University of Zurich[UZH]

B-anomalies in non-universal models

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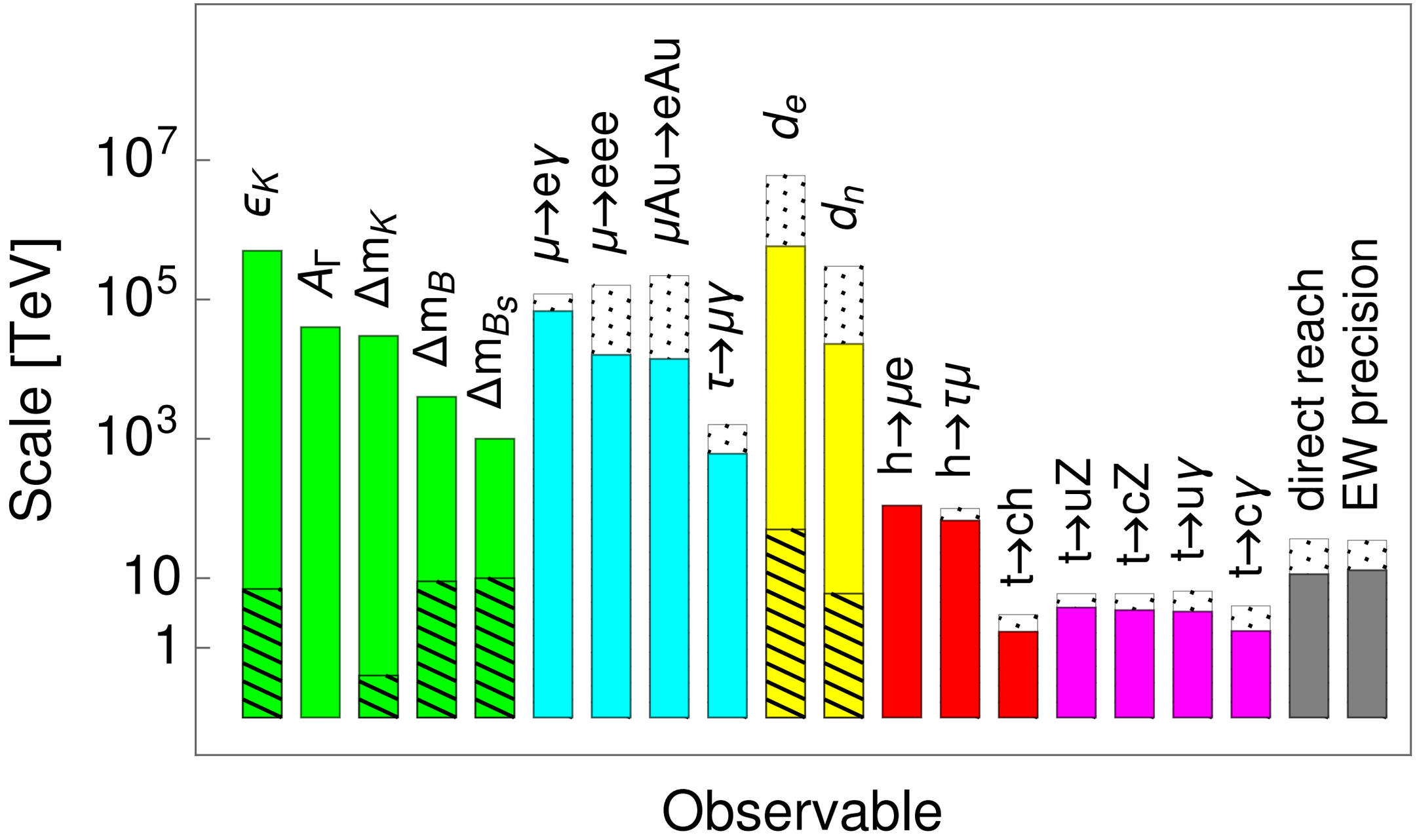
NePSi 23 - Pisa - February 2022

Flavor bounds on NP

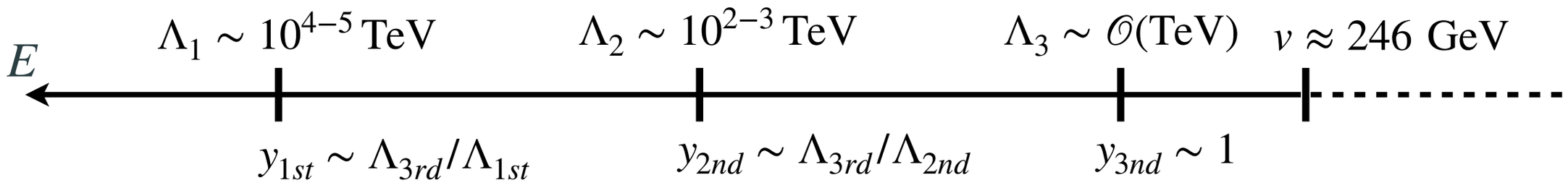


[Physics Briefing Book, 1910.11775]

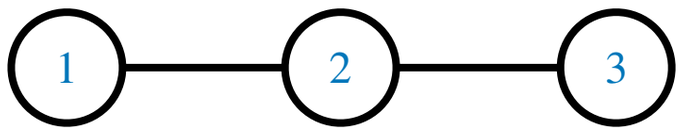
Multiscale flavor

[Dvali, Shiftman, hep-ph/0001072,Panico, Pomarol, 1603.06609
Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368
Barbieri, 2103.15635]

- A safe solution: multiscale origin of the flavor hierarchies.



