What's next in flavor physics

[*a biased point of view…*]

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- The two flavor puzzles
- Flavor non-universal interactions
- The B anomalies [*what we learned, what's left*]
- Leptoquarks & 4321
- Conclusions

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Introduction

There are several reasons why we think the SM must be extended at high energies:

Electroweak hierarchy problem

Flavor puzzle

U(1) charges

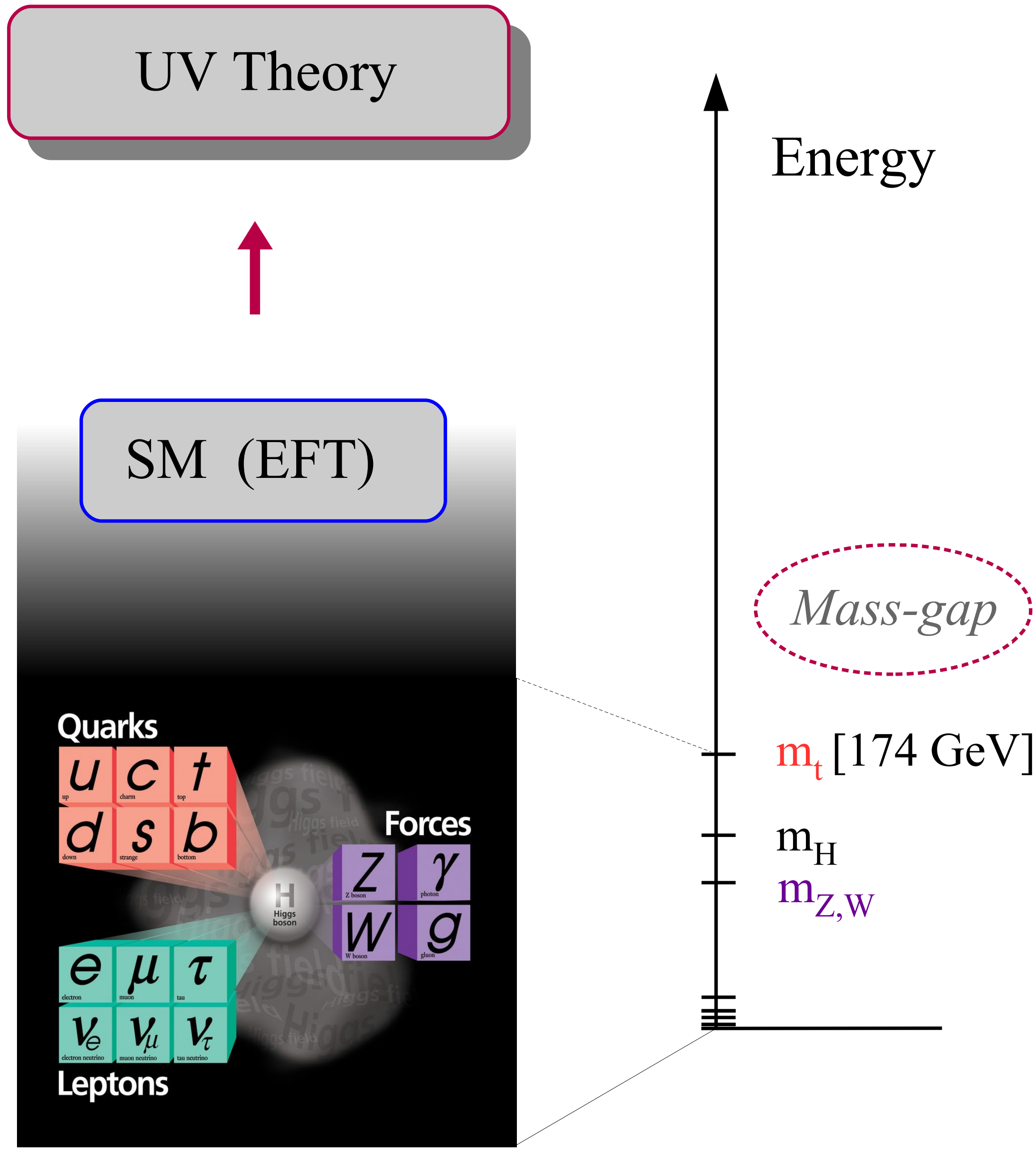
Neutrino masses

Dark-matter

Dark-energy

Inflation

Quantum gravity

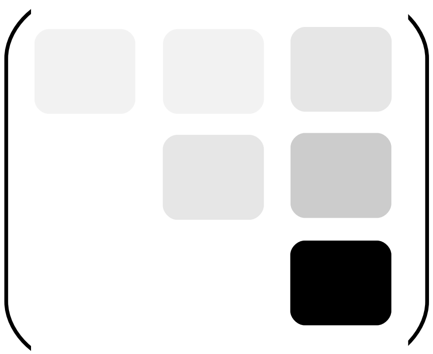


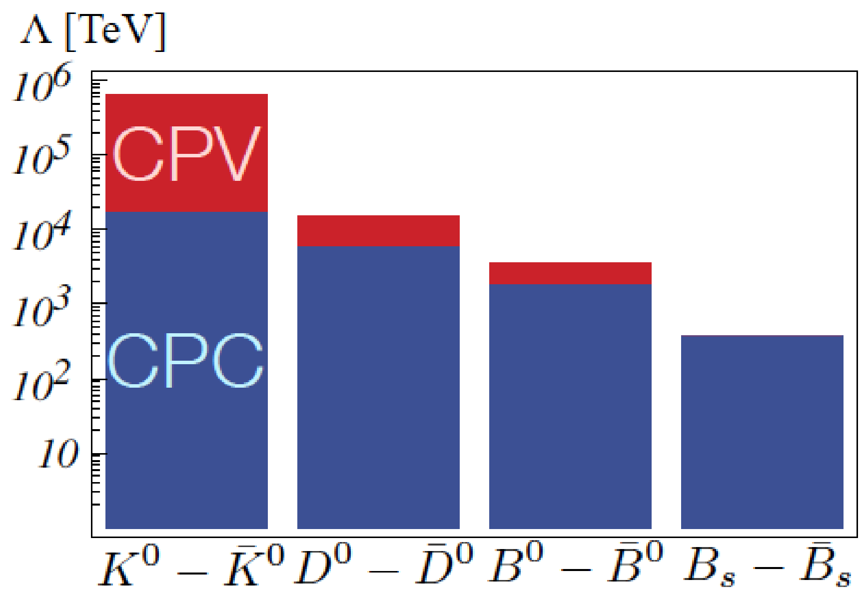
Introduction

There are several reasons why we think the SM must be extended at high energies:

	problem due to...	*...indicating*
Electroweak hierarchy problem	→ *Instability of the Higgs mass term*	non-trivial properties of the SM Lagrangian if interpreted as EFT → Useful hints for its UV completion
Flavor puzzle U(1) charges Neutrino masses	→ *Ad hoc tuning in the model parameters*	
Dark-matter Dark-energy Inflation	→ *Cosmological implementation of the SM*	
Quantum gravity	→ *General problem of any QFT*	

The two flavor puzzles

$Y_U \sim$ 



The two flavor puzzles

Even forgetting current anomalies, there are two (long-standing) open issues in flavor physics:

I. The observed pattern of SM Yukawa couplings does not look accidental [*SM flavor puzzle*]

→ Is there a deeper explanation for this peculiar structures?

Historical note: this year is a special anniversary year for flavor physics:

- '60 anniversary of the Cabibbo paper (1963)
- '50 anniversary of the Kobayashi-Maskawa paper (1973)

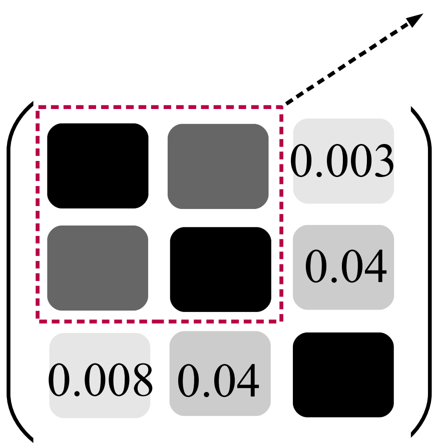
The two flavor puzzles

Even forgetting current anomalies, there are two (long-standing) open issues in flavor physics:

I. The observed pattern of SM Yukawa couplings does not look accidental:

unitarity violation of the 2×2 (light) block below 10^{-3} !

$V_{CKM} \sim$

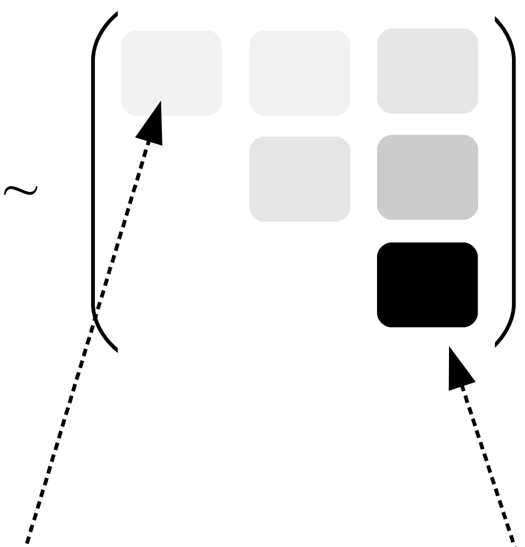


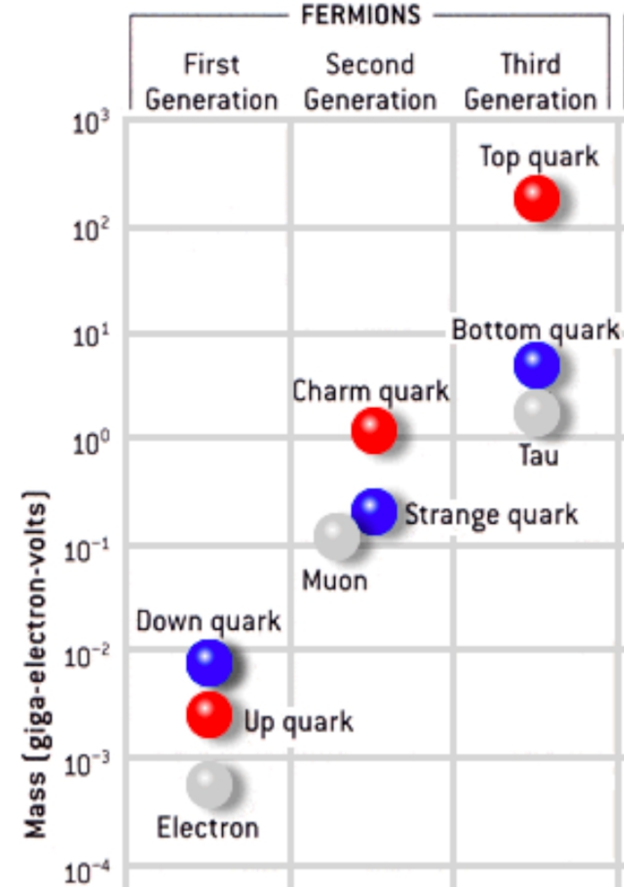
N.B.: Despite the very good knowledge we have nowadays about the CKM matrix, we are <u>not able to detect the presence of the 3rd family</u> by looking only at the 2×2 block (*as one naively would have expected...*)

The two flavor puzzles

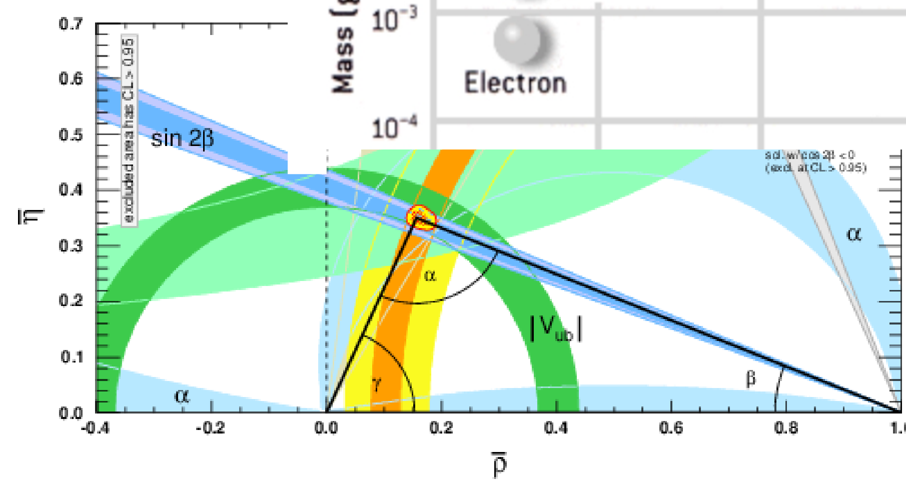
Even forgetting current anomalies, there are two (long-standing) open issues in flavor physics:

I. The observed pattern of SM Yukawa couplings does not look accidental:

$Y_U \sim$ 



$$y_u = \frac{\sqrt{2}\, m_u}{\langle H \rangle} \approx 10^{-5} \qquad y_t = \frac{\sqrt{2}\, m_t}{\langle H \rangle} \approx 1$$



[Y_U in the basis where Y_D is diagonal]

The two flavor puzzles

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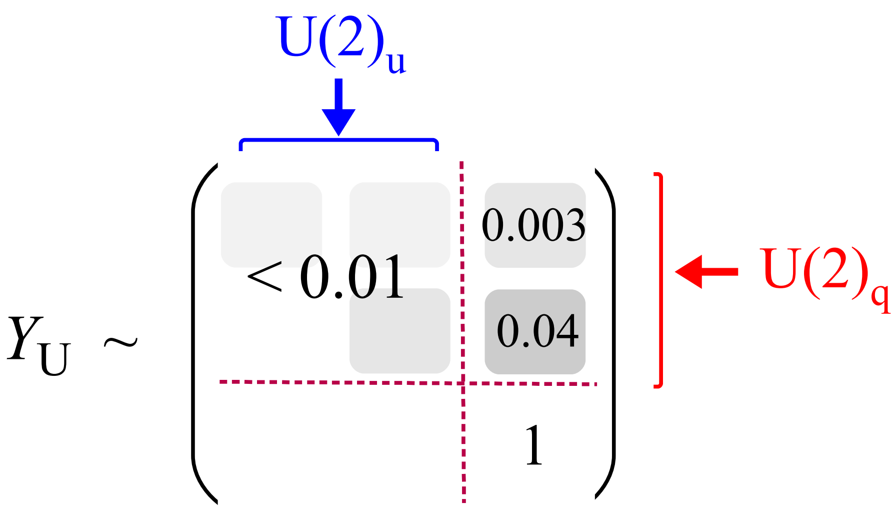
I. The observed pattern of SM Yukawa couplings does not look accidental:



$$\bar{Q}_L\, Y_U\, U_R\, H$$

What we observe in the Yukawa couplings is an <u>approximate $U(2)^n$ symmetry</u> acting on the <u>light families</u>

▶ *The two flavor puzzles*

Even forgetting current anomalies, there are two (long-standing) open issues in flavor physics:

I. The observed pattern of SM Yukawa couplings does not look accidental [*SM flavor puzzle*]

→ Is there a deeper explanation for this peculiar structures?

II. If the SM is only an effective theory, valid below an ultraviolet cut-off , why we do not see any deviation from the SM predictions in the (suppressed) flavor changing processes? What constraints these observations imply on physics beyond the SM? [*NP flavor puzzle*]

→ Which is the flavor structure of physics beyond the SM?

The two flavor puzzles

$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \Sigma_i \frac{1}{\Lambda_i^{d-4}} O_i^{d\geq 5}$$

Large flavor symmetry (→ $\mathscr{L}_{\text{gauge}}$)

Three identical replica of the basic fermion family [$U(3)^5$ symmetry]

Flavor-degeneracy broken by the Yukawa interaction (→ $\mathscr{L}_{\text{Higgs}}$)

$$y_{ij}\, \psi_L^{\,i}\, \psi_R^{\,j}\, H \;\rightarrow\; m_{ij}\, \psi_L^{\,i}\, \psi_R^{\,j}$$

"Peculiar" breaking structure

↓

Exact & approximate (*accidental* ?) symmetries

Eg:

- $U(1)_{L_e}\times U(1)_{L_\mu}\times U(1)_{L_\mu}$ = (individual) Lepton Flavor [*exact symmetry*]
- $m_u \approx m_d \approx 0$ → Isospin symmetry [*approximate symmetry*]

The two flavor puzzles

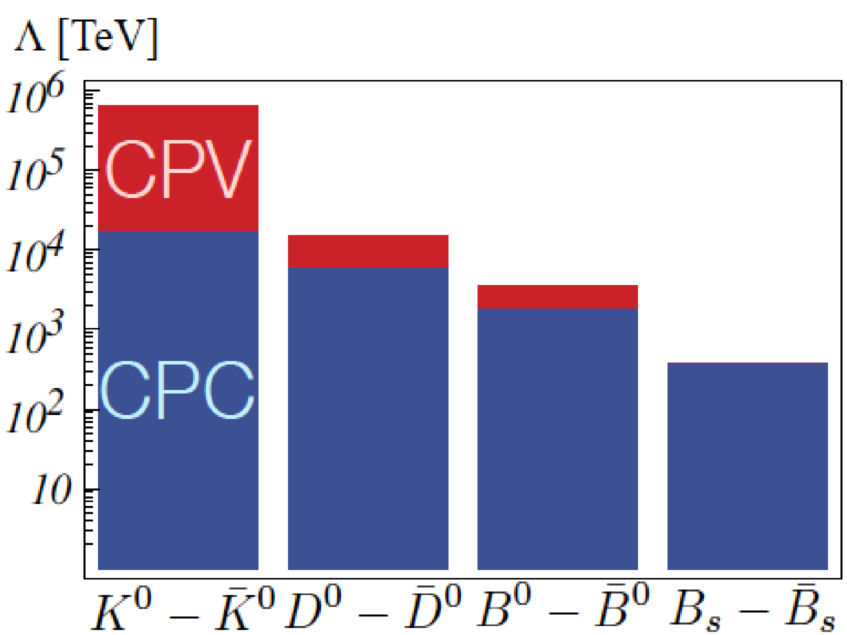
$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \sum_{d,i} \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^{d\geq 5}$$

In principle, we could expect many violations of the accidental symmetries from the heavy dynamics (→ *new flavor violating effects*). However, beside some anomalies in B-physics, we observe none.

