Flavor Deconstruction

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- Introduction
- The two flavor puzzles
- Flavor non-universality & flavor deconstruction
- A brief look to current data & future prospects
- Conclusions

University of Zurich UZH

European Research Council
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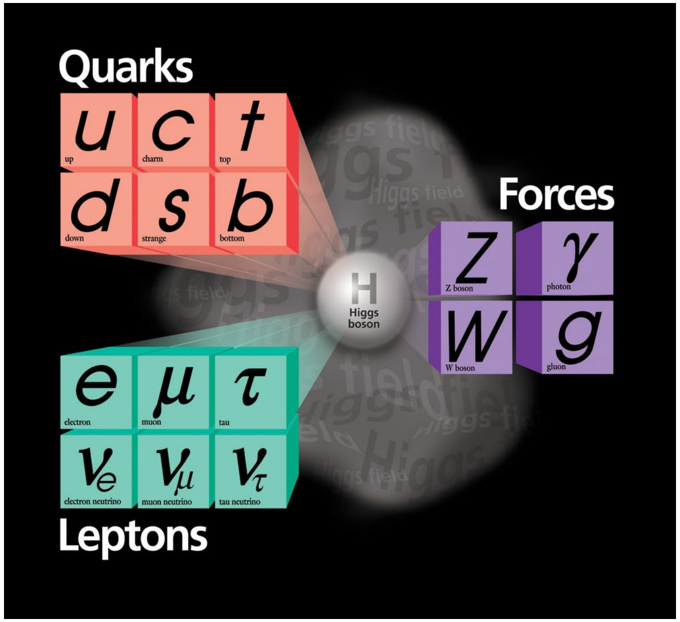
Introduction



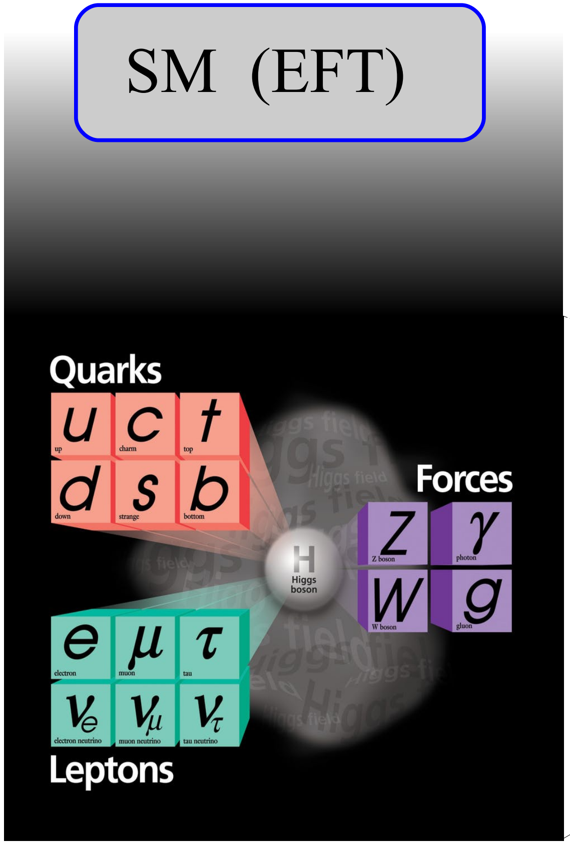
Introduction

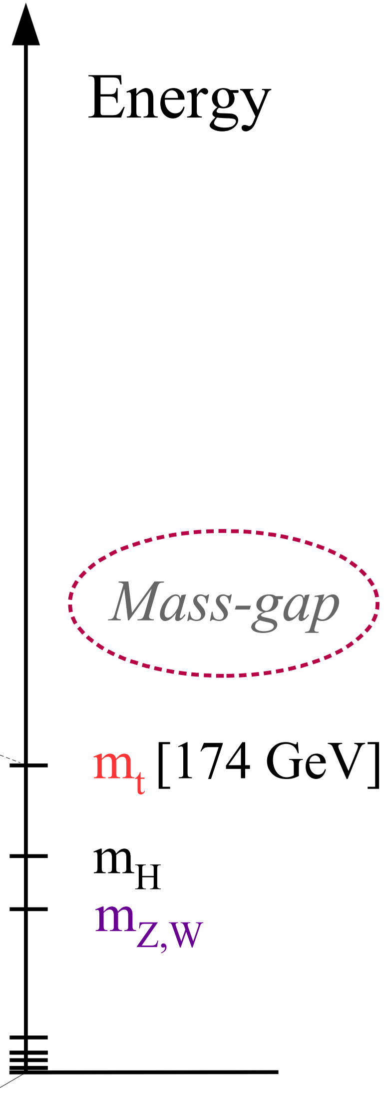
The Standard Model (SM) is provides a remarkably successful descriptions of *fundamental forces* (strong, weak, and e.m.) and *matter constituents*, over a wide range of energies.

However, as for any QFT, it is natural to consider the SM as an Effective Field Theory, i.e. the low energy limit of a more complete theory with more degrees of freedom

$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \ \ldots$$

We identified the *long-range* properties of this EFT





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*

Flavor puzzle

U(1) charges

Neutrino masses

→ *Ad hoc tuning in the model parameters*

non-trivial properties of the SM Lagrangian if interpreted as EFT

Useful hints for its UV completion

Dark-matter

Dark-energy

Inflation

→ *Cosmological implementation of the SM*

Quantum gravity

→ *General problem of any QFT*

Introduction

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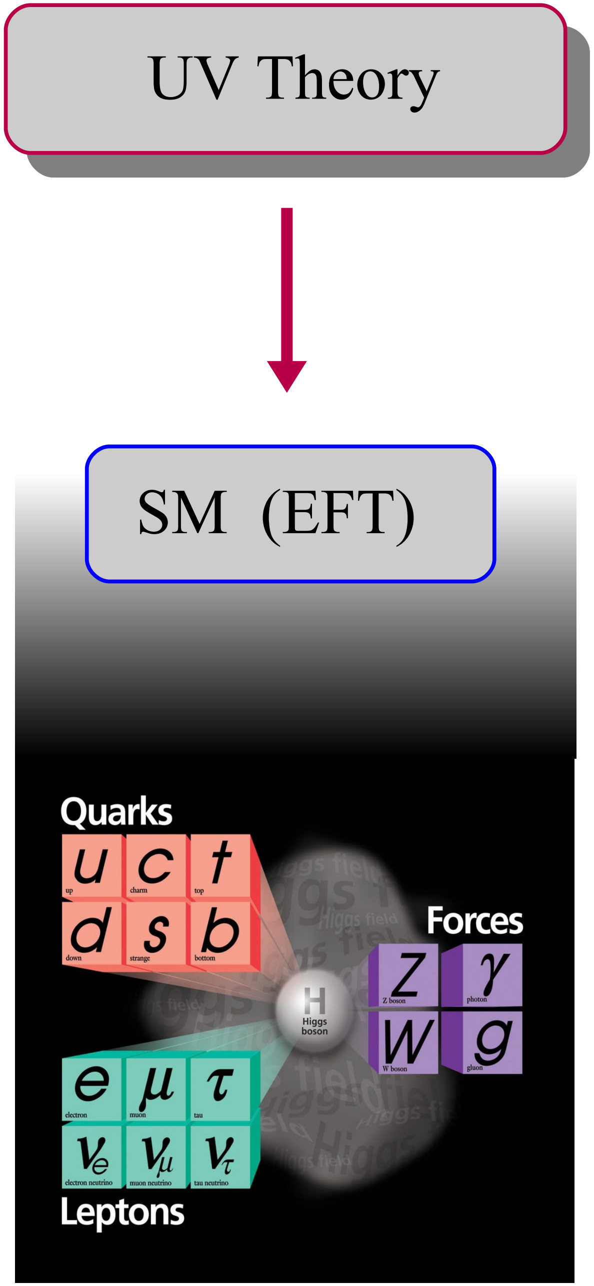
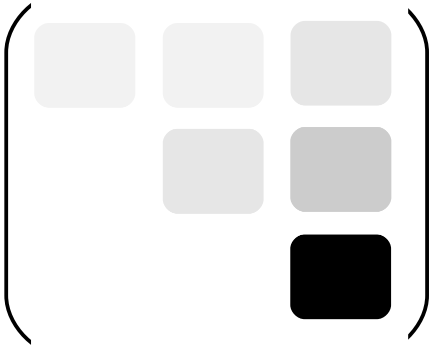

UV Theory

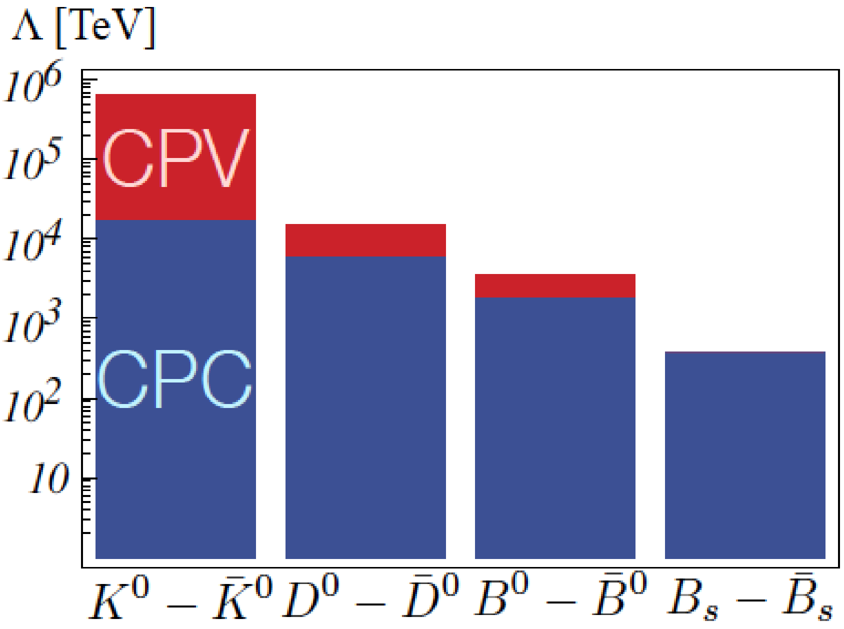
SM (EFT)

Messages from the UV we need to decode..

The two flavor puzzles

$Y_U \sim$





The two flavor puzzles

There are two (long-standing) open issues in flavor physics:

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

→ Is there a deeper explanation for this peculiar structures?

The SM flavor puzzle

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?

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

The NP flavor puzzle

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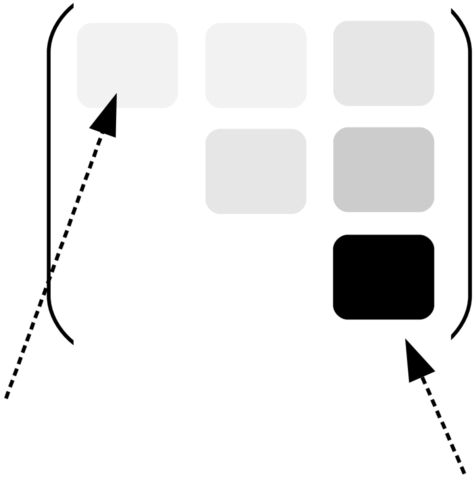
Eg.:

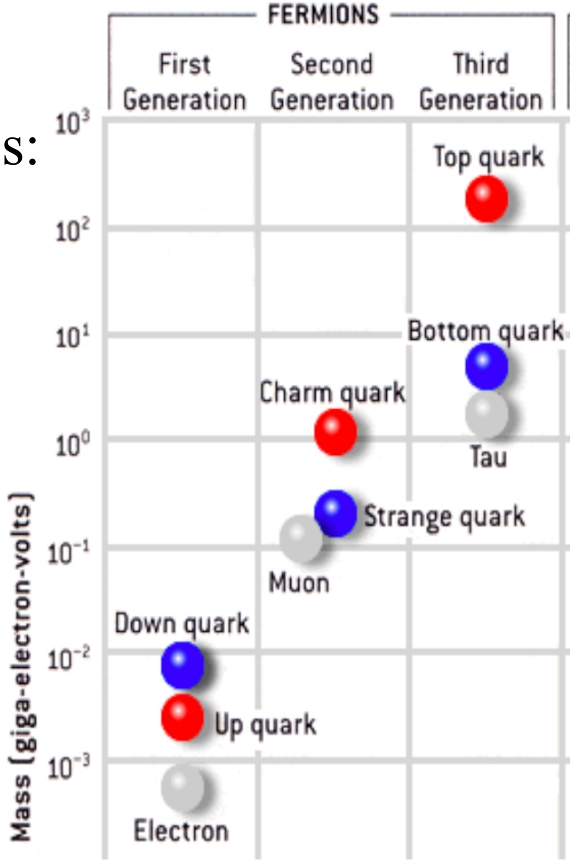
$Y_U \sim$

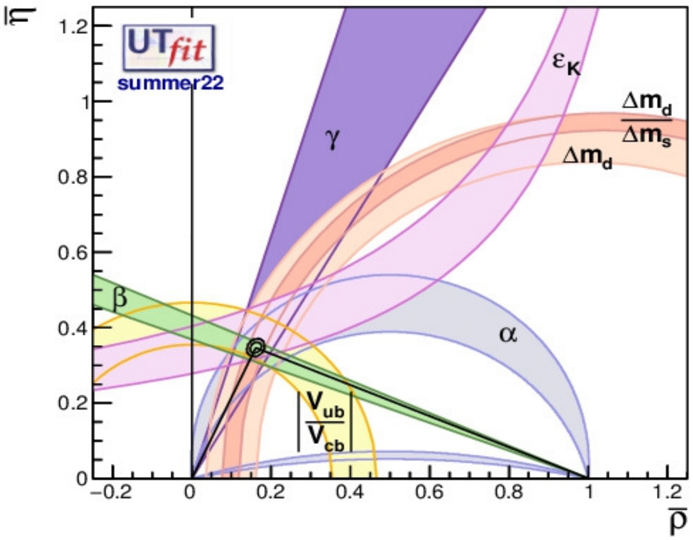


$$y_u = \frac{\sqrt{2}\, m_u}{\langle H \rangle} \approx 10^{-5} \qquad y_t = \frac{\sqrt{2}\, m_t}{\langle H \rangle} \approx 1$$

$$\mathscr{L}_Y = \bar{Q}_L Y_U U_R H + \ldots$$

$\left(Y_U \text{ in the basis where } Y_D \text{ is diagonal} \right)$





The two flavor puzzles

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

Eg.:

$$Y_U \sim \begin{array}{c} \overbrace{\qquad\qquad\quad}^{U(2)_u} \\ \left(\begin{array}{cc|c} \multicolumn{2}{c|}{< 0.01} & 0.003 \\ & & 0.04 \\ \hline & & \boxed{1} \end{array}\right) \end{array} \begin{array}{l} \left.\begin{array}{c} \\ \\ \end{array}\right] U(2)_q \\ \\ \end{array}$$

