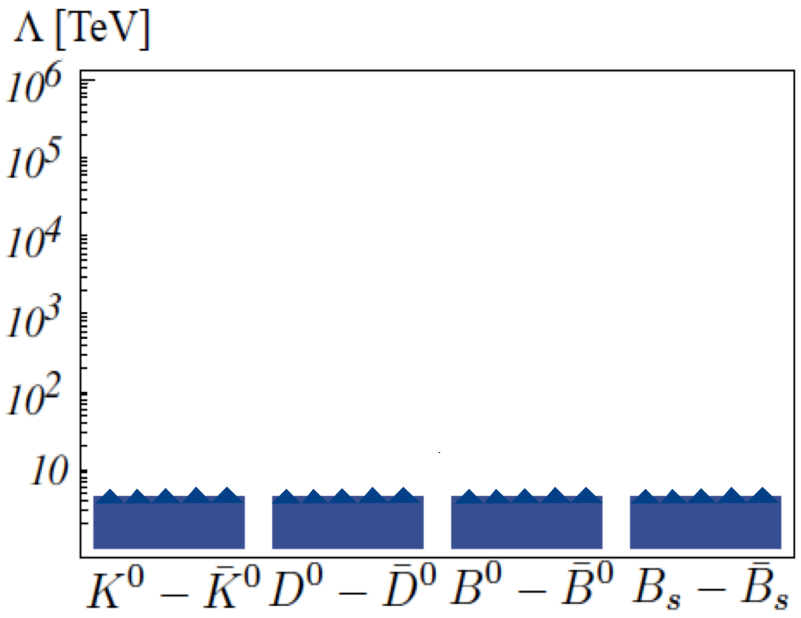
- ★ Coupled dominantly to the **3rd generation**
- ★ $\Lambda_{\text{NP}} \sim \mathcal{O}(1\ \text{TeV})$

Anarchical couplings





Hierarchical couplings



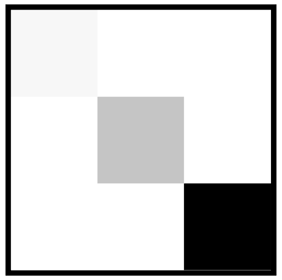
Severe constraints on generic new (BSM) flavor breaking sources
(mis)interpreted as indication of a high flavor scale

$^{(*)}$ N.B.: conclusions driven (mostly) by $R(D^{(*)})$

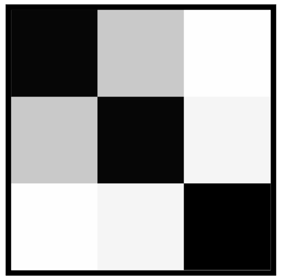
U(2) flavor symmetry as a guiding principle

The SM Yukawas respect an approximate U(2) symmetry [Barbieri et al. 1105.2296]

$M_{u,d} \sim$



$V_{\rm CKM} \sim$



$$\mathbf{U(2)_q} \times \mathbf{U(2)_u} \times \mathbf{U(2)_d}$$

$$\psi = (\boxed{\psi_1\ \psi_2}\,\boxed{\psi_3})$$

$$\boldsymbol{Y_{u,d}} = \left(\begin{array}{c:c} 0 & 0 \\ \hdashline 0 & 1 \end{array}\right) \longrightarrow \left(\begin{array}{c:c} 0 & \boldsymbol{V} \\ \hdashline 0 & 1 \end{array}\right) \longrightarrow \left(\begin{array}{c:c} \Delta & \boldsymbol{V} \\ \hdashline 0 & 1 \end{array}\right)$$

$|\boldsymbol{V}| \sim |V_{ts}|$

$|\boldsymbol{\Delta}| \sim y_c$

Unbroken symmetry — Leading breaking — Final breaking

- ✓ Assuming a single leading breaking ensures an effective protection of FCNCs [**SM-like mixing among light & 3rd generations** ⟶ consistent with CKM fits]
- ✓ Large NP effects in 3rd generation, light-generation effects controlled by the breaking
- ● Compatibility between high-p_T data and $R(D^{(*)})$ require largish 32 couplings

The general approach

We can follow three theoretical approaches to describe the anomalies:

I. EFT	**Starting point** [test of low energy observables & flavor symmetries]
II. Simplified models	**Essential to test high-pT observables**
III. UV complete models	**Essential to test the consistency of the solution** [new correlations among observables, particles…]

Each step is important and complementary to each other
[**any serious theoretical attempt follows epicycles around the three…**]

EFT-type considerations

The $SU(2)_L$ triplet operator is a natural starting point for explaining $R(D^{(*)})$ + $b \to s\ell\ell$

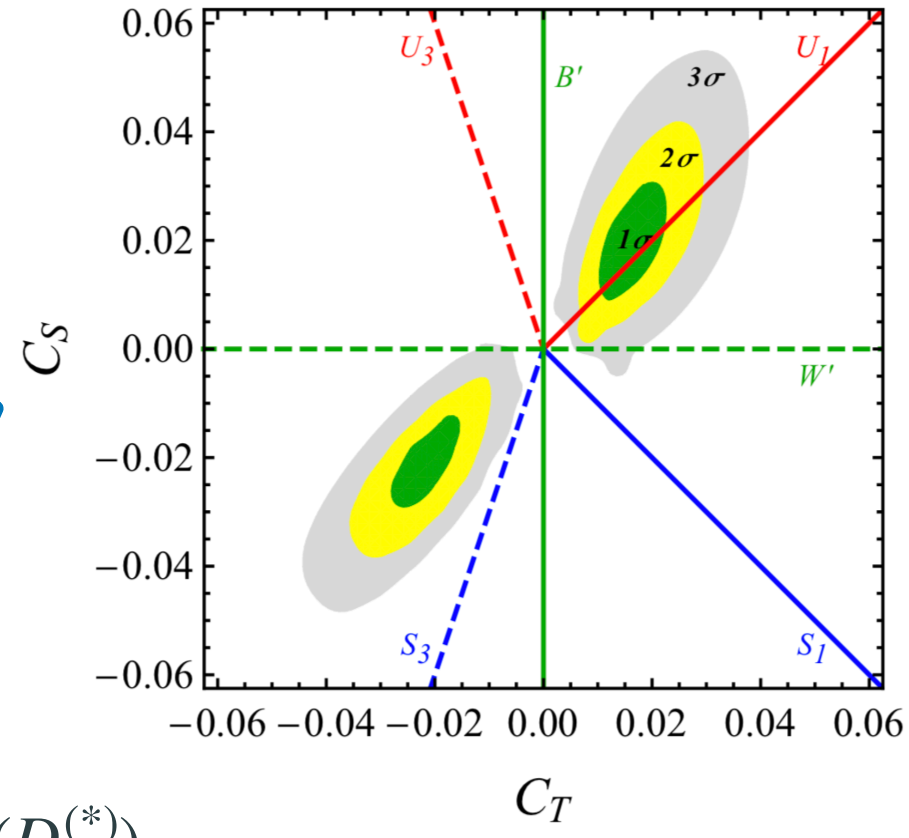
$$-\frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\, C_T\, (\bar q^i_L \gamma^\mu \tau^a b_L)(\ell^\alpha_L \gamma_\mu \tau^a \ell^\beta_L) \supset \frac{1}{\Lambda^2_{R_D^{(*)}}}(\bar c_L \gamma^\mu b_L)(\bar \tau_L \gamma_\mu \nu_L) + \frac{1}{\Lambda^2_{R_{K^{(*)}}}}(\bar s_L \gamma_\mu b_L)(\bar \mu_L \gamma^\mu \mu_L)$$

… but other operators are also needed or useful

- ★ Singlet operator necessary to avoid too large $b \to s\nu\nu$

$$-\frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\,[C_T\,(\bar q^i_L \gamma^\mu \tau^a b_L)(\ell^\alpha_L \gamma_\mu \tau^a \ell^\beta_L) + C_S\,(\bar q^i_L \gamma^\mu b_L)(\ell^\alpha_L \gamma_\mu \ell^\beta_L)]$$

$$\supset \frac{1}{\Lambda^2_{R_D^{(*)}}}(C_T - C_S)\,(\bar s_L \gamma^\mu b_L)(\bar \nu_L \gamma_\mu \nu_L)$$



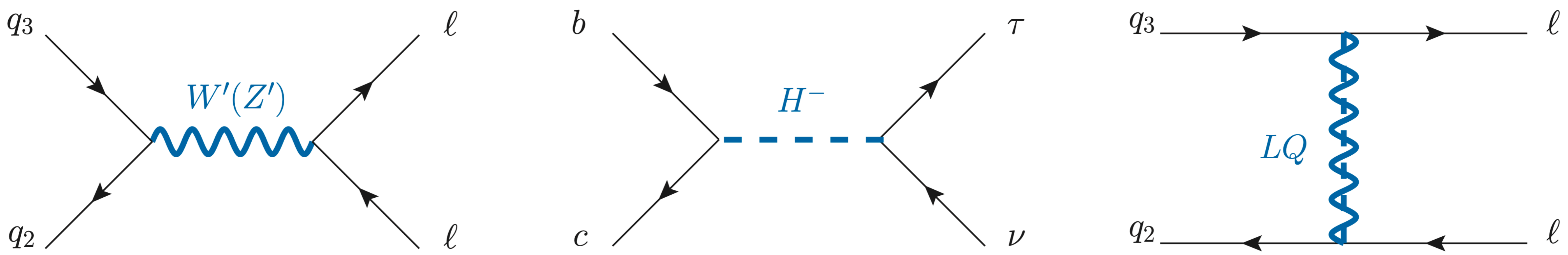
[Buttazzo et al. 1706.07808]

- ★ Right-handed, scalar and/or tensor operators helpful for $R(D^{(*)})$

Solutions based on an **approximate $U(2)$ flavor symmetry** are viable

Simplified models, which mediator?