↓

The NP Flavor puzzle

Stringent bounds on the scale of possible new flavor non-universal interactions:



N.B: These high scales can be a "mirage" (= *artifact of the accidental symmetry*).

The only unambiguous message of these bounds is:

No large breaking of the approximate $U(2)^n$ flavor symmetry at near-by energy scales

The two flavor puzzles

$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \sum_{d,i} \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^{d\geq 5}$$

Flavor-degeneracy:
$U(3)^5$ symmetry

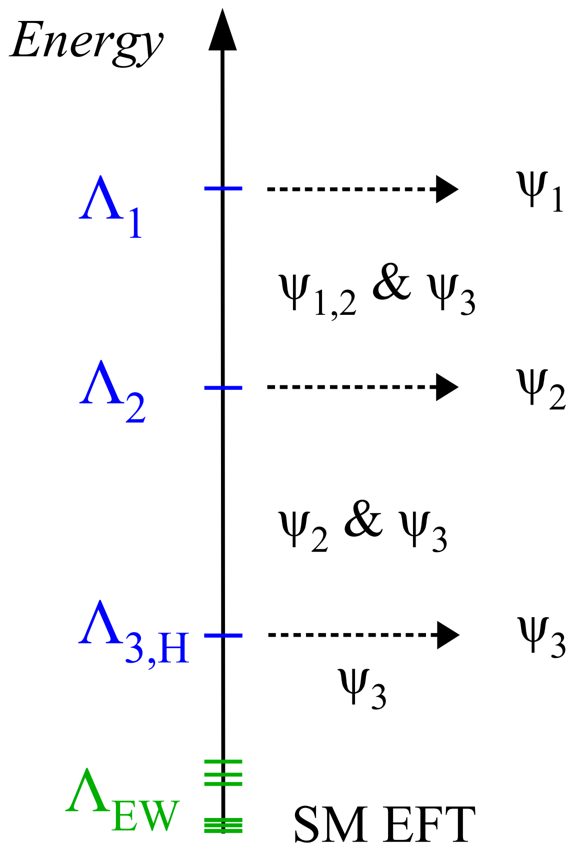
Yukawa couplings:
$U(3)^5 \rightarrow (\sim)\, U(2)^n$
peculiar breaking of the flavor symm.

Stringent bounds on generic flavor-violating ops.
↕
approx. $U(2)^n$ holds also beyond the SM

The big questions in flavor physics:

- Can we find an explanation for the Yukawa hierarchies?
- If the (residual) flavor symmetries are accidental symmetries, at which scale are they broken? Can be there multiple scales behind the origin of flavor?

Flavor non-universal interactions



Flavor non-universal interactions

For a long time, the vast majority of model-building attempts to extend the SM was based on the following two (*implicit*) hypotheses:

- Concentrate on the Higgs hierarchy problem
- "Postpone" the flavor problem

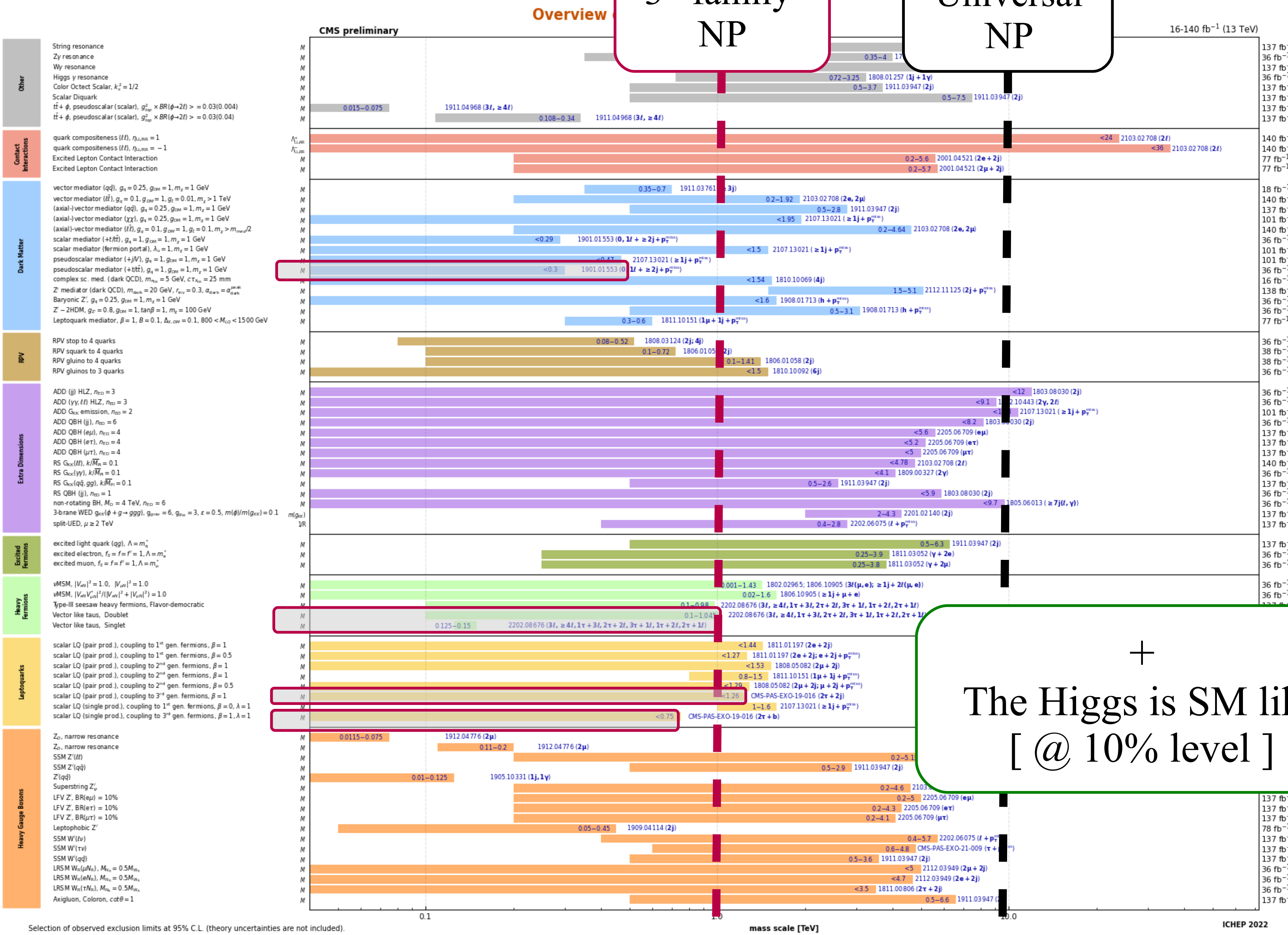
→ *The "MFV paradigm"*:

"Protect" the Higgs sector with (TeV-scale) flavor-universal NP (*supersymmetry or Higgs compositness*), deferring the solution of the flavor problem to higher scales

This was a very motivated possibility in the pre-LHC era...

...but it has become a less compelling option after run-I and run-II results

▸ *Status of high-energy searches*



3[rd] family NP

Universal NP

+ The Higgs is SM like [@ 10% level]

Flavor non-universal interactions

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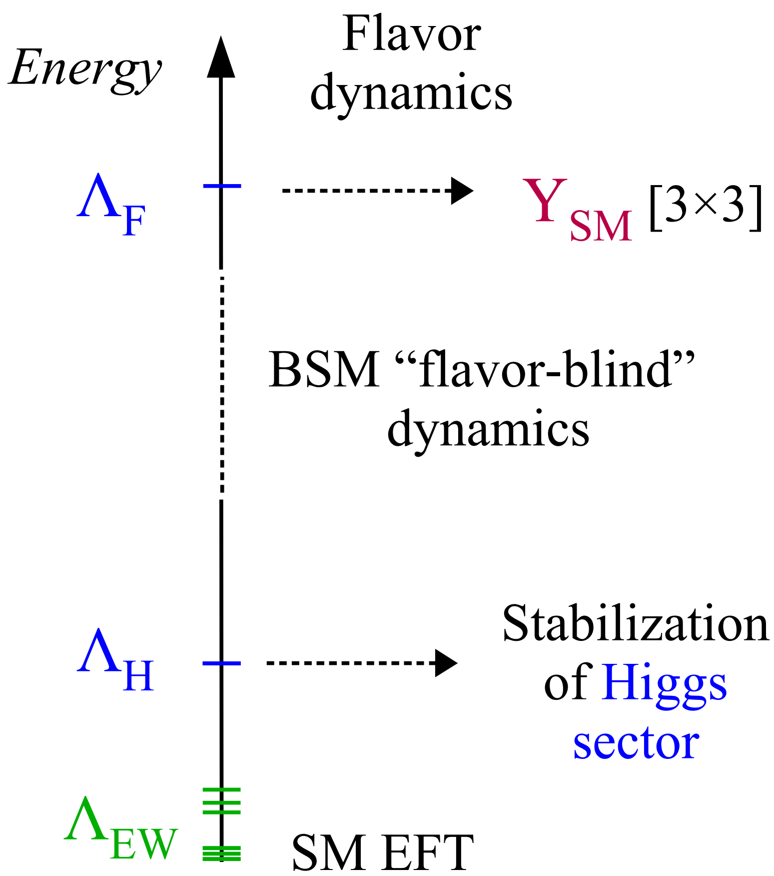


- Concentrate on the Higgs hierarchy problem
- Postpone the flavor problem to higher scales

⬇

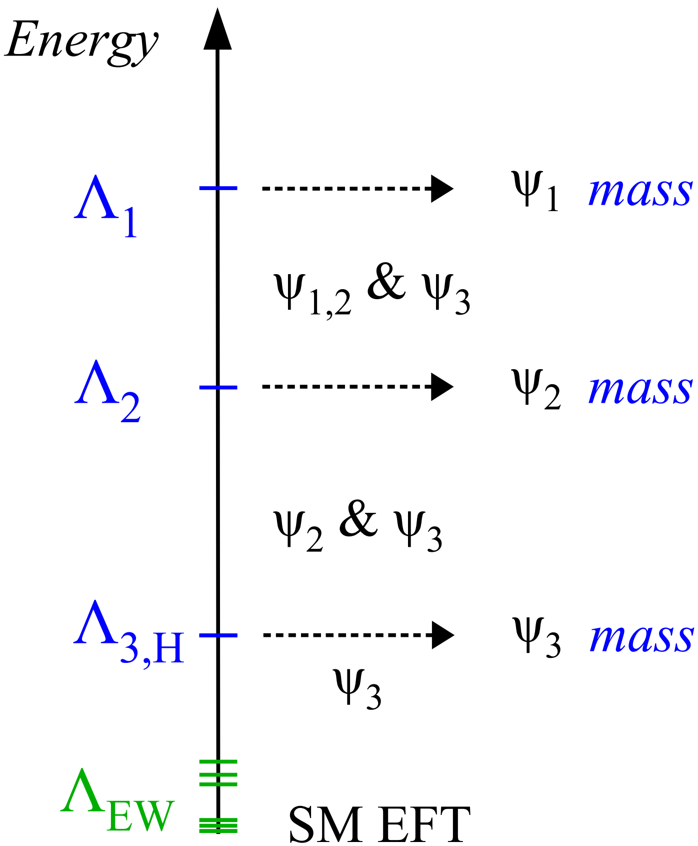
3 gen. = "identical copies" up to high energies

Less compelling after the LHC results:

No clear sign of NP from direct searches
strong bounds on NP coupled universally to all families
worsening of the Higgs hierarchy problem

Flavor non-universal interactions

New paradigm to address both the Higgs hierarchy problem and the flavor puzzle: *multi-scale* UV completion with *flavor non-universal* interactions



Dvali & Shifman '00
Panico & Pomarol '16
⋮
Bordone *et al.* '17
Allwicher, GI, Thomsen '20
Barbieri '21
Davighi & G.I. '23

Main idea:

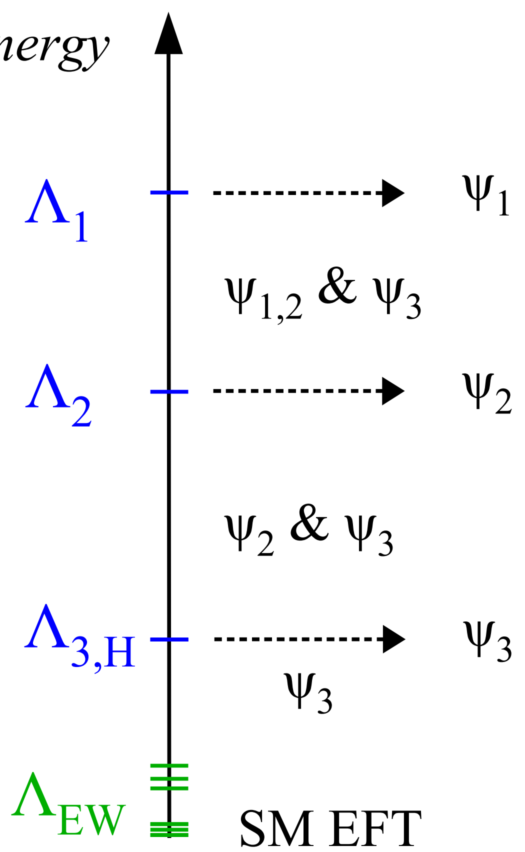
- Flavor non-universal interactions already at the TeV scale:
- 1st & 2nd gen. have small masses because they are coupled to NP at heavier scales

↓

~~3 gen. = "identical copies" up to high energies~~

Flavor non-universal interactions

New paradigm to address both the Higgs hierarchy problem and the flavor puzzle: *multi-scale* UV completion with *flavor non-universal* interactions



A renewed phenomenological interest in this type of approach has been triggered by the B-physics anomalies (*hinting to violations of lepton flavor universality, mainly in 3rd gen.*)

But the construction has an intrinsic, more general, interest:

- ✔ Explain the origin of the flavor hierarchies
- ✔ Allow TeV-scale NP coupled (mainly) to 3rd gen. → Higgs sector stabilization

Allwicher, GI, Thomsen '20
Barbieri '21
Davighi & G.I. '23

Flavor hierarchies from gauge non-universality [a brief detour]

To understand which are the viable options for TeV-scale dynamics, we recently analysed all the extensions of the SM gauge group compatible with the following three general assumptions:

Davighi & G.I. '23

- Obtain the $U(2)^n$ flavor symmetry as accidental symmetry of the (non-universal) gauge sector

- Elementary Higgs up to (at least) the TeV scale → New states should preserve Higgs-mass stability → NP coupled to 3rd generation should occur at the TeV scale

- Explain charge-quantization → Semi-simple embedding in the UV [i.e. no U(1) groups in the UV]

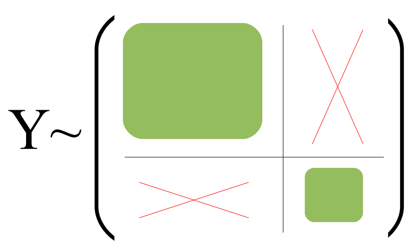
Flavor hierarchies from gauge non-universality [a brief detour]

I. $U(2)^n$ flavor symmetry as accidental symmetry of the gauge sector.

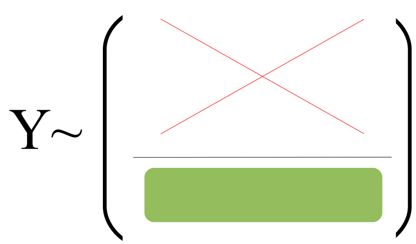
- Classify the allowed Yukawa structures under a *flavor-deconstruction* of three basic factors characterizing the SM fermions and the EW gauge group: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

$$\bar{\psi}_L \, Y \, \psi_R \, H$$

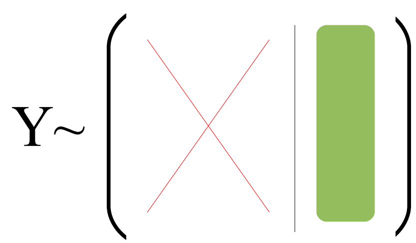
$U(1)_{B-L}^{[3]} \times U(1)_{B-L}^{[12]}$