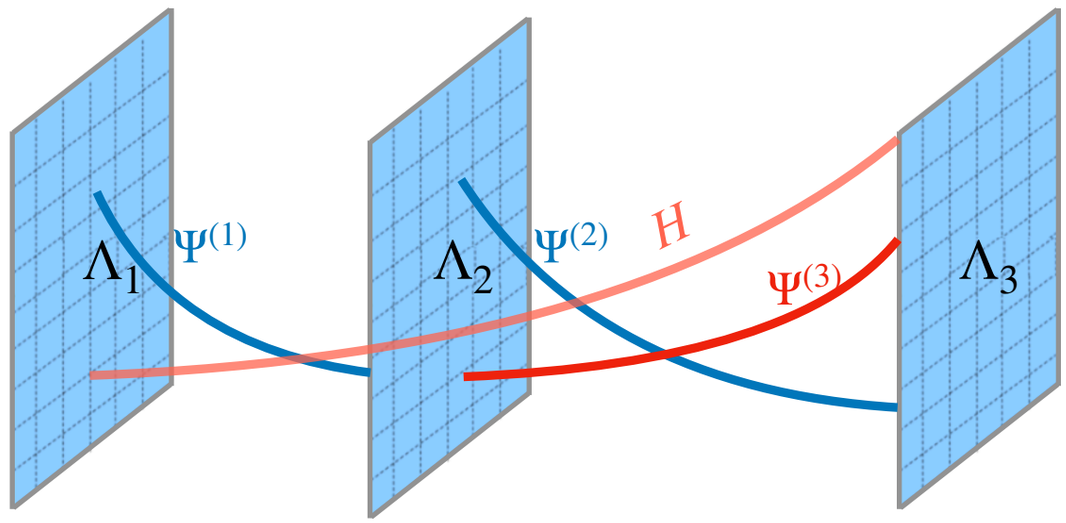
Multi-site



dual

Extra-dimensions

Composite dynamics



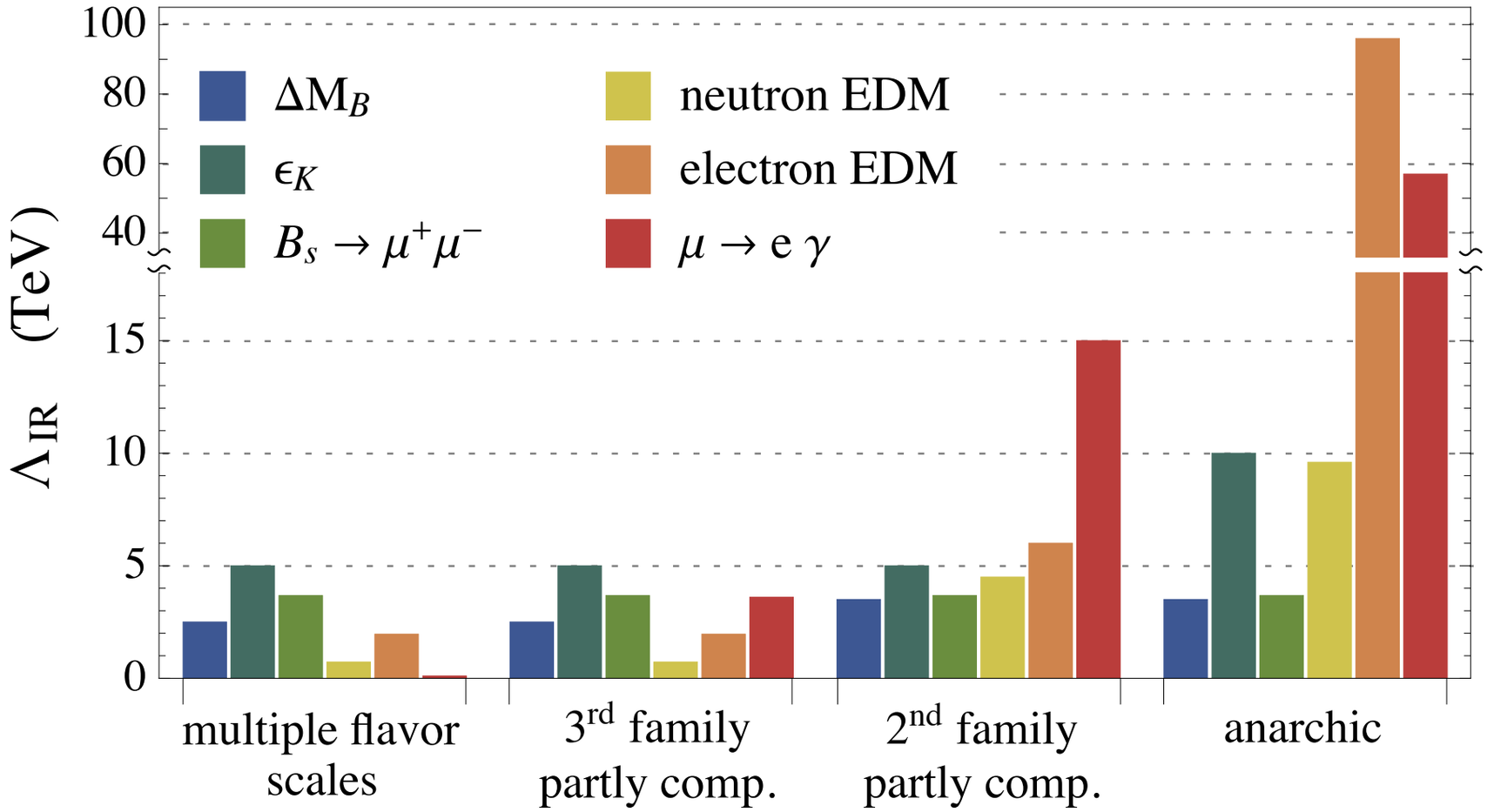
[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368]

[Fuentes-Martin, Isidori, JML, Selimovic, Stefanek, 2203.01952]

Multiscale flavor

[Panico, Pomarol, 1603.06609]

- Example in composite models/RS:

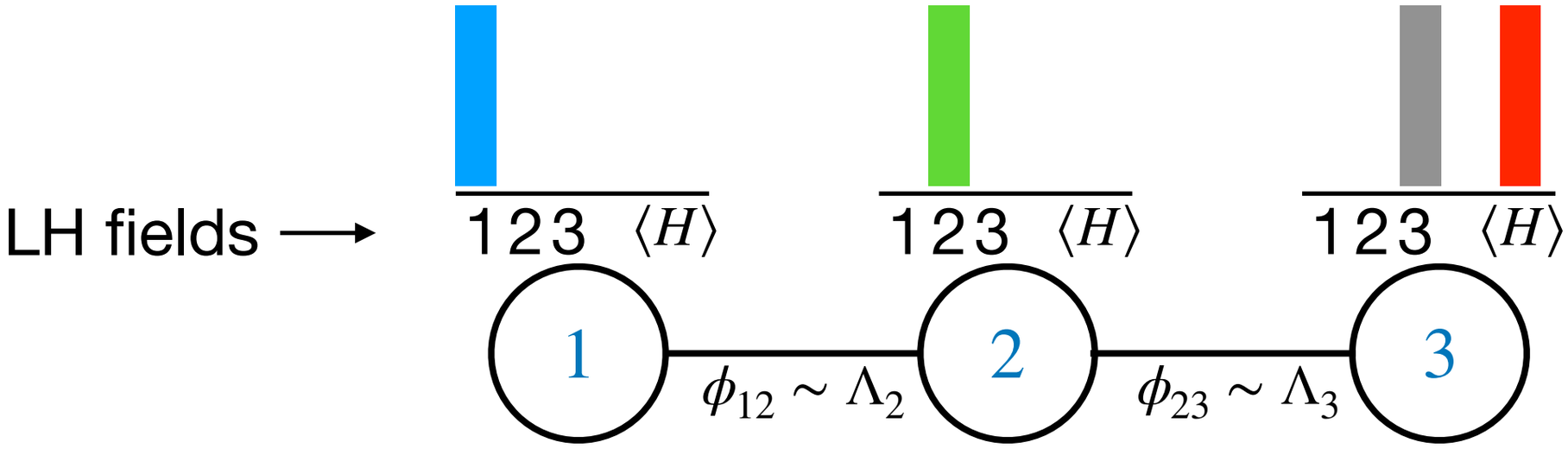


Dangerous dipoles (among others) generated at the IR scale

$$\sim \frac{g_*^2}{16\pi^2}\frac{m_e}{\Lambda_{\rm IR}^2}\,\bar{e}_L\sigma_{\mu\nu}e_R F^{\mu\nu}$$

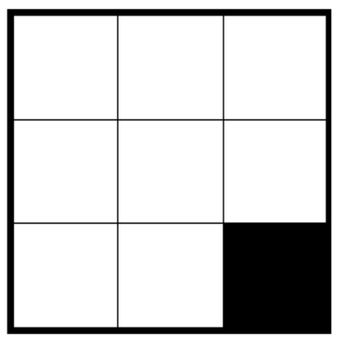
[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, Allwicher, Isidori, Thomsen, 2011.01946]

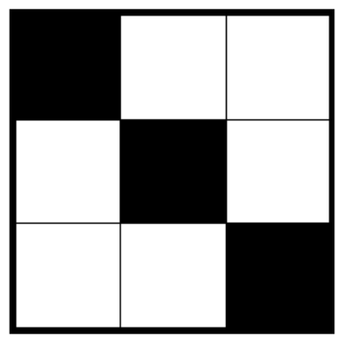
Deconstructing flavor



$$G_1 \times G_2 \times G_3 \xrightarrow{\text{TeV}} \text{SM}$$

(Universal)