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

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

The two flavor puzzles

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The NP flavor puzzle

A brief look to the SM as an effective theory:

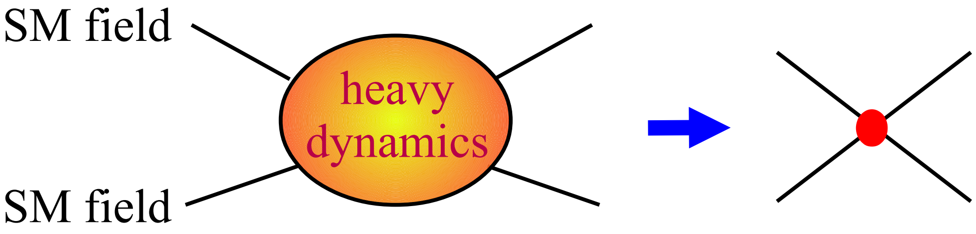
$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \sum_{d,i} \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^{d\geq 5}$$

Interactions surviving @ large distances
(operators with $d \leq 4$)

Long-range forces
of the SM particles
+
ground state (Higgs)

Local contact interactions
(operators with $d > 4$)

“Remnant” of the heavy
dynamics at low energies



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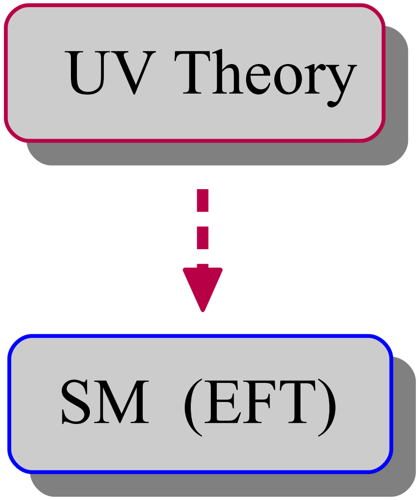
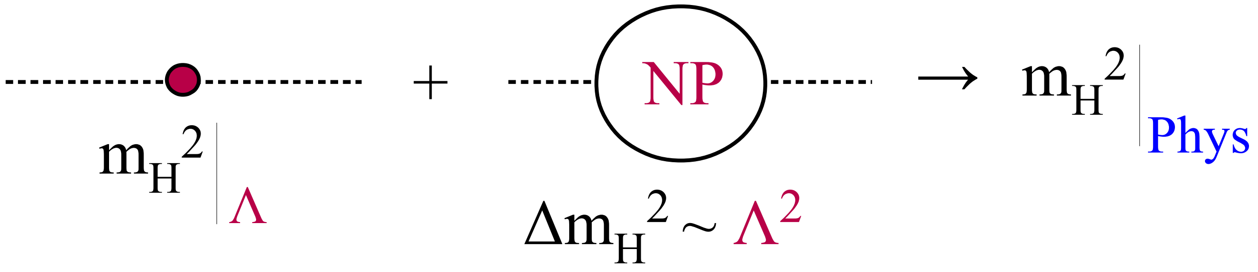

UV Theory

SM (EFT)

What is the cut-off scale Λ of the SMEFT?

A useful (*but somewhat vague*) indication follows from the Electroweak hierarchy problem (↔ *instability of the Higgs mass under quantum corrections*):



→ (*some*) New Physics (*coupled at least to* H & t) in the TeV domain

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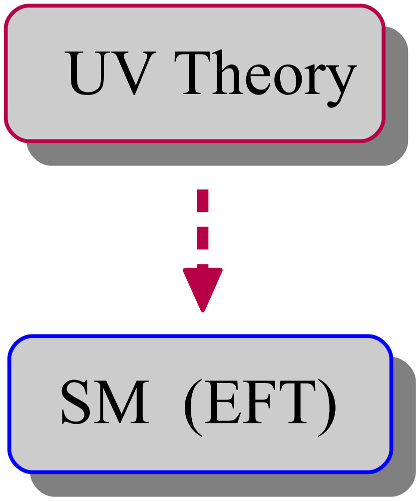
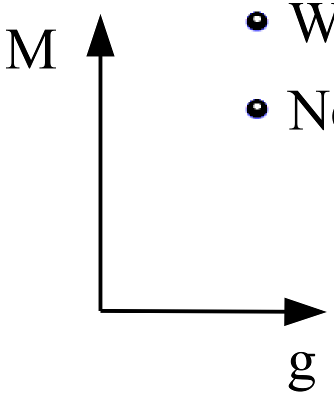
What is the cut-off scale Λ of the SMEFT?
A closer look to this question reveals more “layers”





- What is the mass scale of the new d.o.f. ?
- New dynamics weakly or strongly coupled ?

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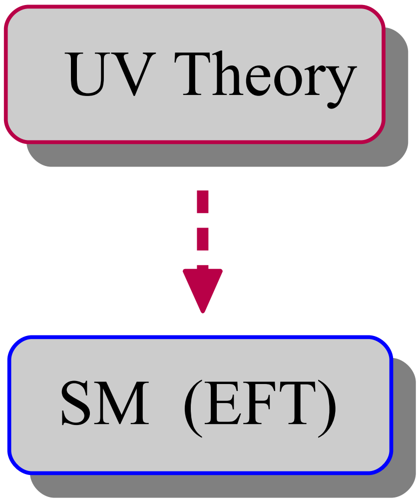

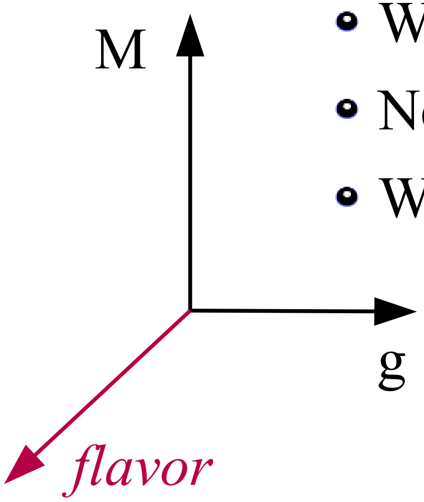

- What is the mass scale of the new d.o.f. ?
- New dynamics weakly or strongly coupled ?
- What is the *flavor structure*?

SM (Yukawa) sector → flavor is highly non trivial

- No flavor symmetry → 2499 free couplings in the SMEFT @ d=6
- Exact $U(3)^5$ → 47 Jenkins, Manohar, Trott '14
- Exact $U(2)^5$ → 120 Faroughi, GI, Wilsh, Yamamoto, '20

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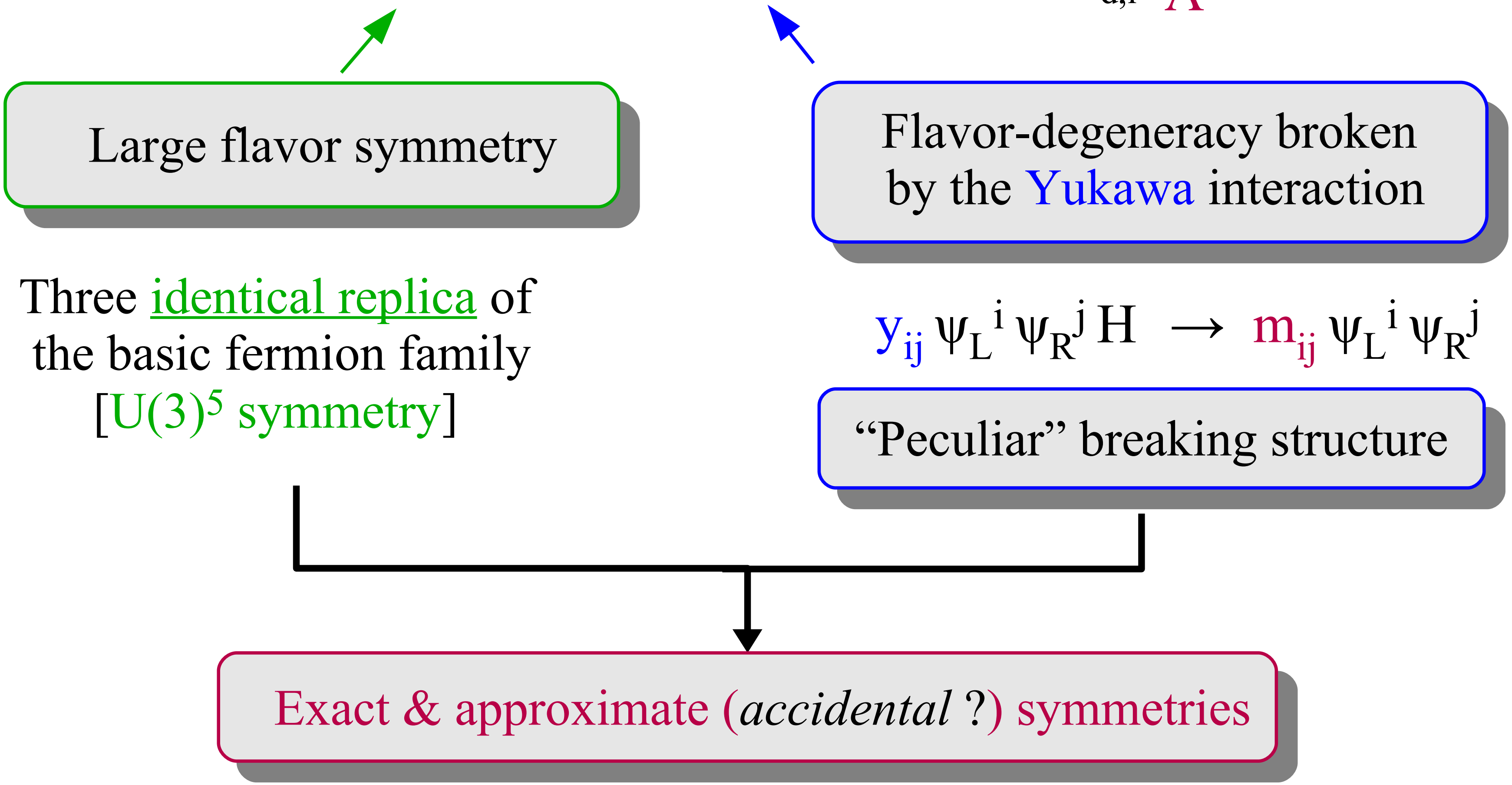

Large flavor symmetry

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

Flavor-degeneracy broken by the Yukawa interaction

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

“Peculiar” breaking structure

Exact & approximate (*accidental* ?) symmetries

Eg:

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

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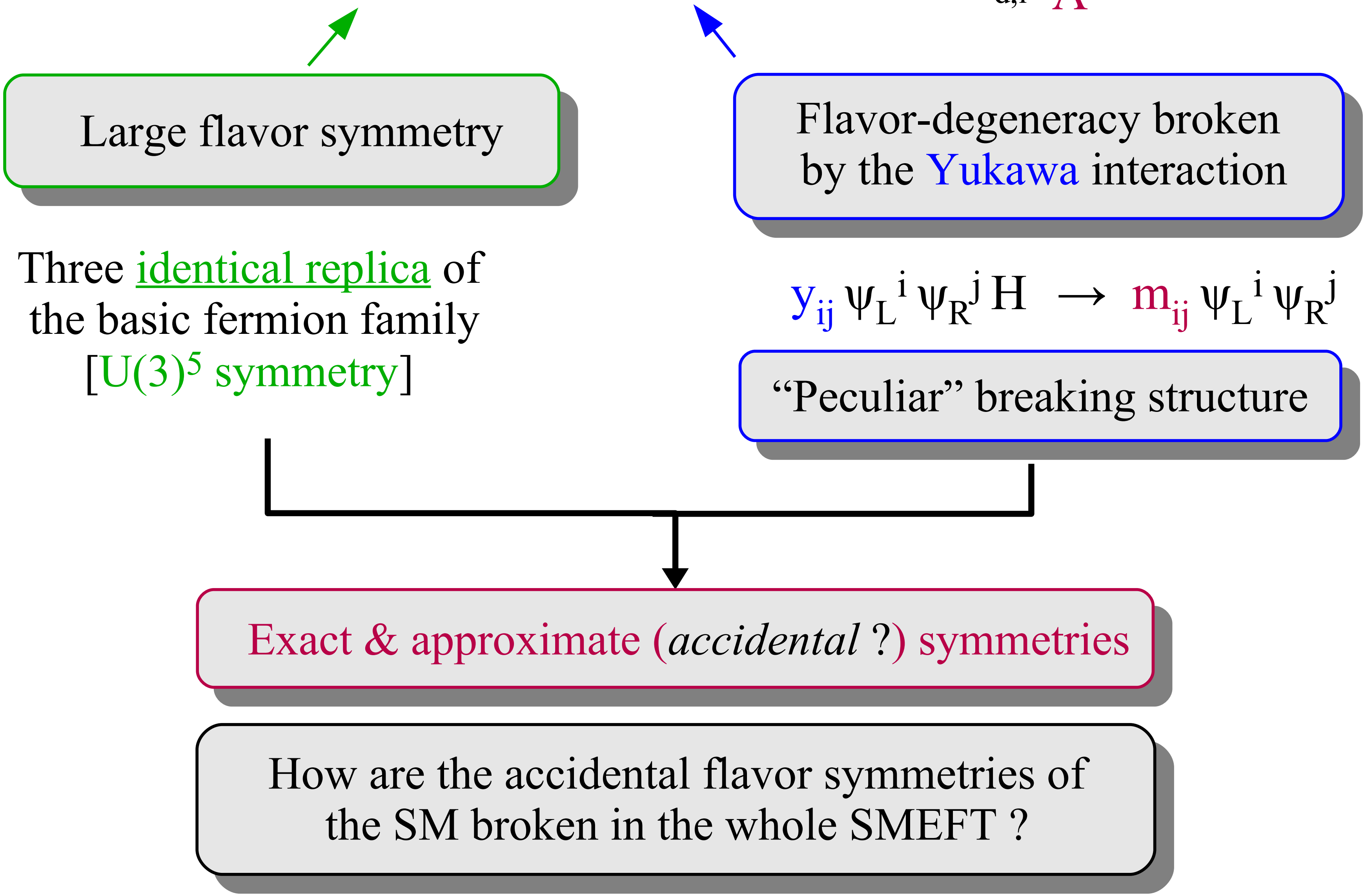

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“Peculiar” breaking structure

Exact & approximate (*accidental* ?) symmetries

How are the accidental flavor symmetries of the SM broken in the whole SMEFT ?