$SU(2)_L^{[3]} \times SU(2)_L^{[12]}$



$SU(2)_R^{[3]} \times SU(2)_R^{[12]}$



↓

- Deconstructing <u>any pair of the three</u> (or all of them) leads to the desired $U(2)^n$ flavor symmetry → <u>four basic options</u>

Flavor hierarchies from gauge non-universality [a brief detour]

II. New states should preserve Higgs-mass stability → NP coupled to 3[rd] generation should occur at the TeV scale

III. Explain charge-quantization → Semi-simple embedding in the UV

↓

Semi-simple embeddings of the SM have been classified and there are very few possibilities, all featuring one of the possible 3 basic options:

Allanach, Gripaios, Tooby-Smith '23

- SU(4)×SU(2)×SU(2) [Pati & Salam '74]
- SU(5) [Georgi & Glashow, '74]
- SO(10) [Georgi '75, Fritzsch & Minkowski '75]

↓

Proton stability → only the Pati-Salam option is possible at low scales

$$SU(3)_c \times U(1)_{B-L} \hookrightarrow SU(4) \sim \left[\begin{array}{c|c} SU(3)_c & 0 \\ \hline 0 & 0 \end{array}\right] \left[\begin{array}{c|c} 0 & LQ \\ \hline LQ & 0 \end{array}\right] \left[\begin{array}{c|c} 1/3 & 0 \\ \hline 0 & -1 \end{array}\right]$$

Flavor hierarchies from gauge non-universality [a brief detour]

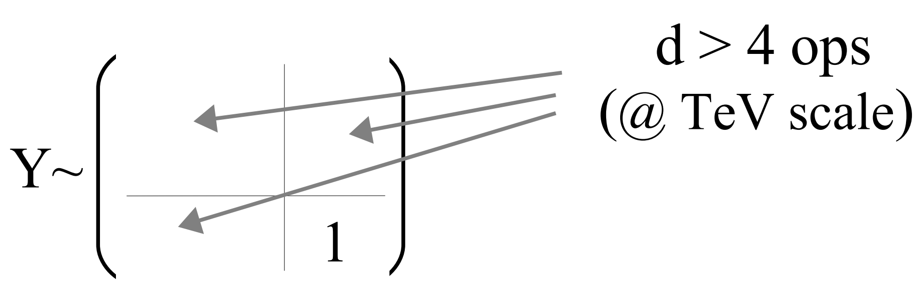
I. + II. + III. : four basic options:

TeV-scale gauge group: $G_U \times G_3 \times H_{12}$			
	G_U	G_3	H_{12}
1	$\mathrm{SU}(2)_L$	$\mathrm{SU}(4)^{[3]} \times \mathrm{SU}(2)_R^{[3]}$	$\mathrm{SU}(3)^{[12]} \times \mathrm{U}(1)_{B-L}^{[12]} \times \mathrm{U}(1)_R^{[12]}$
2	$\mathrm{SU}(2)_R$	$\mathrm{SU}(4)^{[3]} \times \mathrm{SU}(2)_L^{[3]}$	$\mathrm{SU}(3)^{[12]} \times \mathrm{SU}(2)_L^{[12]} \times \mathrm{U}(1)_{B-L}^{[12]}$
3	$\mathrm{SU}(4)$	$\mathrm{SU}(2)_L^{[3]} \times \mathrm{SU}(2)_R^{[3]}$	$\mathrm{SU}(2)_L^{[12]} \times \mathrm{U}(1)_R^{[12]}$
4	$\emptyset$	$\mathrm{SU}(4)^{[3]} \times \mathrm{SU}(2)_L^{[3]} \times \mathrm{SU}(2)_R^{[3]}$	$\mathrm{SU}(3)^{[12]} \times \mathrm{SU}(2)_L^{[12]} \times \mathrm{U}(1)_{B-L}^{[12]} \times \mathrm{U}(1)_R^{[12]}$

UV completion @ higher E

Higgs & 3rd gen. fields charged only under these groups

small impact on δm_h



Flavor hierarchies from gauge non-universality [a brief detour]

I. + II. + III. + general pheno bounds: two viable TeV-scale options:

TeV-scale gauge group: $G_U \times G_3 \times H_{12}$			
	G_U	G_3	H_{12}
1	$SU(2)_L$	$SU(4)^{[3]} \times SU(2)_R^{[3]}$	$SU(3)^{[12]} \times U(1)_{B-L}^{[12]} \times U(1)_R^{[12]}$
2	~~$SU(2)_R$~~	~~$SU(4)^{[3]} \times SU(2)_L^{[3]}$~~	$SU(3)^{[12]} \times SU(2)_L^{[12]} \times U(1)_{B-L}^{[12]}$
3	~~$SU(4)$~~	~~$SU(2)_L^{[3]} \times SU(2)_R^{[3]}$~~	$SU(2)_L^{[12]} \times U(1)_R^{[12]}$
4	$\emptyset$	$SU(4)^{[3]} \times SU(2)_L^{[3]} \times SU(2)_R^{[3]}$	$SU(3)^{[12]} \times SU(2)_L^{[12]} \times U(1)_{B-L}^{[12]} \times U(1)_R^{[12]}$

UV completion @ higher E

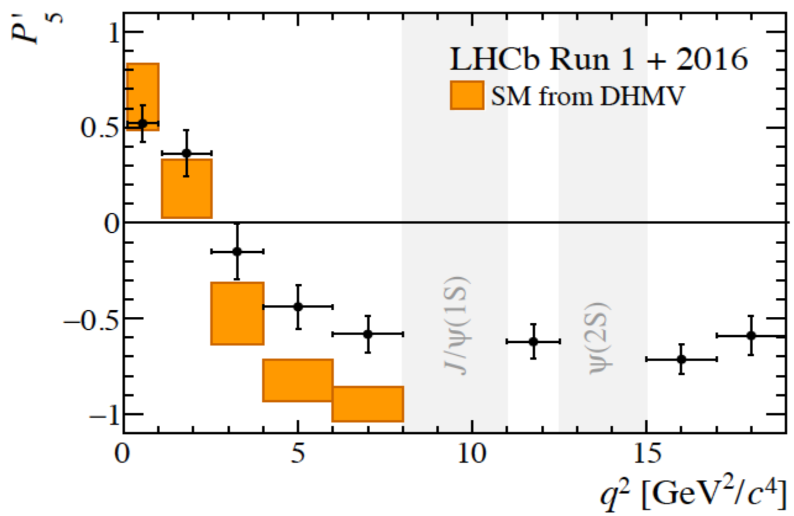
General feature:
SU(4) group acting on the 3rd family, with low-energy breaking scale to avoid fine-tuning on the Higgs mass:

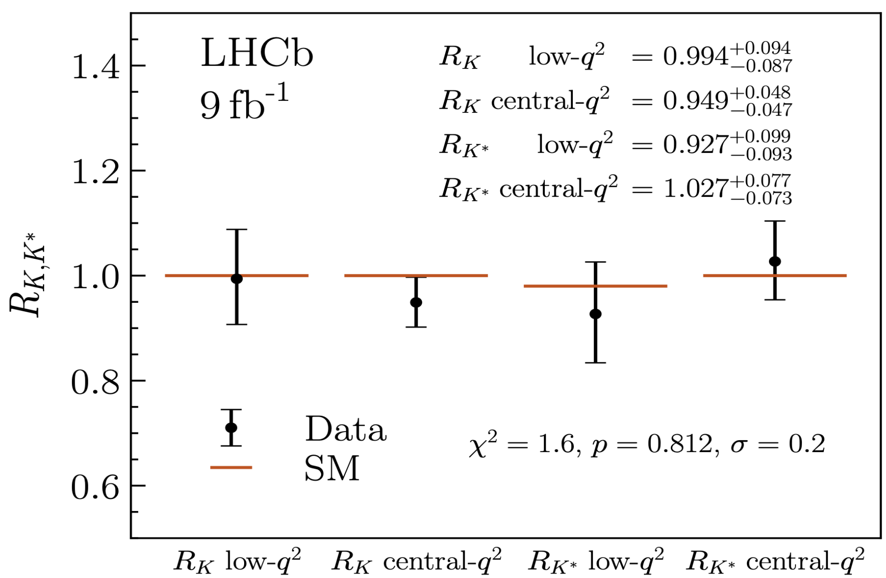
$$\delta m_h^2/m_h^2 < 1 \quad \rightarrow \quad \Lambda_U = M_U/g_U \lesssim 5 \text{ TeV}$$

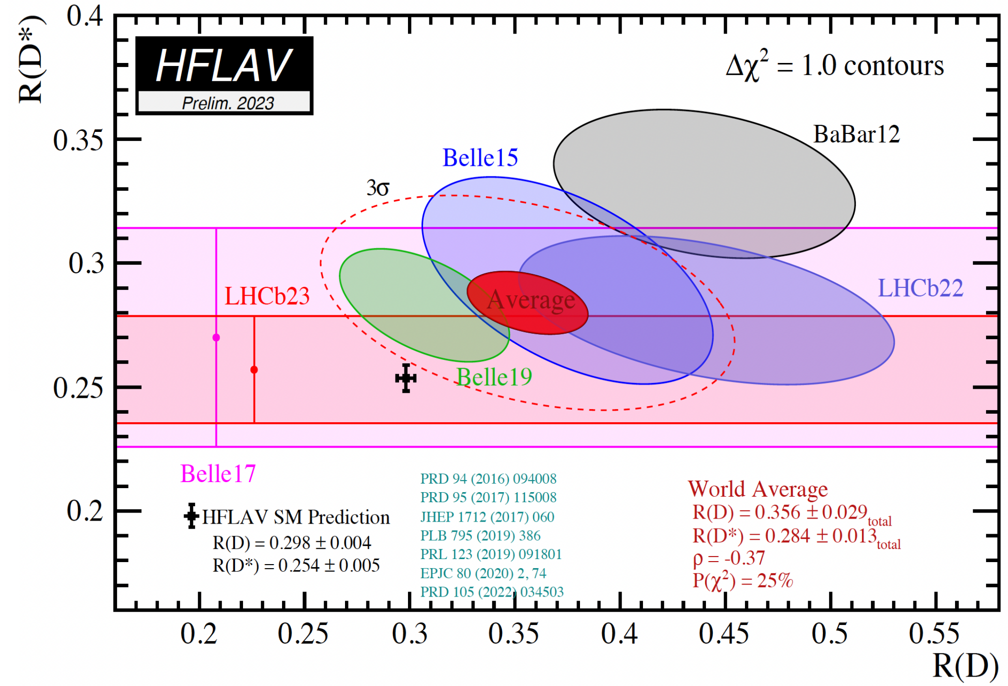
Davighi & G.I. '23

Using only general naturalness arguments (on both flavor & Higgs sectors) we are led to the hypothesis of a low-scale flavor non-universal LQ

The B-physics anomalies







The B-physics anomalies

From 2013 results in (various) semi-leptonic B decays started to exhibit tensions with the SM predictions. Several exclusive channels are involved, but they are all sensitive only to the following two classes of partonic transitions:

$b \to c\, l\nu$ (*Charged Currents*) $b \to s\, l^+l^-$ (*Neutral Currents*)

The anomalies can be grouped into 3 categories:

I. ~~LFU~~ anomaly in CC [τ vs. (μ, e)] → $b \to c\, l\nu$

II. ΔC_9 (*lepton-universal*) anomaly in NC modes

III. ~~LFU~~ anomaly in NC [μ vs. e] & BR($B_s \to \mu\mu$)

(II and III) → $b \to s\, l^+l^-$

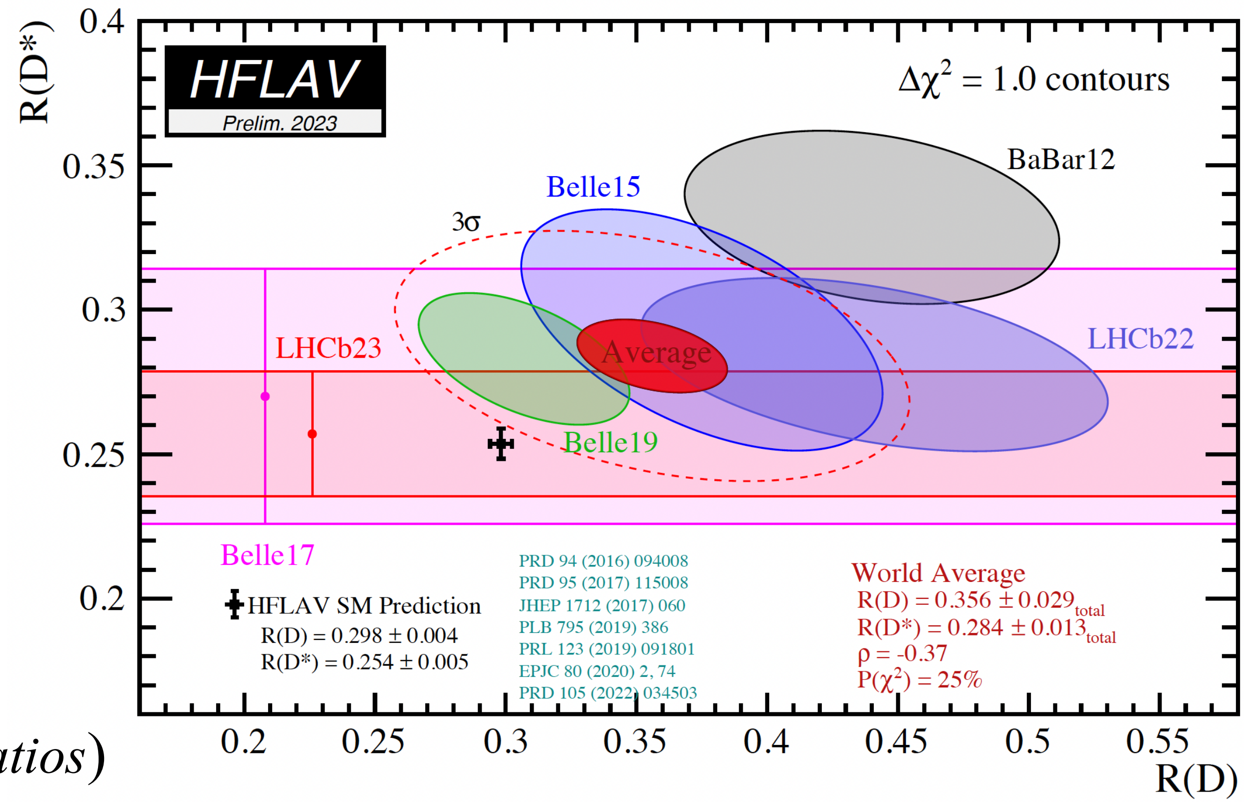
LFU = Lepton Flavor Universality = accidental symmetry of the SM Lagrangian

The B-physics anomalies

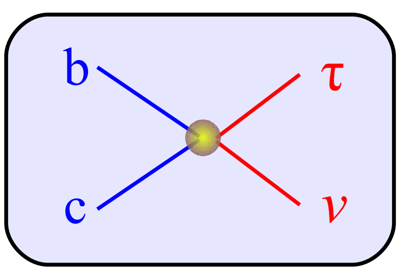
I. ~~LFU~~ anomaly in CC
[τ vs. (μ, e)]

$$R(X) = \frac{\Gamma(B \to X\,\tau\nu)}{\Gamma(B \to X\,l\nu)}$$

X = D or D*



- Clean SM predictions (*uncertainties cancel in the ratios*)
- 3.0σ excess over SM
- Compete with SM @ tree-level → *low scale of NP*



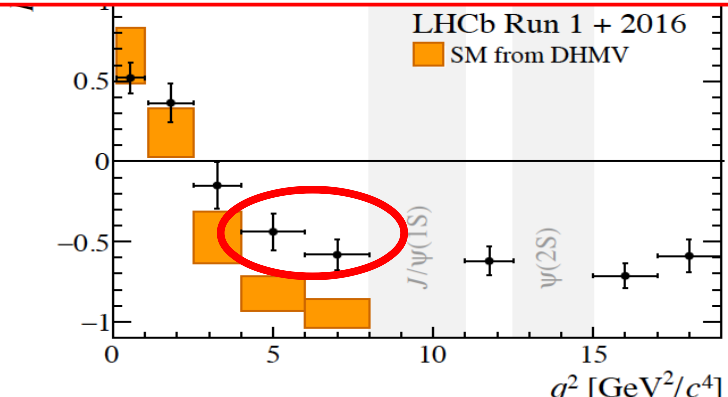
The B-physics anomalies

II. ΔC_9 (*lepton-universal*) anomaly in NC modes

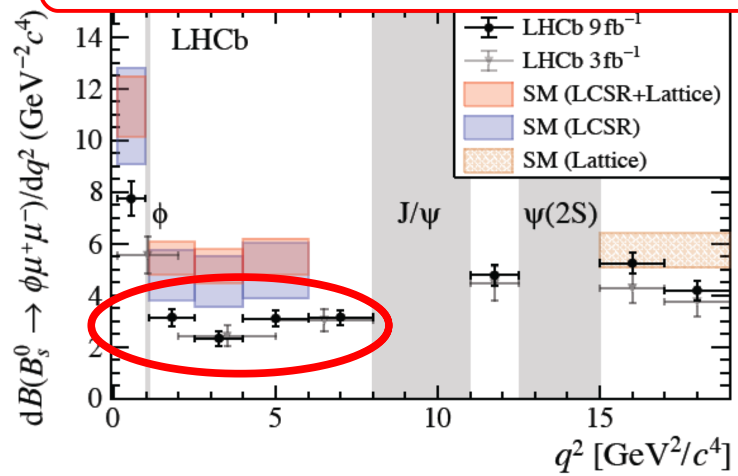
$$\mathcal{O}_9^\ell = (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)$$

- Possible contamination from SM long-distance (*charming penguins*)
- All attempts to <u>compute</u> the effect agree on ~ 3σ deviation from SM
- Compete with SM @ loop-level

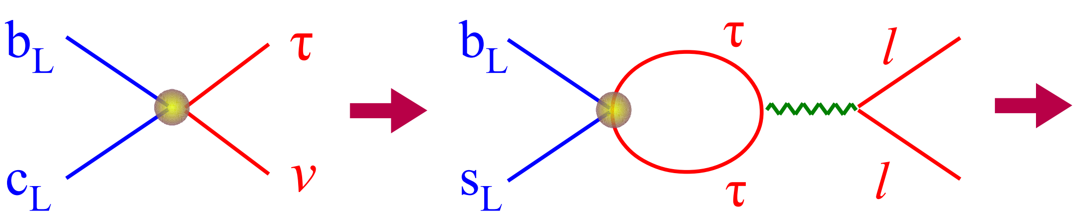
$B \to K^* \mu\mu$ angular distribution



$B \to H\, \mu\mu$ branching ratios



Possible explanation connected to CC (hence 3rd family LFU violation):



$\Delta C_9^{\rm Univ}$

N.B.: correct sign & size !