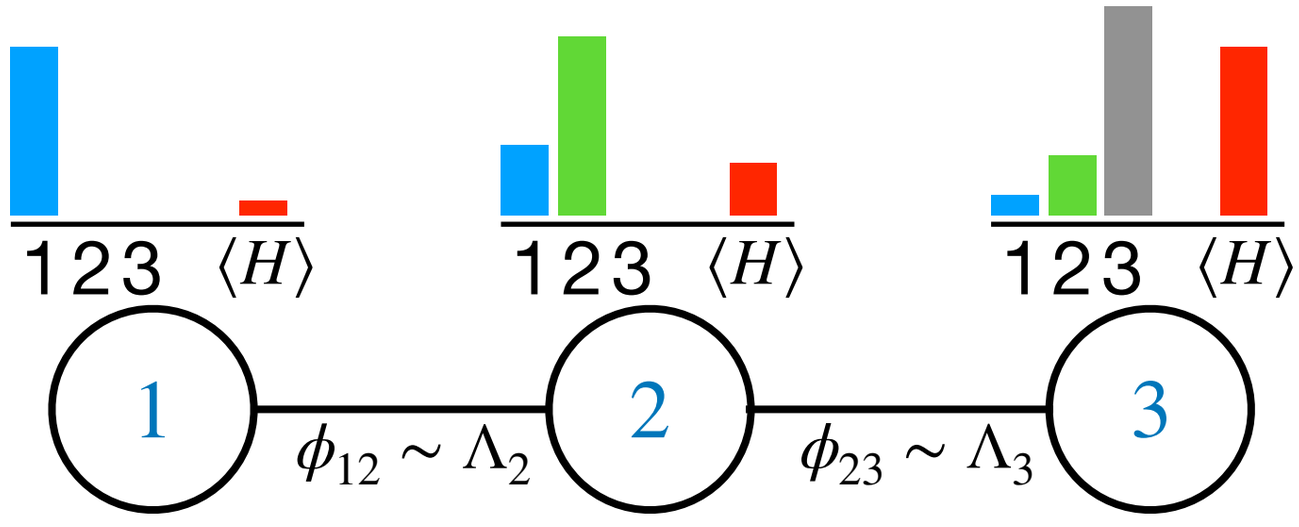
$$M \sim$$ 

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

[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, Allwicher, Isidori, Thomsen, 2011.01946]

Deconstructing flavor

LH fields ⟶



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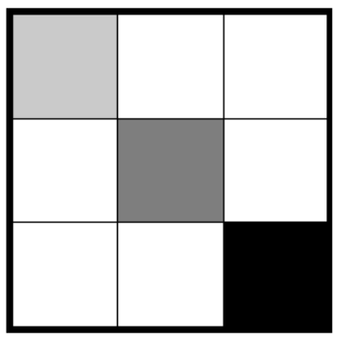
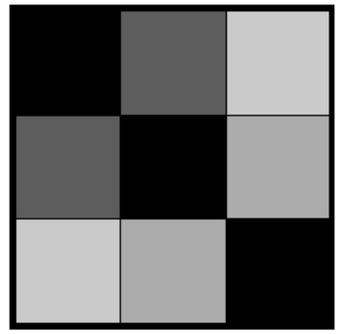
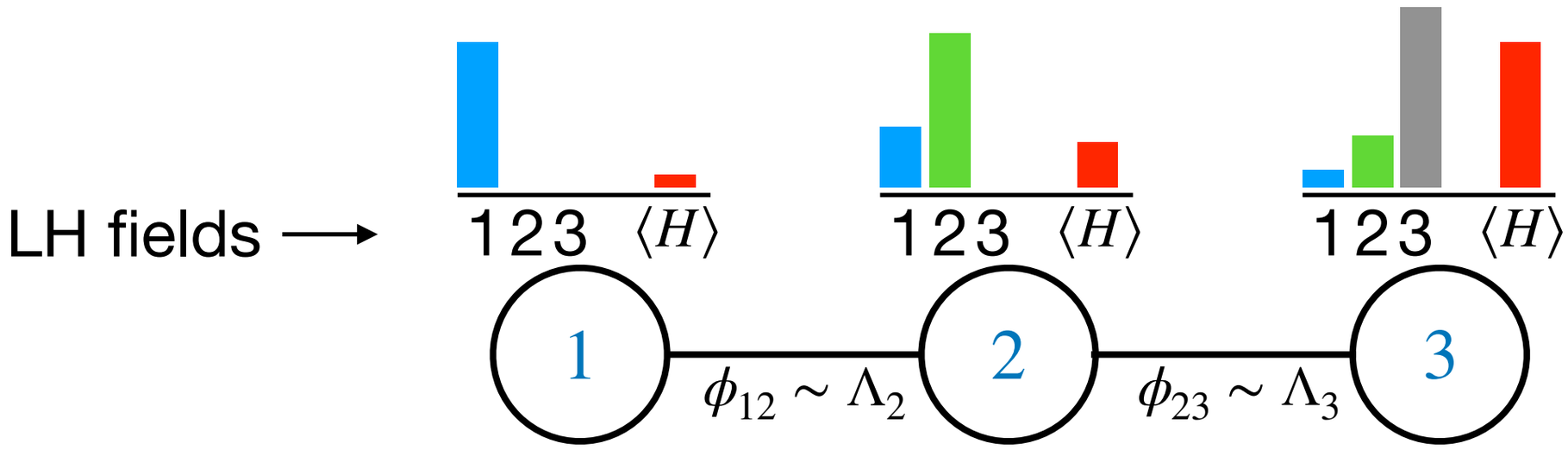
$$M \sim$$ 

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

[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, Allwicher, Isidori, Thomsen, 2011.01946]

Deconstructing flavor



$$G_1 \times G_2 \times G_3 \xrightarrow{\text{TeV}} \text{SM}$$

(Universal)

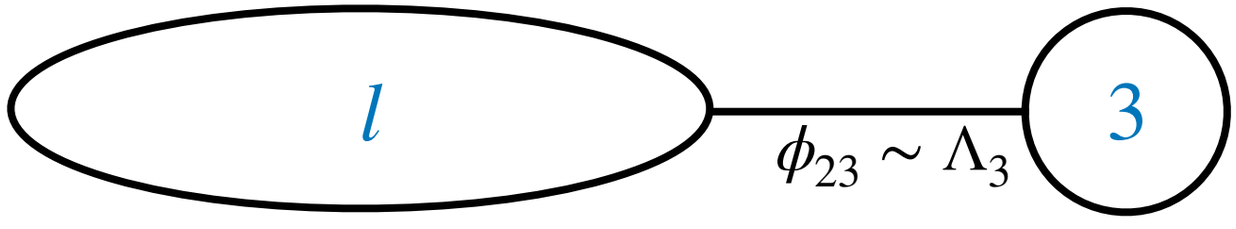
- Only rotations in the LH sector ➡ **No RH or scalar FCNC** ✔

[Crosas, Isidori, JML, Selimović, Stefanek, 2203.01952]

[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, Allwicher, Isidori, Thomsen, 2011.01946]

Deconstructing flavor

- From the TeV, we see…



$$\mathrm{SM}_l \times G_3 \xrightarrow{\text{TeV}} \mathrm{SM}$$

(Universal)

- Emerging flavor symmetry:

$$\boxed{U(2)}$$

(Only broken minimally in the LH sector)

[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, Allwicher, Isidori, Thomsen, 2011.01946]

Deconstructing flavor

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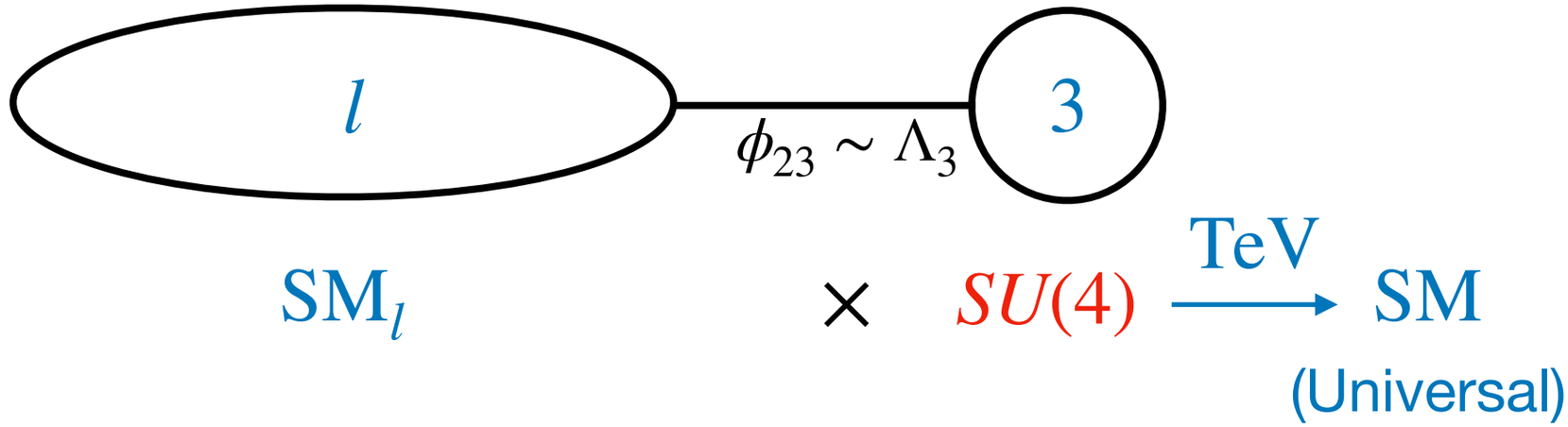