The two flavor puzzles

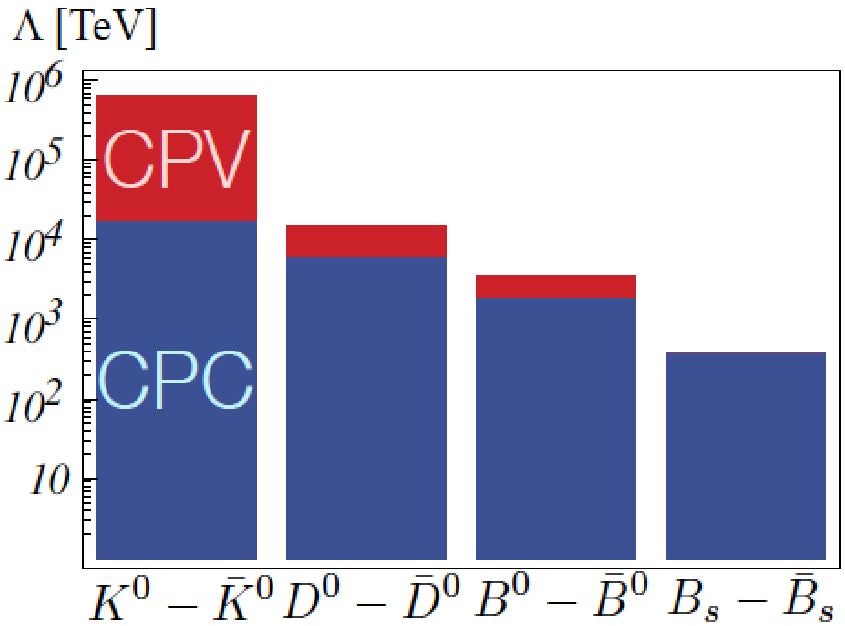
$$\mathscr{L}_{\text{SM-EFT}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \sum_{d,i} \frac{c_i^{[d]}}{\Lambda^{d-4}} O_i^{d\geq5}$$

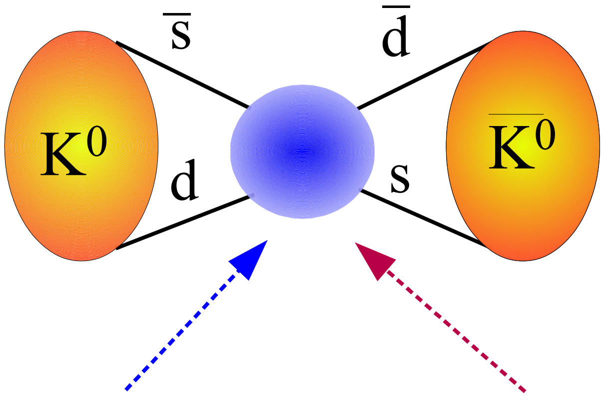
In principle, in the SM-EFT we could expect many violations of the accidental symmetries from the heavy dynamics (→ *new flavor violating effects*). However, no clear deviations observed so far

↓

The NP flavor puzzle

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





measured precisely

SM amplitude, strongly suppressed by approx. flavor symmetries

contact term $\sim \frac{1}{\Lambda}$

▶ The two flavor puzzles

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

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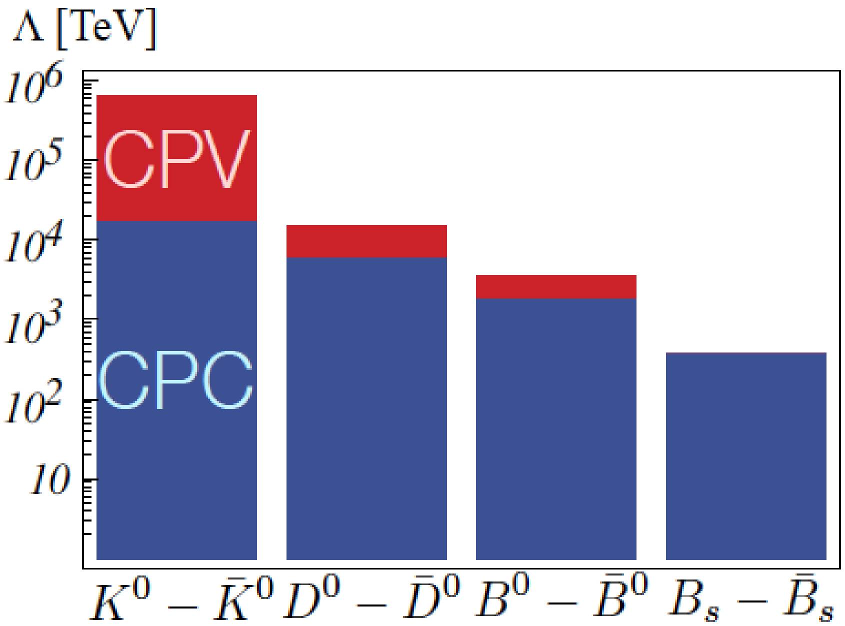
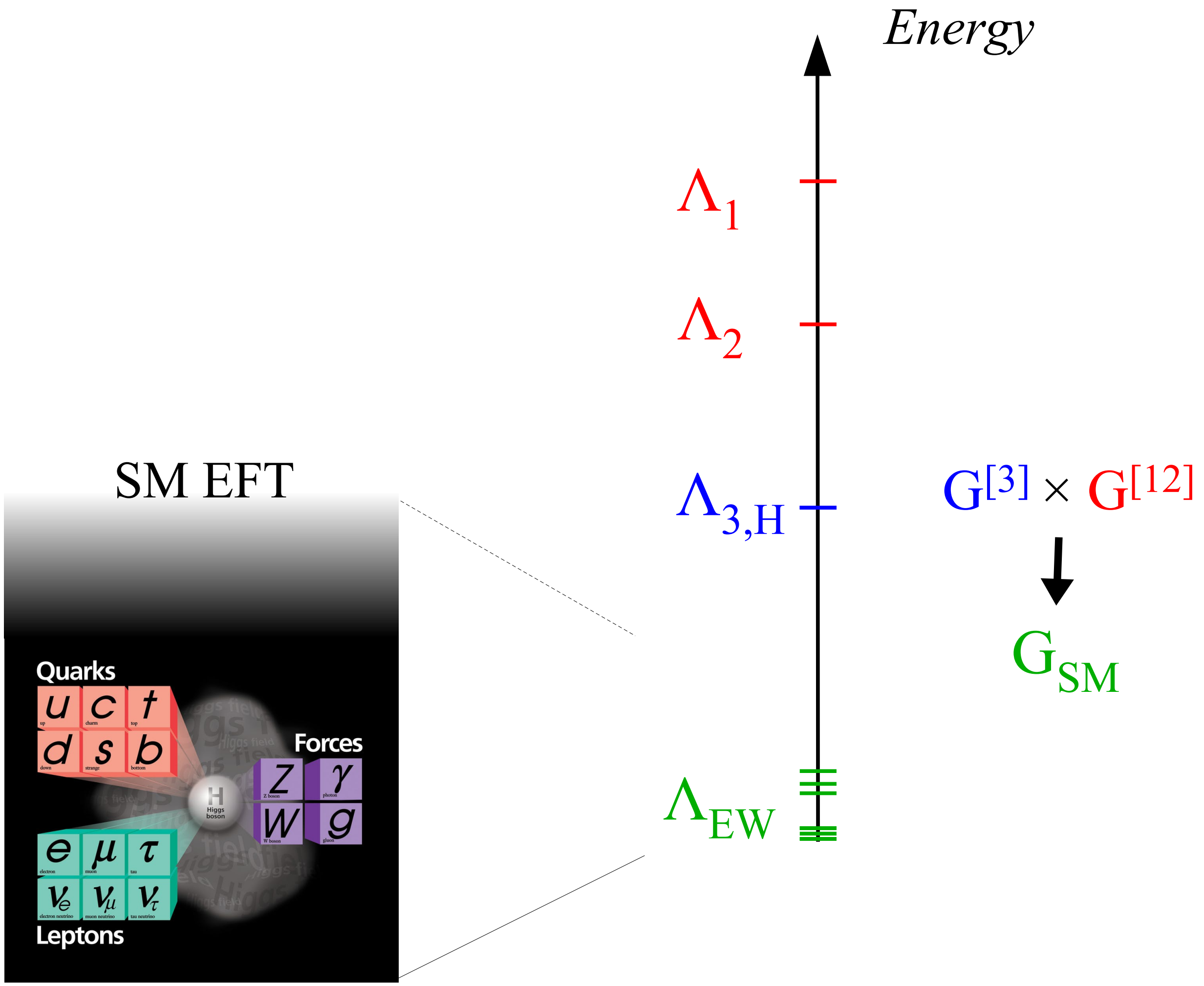


These high scales can be a "mirage"

The only unambiguous message from data is that there are no large breaking of the approximate U(2)^n flavor symmetry at near-by energy scales.

However U(2)^n is not an accidental symmetry of the SM → *indication of specific UV dynamics?*

Flavor non-universality & flavor deconstruction



Energy

Λ_1

Λ_2

$\Lambda_{3,H}$

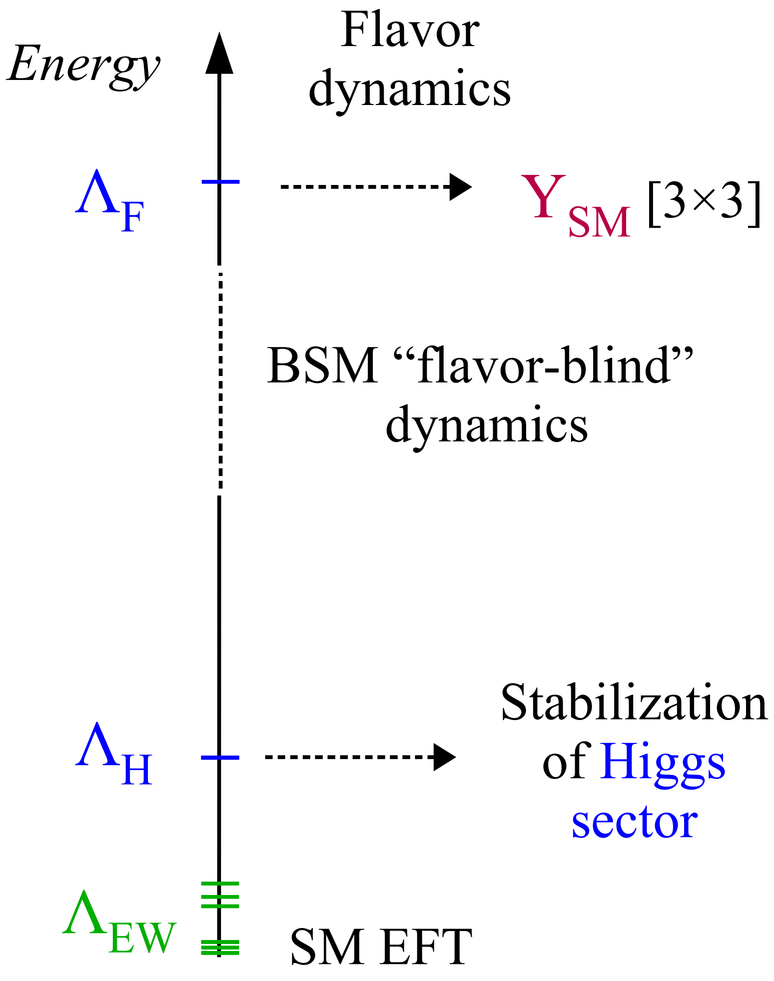
Λ_{EW}

$$G^{[3]} \times G^{[12]} \downarrow G_{SM}$$

SM EFT

General considerations about flavor (non) universality

For a long time, the vast majority of model-building attempts to extend the SM was based on the *implicit* hypotheses of *flavor-universal* New Physics



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

↕

The "MFV paradigm"

The Yukawa couplings are the only sources of flavor symmetry breaking accessible at low energies

3 families = "identical copies" up to high energies

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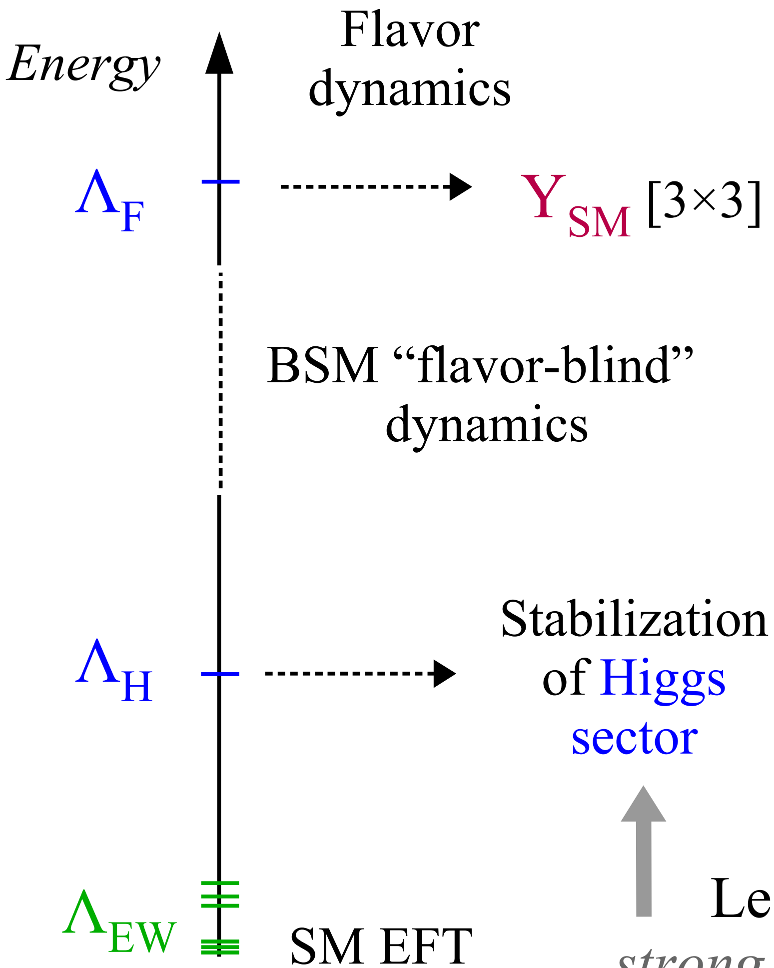