Only few possibilities are available to “UV-complete” the EFT…



Long story short…

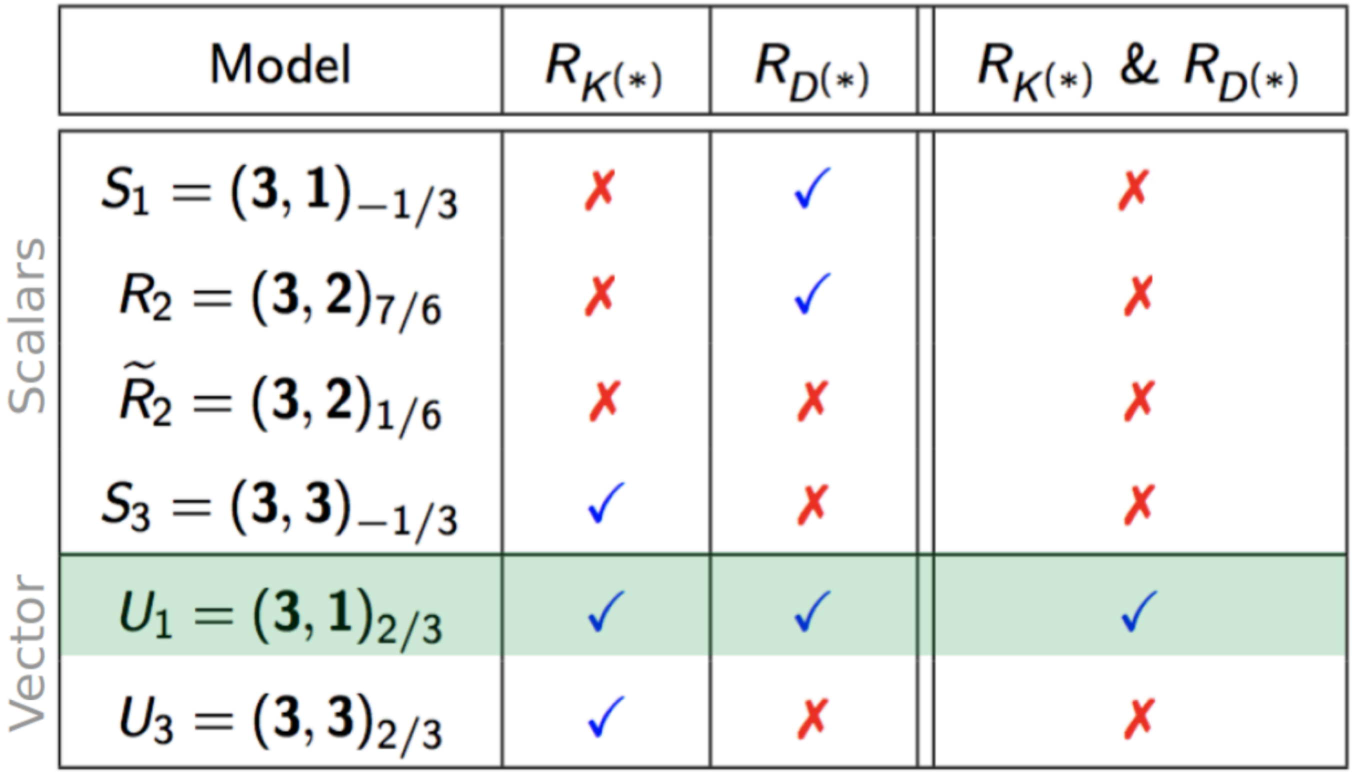
- ★ **Charged Higgs** solutions are excluded by measurements of τ_{B_c}
  [Contributions to $\mathscr{B}(B_c \to \tau\nu)$ are scalar enhanced and huge] [Alonso et al. 1611.06676]

- ★ **Minimal W'/Z' models** in large tension with high-p_T data [Faroughy et al. 1609.07138]
  W' + light ν_R in better shape but still in tension with $pp \to \tau\nu$
  [Greljo et al. 1811.07920]

- ★ **Scalars** and **vector leptoquarks** are the best candidates so far

Simplified dynamical models: the main suspects

Faroughi @ CKM18



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

Angelescu, Becirevic, DAF, Sumensari [1808.08179]

(*) Assuming no light ν_R

Three viable options in the market $^{(*)}$:

- ★ U_1 + 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]

- ★ $S_3 + R_2$

  [Bečirević et al., 1806.05689]

Only one single-mediator possibility… that needs to be UV completed

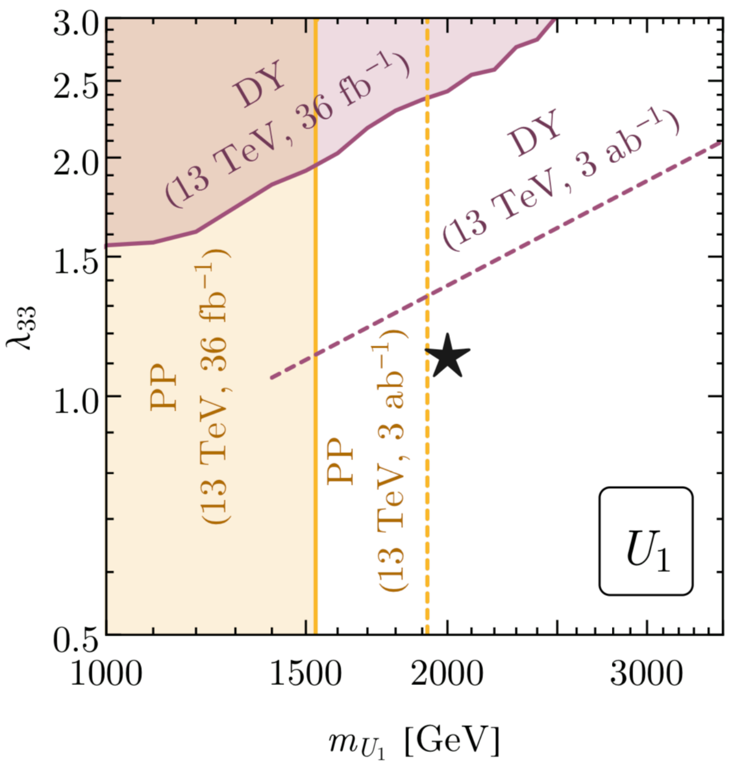
[two scalar leptoquarks can also do the job…]

The U_1 leptoquark: the pure LH case

$$\mathscr{L} \supset \frac{g_U}{\sqrt{2}} U_1^{\mu} \left[\beta^L_{i\alpha} (\bar{q}^i_L \gamma_\mu \ell^\alpha_L) + \xcancel{\beta^R_{i\alpha} (\bar{d}^i_R \gamma_\mu e^\alpha_R)} \right] + \mathrm{h.c.}$$

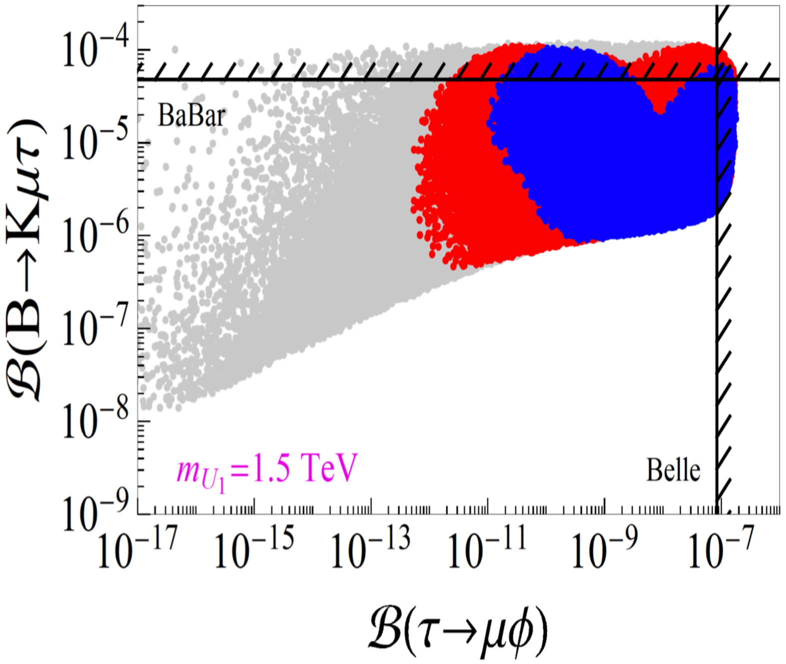
Pure LH U_1 (i.e. $\beta^R_{i\alpha} = 0$) extensively analyzed in the literature…