- Emerging flavor symmetry:

$$\boxed{U(2)}$$

(Only broken minimally in the LH sector)

4321 model

[Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368, 1805.09328;
Greljo, Stefanek, 1802.04274;
Cornella, Fuentes-Martin, Isidori 1903.11517]

Third family quark-lepton unification:

$$SU(4)_h \times SU(3)_l \times SU(2)_L \times U(1)_{R+\frac{(B-L)_l}{2}} \xrightarrow{\sim \text{TeV}} SU(3)_c \times SU(2)_L \times U(1)_Y$$

$SU(3)_h \longrightarrow SU(3)_c$ (with $SU(3)_h \cap SU(4)_h$ and $SU(3)_c \uparrow SU(3)_l$)

$U(1)_{(B-L)_h} \cup SU(4)_h \longrightarrow U(1)_Y$ (with $U(1)_{R+\frac{(B-L)_l}{2}} \downarrow U(1)_Y$)

$$+ \begin{cases} U_1 \sim (\mathbf{3},\mathbf{1})_{2/3} \\ G' \sim (\mathbf{8},\mathbf{1})_0 \\ Z' \sim (\mathbf{1},\mathbf{1})_0 \end{cases}$$

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

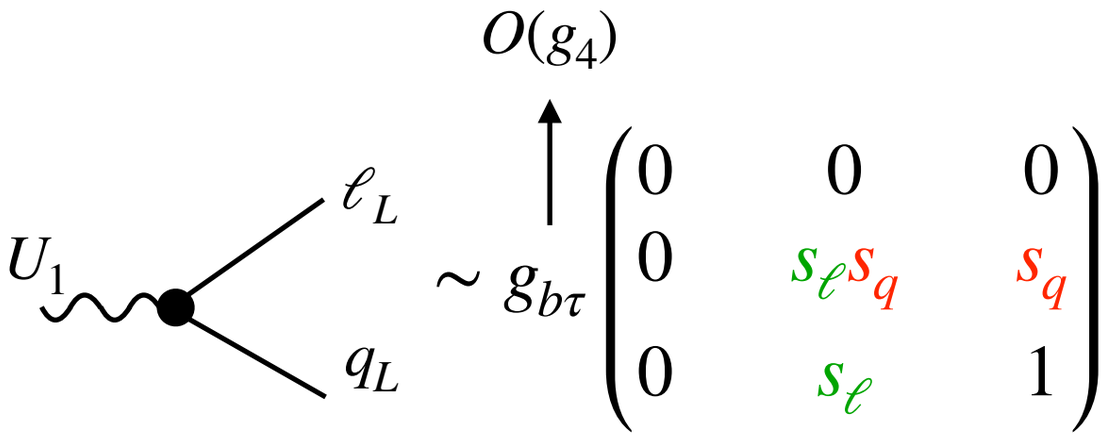
$$g_4 \gg g_3 \Rightarrow \begin{cases} g_s \approx g_3 \\ g_h^{G'} \approx g_4 \\ g_l^{G'} \approx g_s^2/g_4 \end{cases}$$

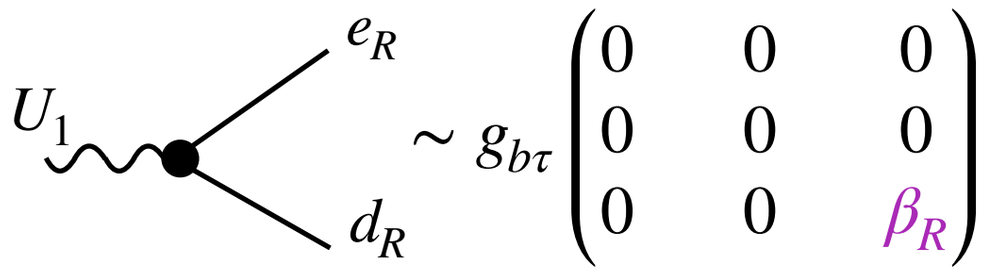
LHC bounds:

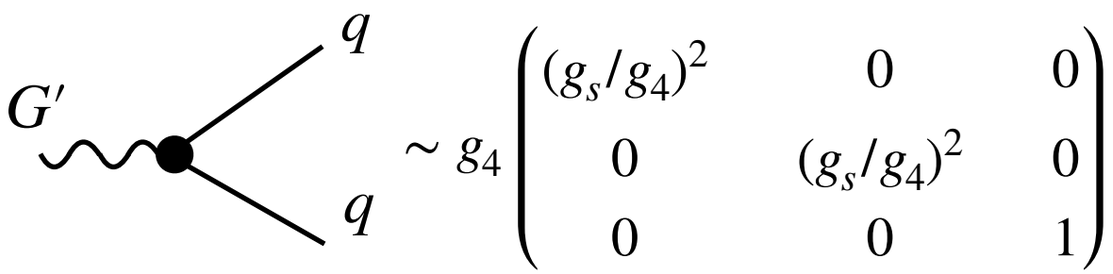
$$M_{G'} \gtrsim 3 - 3.5\,\text{TeV}$$

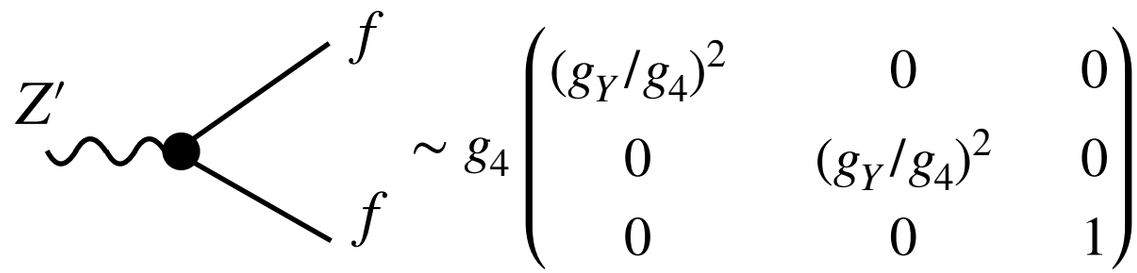
[Cornella, Faroughy, Fuentes-Martin, Isidori, Neubert, 2103.16558]