Energy

Flavor dynamics

Λ_F → Y_{SM} [3×3]

BSM "flavor-blind" dynamics

Λ_H → Stabilization of Higgs sector

Λ_{EW} SM EFT

- Concentrate on the Higgs hierarchy problem
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↕

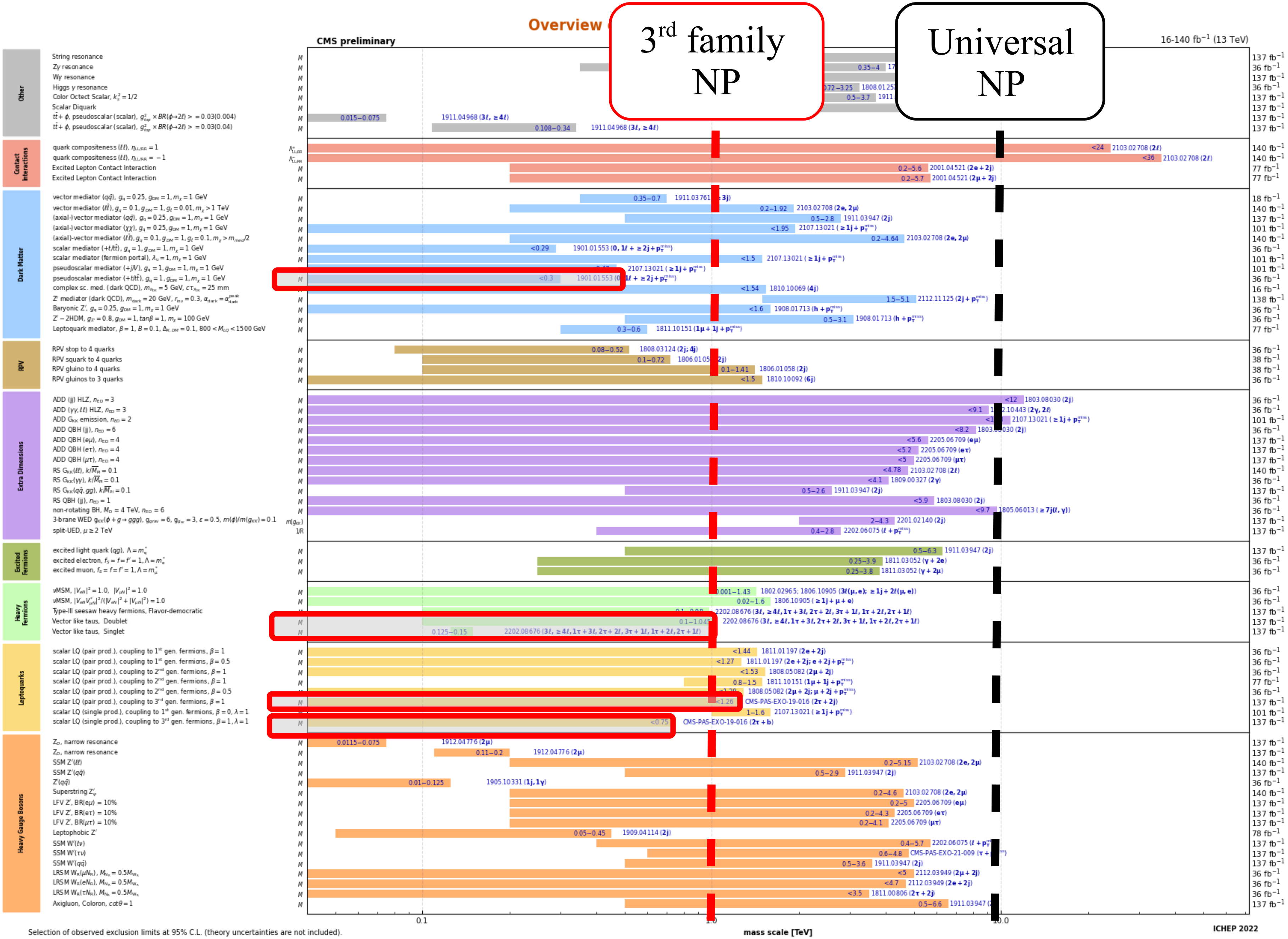
The "MFV paradigm"

Less compelling after LHC results (run I+II):

strong bounds on NP coupled universally to all families

worsening of the Higgs hierarchy problem

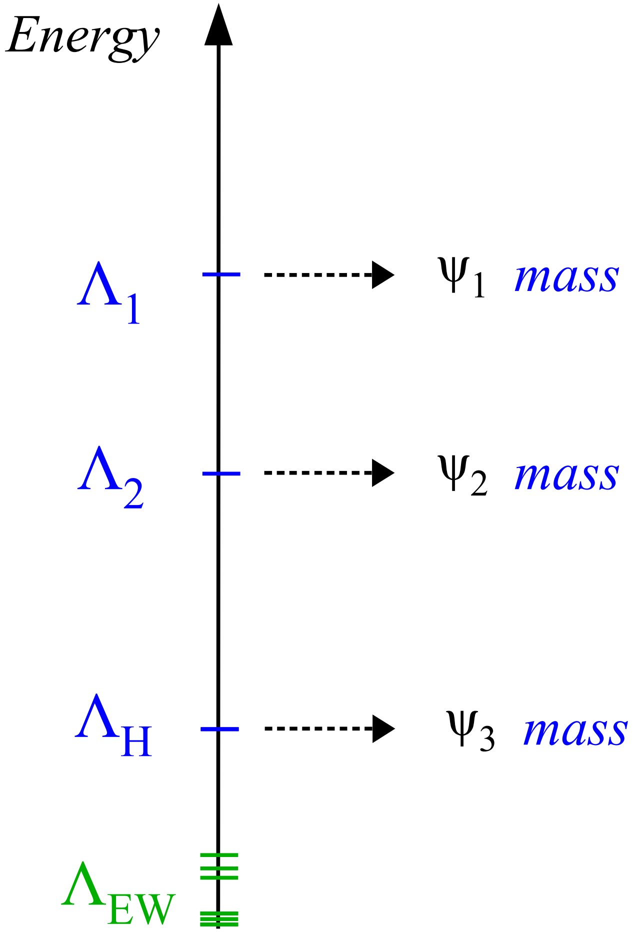
General considerations about flavor (non) universality



General considerations about flavor (non) universality

A more efficient paradigm to address both flavor puzzles (I+II), & *possibly* the Higgs hierarchy, is a *multi-scale* UV with *flavor non-universal* interactions

Dvali & Shifman '00
Panico & Pomarol '16
Bordone *et al.* '17
Allwicher, GI, Thomsen '20
Barbieri '21
Navarro & King '22
⋮



Basic idea:

1st & 2nd generations have small masses (+ small coupling to NP) because these are generated by new dynamics at heavier scales

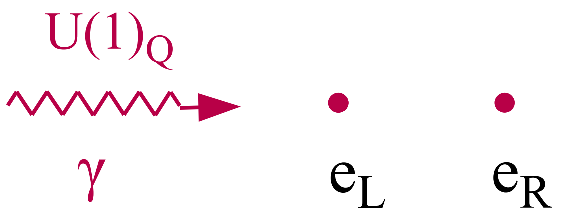
⬇

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

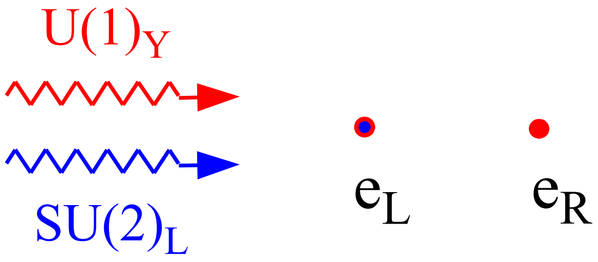
General considerations about flavor (non) universality

To better appreciate the change of perspective, consider the following analogy:

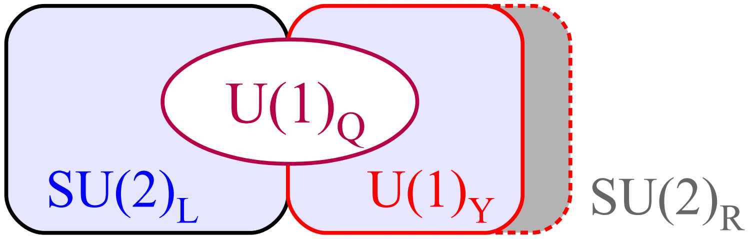
In the low-energy limit of the SM (= QED×QCD) we observe perfect universality of LH and RH gauge couplings. However, we know this is a low-energy artifact:



Low energies



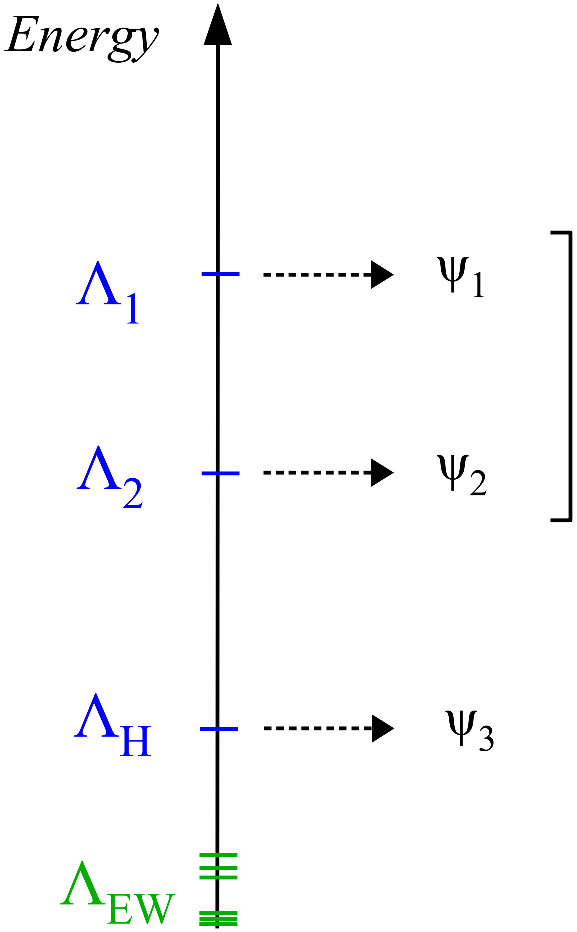
High energies



In a similar fashion, the flavor universality of all SM gauge interactions could be a low-energy artifact...

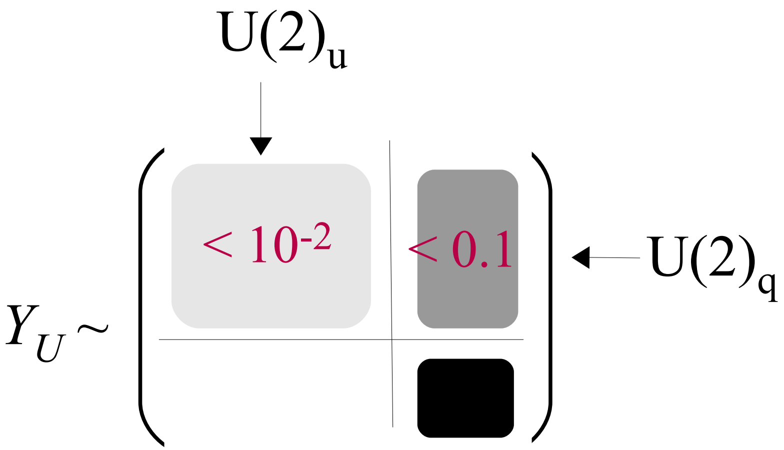
General considerations about flavor (non) universality

A more efficient paradigm to address both flavor puzzles (I+II), & *possibly* the Higgs hierarchy, is a *multi-scale* UV with *flavor non-universal* interactions



- The 2×2 light block of the Yukawa coupling originates from high-scale physics [→ origin of the *Cabibbo angle*]
- No additional breaking of $U(2)^n$ is mediated at low energies