Bobeth & Haisch '11
Crivellin *et al.* '18
Alguero *et al.* '18

The B-physics anomalies

(II.) ΔC_9 (*lepton-universal*) anomaly in NC modes

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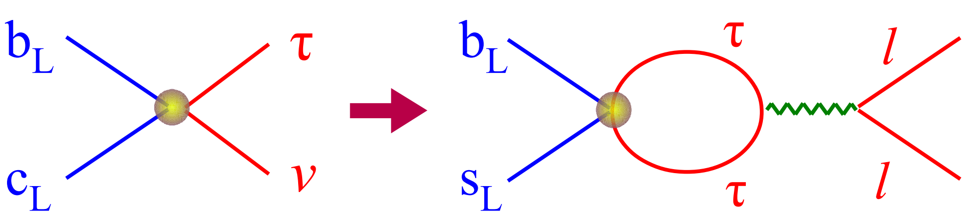
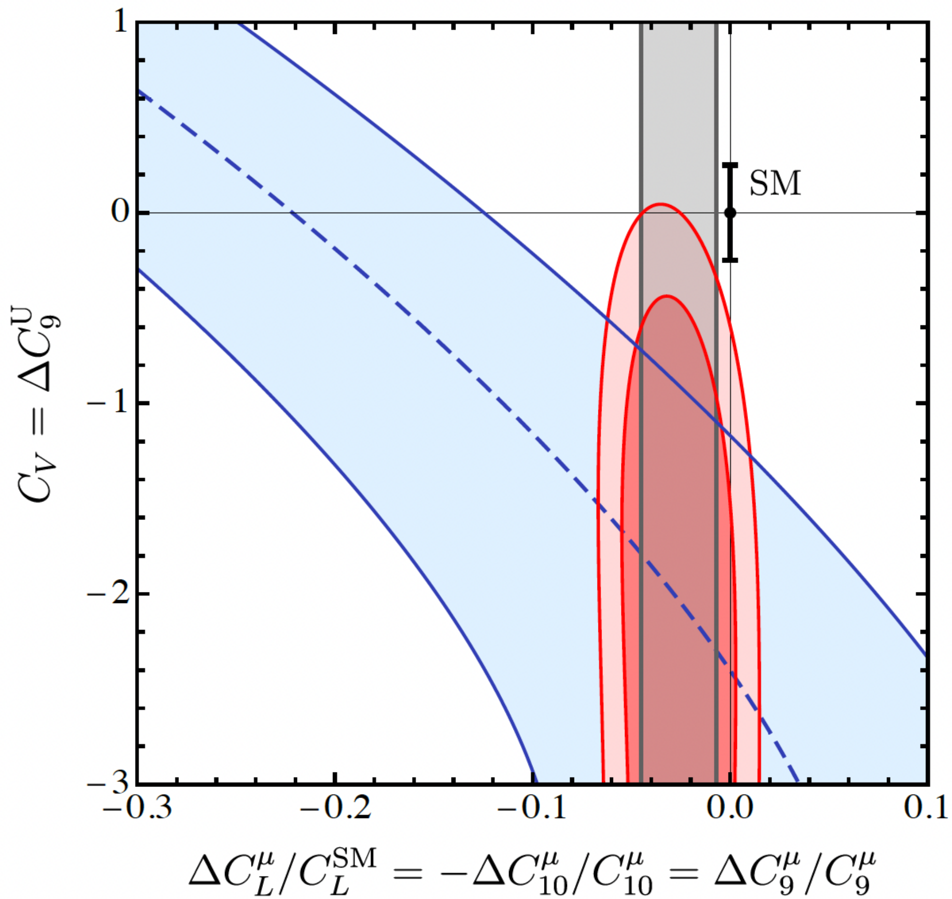


2σ consistent indication from b → s l^+l^- (*semi-inlcusive*) at high q2

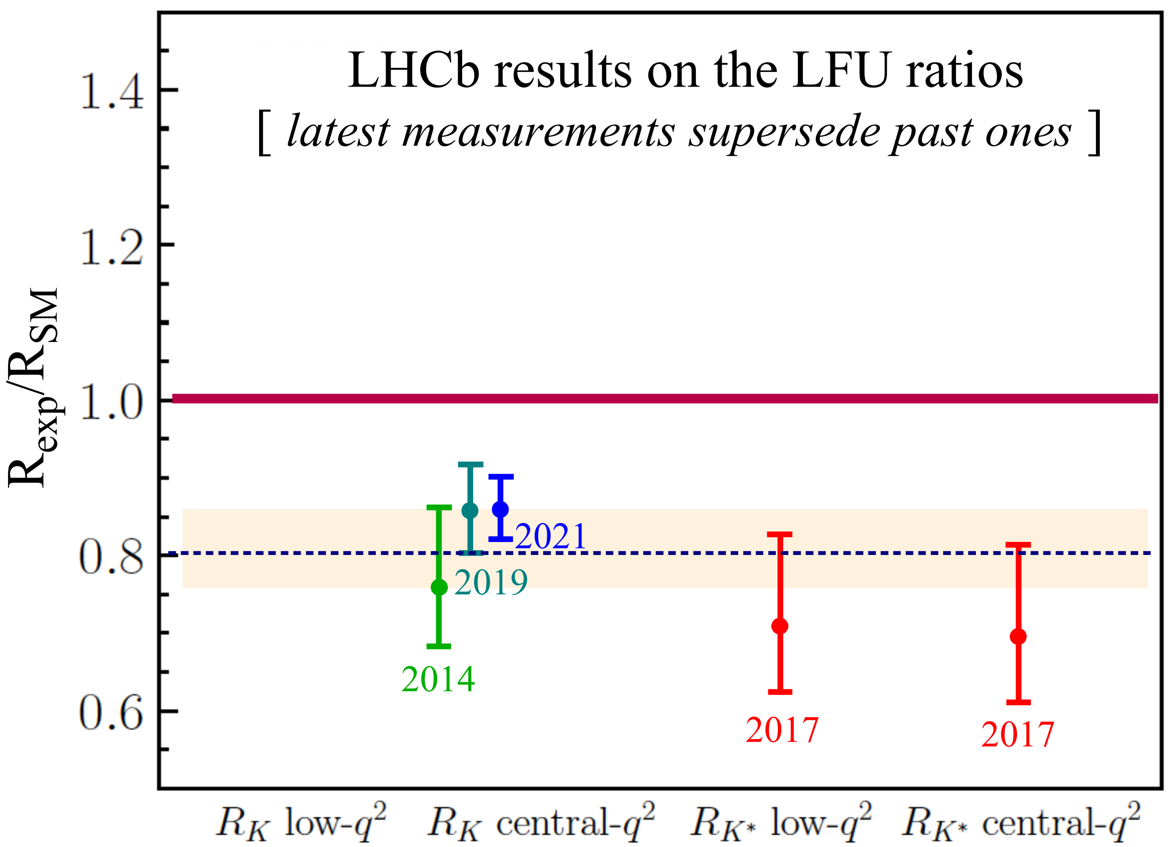
GI, Poloski, Tinari '23



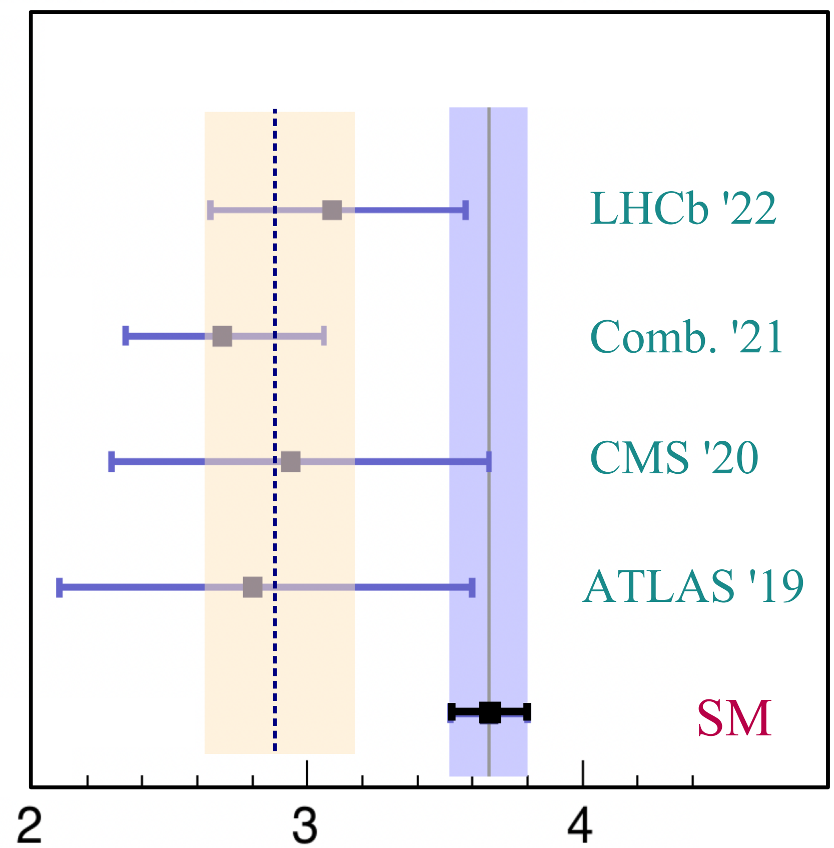
The B-physics anomalies

III. ~~LFU~~ anomaly in NC [μ vs. e] & BR($B_s \to \mu\mu$)

- Clean SM predictions
  (*LFU ratios + no long-distance in* $B_s \to \mu\mu$)
- Highest significance till summer 2022



$10^9 \times B(B_s \to \mu\mu)$



The B-physics anomalies

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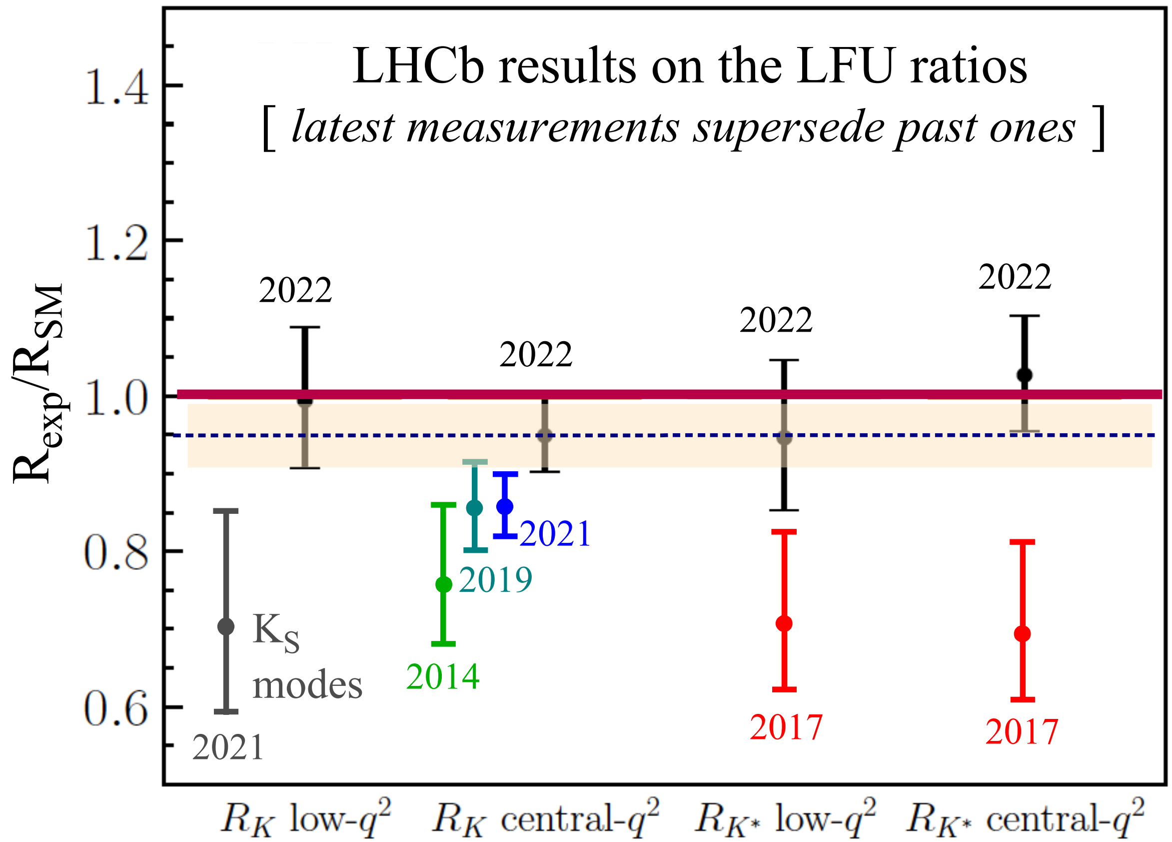
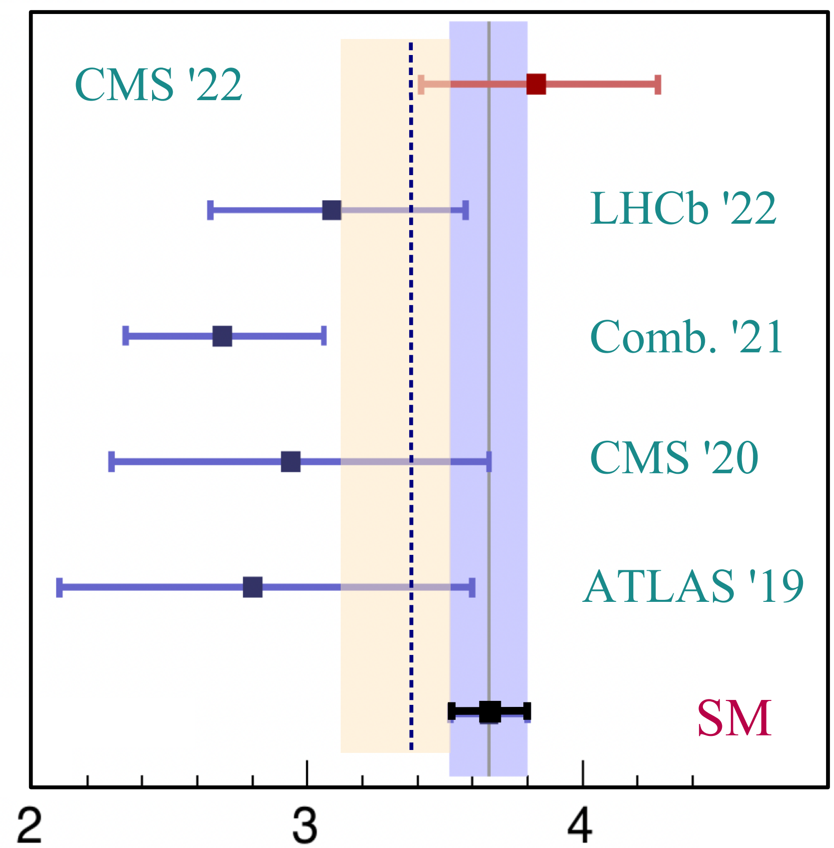
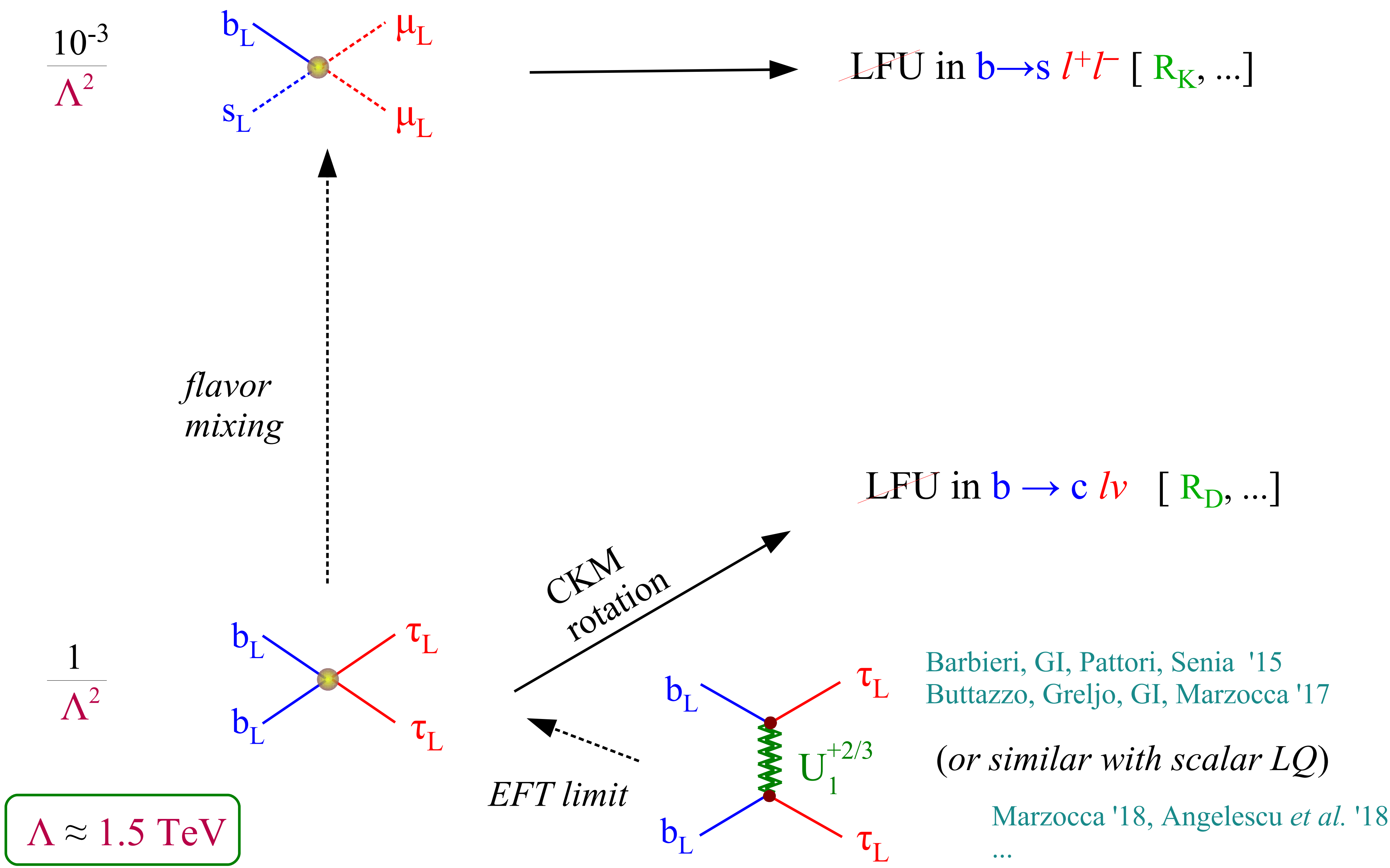
- Clean SM predictions
  (*LFU ratios + no long-distance in* $B_s \to \mu\mu$)
- ~~Highest significance till summer 2022~~