4321 massive vector bosons









$\Lambda_U = \sqrt{2}\, m_{U_1}/g_{b\tau}$

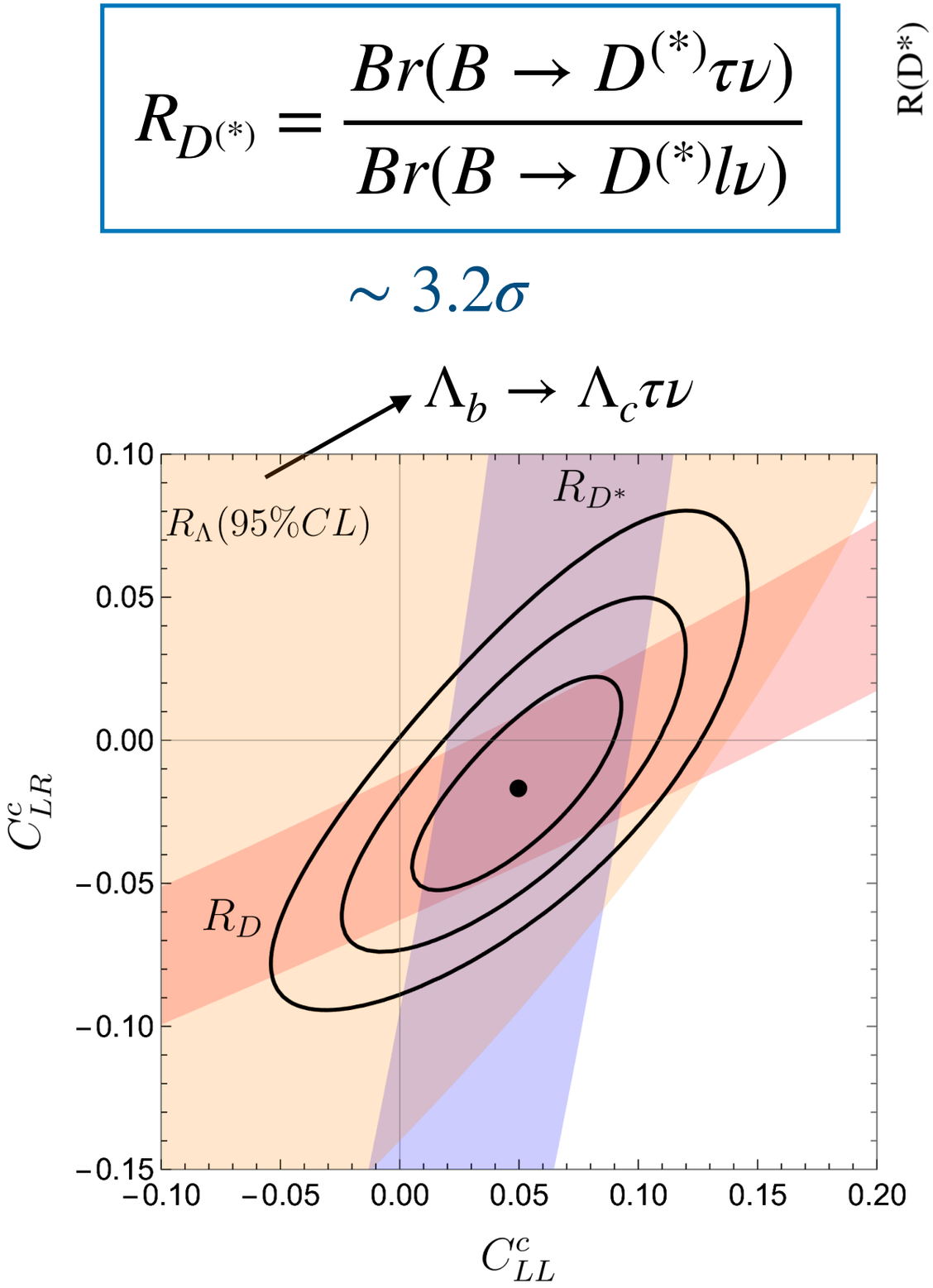
$\Lambda_U,\ s_q,\ s_\ell,\ \beta_R$

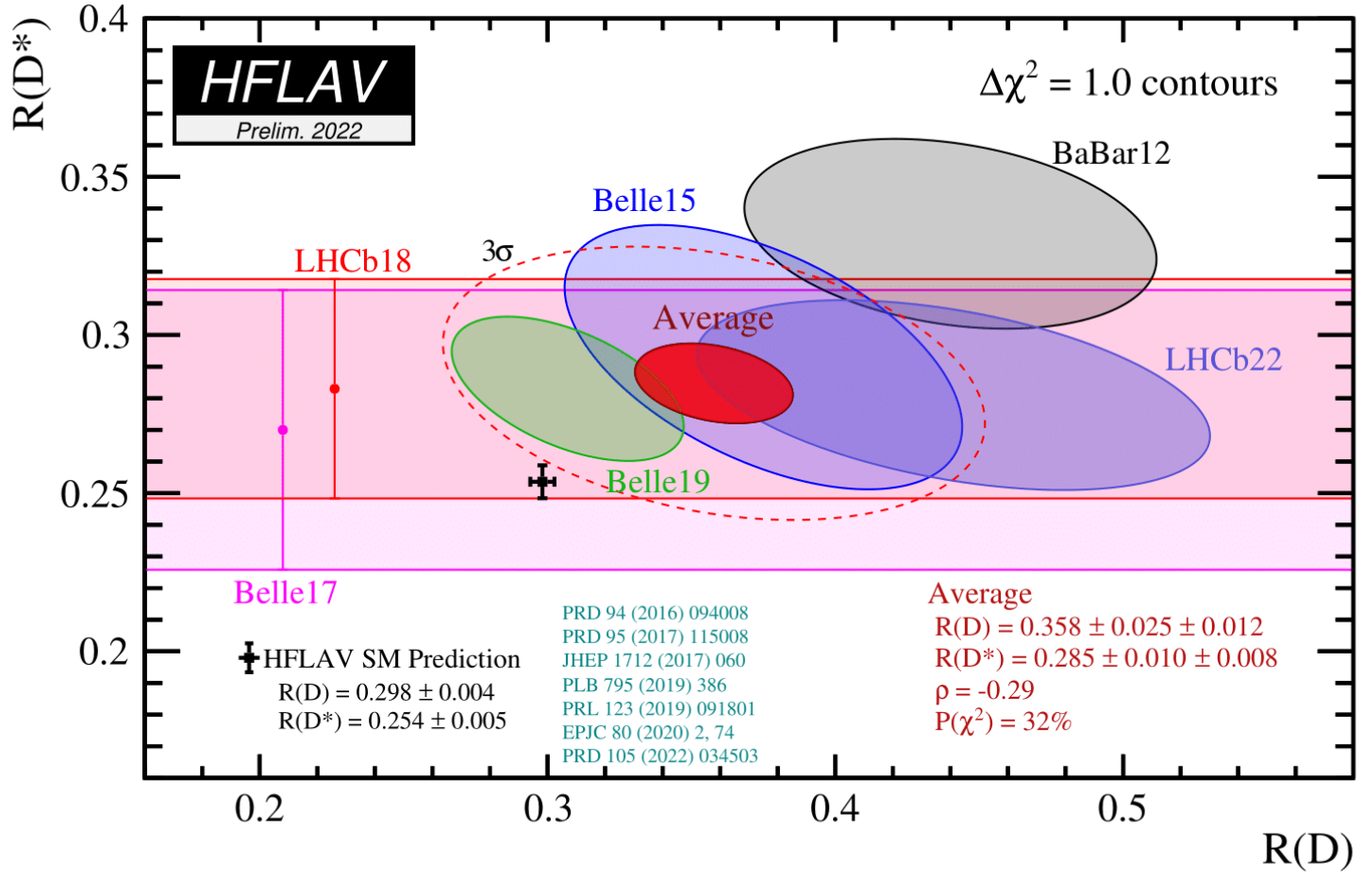
Necessary for CKM

B-anomalies: $R_{D^{(*)}}$

$$R_{D^{(*)}} = \frac{Br(B \to D^{(*)}\tau\nu)}{Br(B \to D^{(*)}l\nu)}$$

$\sim 3.2\sigma$



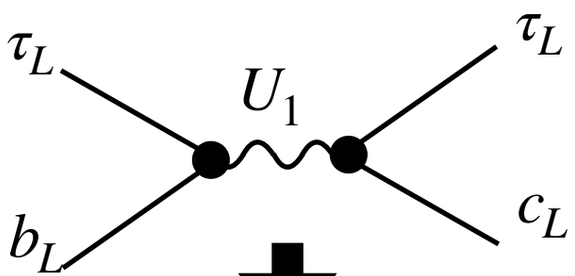


$$\mathscr{L} \supset \frac{2}{v^2} V_{cb}\Big[\big(1 + C^c_{LL}\big)(\bar{c}_L\gamma_\mu b_L)(\bar{\tau}_L\gamma^\mu\nu_L) - 2C^c_{LR}(\bar{c}_L b_R)(\bar{\tau}_L\nu_L)\Big]$$

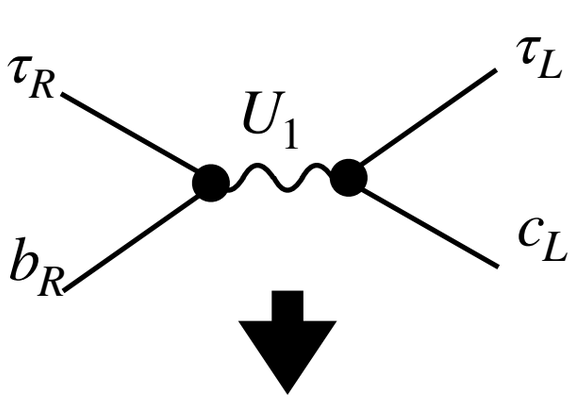
[J. Aebischer, G. Isidori, M. Pesut, B. Stefanek, F. Wilsch, 2210.13422]