"UV imprint" in the Yukawa couplings



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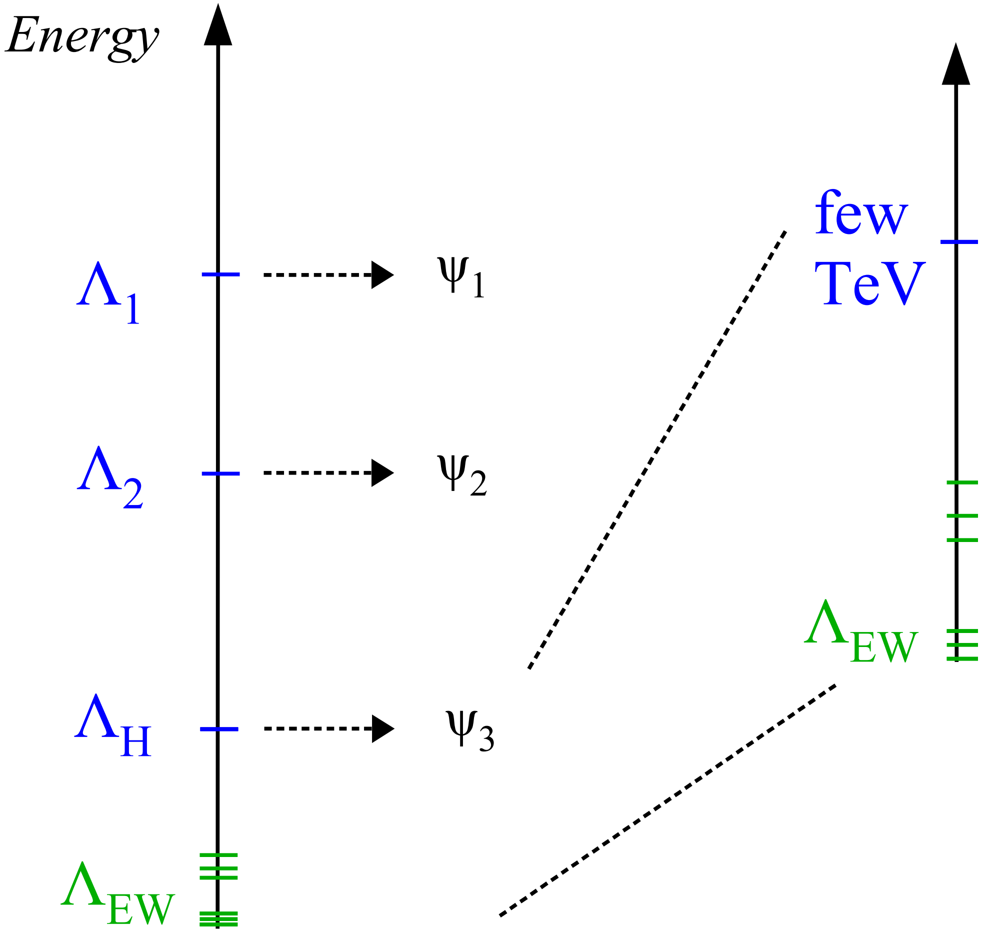
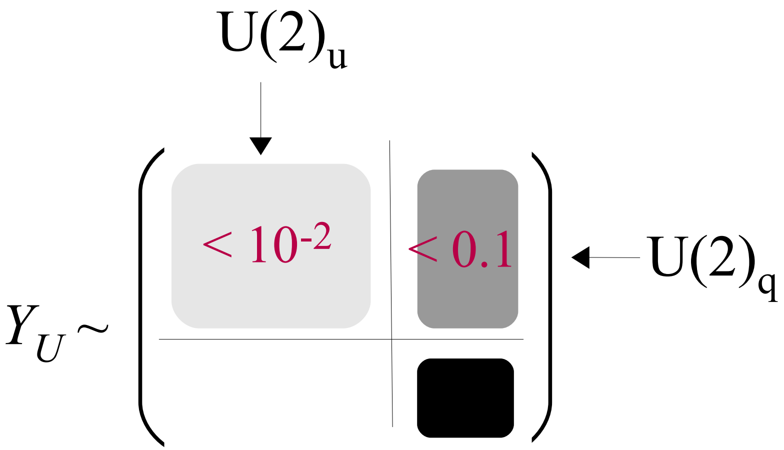


NP coupled mainly to ψ_3

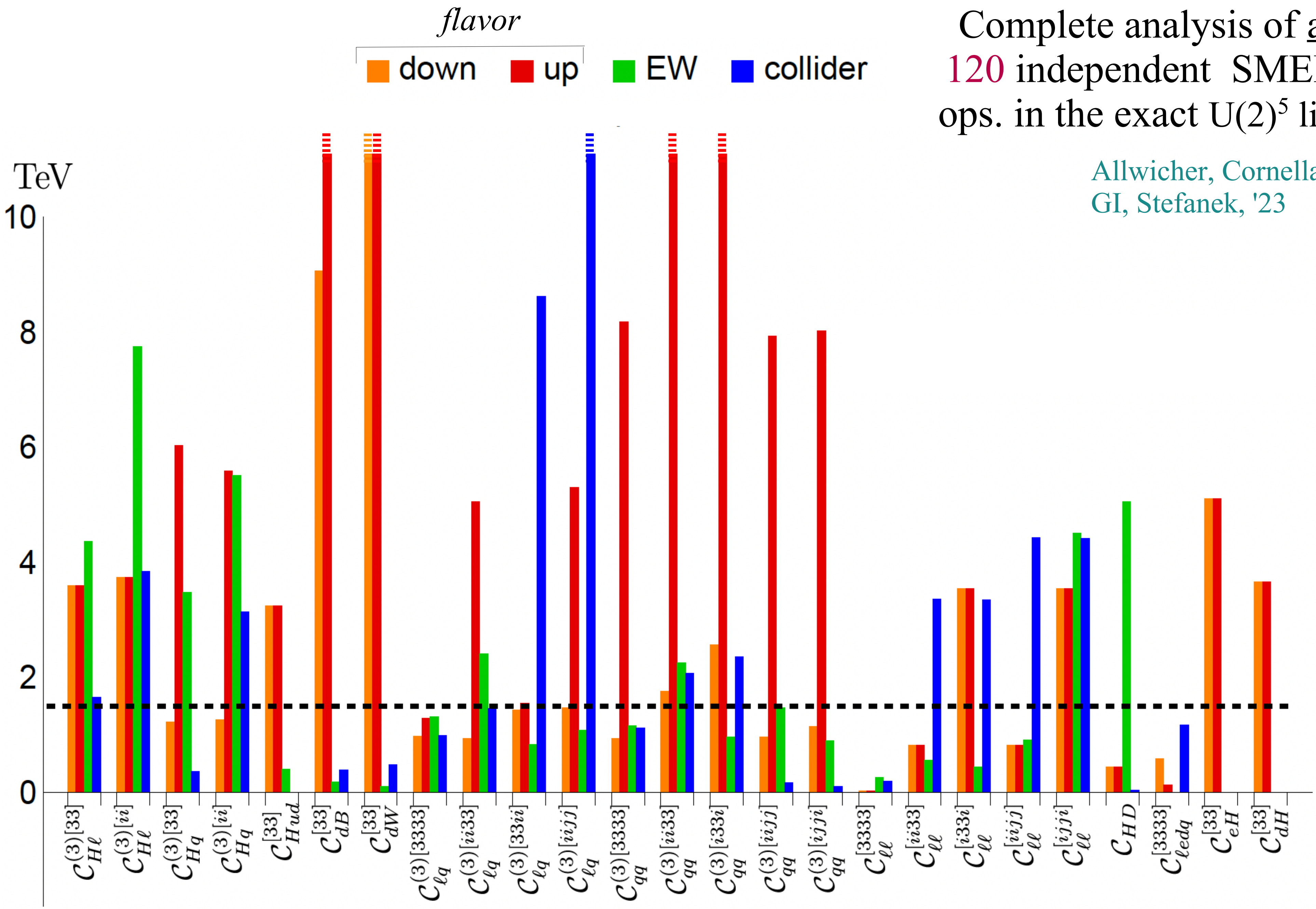
$\psi_{1,2}$ ~ massless [$U(2)^n$ symm.]

Barbieri *et al.* '11
GI & Straub '12



Effective organizing principle for the flavor structure of the SMEFT

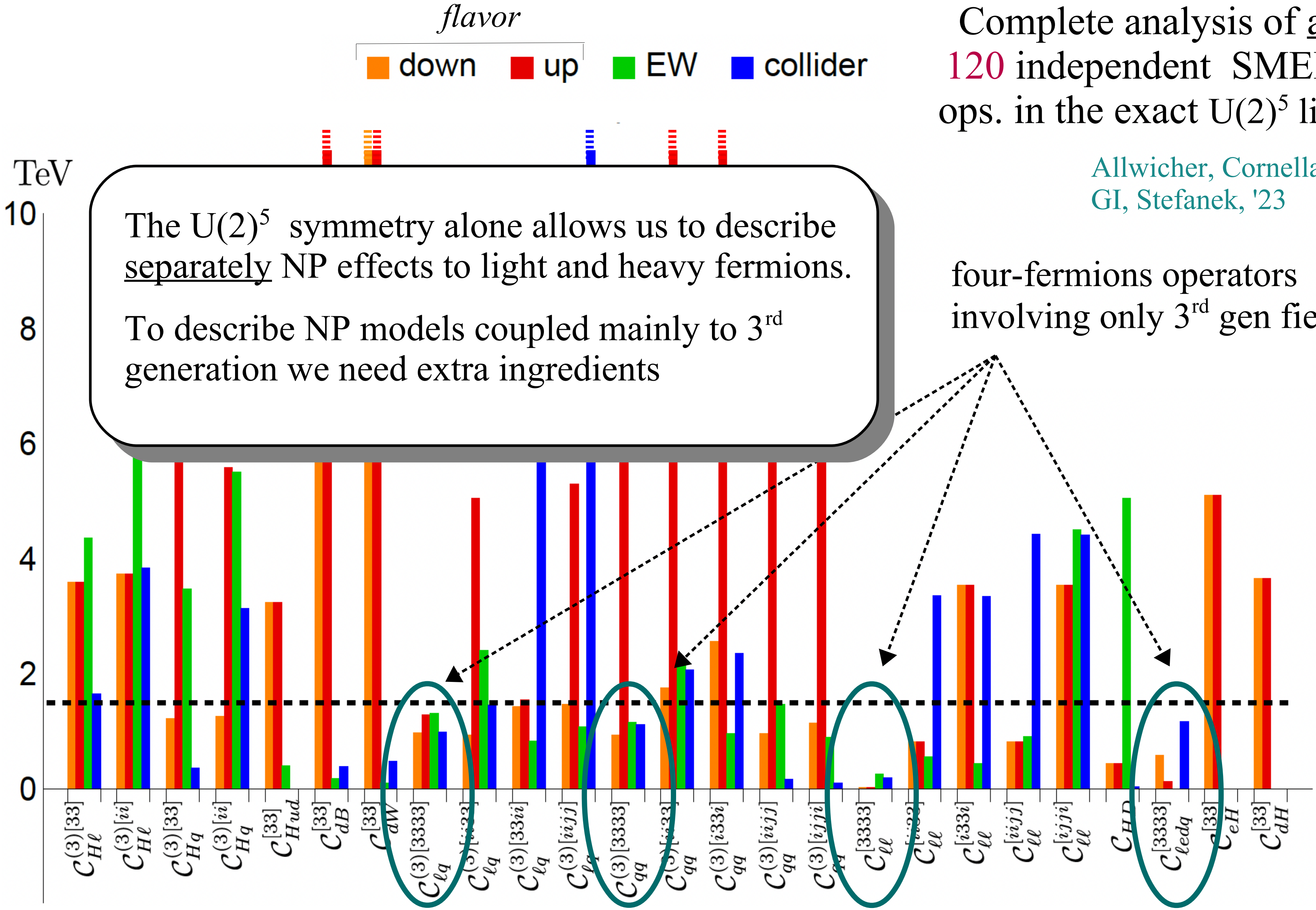
SM-EFT bounds in the U(2)^5 *symmetric limit*



Complete analysis of <u>all</u>
120 independent SMEFT
ops. in the exact U(2)^5 limit

Allwicher, Cornella,
GI, Stefanek, '23

SM-EFT bounds in the U(2)^5 symmetric limit



The U(2)^5 symmetry alone allows us to describe <u>separately</u> NP effects to light and heavy fermions.

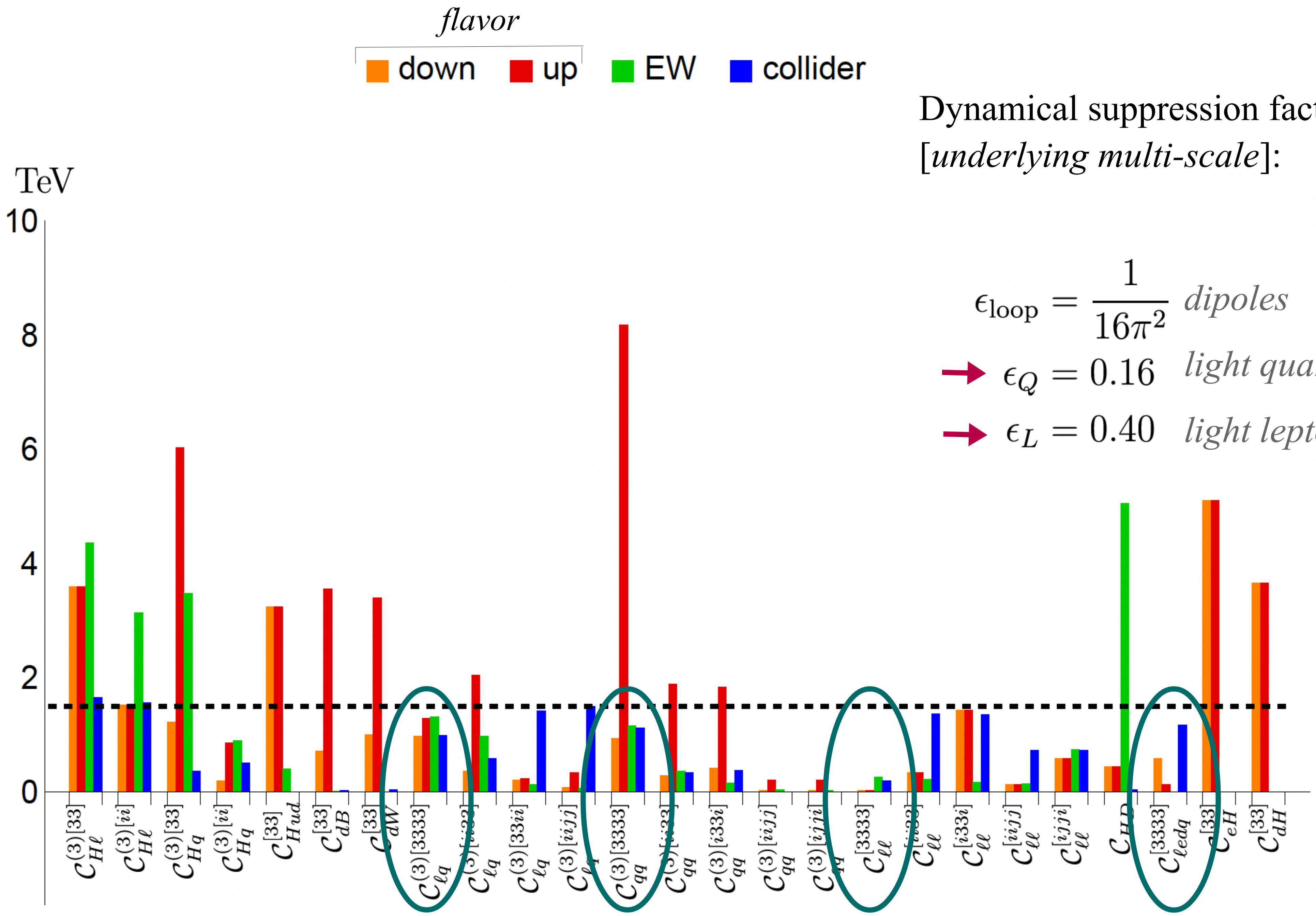
To describe NP models coupled mainly to 3rd generation we need extra ingredients