N.B.: *While the overall loss of significance is high, the overall implications for the class of NP models I advocate, are modest*

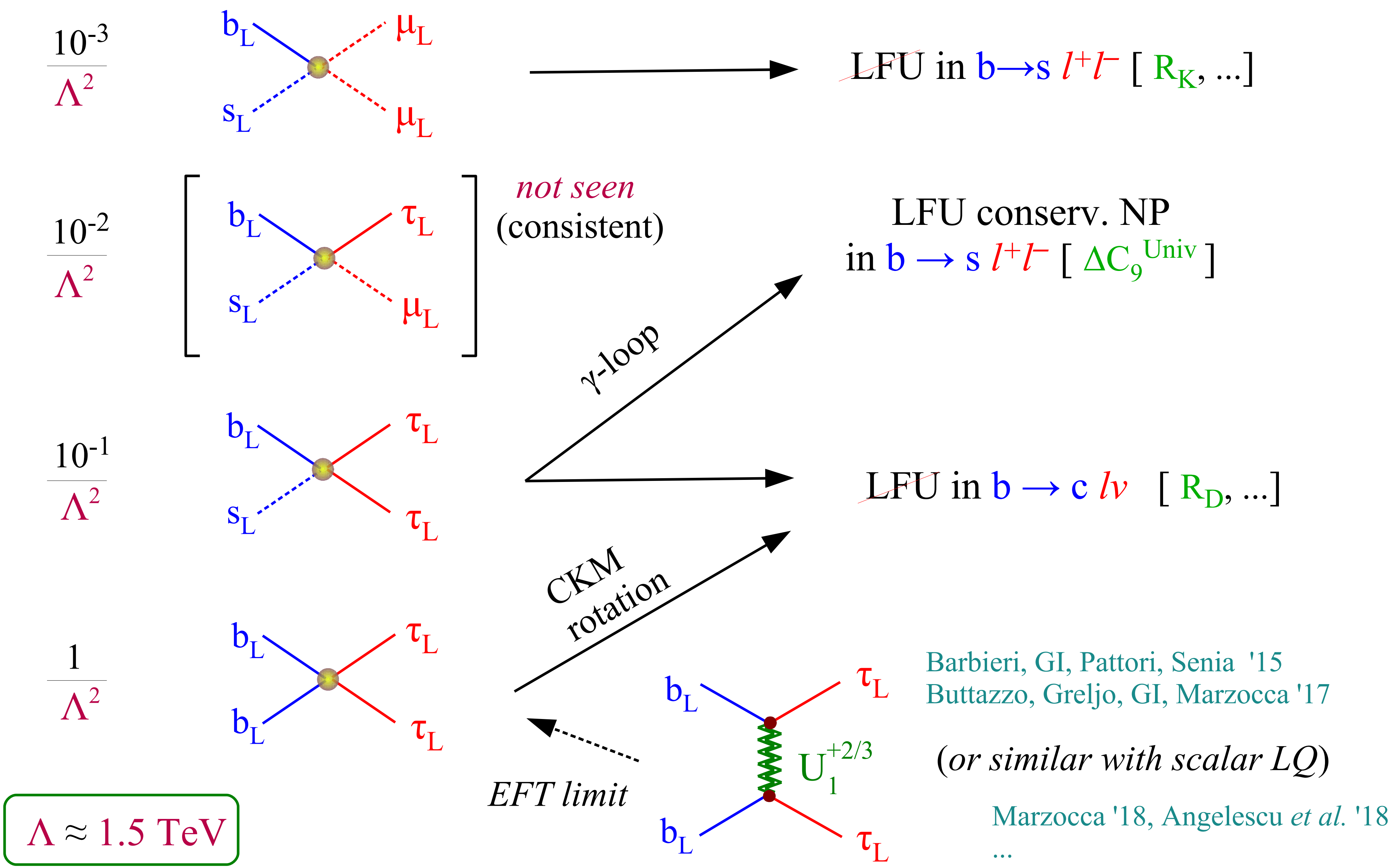




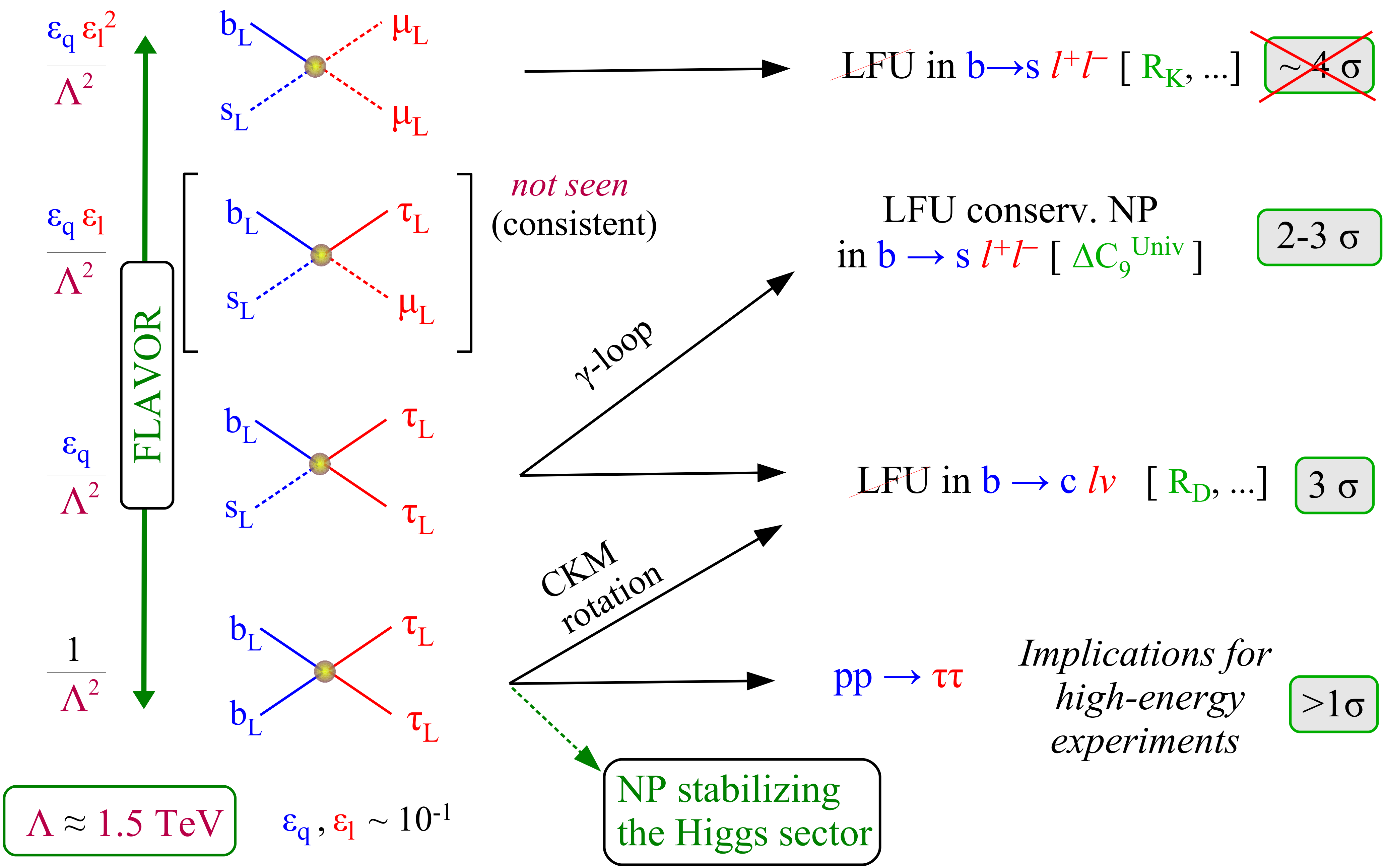
The B-physics anomalies



The B-physics anomalies



The B-physics anomalies



Leptoquarks & 4321

$$\begin{bmatrix} Q^{\alpha} \\ Q^{\beta} \\ Q^{\gamma} \\ L \end{bmatrix}$$

Leptoquarks & 4321

Theory arguments
[flavor hierarchies,
charge quantization]

$SU(4)^{[3]} \times SU(3)^{[12]} \times G_{EW}$

$SU(4)^{[3]} \times SU(3)^{[12]} \times SU(2)_L \times U(1)'$

B-physics anomalies
[mainly CC]

U_1

minimal choice
[*last step of the SSB chain*]

Di Luzio, Greljo, Nardecchia, '17
Bordone, Cornella, Fuentes-M, GI '17
Greljo & Stefanek, '18

Leptoquarks & 4321

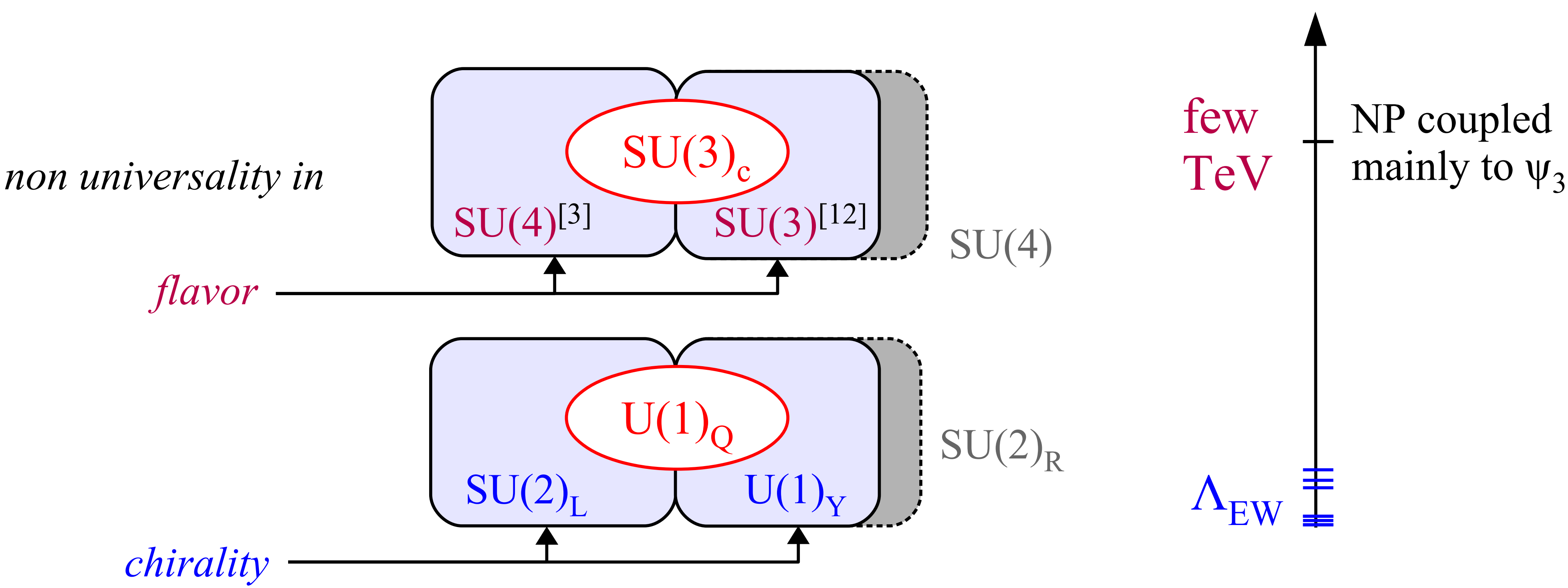
Theory arguments [flavor hierarchies, charge quantization] → $SU(4)^{[3]} \times SU(3)^{[12]} \times G_{EW}$

↓

$SU(4)^{[3]} \times SU(3)^{[12]} \times SU(2)_L \times U(1)'$

minimal choice [*last step of the SSB chain*]

B-physics anomalies [mainly CC] → U_1



Leptoquarks & 4321

Even in more ambitious UV models, collider and low-energy pheno are controlled by the 4321 gauge group that rules TeV-scale dynamics
→ new heavy mediators [G' & Z']

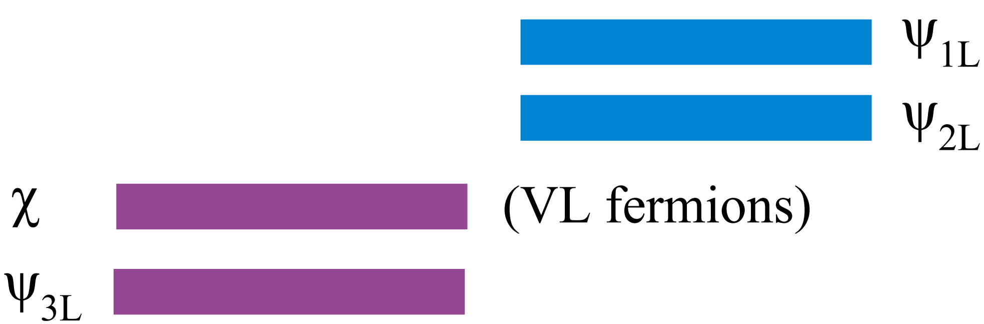
$SU(4)^{[3]} \times SU(3)^{[12]} \times SU(2)_L \times U(1)'$
ψ_3 $\psi_{1,2}$

→ LQ [U_1] + Z' + G'

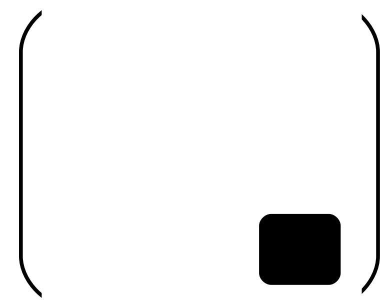
SM

A key role is played by at least one family of
→ vector-like fermions (= fermions with both chiralities having same gauge quantum numbers) that mix with the 3 families of chiral fermions