B-anomalies: $R_{D^{(*)}}$

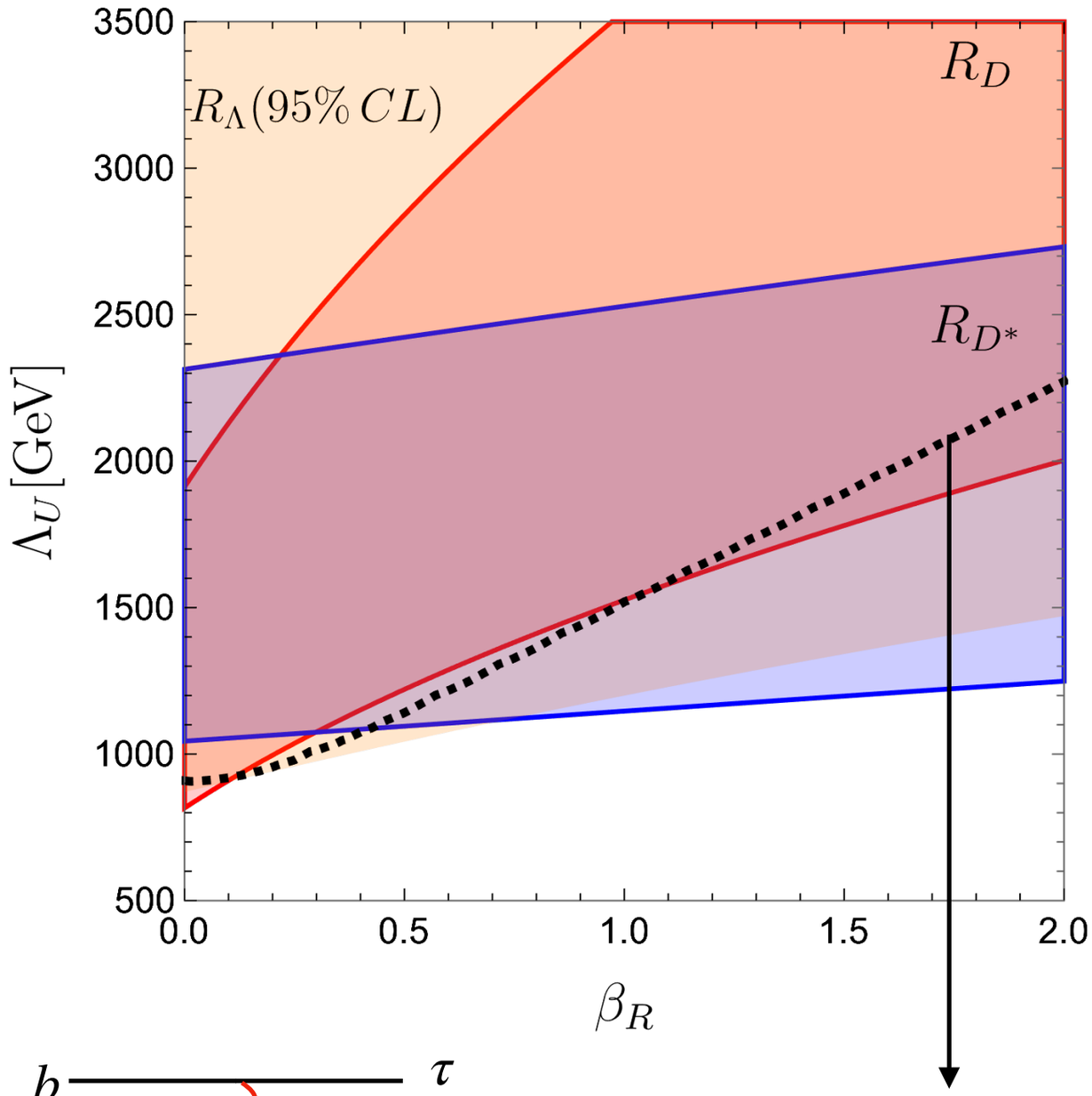
$$s_q = 0.1 \approx 2.4 V_{cb}$$

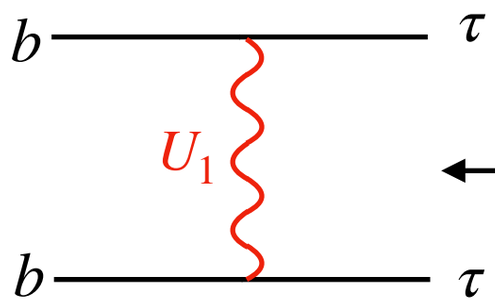


$$C^c_{LL} \propto \frac{s_q}{\Lambda^2}$$



$$C^c_{LR} \propto \frac{\beta_R s_q}{\Lambda^2_U}$$





95% CL CMS exclusion limits on $pp \to \tau\tau$

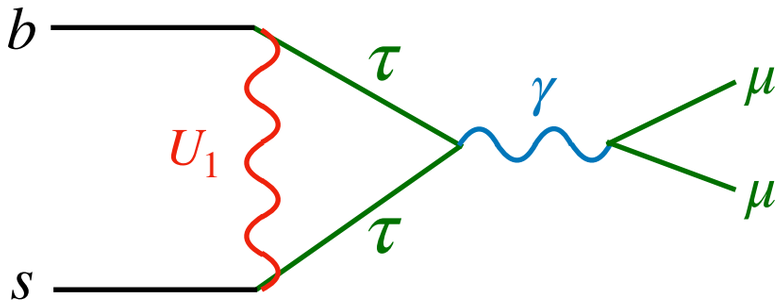
[W. Altmannshofer, P. Stangl, 2103.13370]

B-anomalies: $b \to s\mu\mu$

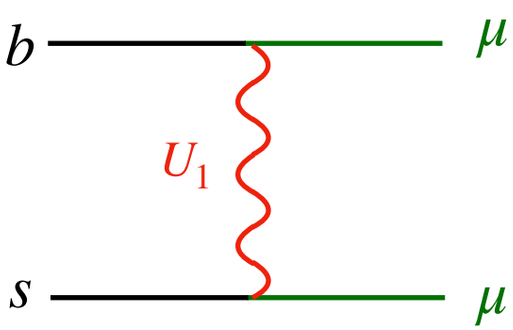
$$B \to K^*\mu\mu$$

$$\mathscr{L} \supset \frac{2}{v^2} V_{ts}^* V_{tb}\, C_9 (\bar{s}_L \gamma^\mu b_L)(\mu \gamma_\mu \mu)$$