Safe from high-pT



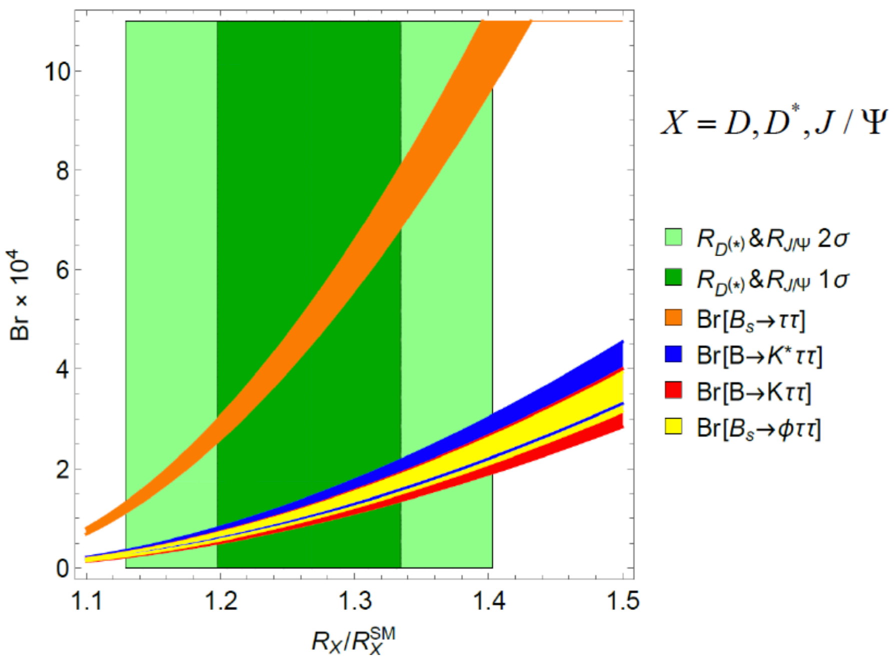
[Schmaltz, Zhong, 1810.10017]
(see also 1808.08179, 1609.07138)

LFV around the corner



[Angelescu et al., 1808.08179]

Huge effects in $b \to s\tau\tau$



[Capdevila et al., 1712.01919]

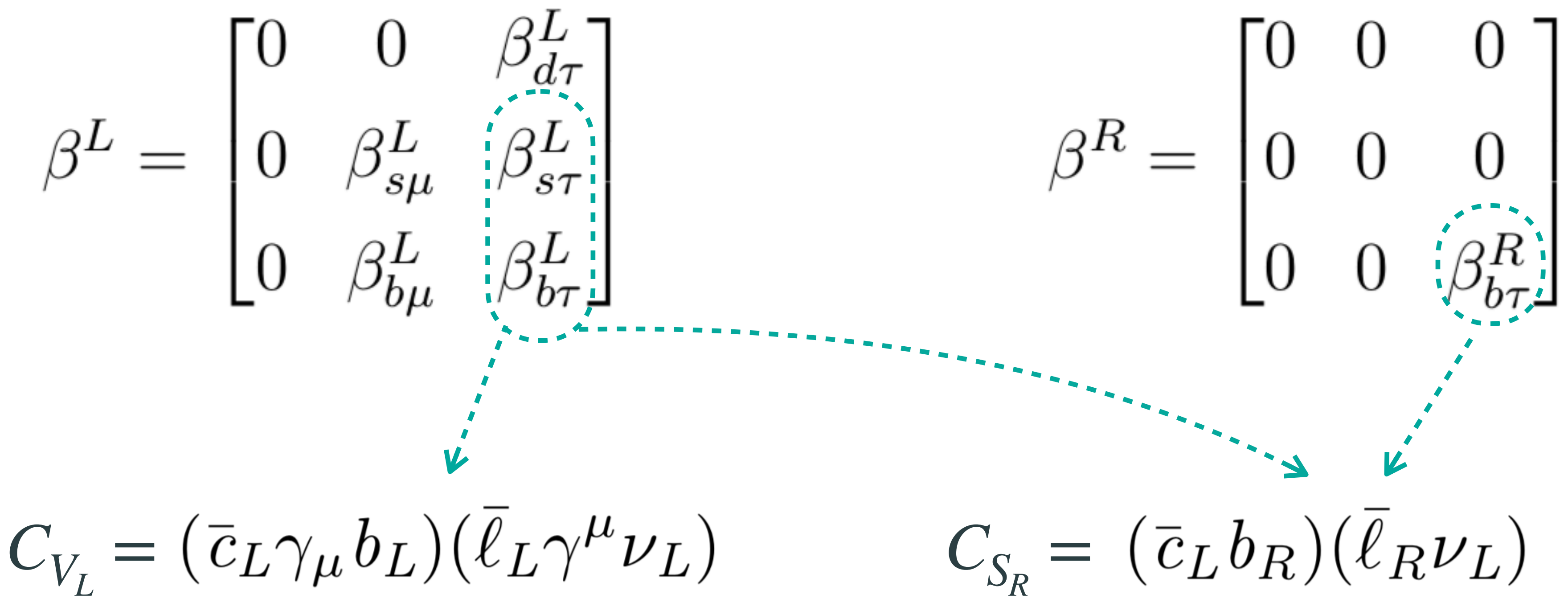
The U_1 leptoquark: all in

$$\mathscr{L} \supset \frac{g_U}{\sqrt{2}} U_1^\mu \left[\beta^L_{i\alpha}\,(\bar{q}^i_L \gamma_\mu \ell^\alpha_L) + \beta^R_{i\alpha}\,(\bar{d}^i_R \gamma_\mu e^\alpha_R)\right] + \mathrm{h.c.}$$

Pure LH U_1 (i.e. $\beta^R_{i\alpha} = 0$) extensively analyzed in the literature…

… RH U_1 coupling usually ignored. Important pheno implications!

Flavor assumptions:

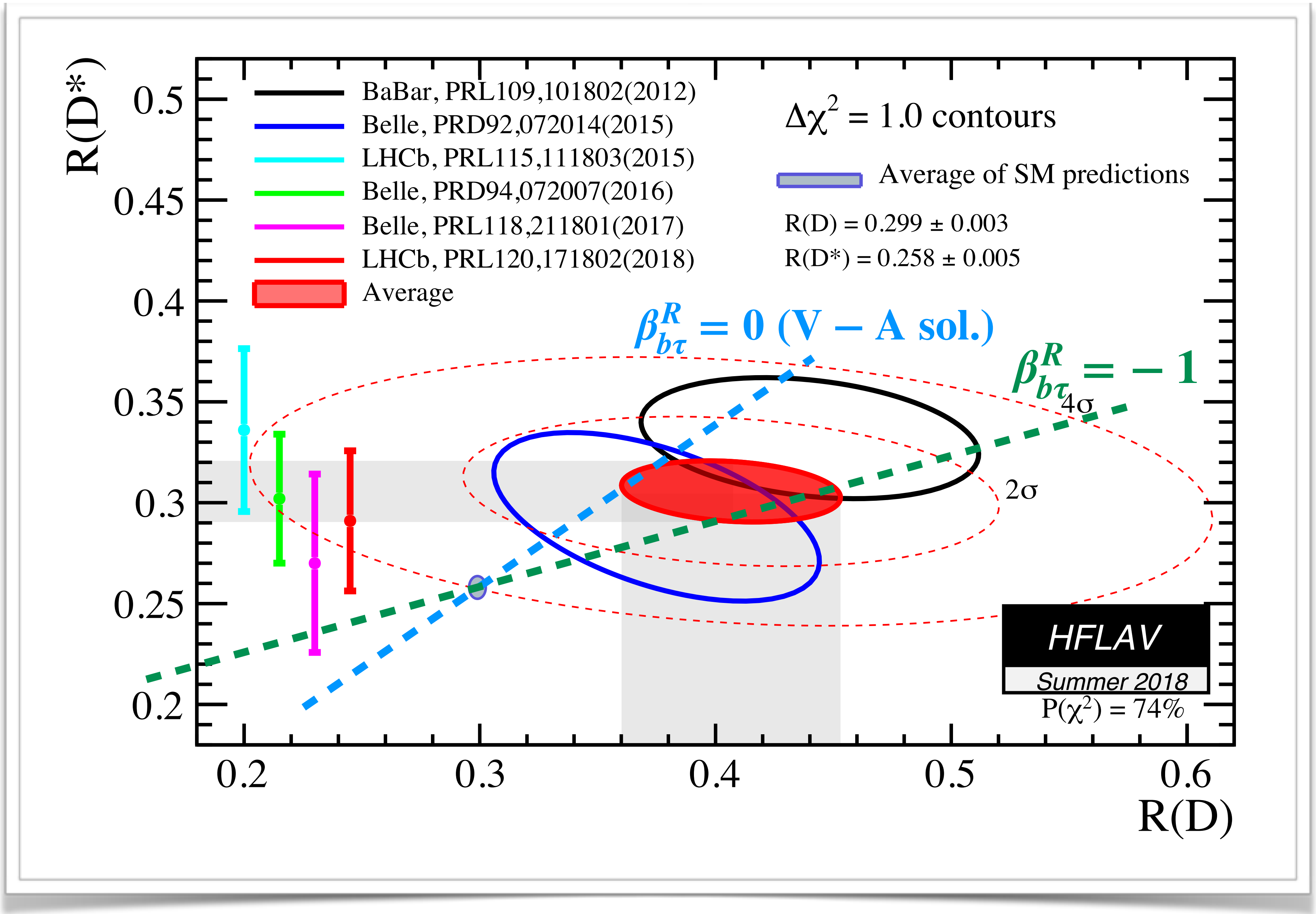


$$\beta^L = \begin{bmatrix} 0 & 0 & \beta^L_{d\tau} \\ 0 & \beta^L_{s\mu} & \beta^L_{s\tau} \\ 0 & \beta^L_{b\mu} & \beta^L_{b\tau} \end{bmatrix} \qquad \beta^R = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \beta^R_{b\tau} \end{bmatrix}$$