Complete analysis of <u>all</u> 120 independent SMEFT ops. in the exact U(2)^5 limit

Allwicher, Cornella, GI, Stefanek, '23

four-fermions operators involving only 3rd gen fields

SM-EFT bounds in the $\mathrm{U}(2)^5$ symmetric limit



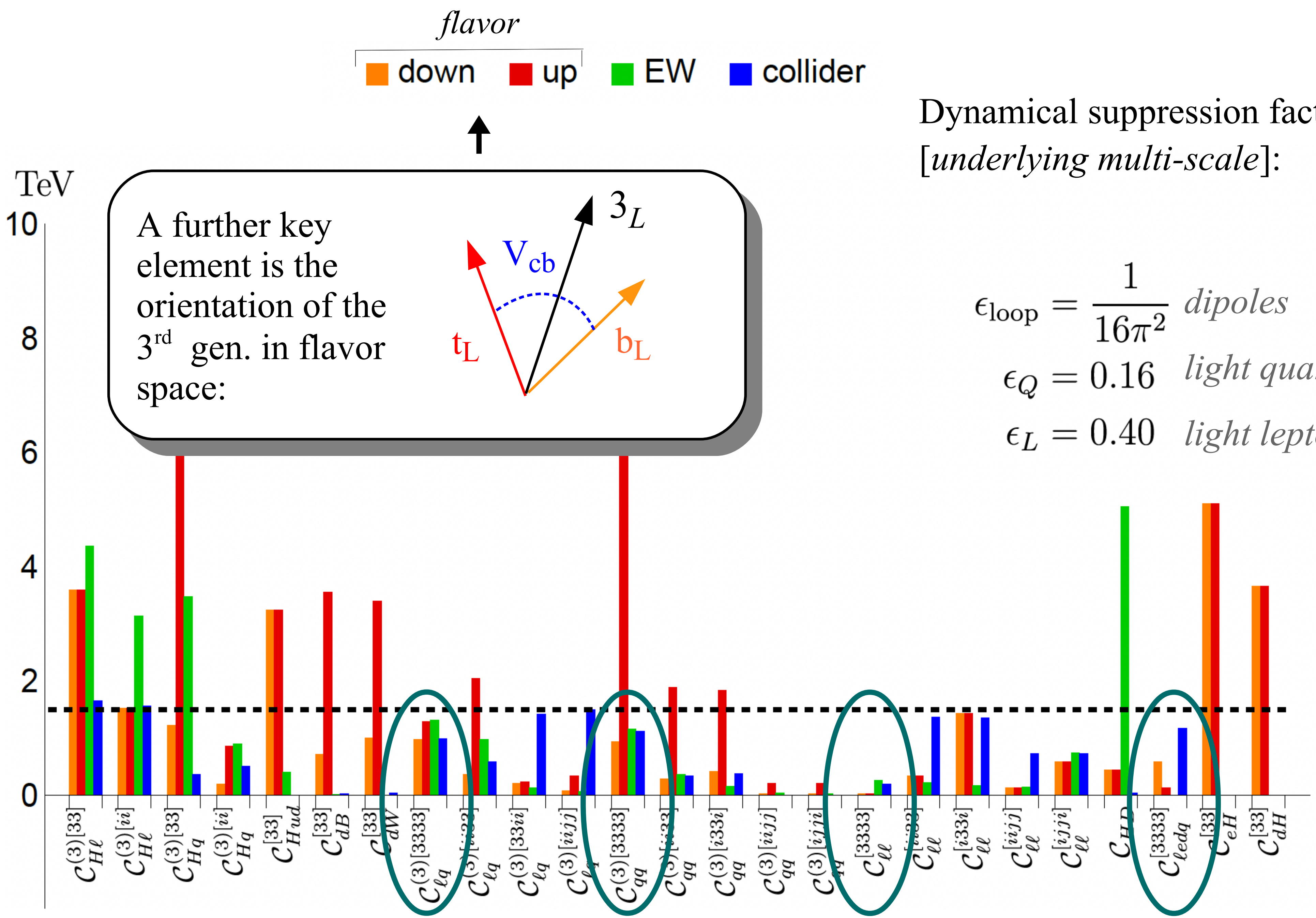
Dynamical suppression factors [*underlying multi-scale*]:

$$\epsilon_{\rm loop} = \frac{1}{16\pi^2}$$ *dipoles*

→ $\epsilon_Q = 0.16$ *light quarks*

→ $\epsilon_L = 0.40$ *light leptons*

SM-EFT bounds in the U(2)^5 symmetric limit



A further key element is the orientation of the 3$^{\text{rd}}$ gen. in flavor space:

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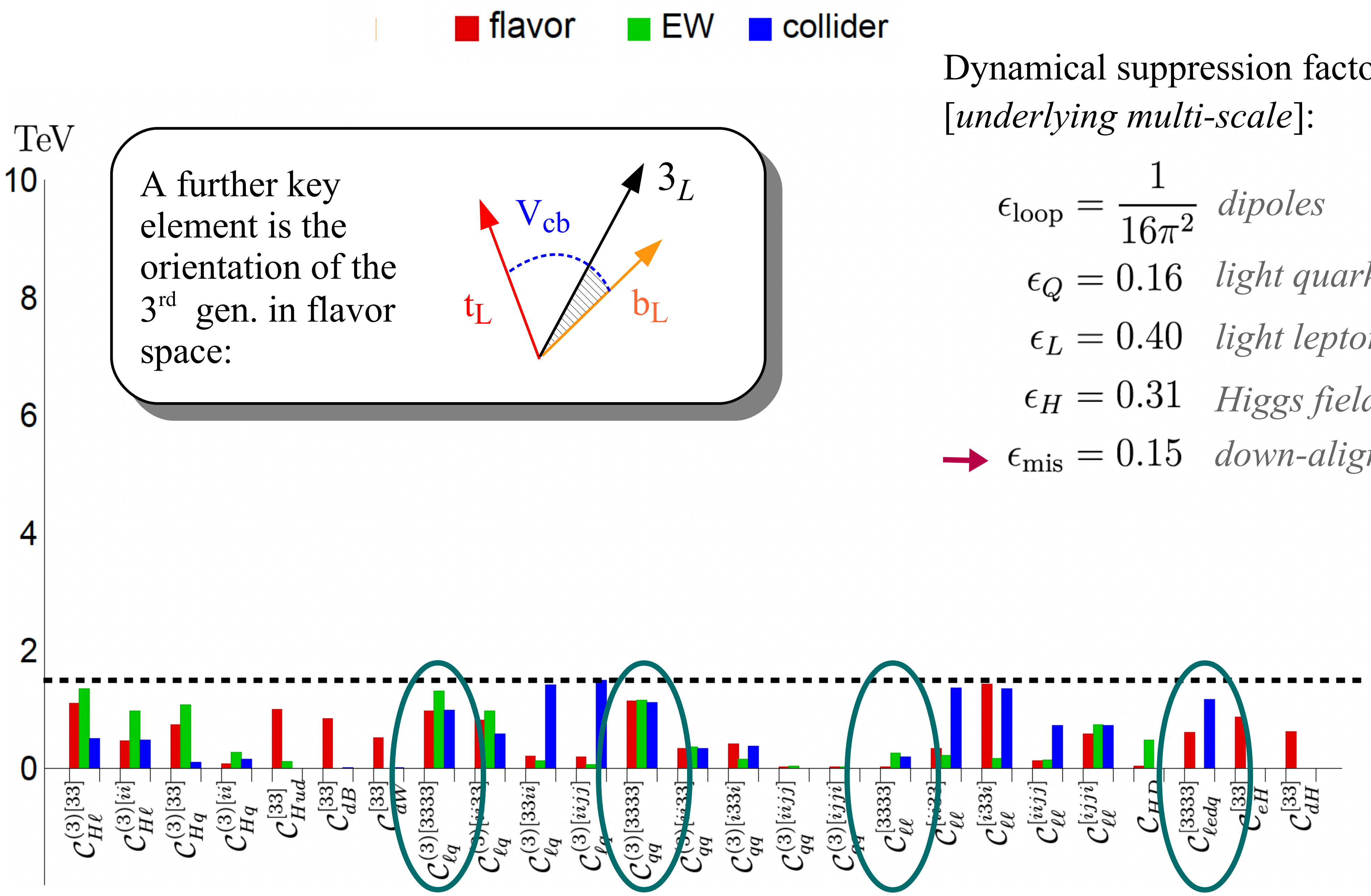

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$$\epsilon_{\text{loop}} = \frac{1}{16\pi^2}$$ *dipoles*

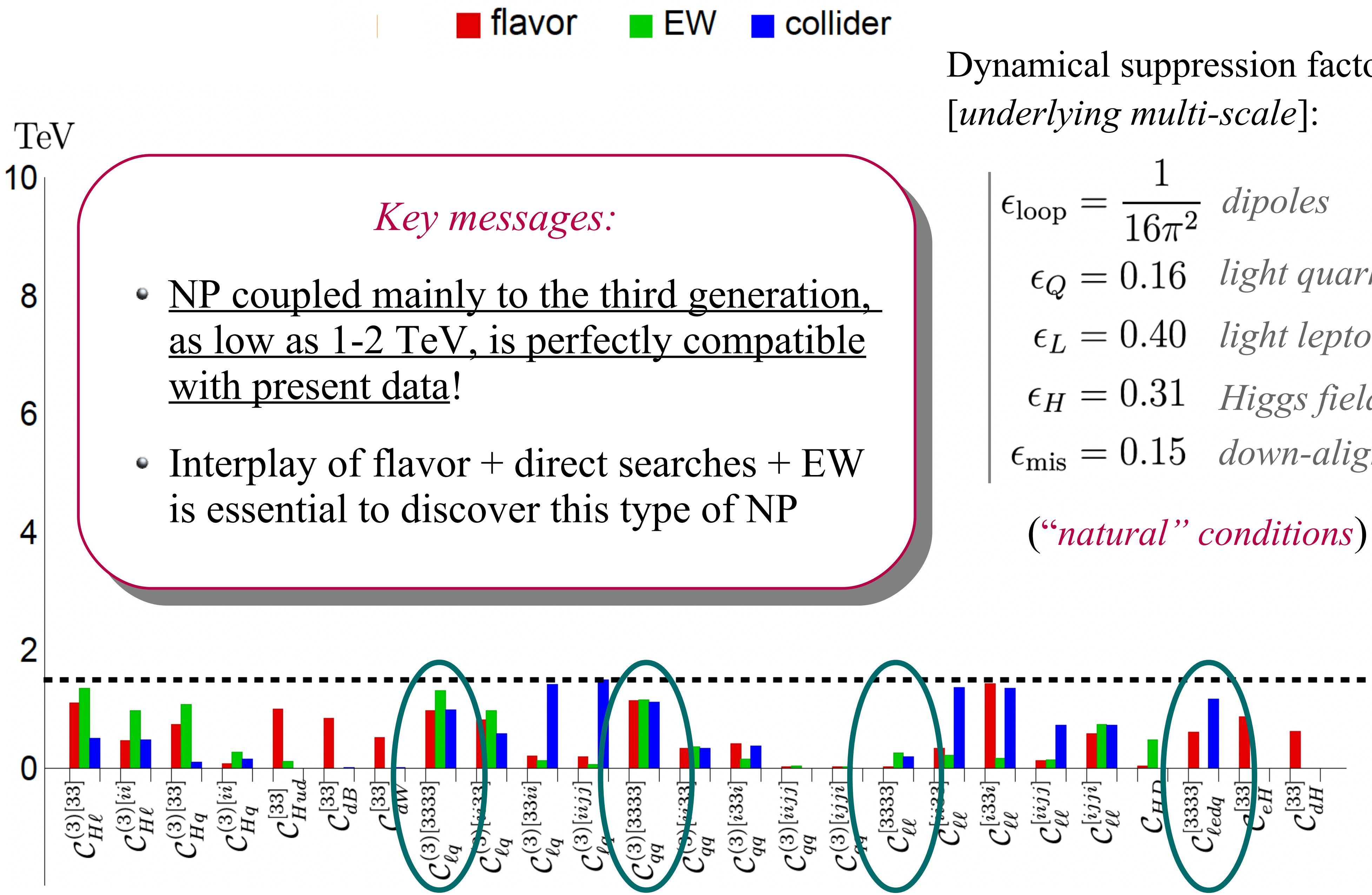
$$\epsilon_Q = 0.16$$ *light quarks*

$$\epsilon_L = 0.40$$ *light leptons*

$$\epsilon_H = 0.31$$ *Higgs fields*

→ $$\epsilon_{\text{mis}} = 0.15$$ *down-align.*

SM-EFT bounds in the U(2)^5 symmetric limit



Key messages:

- NP coupled mainly to the third generation, as low as 1-2 TeV, is perfectly compatible with present data!
- Interplay of flavor + direct searches + EW is essential to discover this type of NP

Dynamical suppression factors [*underlying multi-scale*]:

$$\epsilon_{\rm loop} = \frac{1}{16\pi^2} \quad \textit{dipoles}$$
$$\epsilon_Q = 0.16 \quad \textit{light quarks}$$
$$\epsilon_L = 0.40 \quad \textit{light leptons}$$
$$\epsilon_H = 0.31 \quad \textit{Higgs fields}$$
$$\epsilon_{\rm mis} = 0.15 \quad \textit{down-align.}$$

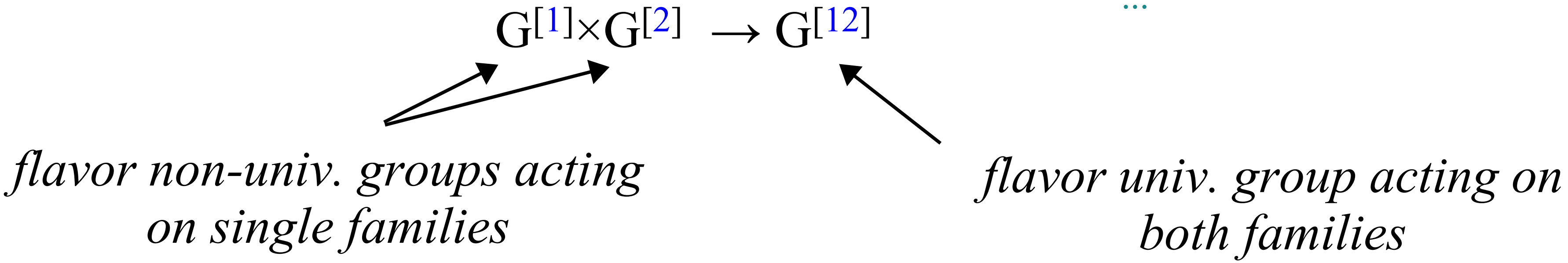
(*"natural" conditions*)

Flavor Deconstruction

Going beyond the EFT approach, a consistent way to construct a multi-scale theory with flavor non-universal interactions is via the *"flavor deconstruction"* of the SM gauge symmetries:

Arkani-Hamed, Cohen, Georgi '01
Craig, Green, Katz, '11
...