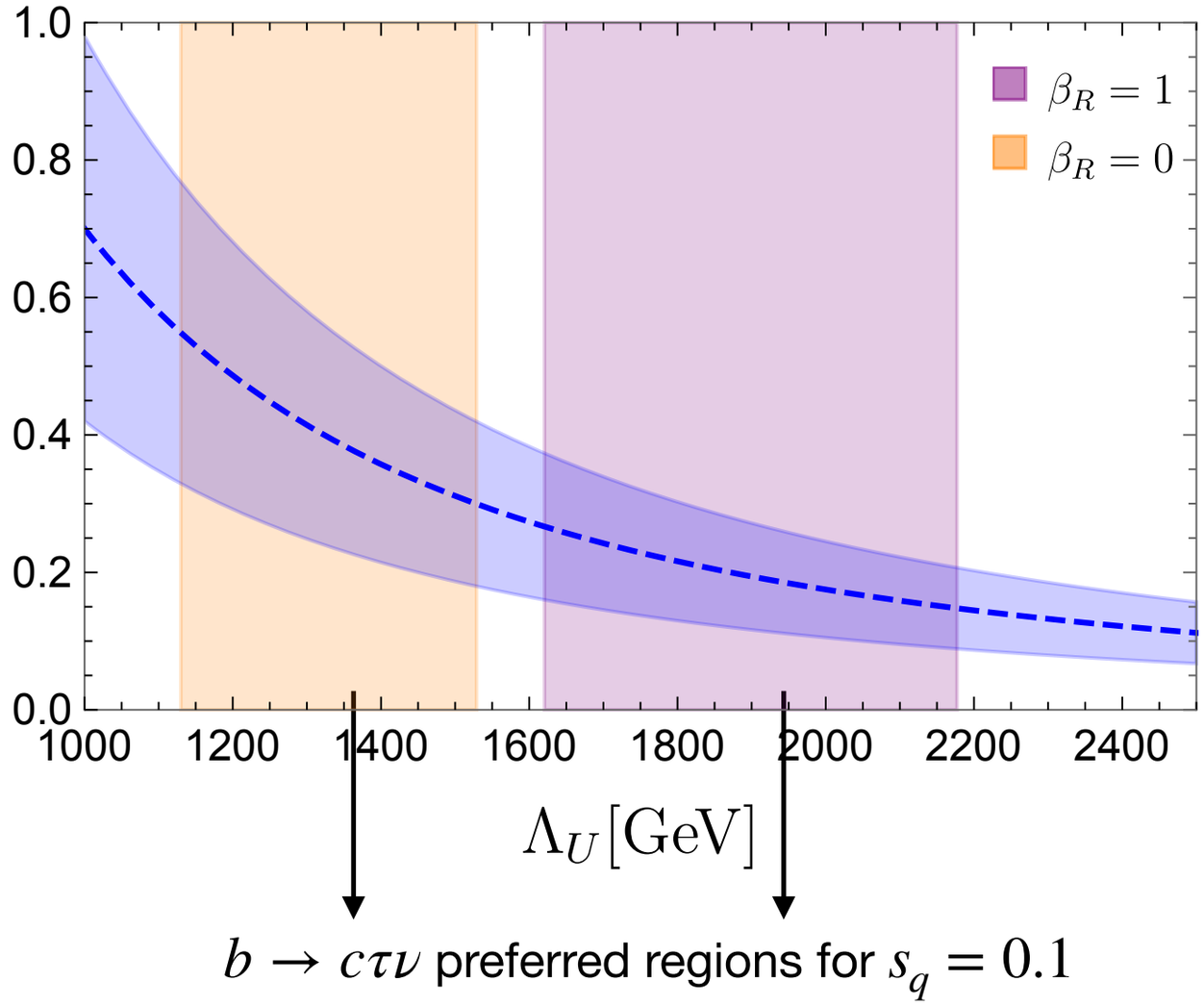
$$C_9^{\rm NP} = -0.75 \pm 0.23 \ \ (\sim 3.4\sigma)$$



$$\sim \frac{s_q}{\Lambda_U^2} \times \text{loop} \quad \text{(Universal)}$$

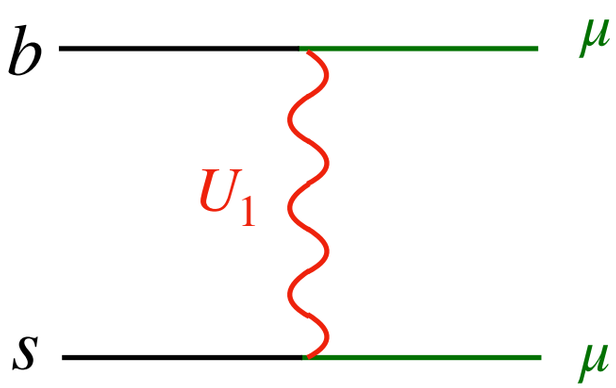


$$\sim \frac{s_q\, s_l^2}{\Lambda_U^2}$$



And what about $R_{K^{(*)}}$...?

$$R_{K^{(*)}} = \frac{Br(B \to K^{(*)}\mu\mu)}{Br(B \to K^{(*)}ee)}$$



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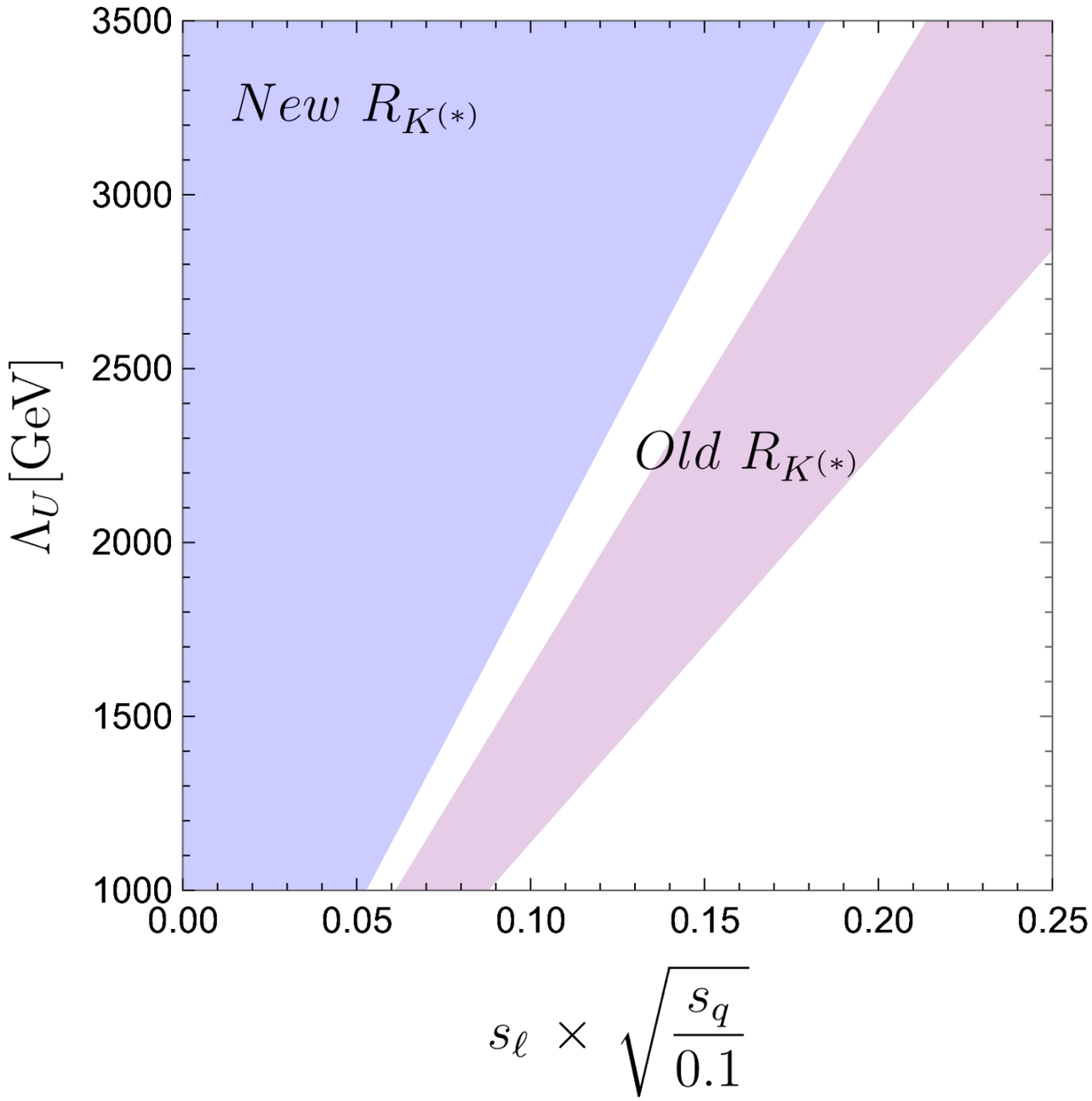
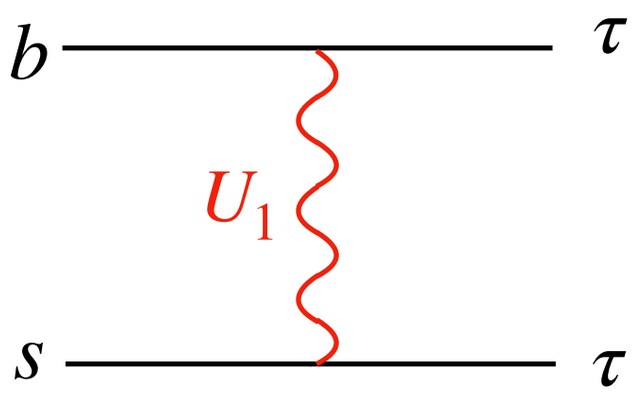