$$C_{V_L} = (\bar{c}_L \gamma_\mu b_L)(\bar{\ell}_L \gamma^\mu \nu_L) \qquad C_{S_R} = (\bar{c}_L b_R)(\bar{\ell}_R \nu_L)$$

(RGE enhanced)

The U_1 leptoquark: $R(D^{(*)})$ projections



Differential distributions, polarizations,… could also be different from the SM

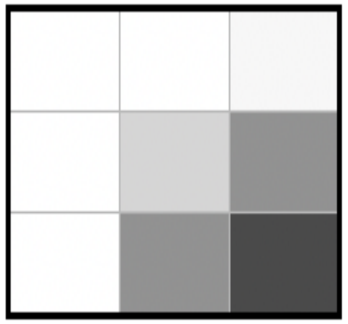
[Essential to test at future facilities like Belle II]

Low energy implications of the U_1 leptoquark

$\Delta R_K\,,\Delta R_{K^*}$

$B_s \to \mu\mu$ chiral-enhanced scalar contribution if $\beta^R_{b\mu} \neq 0$

$$\beta^L = \begin{bmatrix} 0 & 0 & \beta_{d\tau} \\ 0 & \beta_{s\mu} & \beta_{s\tau} \\ 0 & \beta_{b\mu} & \beta_{b\tau} \end{bmatrix}$$



$$\beta^R = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \boxed{1} \end{bmatrix}$$

$\Delta R_{D^{(*)}}$
- scalar contr. RGE enhanced
- non universal (~~V-A*V-A~~)

$B_s \to \tau\tau$ chiral enhanced
→ close to exp. limit

$B \to \tau\nu$ chiral enhanced
[alleviated by $\beta_{d\tau}$]

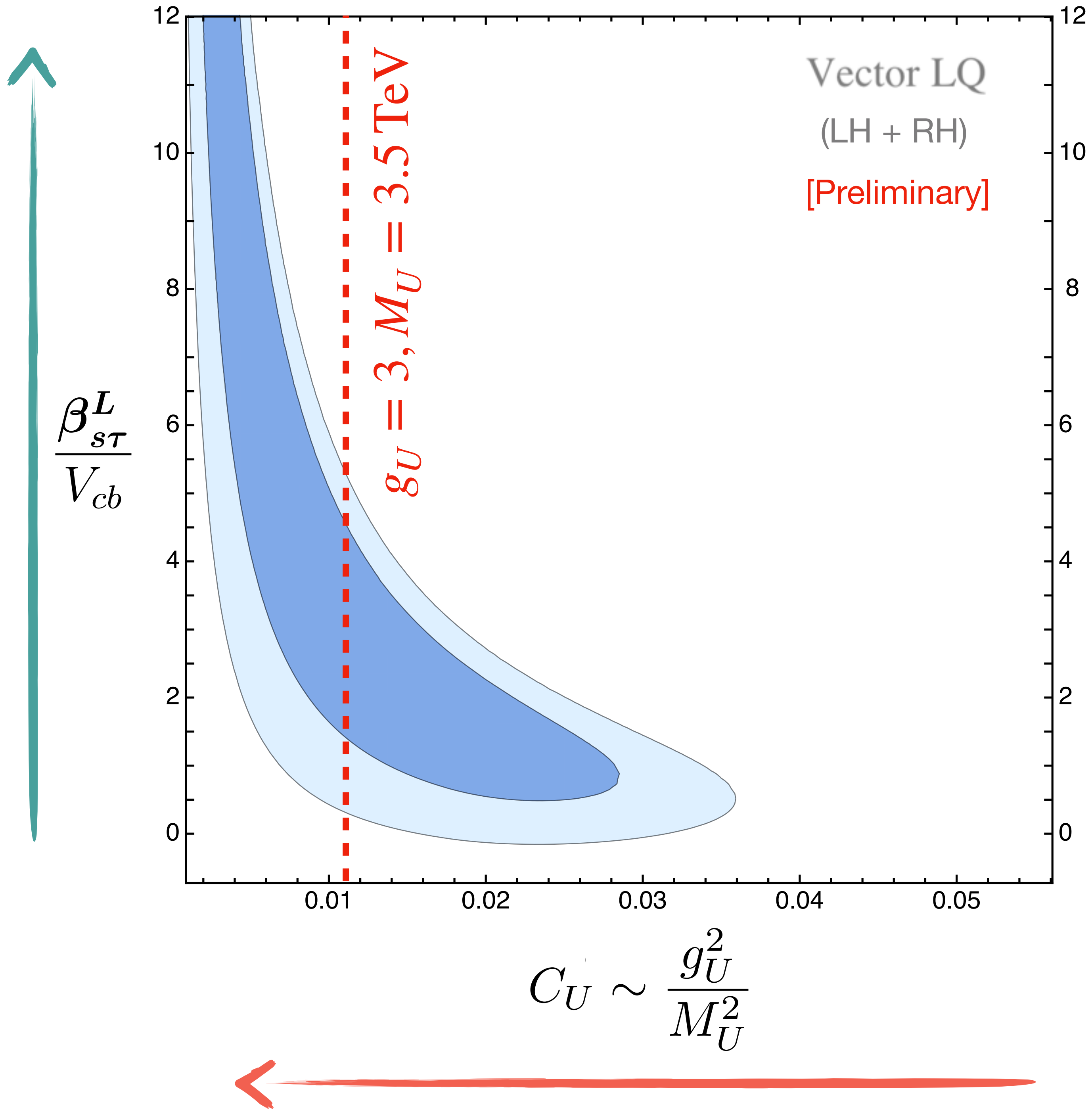
LFV in $\tau \to \mu$ transitions

$\tau \to \mu\phi$ $\tau \to \mu\gamma$

$B \to K^*\tau^+\mu^-$

$B_s \to \tau^+\mu^-$ Chiral enhanced
[**soon new result**
from LHCb]

Low-energy vs high-pT



NP scale goes up

[JFM, Cornella, Isidori, in preparation]

In contrast to the chiral (pure LH) U_1, limits on $pp \to \tau^+\tau^-$ are **around the corner** in the LH + RH solution…