- Basic idea:



$$G^{[1]}\times G^{[2]} \to G^{[12]}$$

flavor non-univ. groups acting on single families

flavor univ. group acting on both families

General model-building features:

- ✓ The symmetry breaking pattern is very general: any scalar rep. (provided $R_{[1]}, R_{[2]} \neq 1$) breaks to the diagonal subgroup → flavor universality emerges "naturally" at low energies

Michel & Radicati '68
Craig, Garcia-Garcia, Sutherland '17

- ✓ Flavor hierarchies obtained without the need of peculiar choices for the "flavor charges" [e.g. U(1) charges as in Froggatt & Nielsen]

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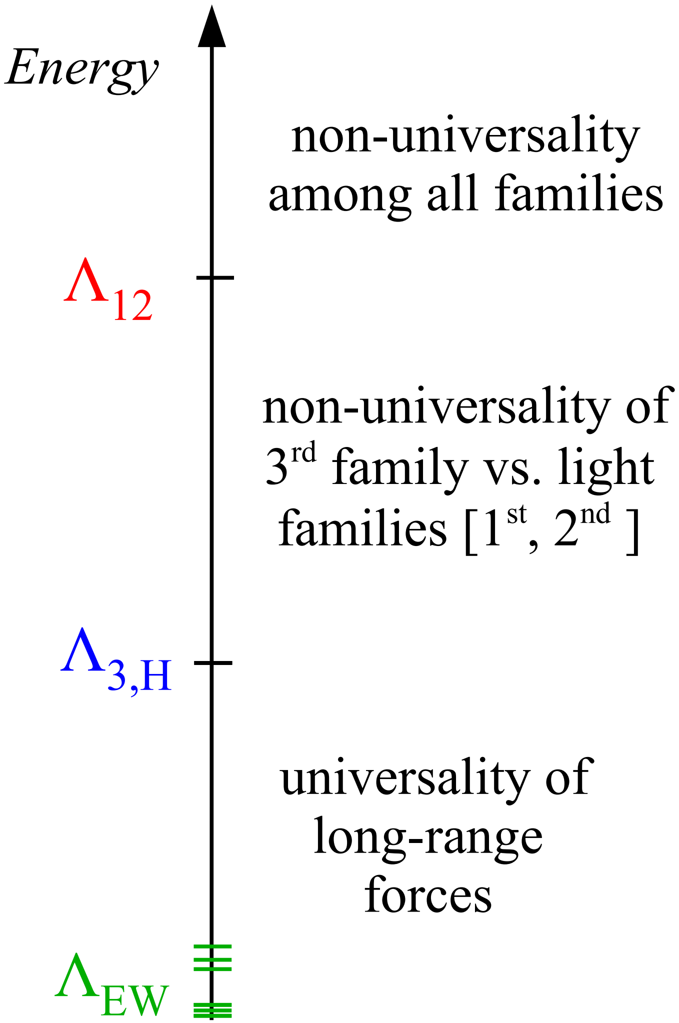
Bordone *et al.* '17, Allwicher *et al.* '20
Davighi & GI '23, Davighi & Stefanek '23
Navarro & King '22 & '23
Barbieri & GI '24



Energy

non-universality among all families

Λ_{12}

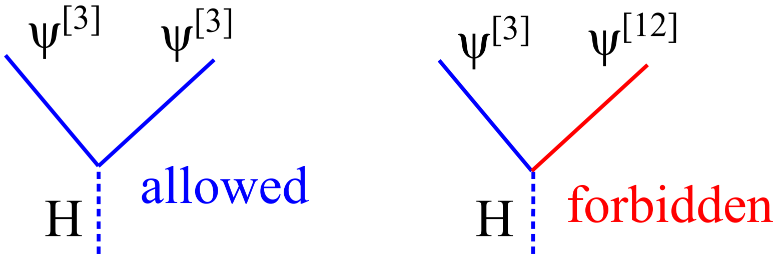
non-universality of 3rd family vs. light families [1st, 2nd]

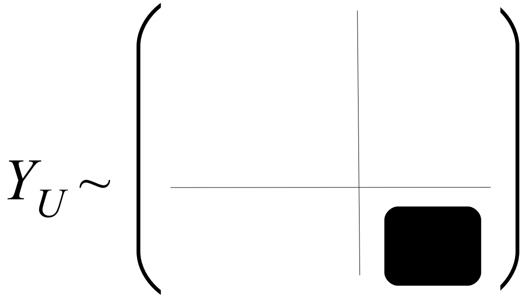
$\Lambda_{3,H}$

universality of long-range forces

Λ_{EW}

$G^{[3]} \times G^{[12]}$





▶ *Flavor Deconstruction*

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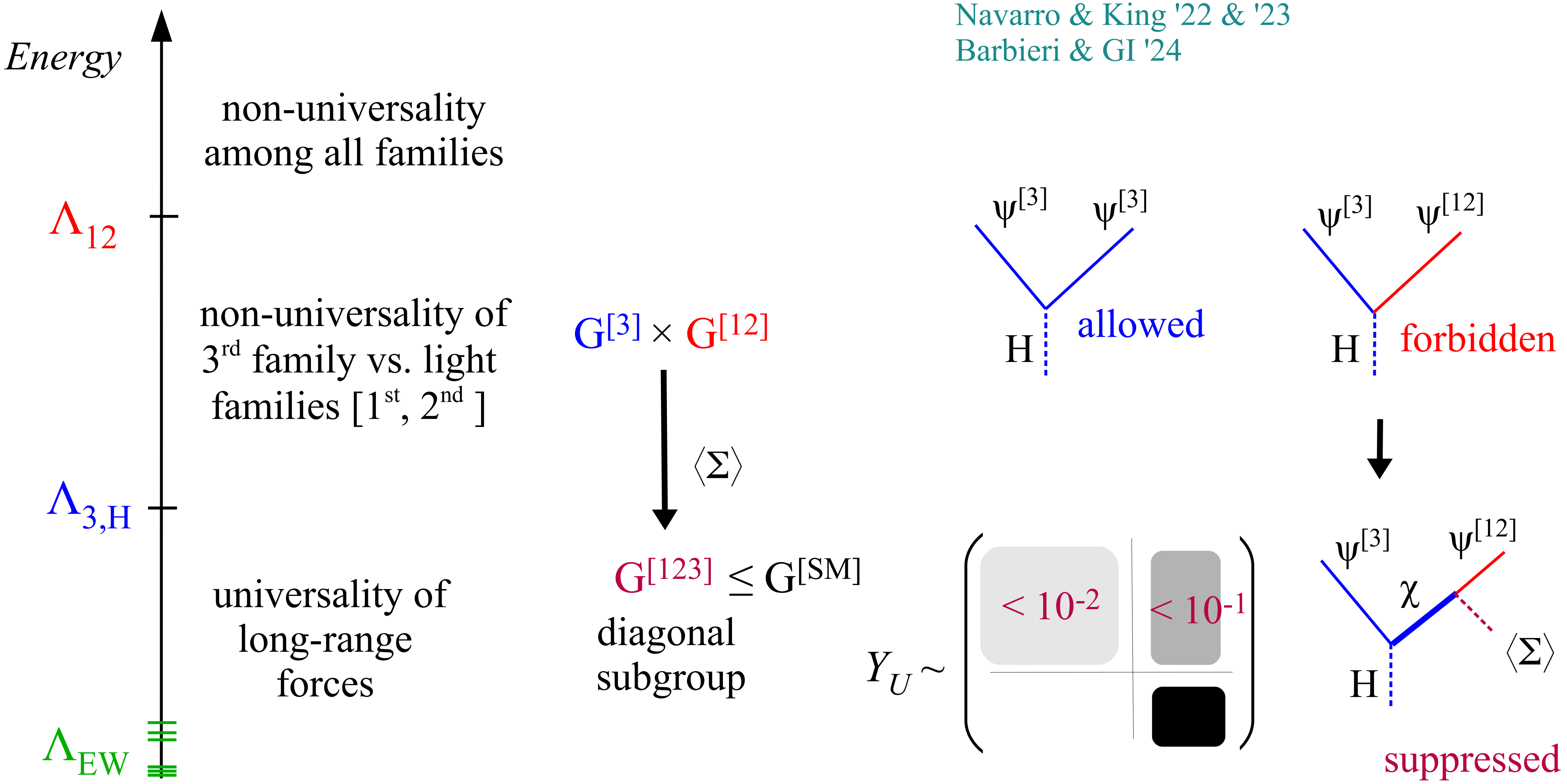


non-universality among all families

non-universality of 3rd family vs. light families [1st, 2nd]

universality of long-range forces

$$G^{[3]} \times G^{[12]} \xrightarrow{\langle\Sigma\rangle} G^{[123]} \leq G^{[SM]}$$

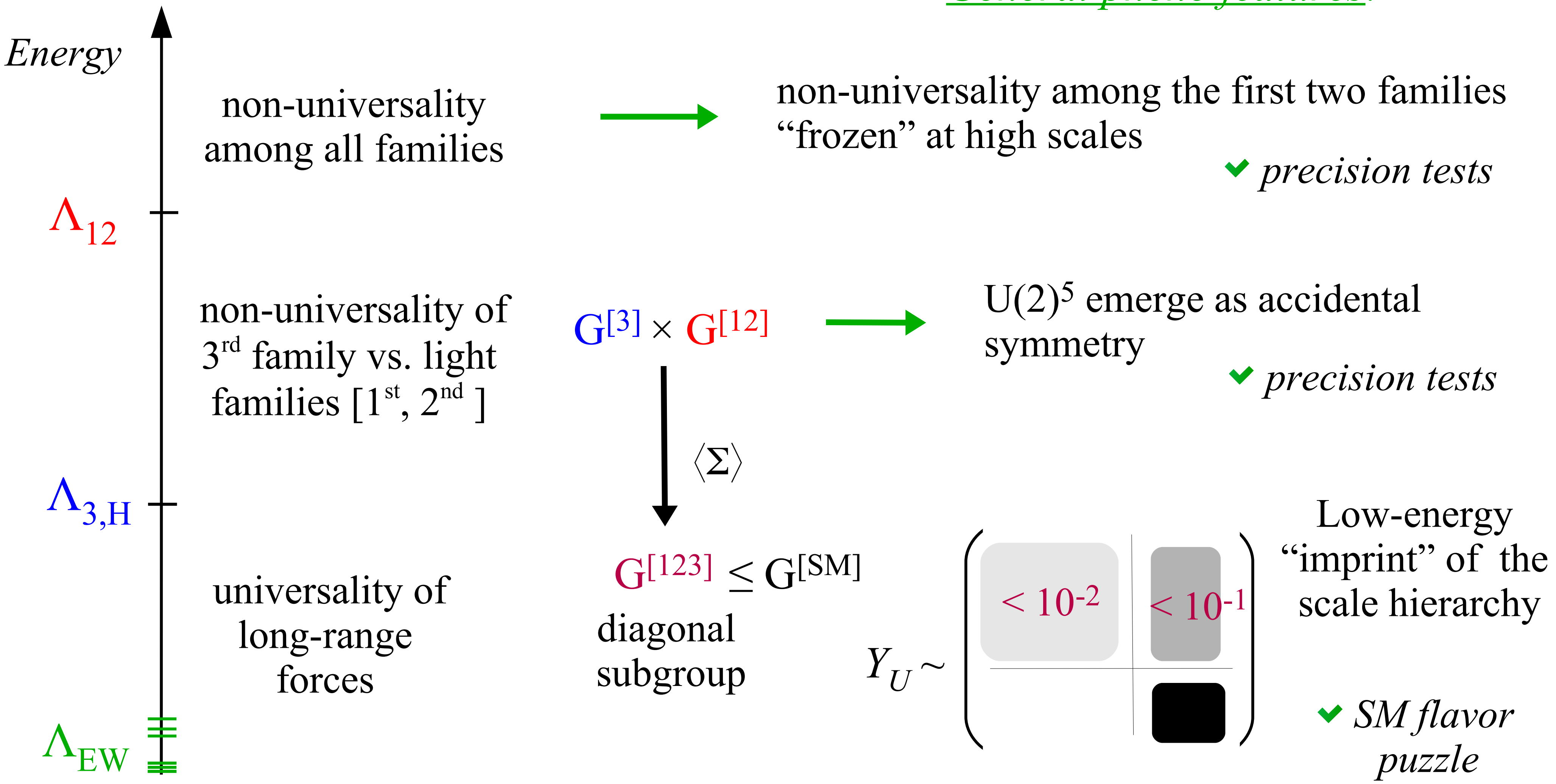
diagonal subgroup

$$Y_U \sim \begin{pmatrix} < 10^{-2} & < 10^{-1} \\ & \blacksquare \end{pmatrix}$$