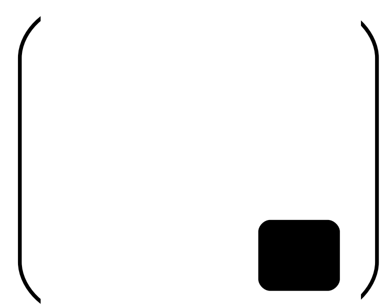
$SU(4)^{[3]} \times SU(3)^{[12]}$



SM Yukawa coupling → $Y \sim$



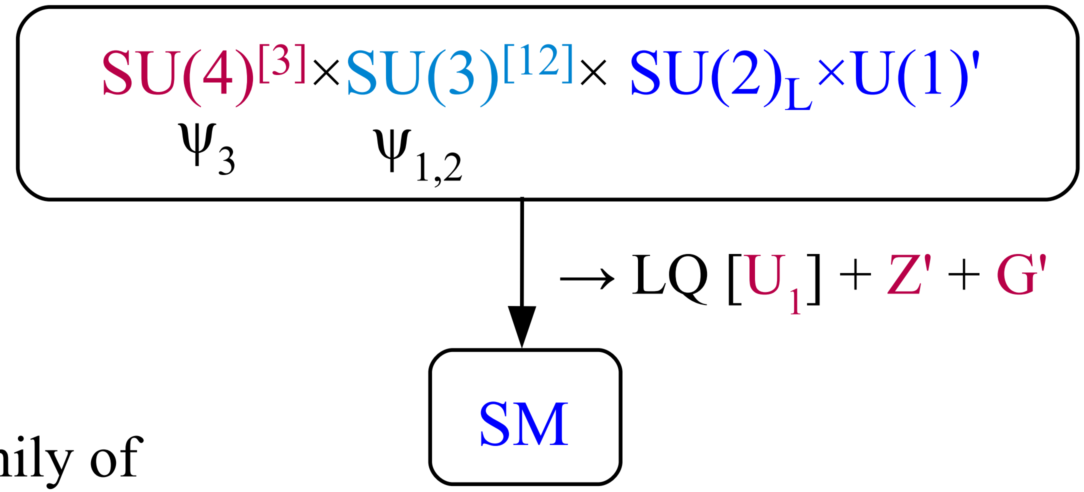
LQ eff. coupling → $\beta_L \sim$



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

Leptoquarks & 4321

Even in more ambitious UV models, collider and low-energy pheno are controlled by the 4321 gauge group that rules TeV-scale dynamics
→ new heavy mediators [G' & Z']



A key role is played by at least one family of
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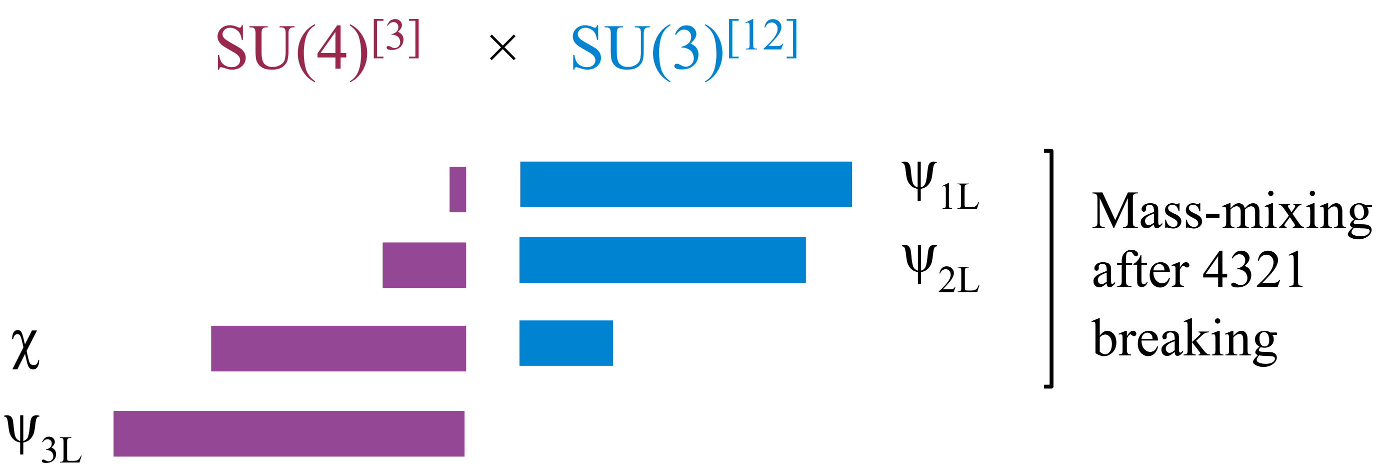
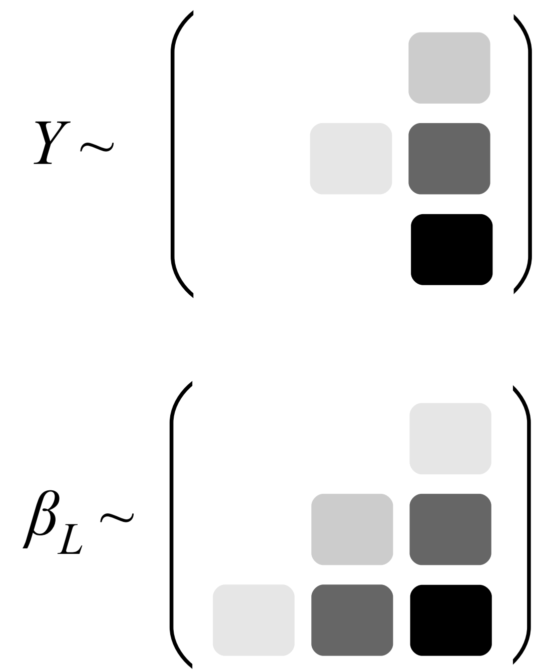
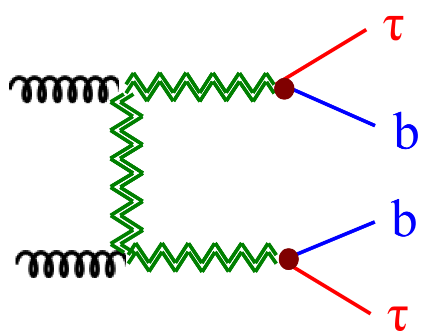


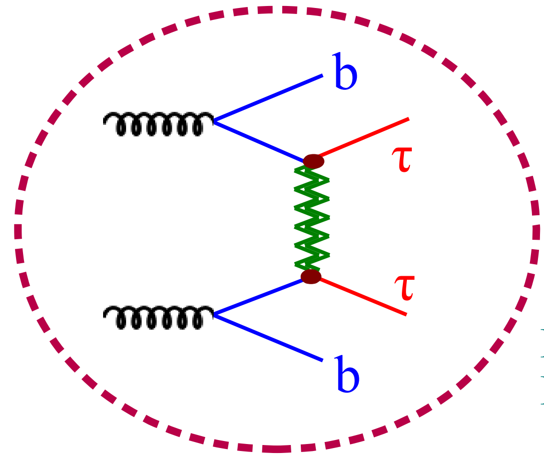


$$\mathscr{L} \supset \frac{g_U}{\sqrt{2}} U_1^\mu \left[\beta_{i\alpha}^L (\bar{q}_L^i \gamma_\mu \ell_L^\alpha) - \beta_{i\alpha}^R (\bar{d}_R^i \gamma_\mu e_R^\alpha)\right] + \mathrm{h.c.}$$

▶ Leptoquarks & 4321: implications

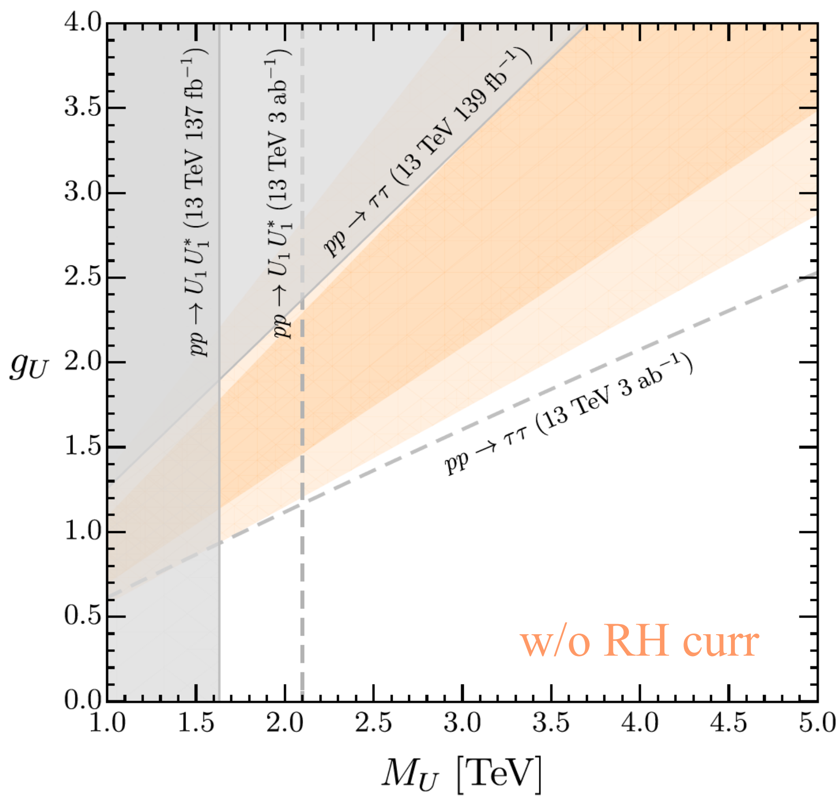
I The U_1 leptoquark at high energies:

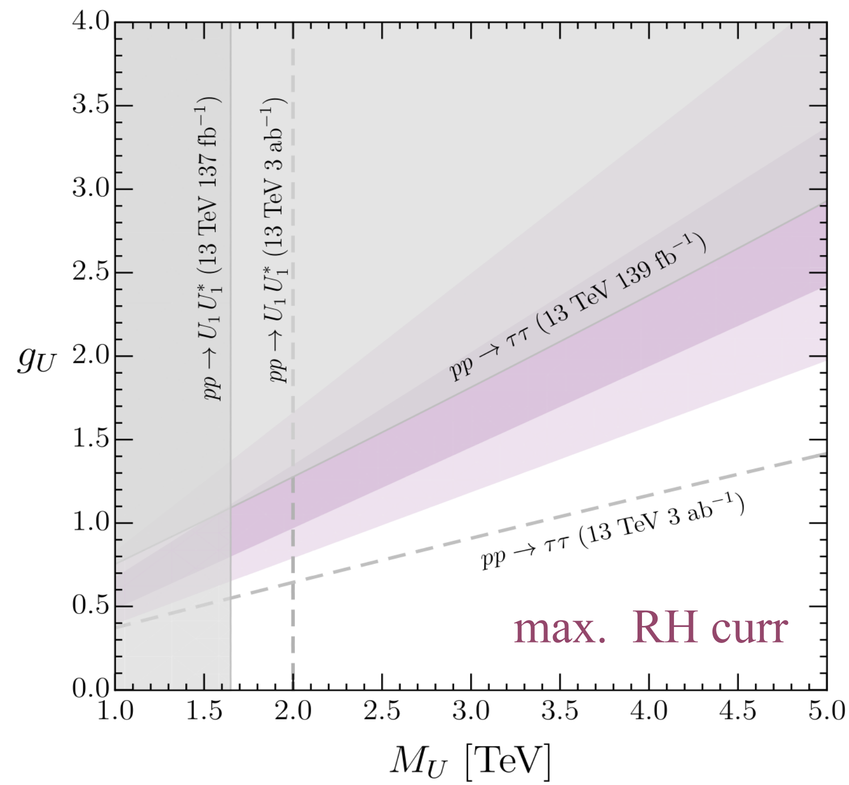




$pp \to \tau\tau$

Faroughi, Greljo, Kamenik '16





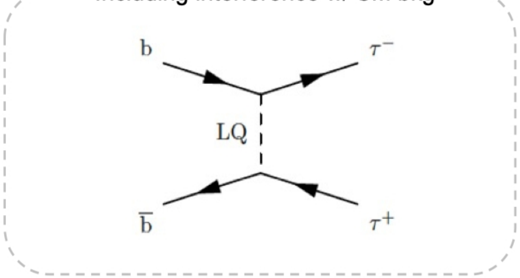
Cornella, Faroughi, Fuentes-Martin, GI, Neubert, '21

Leptoquarks & 4321: implications

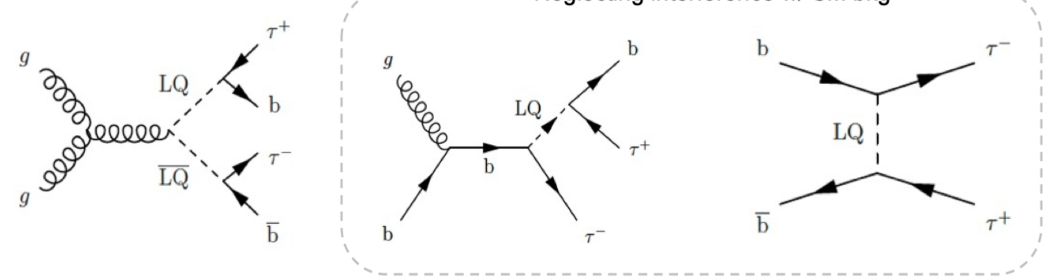
Aurelio Juste [*Moriond EW* '23]

LQ-b-τ: Comparison of recent results

Including interference w/ SM bkg

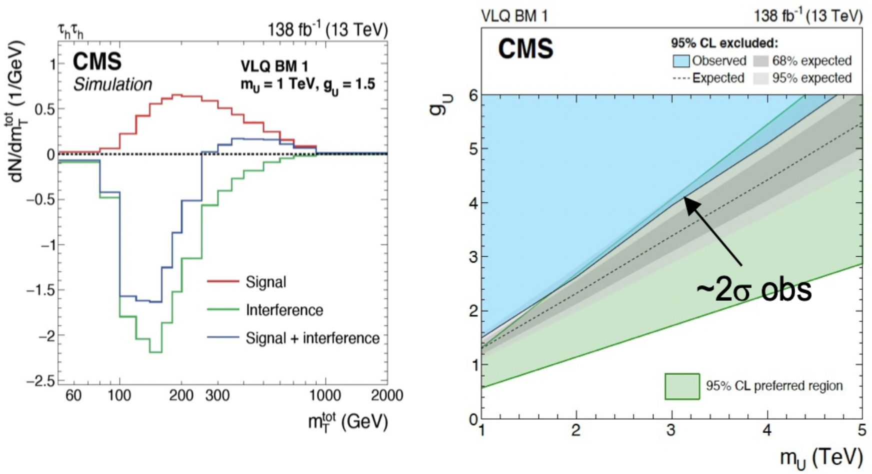


Neglecting interference w/ SM bkg



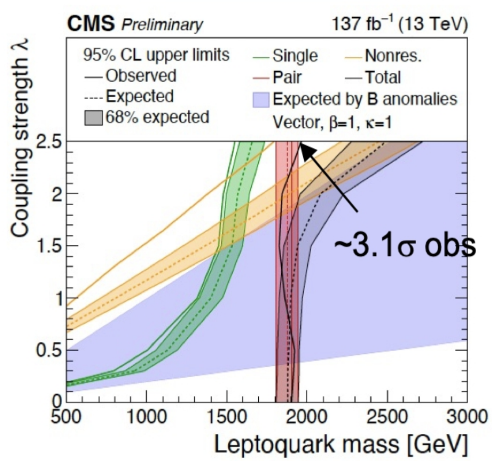
Caveat: BR=1 (CMS) vs BR=0.5 (ATLAS)