… e.g. for $g_U = 3.0$

$M_U \gtrsim 3.5\ \text{TeV}$ **[LH + RH]**

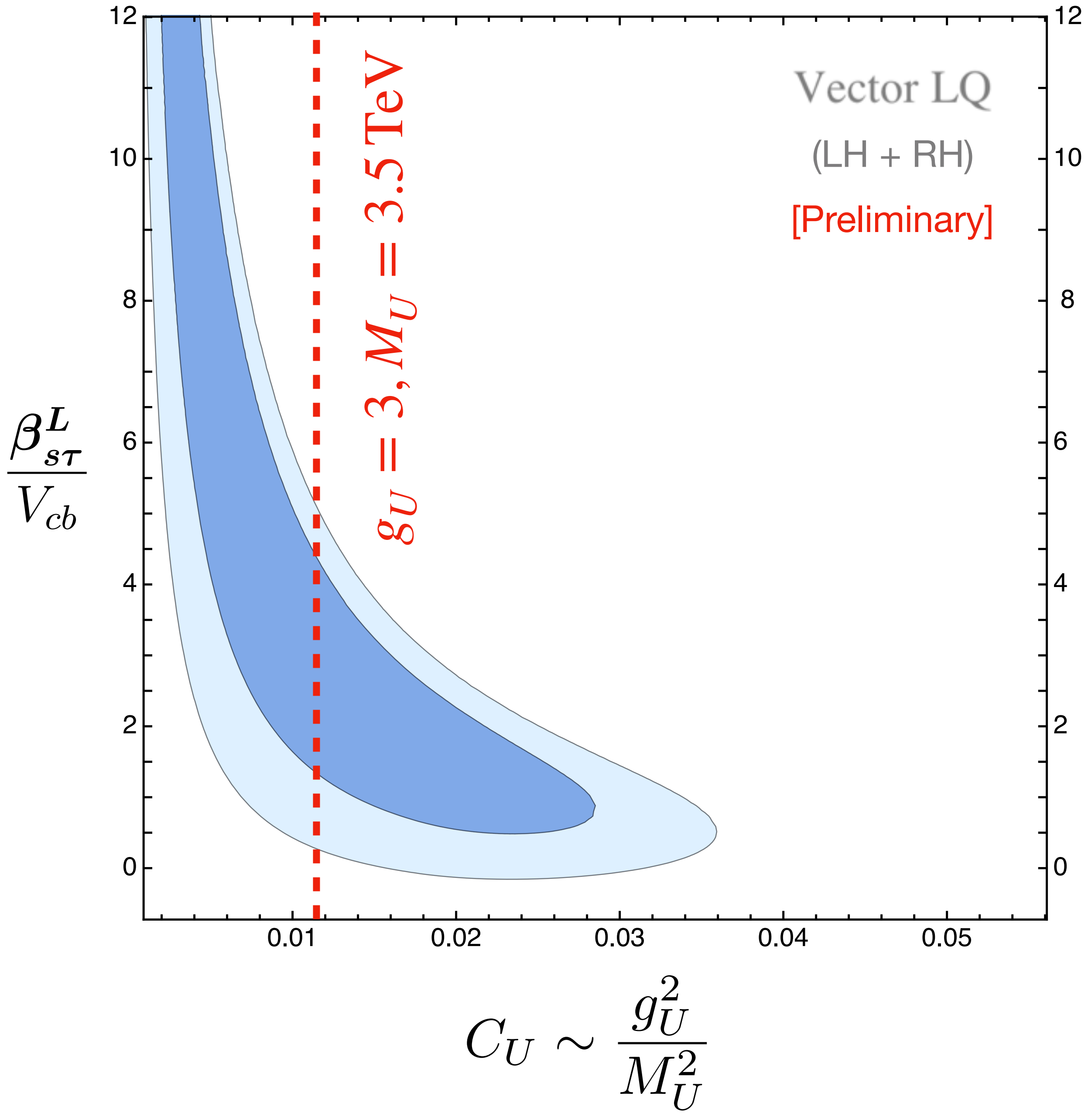
$M_U \gtrsim 2\ \text{TeV}$ **[LH only]**

[Baker, JFM, Isidori, König, in preparation]

$\beta_{s\tau} \sim$ **few** V_{cb}

[Non-trivial but possible in specific UV models]

Comparison among U_1 solutions

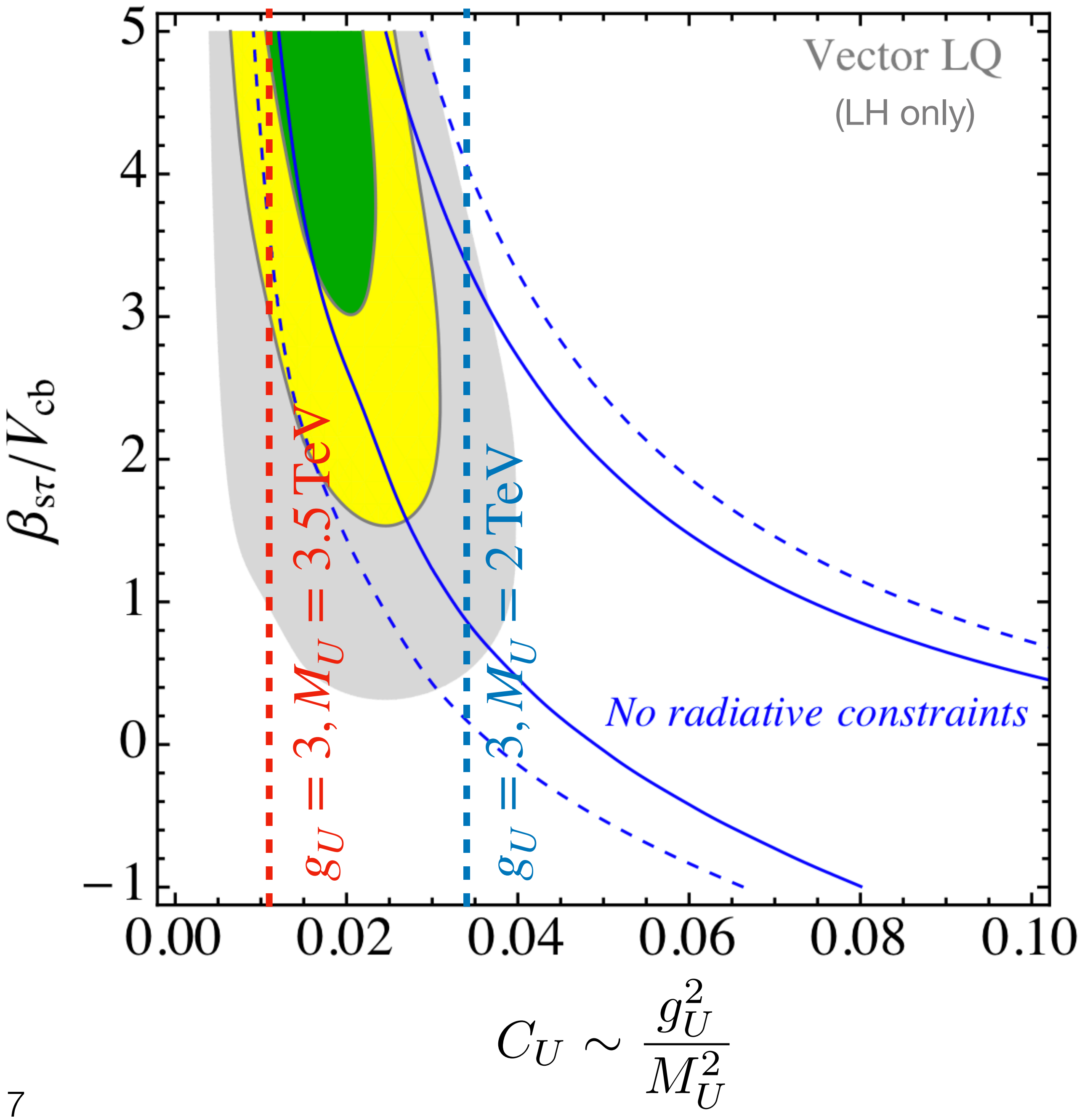


LH + RH

[JFM, Cornella, Isidori, in preparation]

LH only

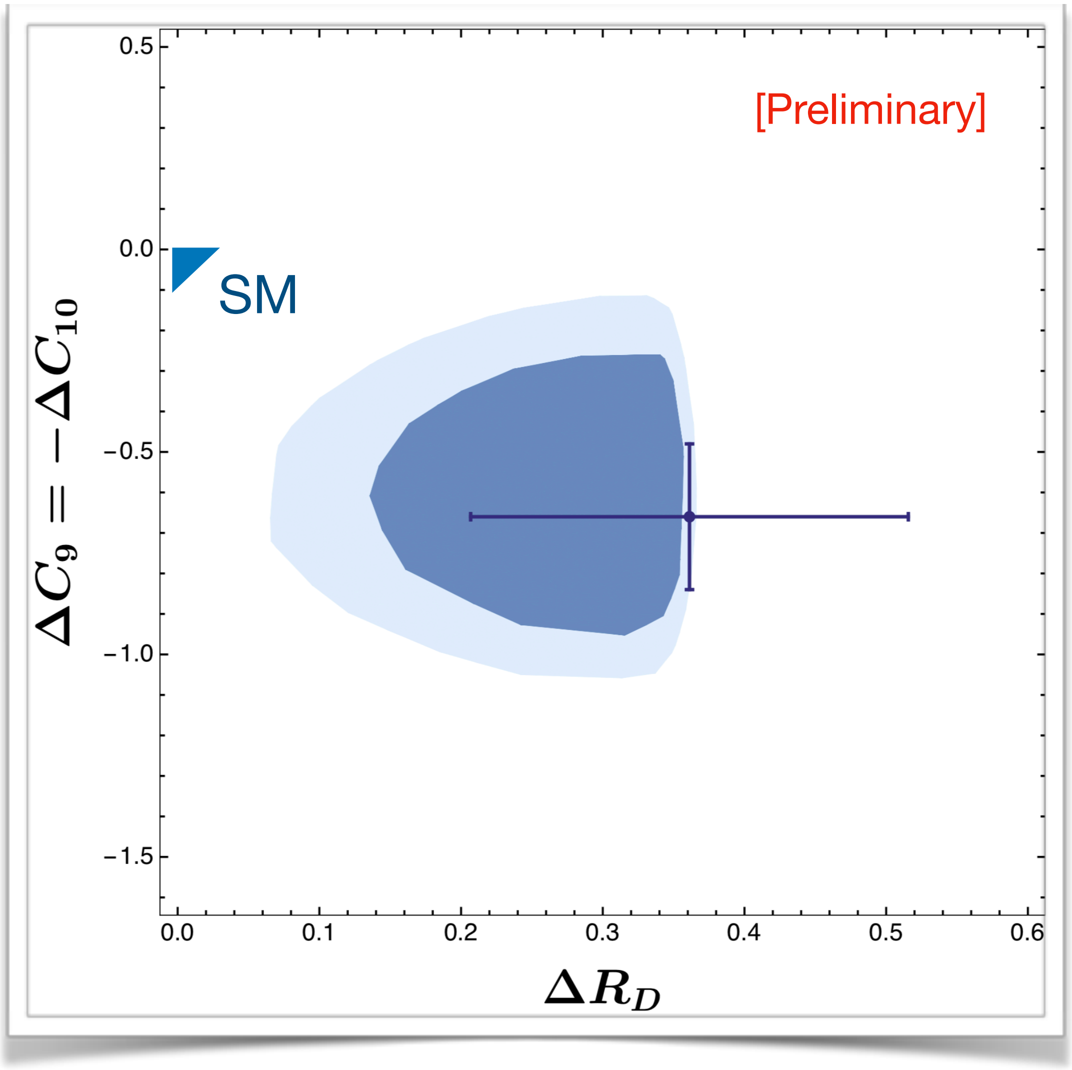
[Buttazzo et al. 1706.07808]