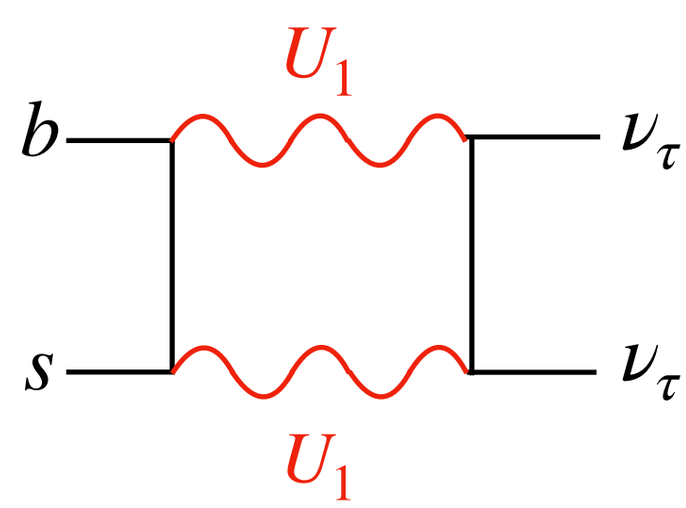
Other interesting observables

- $B_s \to \tau\tau$



$$\sim \frac{s_q}{\Lambda_U^2}$$

- $B \to K\tau\tau$



$$\sim \frac{s_q}{\Lambda_U^2} \times \text{loop}$$

- $B \to K\nu\bar{\nu}$

- …

[Cornella, Faroughy, Fuentes-Martin, Isidori, Neubert, 2103.16558]

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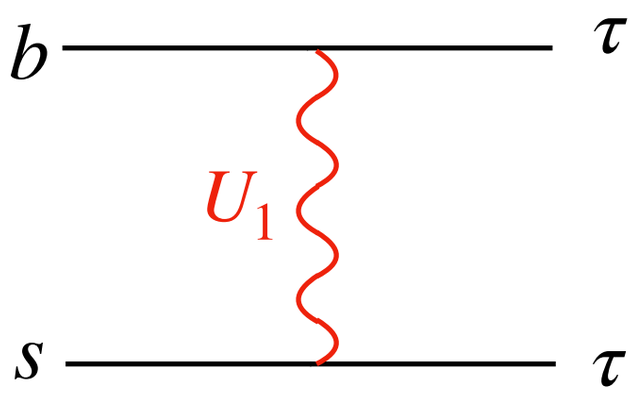

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- $B \to K\tau\tau$

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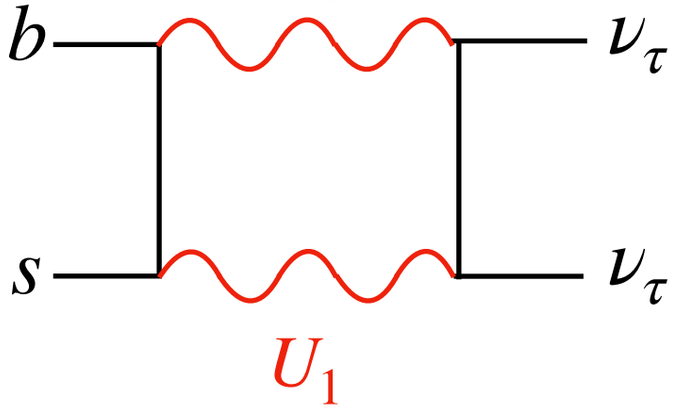

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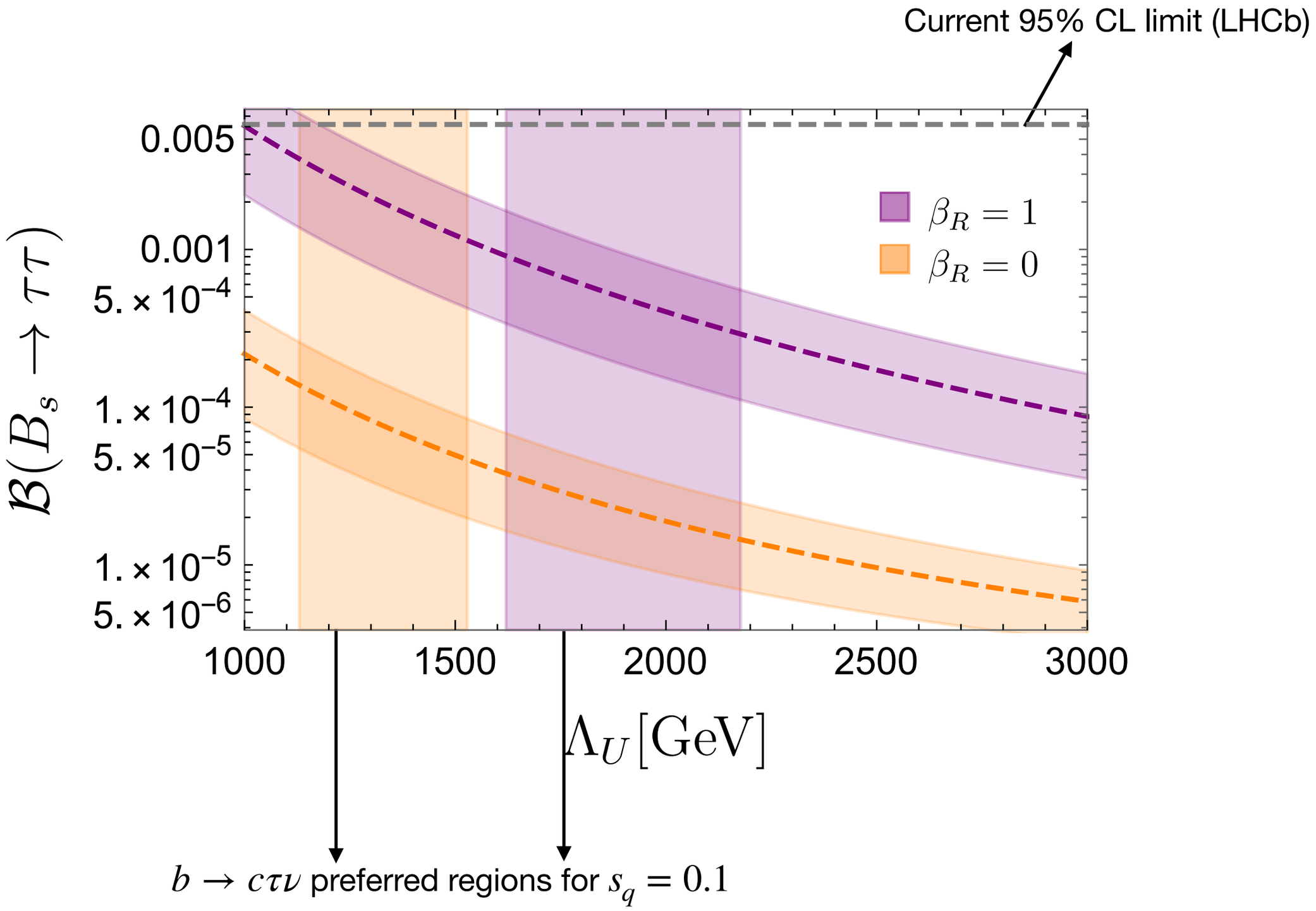

[Cornella, Faroughy, Fuentes-Martin, Isidori, Neubert, 2103.16558]

Conclusions

- A multiscale solution to the flavor puzzle improves flavor bounds on NP.

- In this scenario, one expects NP with large couplings to the third family at the TeV scale.

- It opens the possibility to have quark-lepton unification of the third family à la Pati-Salam at the TeV scale with a rich B-physics phenomenology.

Thank you!