CMS-HIG-21-001

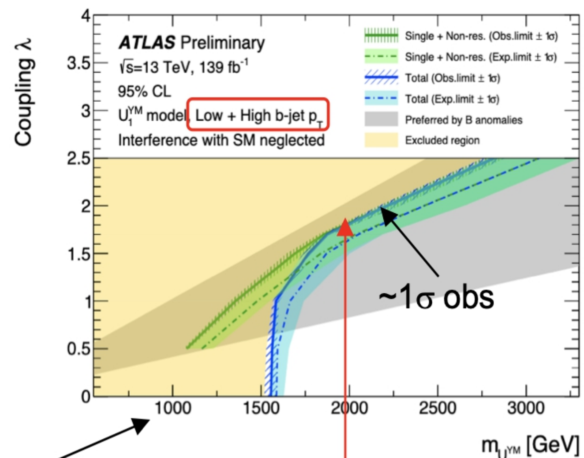


Shown at Moriond EW 2022

CMS-PAS-EXO-19-016



EXOT-2022-39



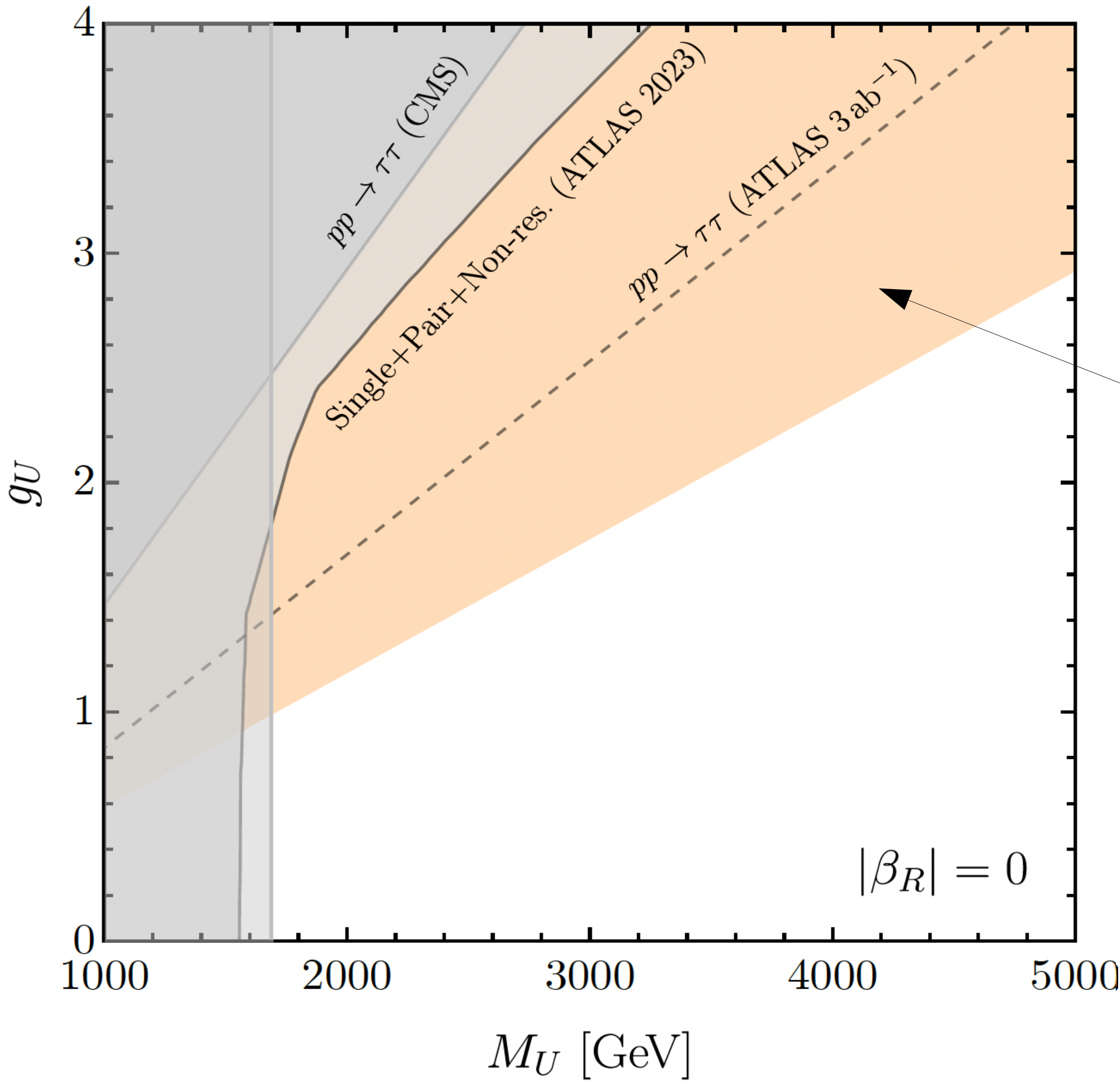
Large improvement in sensitivity when adding low b-jet p_T category

Excludes CMS' excess

Need to clarify interference issue for future interpretations

▶ *Leptoquarks & 4321: implications*

I The U_1 leptoquark at high energies:



Updated preferred region by b → c low-energy data

Aebischer *et al.* '22

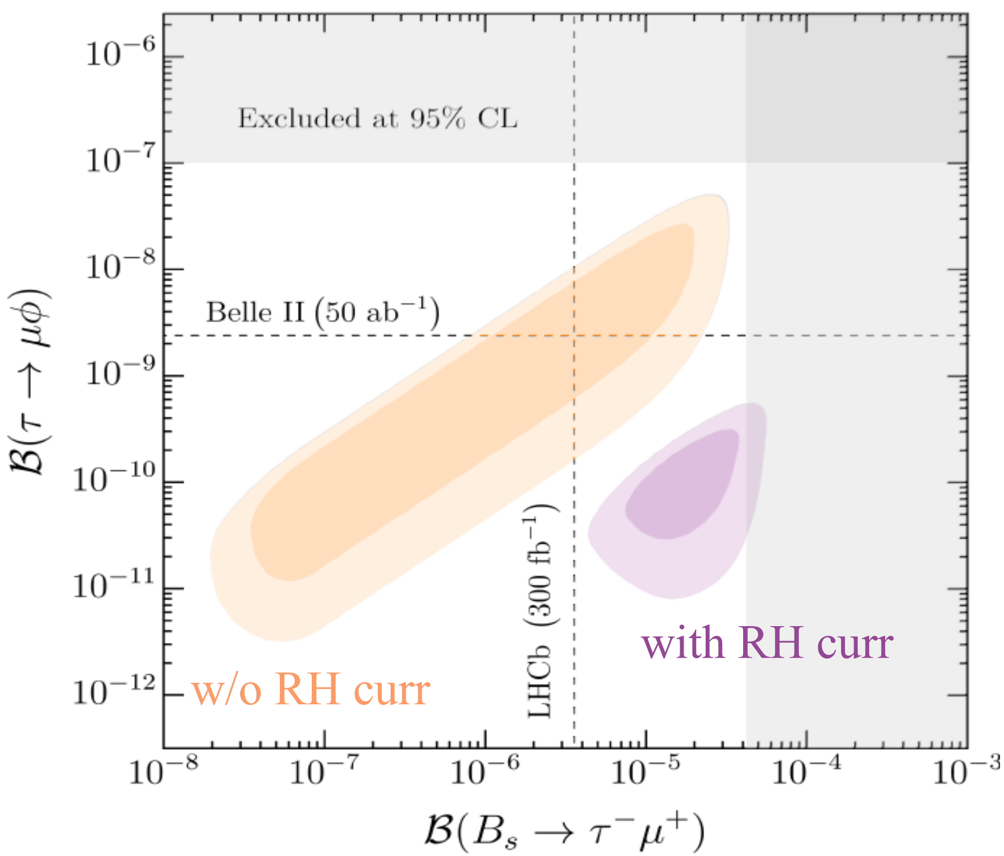
Relevant NLO QCD corrections

Haisch, Schnell, Schulte '22

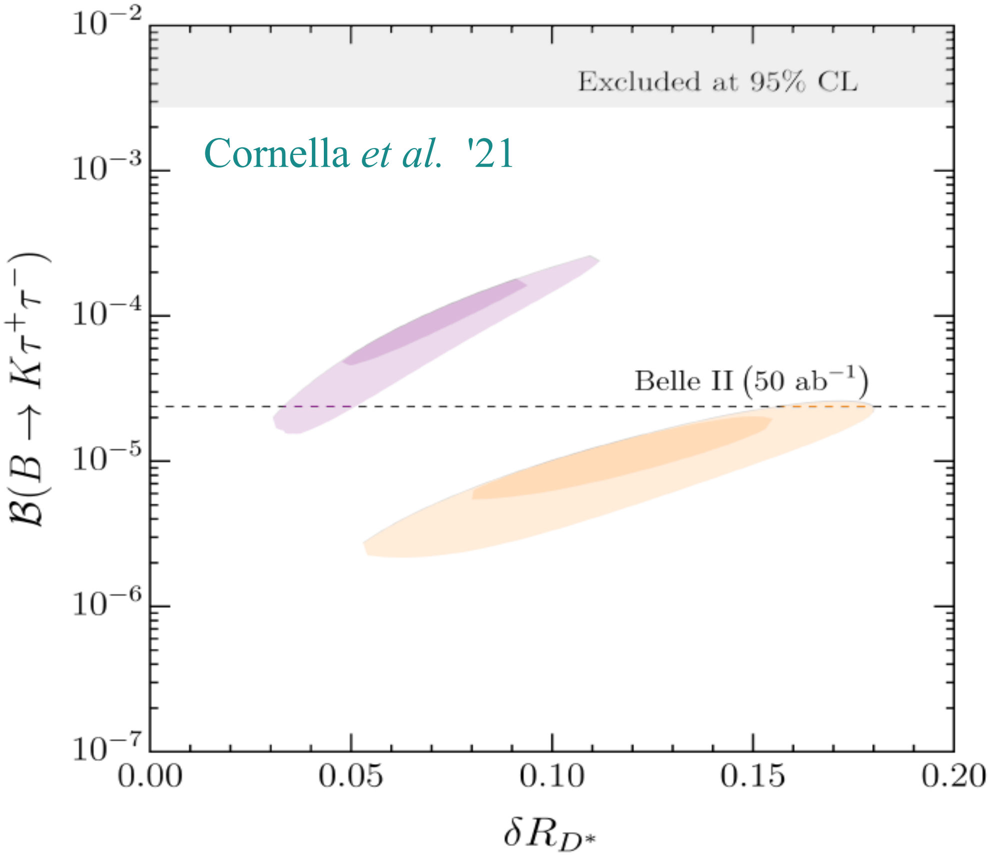
Leptoquarks & 4321: implications

II Rare decays of b and τ

$\tau \to \mu$ LFV
(in B and tau decays)

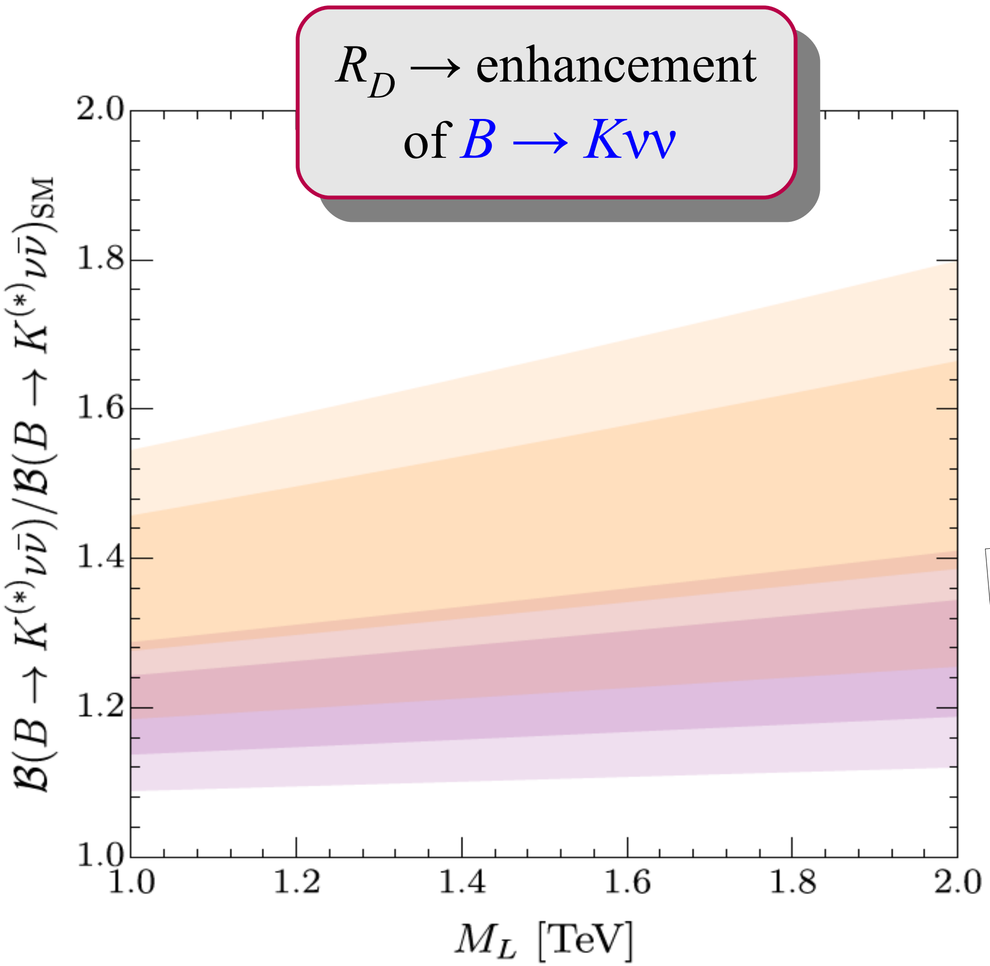


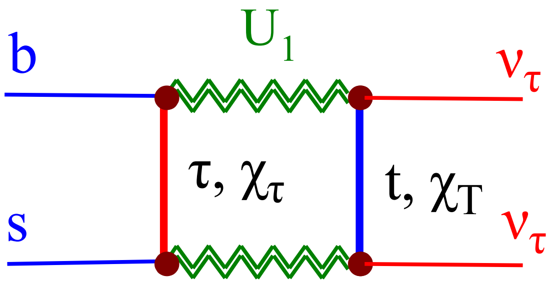
largely enhanced $b \to s\tau\tau$ rates
(in all channles)

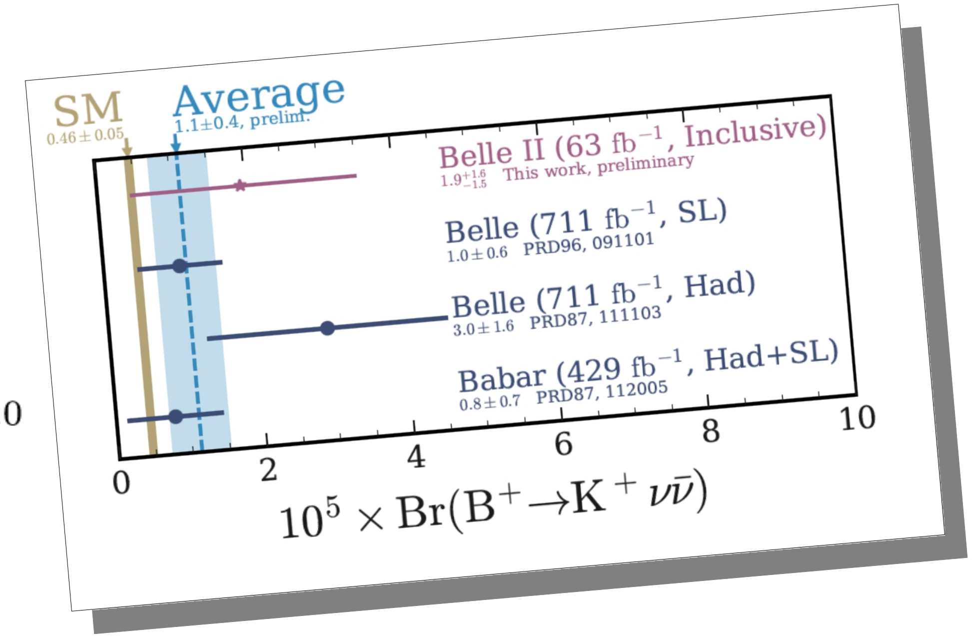


Leptoquarks & 4321: implications

III The vector-like fermions in low-energy observables







Fuentes-Martin, GI, Konig, Selimovic, '20
Cornella *et al.* '21

Conclusions

- Flavor physics represents one the most intriguing aspects of the SM and, at the same time, a great opportunity to investigate the nature of physics beyond the SM.

- The idea of a *multi-scale construction at the origin of the flavor hierarchies* has several appealing aspects. Key observation: non-universal gauge interactions at the TeV scale, involving mainly the 3rd family, offer a new way to look at the EW hierarchy problem (and the absence of direct signals of NP so far).

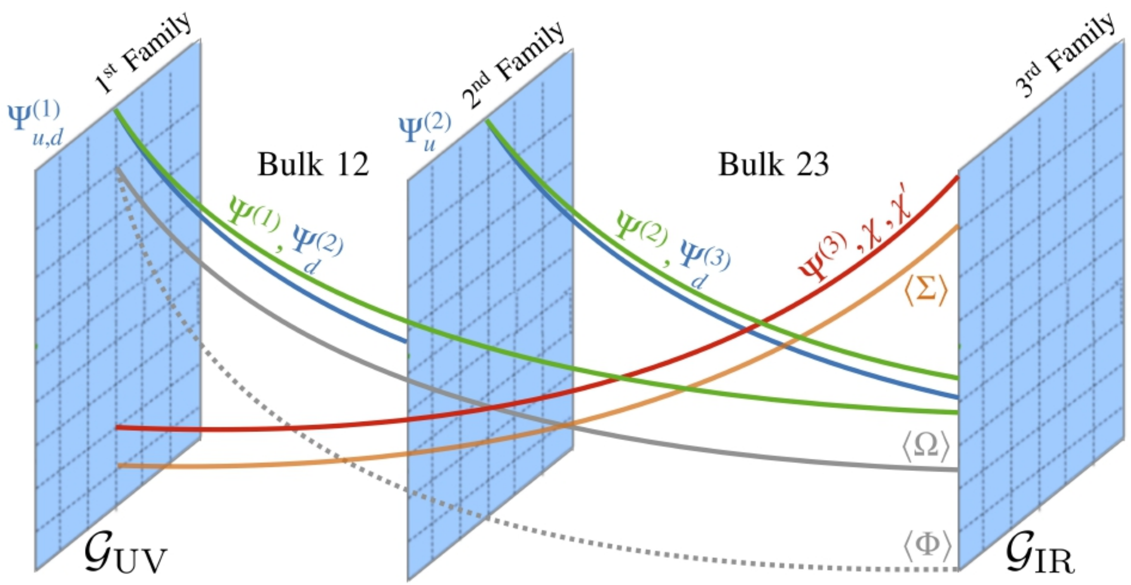
- The model-building efforts along this direction, triggered by the B anomalies, are still very motivated and mildly affected by the recent change in low-energy data.