Fitting the anomalies with a U_1 leptoquark

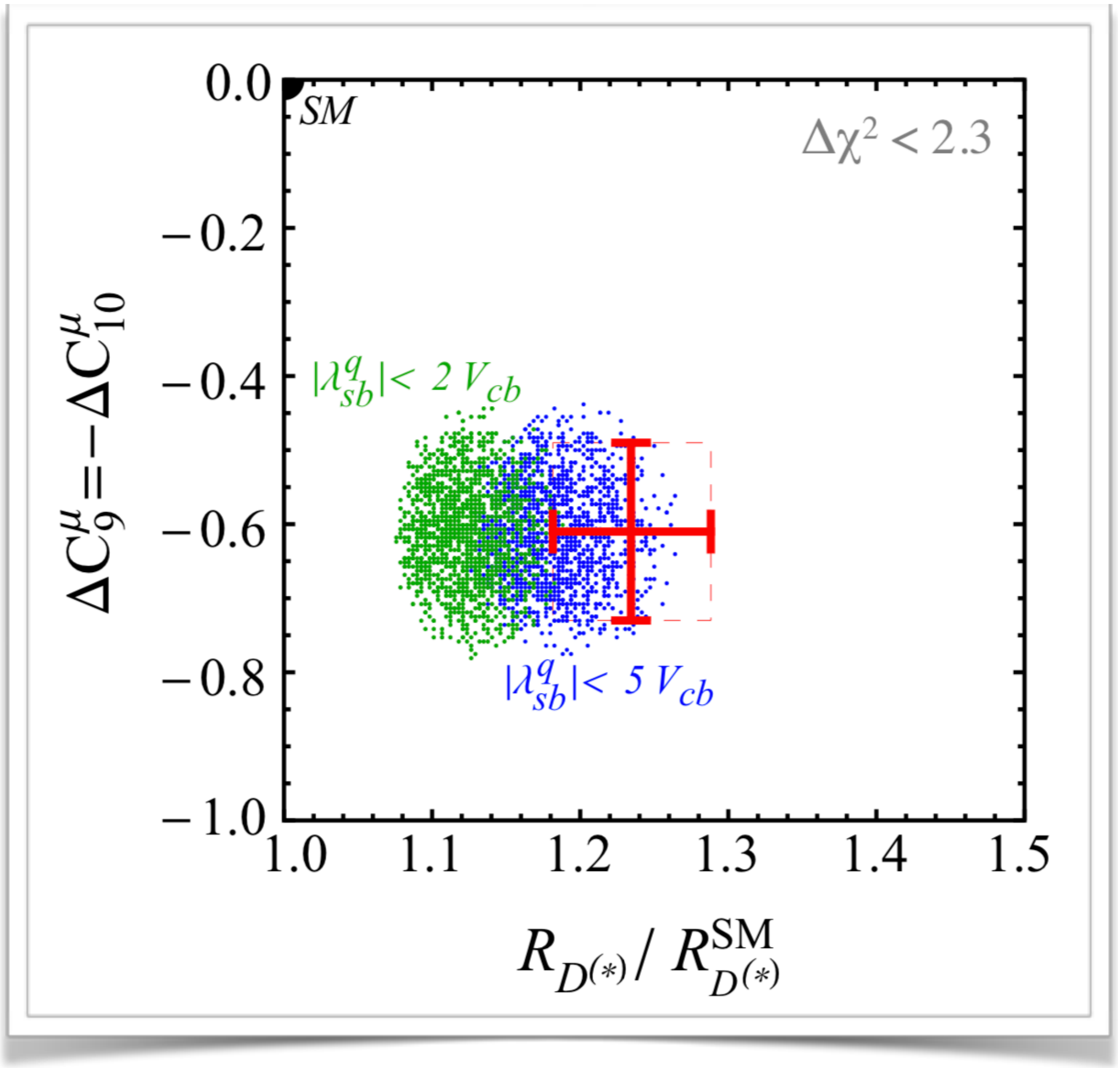
In both solutions the fit to low-energy data is very good

LH + RH



[JFM, Cornella, Isidori, in preparation]

LH only

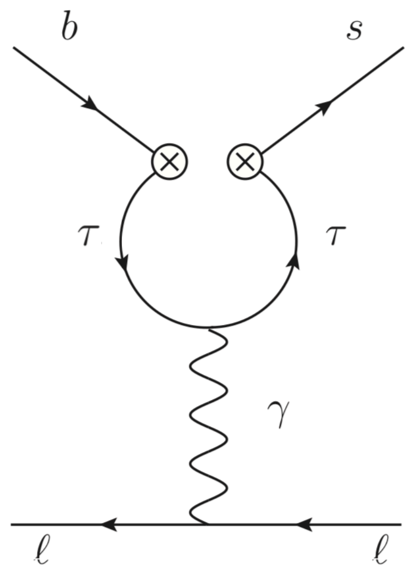


[Buttazzo et al. 1706.07808]

The need for a UV-complete U_1

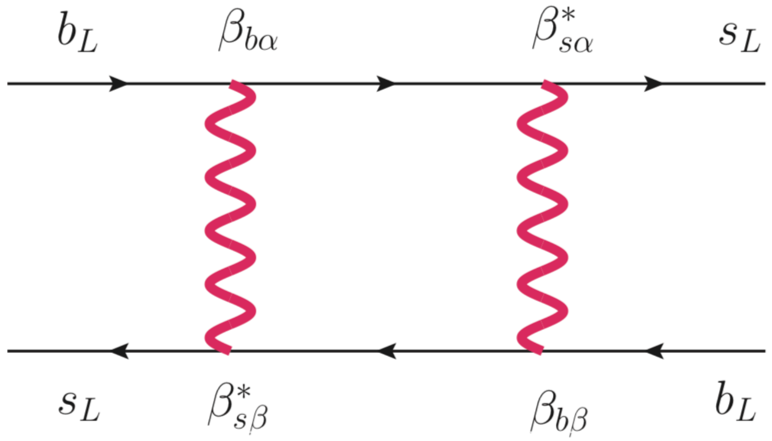
Loop effects are crucial…

For some loops the dominant effect is captured in the EFT…



Important (universal) contributions to $\Delta C_9^\ell = \Delta C_{10}^\ell$

[Bobeth, Haisch, 1109.1826
Crivellin, et al., 1807.02068]



Others, like $\Delta F = 2$ observables, are not calculable without a UV-completion

The need for a UV-completion of the vector leptoquark is unavoidable

Why not the Pati Salam model?

The vector-leptoquark solution points to Pati-Salam unification

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

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

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

[Lepton number as the 4th “color”]

✓ $\mathrm{SU}(4)$ is the smallest group containing the required vector LQ $[U_1 \sim (\mathbf{3},\mathbf{1})_{2/3}]$

✓ No proton decay (protected by symmetry)

✗ The (flavor blind) Pati-Salam model cannot work

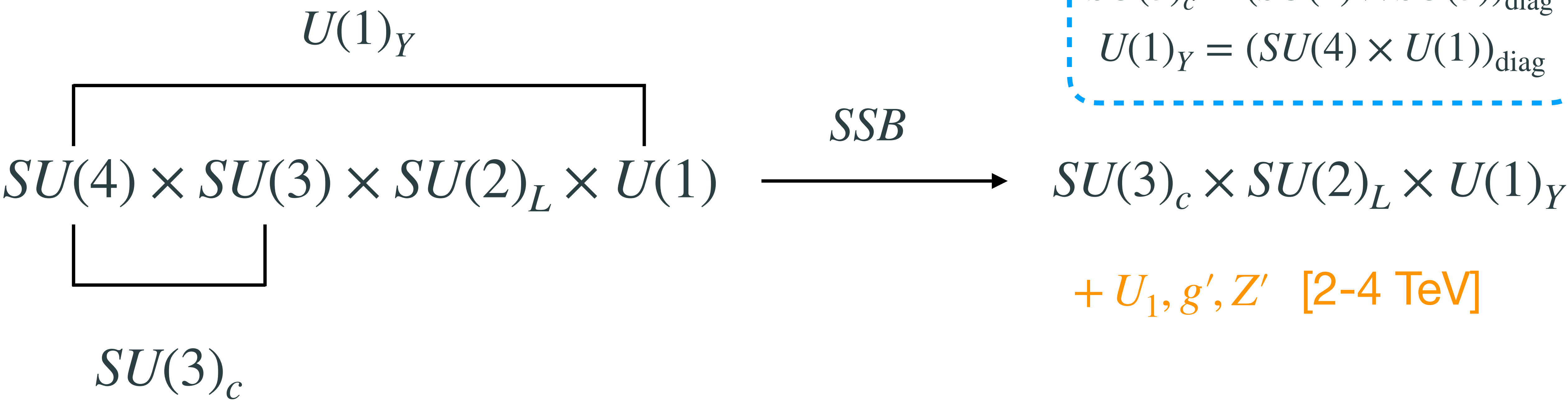
→ The bounds from $K_L \to \mu e$ and $D - \bar{D}$ lift the LQ mass to 100 TeV

✗ The associated Z' would be excessively produced at LHC

→ $M_U \sim M_{Z'} \sim \mathcal{O}(\mathrm{TeV})$ & $\mathcal{O}(g_s)$ Z' couplings to valence quarks

The 4321 model(s)

$$SU(3)_c = (SU(4)\times SU(3))_{\rm diag}$$
$$U(1)_Y = (SU(4)\times U(1))_{\rm diag}$$



$$\underbrace{SU(4)\times SU(3)}_{SU(3)_c}\times SU(2)_L\times U(1) \xrightarrow{SSB} SU(3)_c\times SU(2)_L\times U(1)_Y$$

$+\,U_1, g', Z'$ [2-4 TeV]

Why an additional $SU(3)$?

✗ The extra $SU(3)$ gives a g' (**coloron**), apart from the Z' already present in PS

✓ It allows to **decorrelate** the $SU(4)$ from the SM color group. In the limit $g_4 \gg g_{3,1}$, this “solves” the high-p_T problem

→ $\mathcal{O}(g_3/g_4)$ and $\mathcal{O}(g_1/g_4)$ g' and Z' couplings to valence quarks

[**Very interesting collider signatures!**]

The 4321 model(s)

$$\overbrace{\underbrace{SU(4)\times SU(3)}_{SU(3)_c}\times SU(2)_L\times U(1)}^{U(1)_Y} \xrightarrow{SSB} SU(3)_c\times SU(2)_L\times U(1)_Y$$

$+\,U_1, g', Z'$ [2-4 TeV]

Different fermion embeddings give two distinct solutions:

★ The “original” 4321 **[U_1 LH couplings only]**

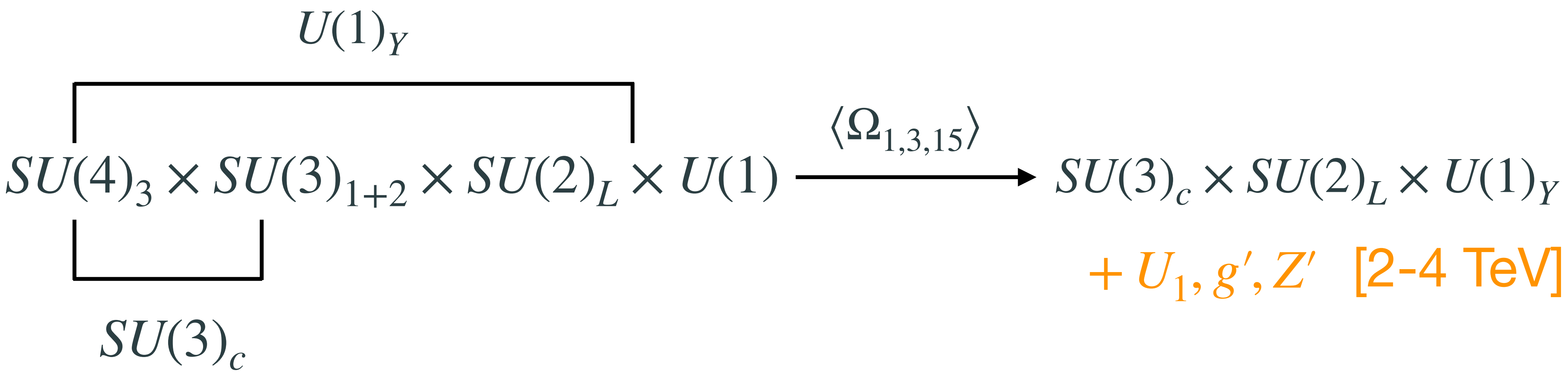
[di Luzio, Greljo, Nardecchia 1708.08450; Diaz, Schmaltz, Zhong 1706.05033;
di Luzio, JFM, Greljo, Nardecchia, Renner, 1808.00942]

★ “Flavored” 4321 (“natural” low-energy limit of PS^3) **[U_1 LH + RH couplings]**

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

"Flavored" 4321

Bordone et al. 1712.01368
Cornella, JFM, Isidori, in preparation



$U(1)_Y$

$$SU(4)_3 \times SU(3)_{1+2} \times SU(2)_L \times U(1) \xrightarrow{\langle \Omega_{1,3,15} \rangle} SU(3)_c \times SU(2)_L \times U(1)_Y$$

$SU(3)_c$

$+ U_1, g', Z'$ [2-4 TeV]

1st & 2nd families

3rd family

$n_{\mathrm{VL}} = 2$

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
ψ_L^3	**4**	**1**	**2**	0
$\psi_{R_{u,d}}^3$	**4**	**1**	**1**	$\pm 1/2$
χ_L^i	**4**	**1**	**2**	0
χ_R^i	**4**	**1**	**2**	0
$H_{1,15}$	**1, 15**	**1**	**2**	1/2
Ω_1	$\bar{\mathbf{4}}$	**1**	**1**	$-1/2$
Ω_3	$\bar{\mathbf{4}}$	**3**	**1**	$1/6$
Ω_{15}	**15**	**1**	**1**	0

"Flavoring" of the gauge group has interesting implications

✓ U(2)-like Yukawa textures (explanation to the SM flavor hierarchies)

✓ Couplings to 3rd family naturally big

Smaller effects in 1st & 2nd families through SM-Vector-like mixing

Gauge anomaly cancellation implies large U_1 **couplings also to RH fields**

Concluding remarks

Current data is still inconclusive and the overall picture might change but…

… it is still possible to find interesting solutions to the current B anomalies while remaining consistent with other low- and high-energy data

Connection to the SM Yukawa structure, based on a U(2) structure still viable

Going beyond simplified dynamical models is important

Lesson from 4321: unexpected experimental signatures (g', Z' , VL fermions,…)

If the anomalies are really pointing to NP, **new experimental indications** (both in high-p_T and at low energies) should show up soon in several observables

… However this conclusion is strongly driven by $R(D^{(*)})$

Thank you!

Backup slides

The 4321 model(s)

$$\overbrace{\underbrace{SU(4)_3 \times SU(3)_{1+2}}_{SU(3)_c} \times SU(2)_L}^{U(1)_Y} \times U(1) \xrightarrow{\langle \Omega_{1,3,15} \rangle} SU(3)_c \times SU(2)_L \times U(1)_Y$$

The “original” 4321

$n_{\mathrm{SM-like}} = 3$

$n_{\mathrm{VL}} = 3$

Field	$SU(4)$	$SU(3)'$	$SU(2)_L$	$U(1)'$
$q_L'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{2}$	$1/6$
$u_R'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$2/3$
$d_R'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$
$\ell_L'^i$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$e_R'^i$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	-1
χ_L^i	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{2}$	0
χ_R^i	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{2}$	0
H	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$1/2$
Ω_1	$\bar{\mathbf{4}}$	$\mathbf{1}$	$\mathbf{1}$	$-1/2$
Ω_3	$\bar{\mathbf{4}}$	$\mathbf{3}$	$\mathbf{1}$	$1/6$
Ω_{15}	$\mathbf{15}$	$\mathbf{1}$	$\mathbf{1}$	0