- If these ideas corrects, new non-standard effects should emerge soon both at low and at high energies (→ very interesting opportunities for run-3...).


Backup

▶ Leptoquarks & 4321: UV completions

An ambitious attempt to construct a *full theory of flavor* has been obtained embedding (a variation of the) Pati-Salam gauge group into an extra-dimensional construction:



Flavor ↔ special position (*topological defect*) in an extra (compact) space-like dimension

Dvali & Shifman, '00

Higgs and SU(4)-breaking fields with oppositely-peaked profiles, leading to the desired flavor pattern for masses & anomalies

Bordone, Cornella, GI, Javier-Fuentes '17

- Anarchic neutrino masses via inverse see-saw mechanism — Fuentes-Martin, GI, Pages, Stefanek '22

- "Holographic" Higgs from appropriate choice of bulk/brane gauge symm.
  [$G_{\text{bulk-23}} = SU(4)_3 \times SU(3)_{1,2} \times U(1) \times SO(5)$ $G_{IR} = SU(3)_c \times U(1)_{B\text{-}L} \times SO(4)$]

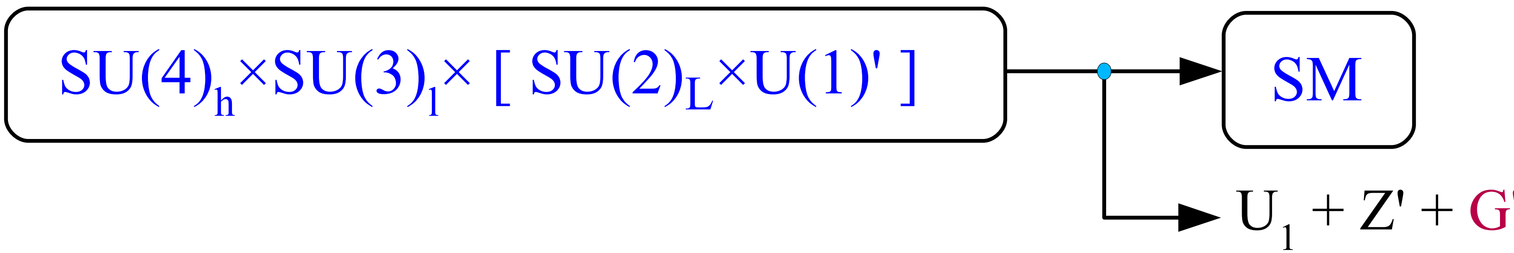
Fuentes-Martin, Stangl '20
Fuentes-Martin, GI, Lizana, Selimovic, Stefanek '22

→ Light Higgs as pseudo Goldstone

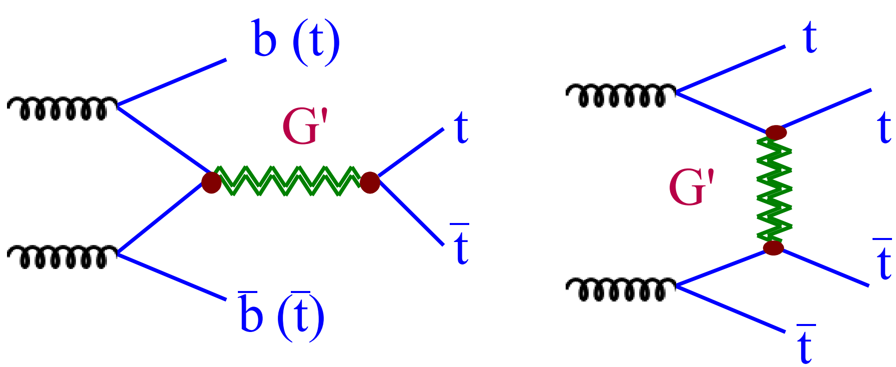
Agashe, Contino, Pomarol '05

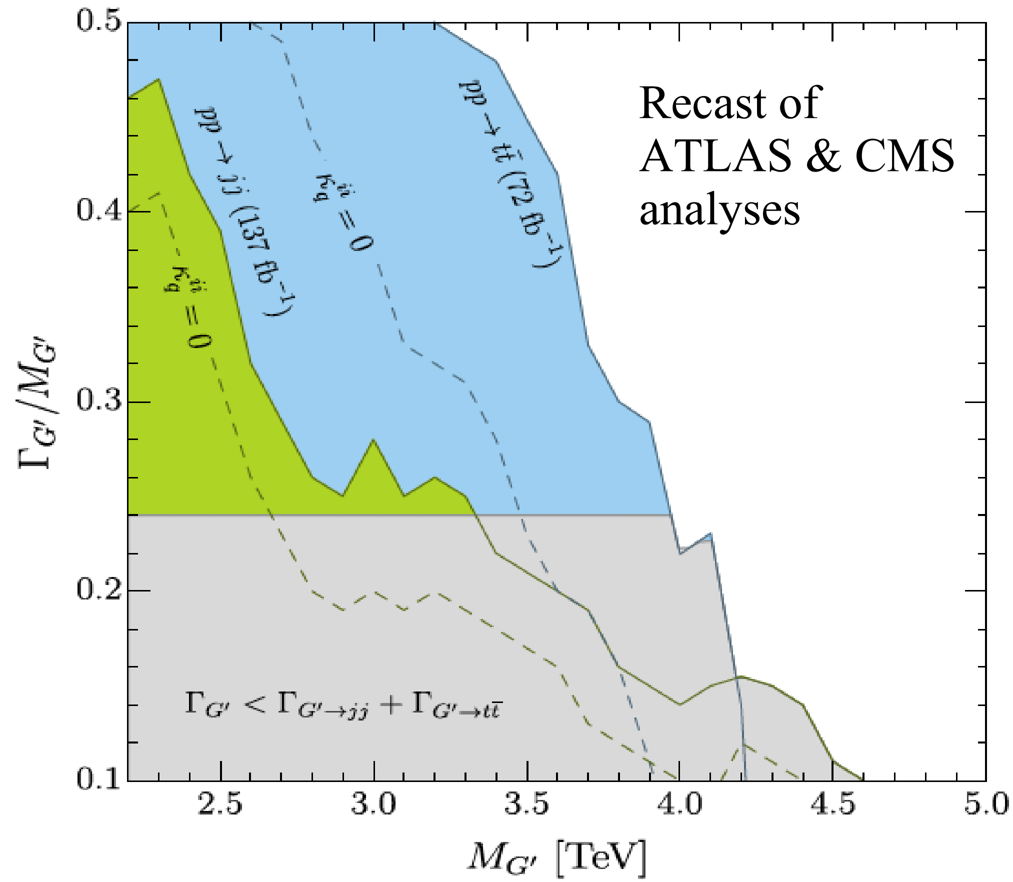
Leptoquarks & 4321: implications

IV The other heavy vectors of 4321 (*more model dependent*)



New striking collider signature:
G' ("*coloron*") = heavy color octet, coupled mainly to 3rd generation quarks

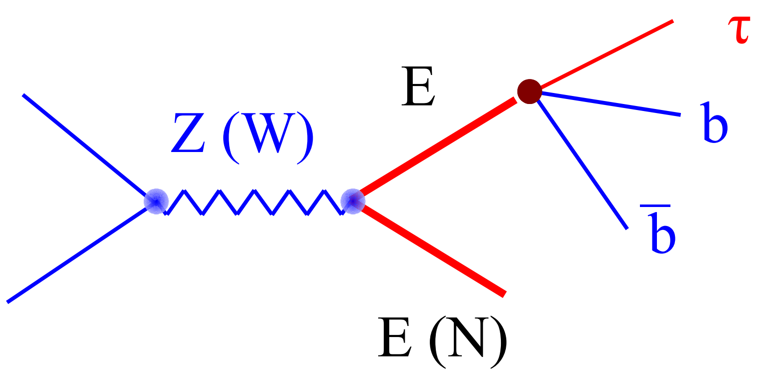




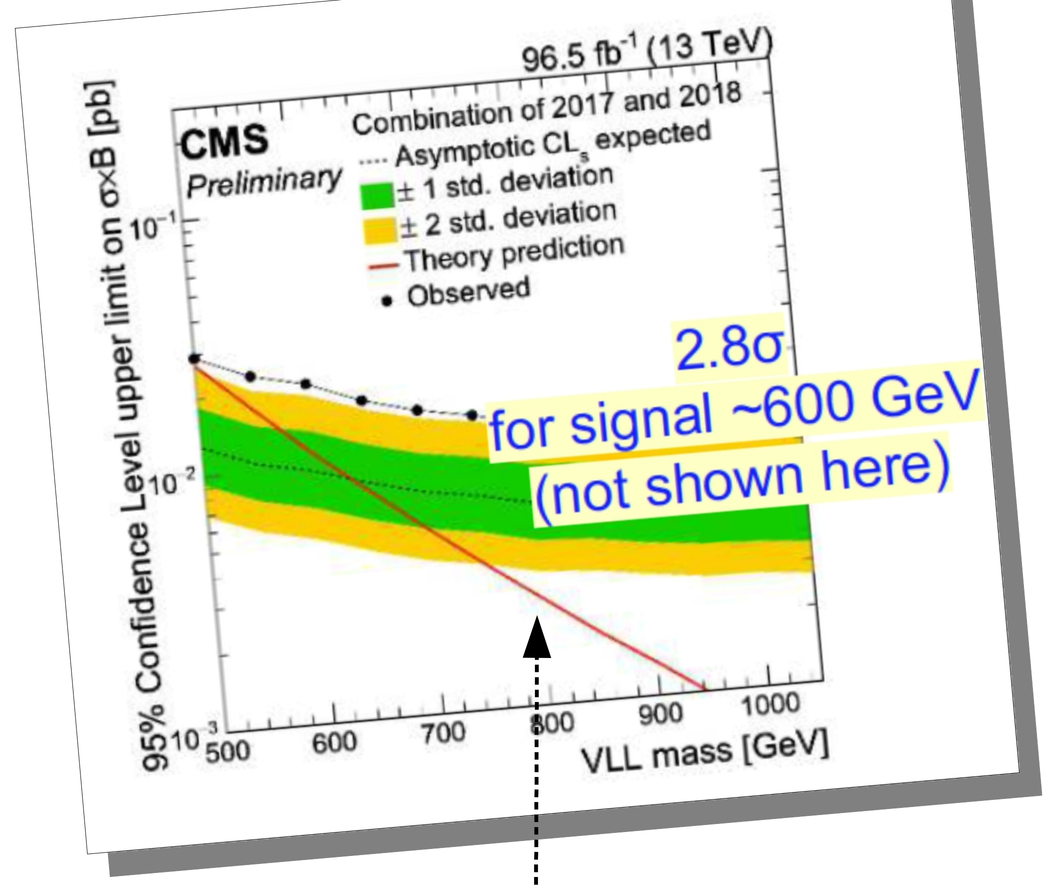
→ strongest constraint on the scale of the model from pp → $\bar{t}\, t$

Leptoquarks & 4321: implications

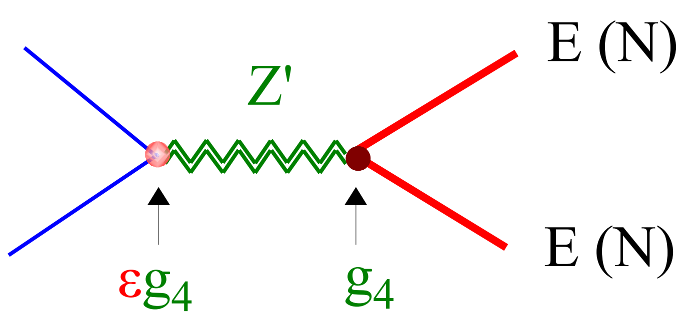
V The vector-like fermions



CMS-PAS-B2G-21-004



Additional production via heavy Z' exchange (model-dependent):

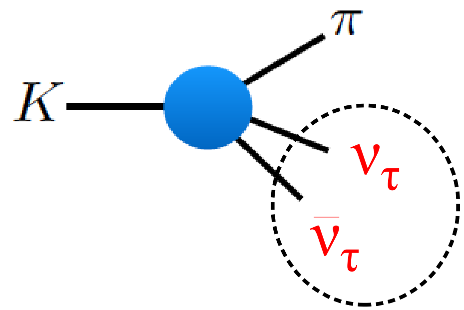


$\varepsilon = (g_2/g_4)^2 \sim 10\%$

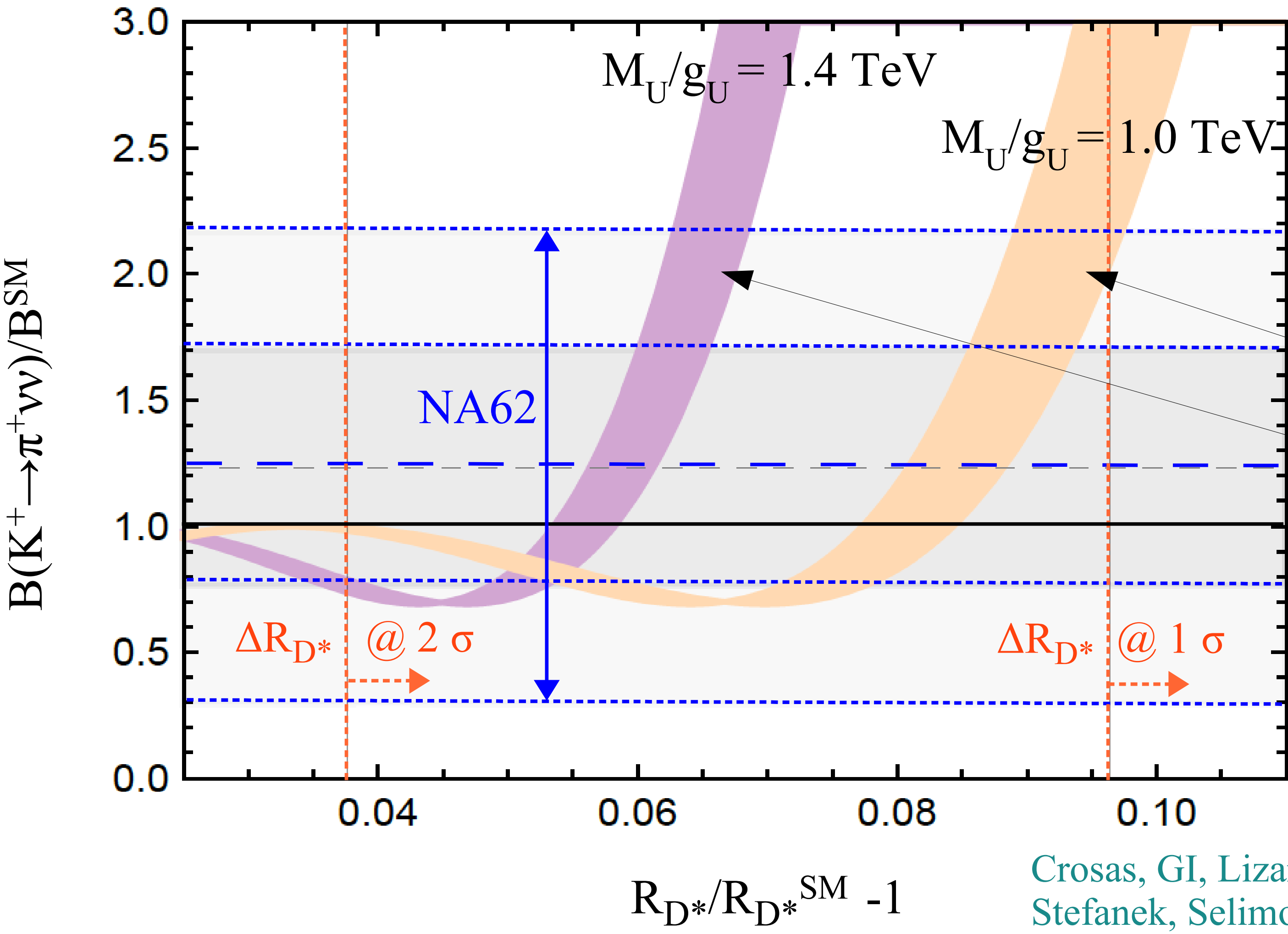
N.B.: the two amplitudes interfere (*for same initial & final state*) possibly giving rise to sizable enhancements

▶ Leptoquarks & 4321: implications

V Kaon physics



direct access to 3^{rd} gen. leptons as in R(D) & R(D*)



Correlations depending on high-energy parameters (LQ mass & coupling)

Crosas, GI, Lizana, Stefanek, Selimovic, '22