“Flavored” 4321

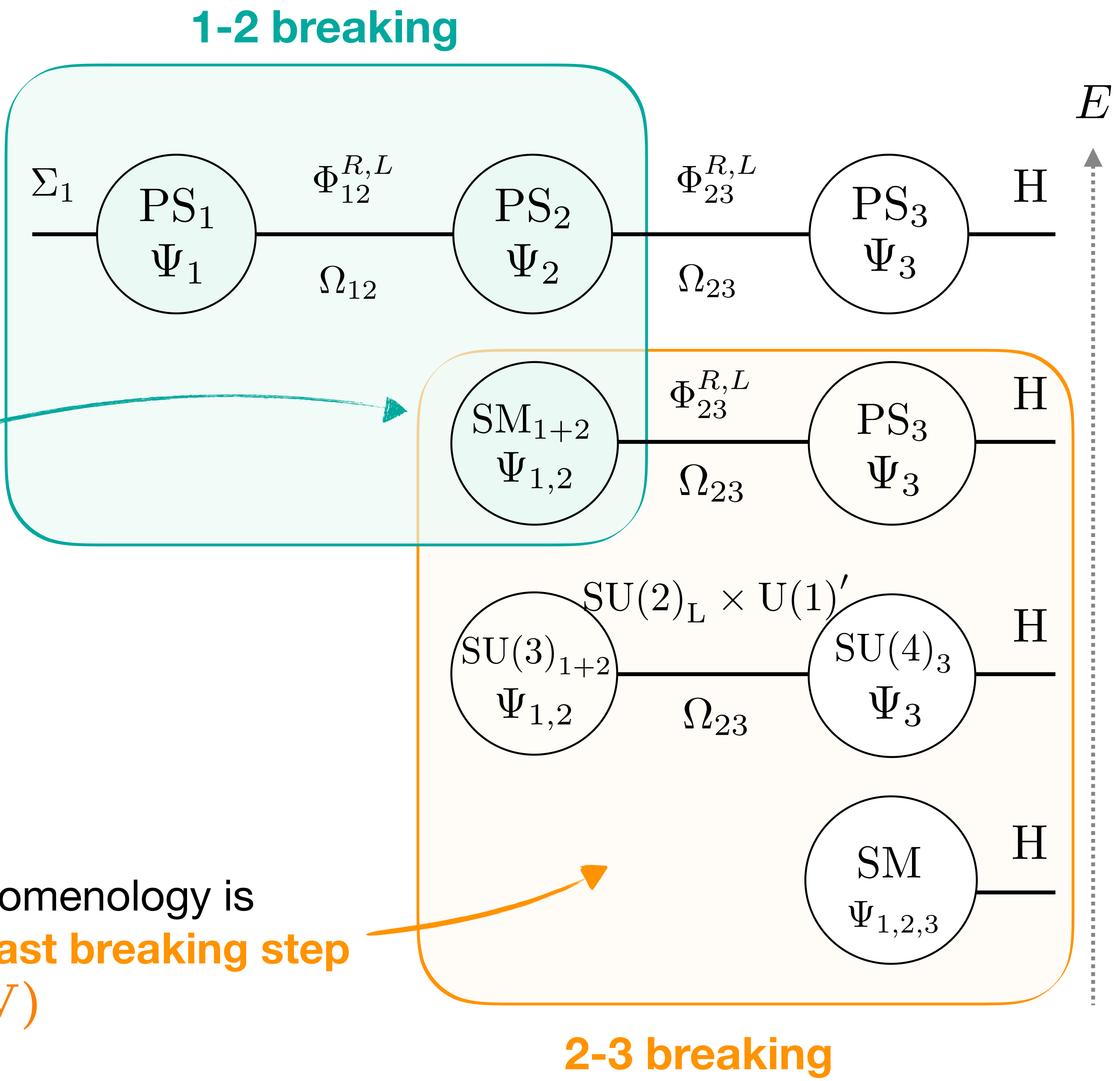
Field	$SU(4)$	$SU(3)'$	$SU(2)_L$	$U(1)'$
$q_L'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{2}$	$1/6$
$u_R'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$2/3$
$d_R'^i$	$\mathbf{1}$	$\mathbf{3}$	$\mathbf{1}$	$-1/3$
$\ell_L'^i$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$-1/2$
$e_R'^i$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$	-1
ψ_L^3	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{2}$	0
$\psi_{R_{u,d}}^3$	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{1}$	$\pm 1/2$
χ_L^i	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{2}$	0
χ_R^i	$\mathbf{4}$	$\mathbf{1}$	$\mathbf{2}$	0
$H_{1,15}$	$\mathbf{1}, \mathbf{15}$	$\mathbf{1}$	$\mathbf{2}$	$1/2$
Ω_1	$\bar{\mathbf{4}}$	$\mathbf{1}$	$\mathbf{1}$	$-1/2$
Ω_3	$\bar{\mathbf{4}}$	$\mathbf{3}$	$\mathbf{1}$	$1/6$
Ω_{15}	$\mathbf{15}$	$\mathbf{1}$	$\mathbf{1}$	0

1st & 2nd families

3rd family

$n_{\mathrm{VL}} = 2$

$\mathbf{PS^3}$ symmetry breaking pattern



lower limit on 1-2 scale
set by FC processes
involving light generations

$> \mathbf{10^3\ TeV}$

accidental $U(2)^5$ **flavour symmetry**
In the gauge sector

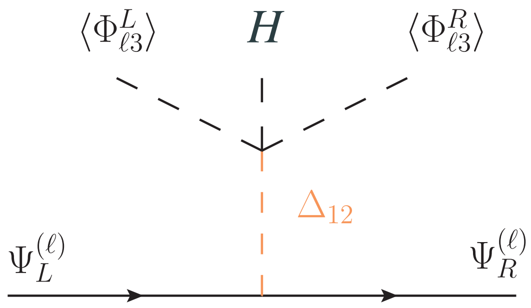
all low energy phenomenology is
determined by the very **last breaking step**
$\sim \mathcal{O}(\mathrm{TeV})$

PS^3 flavor structure

Yukawa hierarchies from a **flavored gauge structure** + **NP scale hierarchies**

[Bordone, Cornella, JF, Isidori 1712.01368]

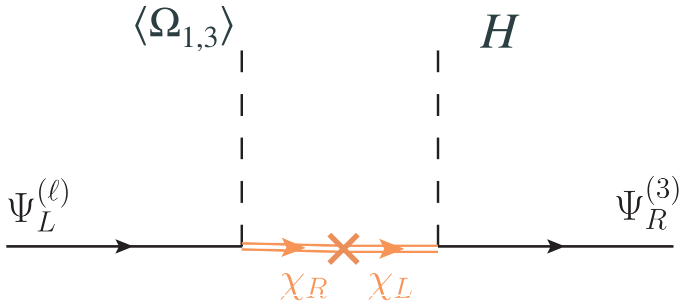
SM Yukawas: $\mathscr{L}_Y^{\mathrm{ren}} \supset y_u\, \bar\psi_L^3\, \tilde H\, \psi_{R_u}^3 + y_d\, \bar\psi_L^3\, H\, \psi_{R_d}^3$



$$|\Delta| \sim \frac{\langle\Phi^L_{\ell 3}\rangle\langle\Phi^R_{\ell 3}\rangle}{\Lambda^2} \sim y_c$$

At the NP scale I'm discussing this would be $d = 4$

$$Y_f \sim \begin{bmatrix} \Delta & V \\ 0 & 1 \end{bmatrix}$$



$$|V| \sim \frac{\langle\Omega_{1,3}\rangle}{M_\chi} \sim |V_{ts}|$$

[see also Greljo, Stefanek, 1802.04274]

$y_b \approx y_\tau$ ✓

$y_t \approx y_{\nu_3}$ → Requires low-scale seesaw

PS^3 flavor structure

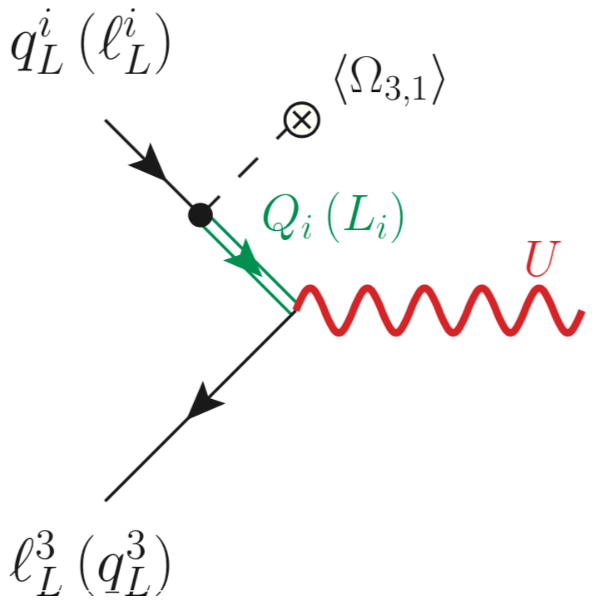
Yukawa hierarchies from a **flavored gauge structure** + **NP scale hierarchies**

SM-VL mixing: $\mathscr{L}_\Psi \supset \lambda_\ell\, \bar{\ell}'_L\, \Omega_1 \chi_R + \lambda_q\, \bar{q}'_L\, \Omega_3\, \chi_R + \lambda_{15}\, \bar{\chi}_L\, \Omega_{15}\, \chi_R + M\, \bar{\chi}_L\, \chi_R$

Ω_{15} is a new a source of flavor:

$$\lambda'_{15}\, \bar{\Psi}^3_L\, \Omega_{15}\, \chi_R$$

[Cornella, JF, Isidori, in preparation]



Large 2-3 misalignment
only in LQ transitions!