Flavor Deconstruction

Going beyond the EFT approach, a consistent way to construct a multi-scale theory with flavor non-universal interactions is via the *"flavor deconstruction"* of the SM gauge symmetries:

General pheno features:



non-universality among all families → non-universality among the first two families "frozen" at high scales

✓ *precision tests*

non-universality of 3rd family vs. light families [1st, 2nd]

$G^{[3]} \times G^{[12]}$ → U(2)^5 emerge as accidental symmetry

✓ *precision tests*

$\langle\Sigma\rangle$

universality of long-range forces

$G^{[123]} \leq G^{[SM]}$

diagonal subgroup

$$Y_U \sim \begin{pmatrix} < 10^{-2} & < 10^{-1} \\ & \blacksquare \end{pmatrix}$$

Low-energy "imprint" of the scale hierarchy

✓ *SM flavor puzzle*

Flavor Deconstruction & partial compositeness

The FD hypothesis alone does not address the EW hierarchy problem. However, it provides some basic ingredients (*“light” new states coupled to Higgs and 3rd gen.*) which can help to address it → interesting specific advantage when merged to Higgs compositness

Fuentes-Martni & Stangl '20
Fuentes-Martin *et al.* '22

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Fuentes-Martni & Stangl '20
Fuentes-Martin *et al.* '22

Toy example [Covone, GI, Pesut '24]:

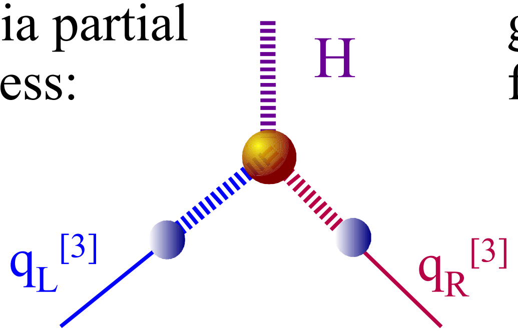
Minimal Composite Higgs:

$$\begin{array}{c} Sp(4) \\ \Big\downarrow \quad H \sim (2,2) \\ SU(2)_L \times SU(2)_R^{[3]} \end{array}$$

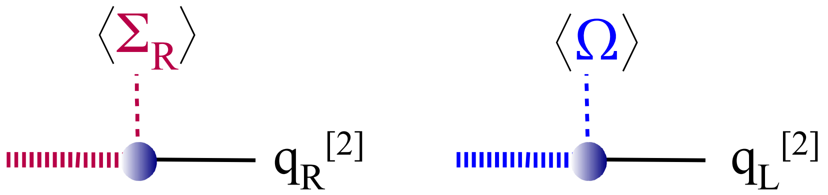
Flavor Deconstruction of Hypercharge:

$$\begin{array}{c} SU(2)_R^{[3]} \times U(1)_{B-L}^{[3]} \times U(1)_Y^{[12]} \\ \Big\downarrow \quad \langle \Sigma_R \rangle, \ \langle \Omega \rangle \\ U(1)_Y \end{array}$$

3rd family Yukawa couplings via partial compositeness:



Light Yukawas suppressed → higher-dim ops. generated by heavy (elementary) dynamics (e.g. VL fermions) above the compositeness scale:



Flavor Deconstruction & partial compositeness

An interesting feature emerges when computing explicitly the radiatively-induced Higgs potential:

$$V(h) = \Delta V_f(h) + \Delta V_A(h) \approx c_0 - c_1 \sin^2\left(\frac{h}{2F}\right) + c_2 \sin^4\left(\frac{h}{2F}\right)$$

$$\left.\frac{c_1}{F^4}\right|_{\text{phys.}} = \frac{m_h^2}{F^2} \lesssim 0.06$$

Unavoidable tuning
[given current bounds on F]

- Model-independent O(1) fermion contribution (y_t)
- Possible cancellation from gauge sector <u>if</u> $g_R^{[3]} \gtrsim 1$ & $g_R\langle\Sigma_R\rangle < M_\rho$

$$\left.\frac{c_2}{F^4}\right|_{\text{phys.}} = \frac{2m_h^2}{v^2} \approx \frac{1}{2}$$

requires light top partners
(*as in ordinary CH*)

The cancellation occurs in the "natural" parameter space dictated by the flavor-deconstruction hypothesis

Flavor Deconstruction & partial compositeness

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Benchmark scenario

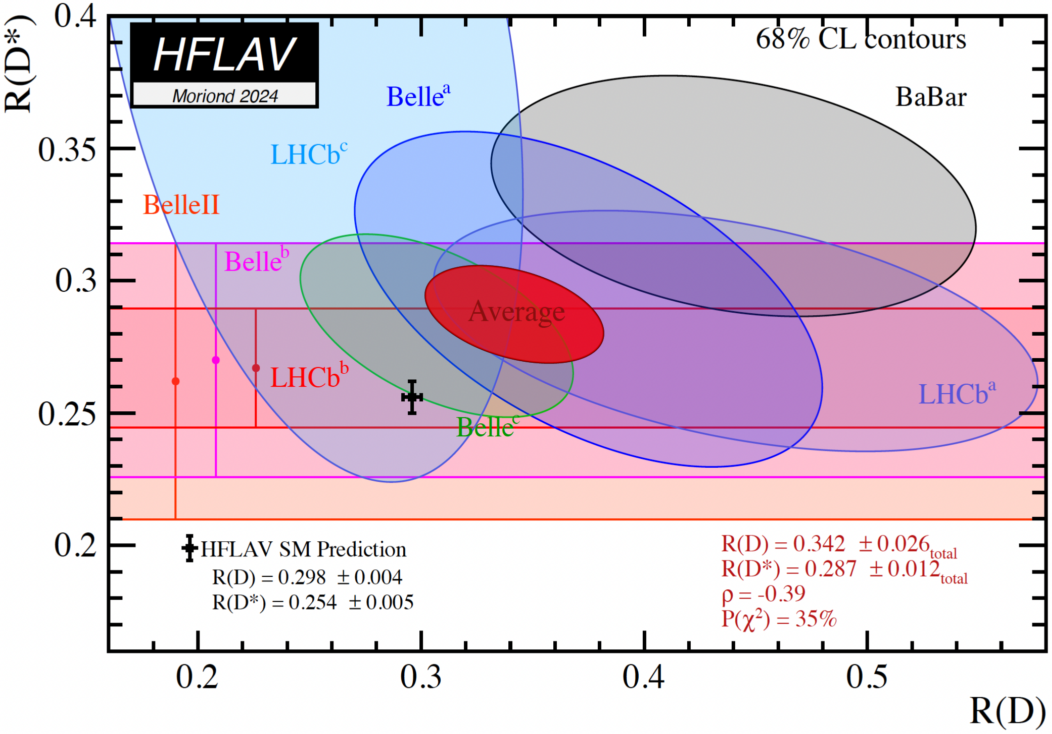
- Large 3rd gen. RH gauge coupling: $g_{R,3} = O(1)$
- Light Top partner $M_T \approx 2$ TeV and $M_\rho \approx 10$ TeV
- Compositeness scale $F \approx 750\,\text{GeV}$ and $v_\Sigma \approx 3$ TeV

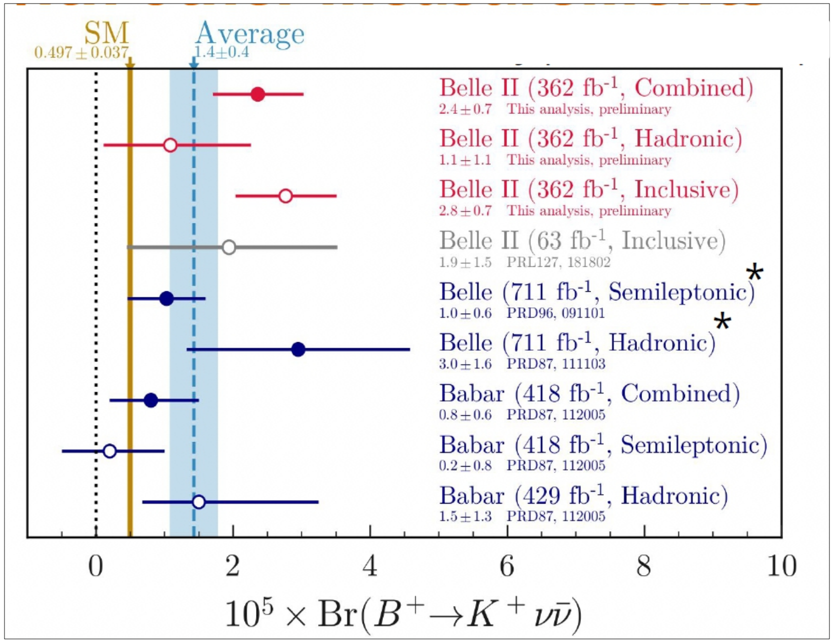
All constraints are satisfied and $\delta_{\text{EW}} \lesssim 10^{-3}$

→ 3% tuning in the potential

→ $O(1\%)$ corrections to Higgs couplings

A brief look to current data & future prospects





Premise: 3rd family quark-lepton unification

All possible flavor-deconstructed versions of the SM gauge group with I) semi-simple embedding in the UV + 1I) FD affecting 3rd family @ TeV scale have been classified [Davighi & GI '23] (*not many options*) → general expectation: quark-lepton unification a la Pati-Salam for the 3rd gen:

$$\begin{array}{c} \mathrm{SU}(4)^{[3]}\times \mathrm{SU}(3)^{[12]}\times G_{EW} \\ \Big\downarrow \\ \mathrm{SU}(3)\times \mathrm{SU}(2)_L\times \mathrm{U}(1)_Y \end{array}$$

Fermions in SU(4): $\begin{bmatrix} Q^\alpha \\ Q^\beta \\ Q^\gamma \\ L \end{bmatrix}$

Main Pati-Salam idea:
Lepton number as "the 4th color"

- ✓ Explain charge quantization

$$\mathrm{SU}(4)\sim \left[\begin{array}{c:c} \mathrm{SU}(3)_C & 0 \\ \hdashline 0 & 0 \end{array}\right] + \left[\begin{array}{c:c} 0 & LQ \\ \hdashline LQ & \end{array}\right] + \left[\begin{array}{c:c} \frac{1}{3} & 0 \\ \hdashline 0 & -1 \end{array}\right]$$

B-L generator

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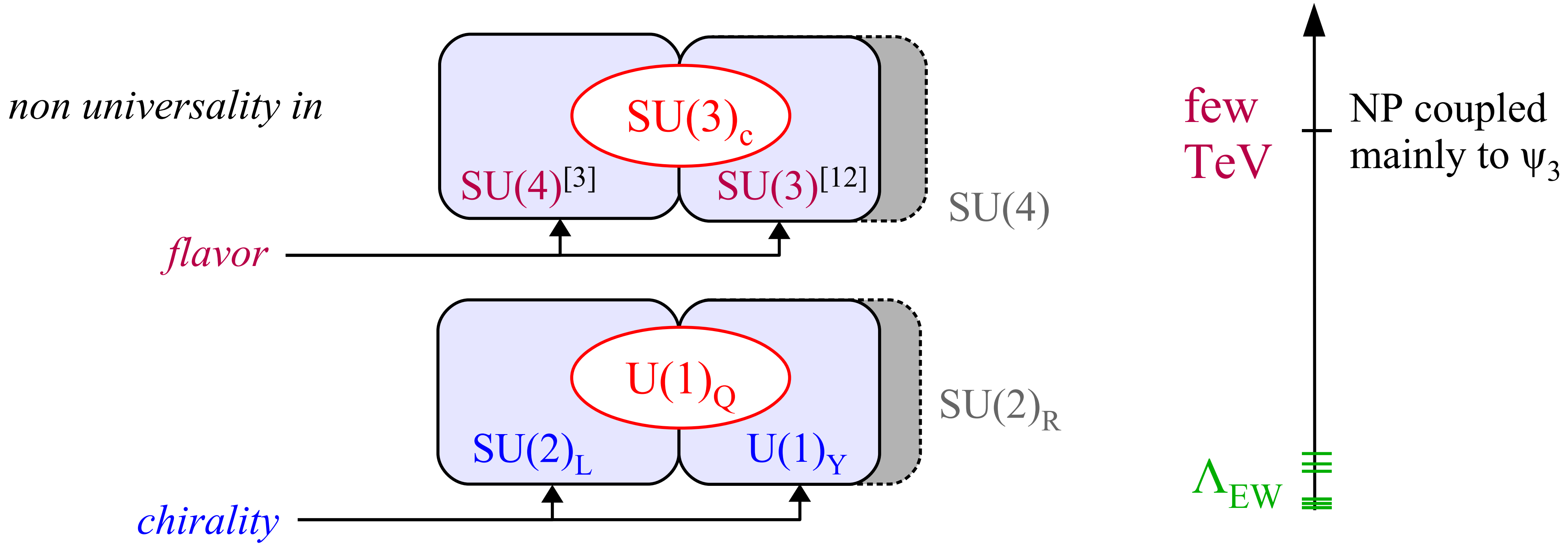

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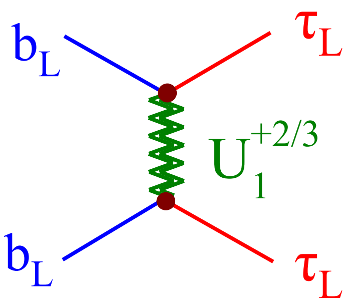
$$\begin{tikzcd}
SU(4)^{[3]}\times SU(3)^{[12]}\times G_{EW} \arrow[d] \arrow[r] & \text{vector leptoquark} \\
SU(3)\times SU(2)_L\times U(1)_Y &
\end{tikzcd}$$



✓ Explain charge quantization

✓ Might explain some existing tensions in B-physics data

$$SU(4) \sim \left[\begin{array}{c|c} SU(3)_C & 0 \\ \hline 0 & 0 \end{array}\right] + \left[\begin{array}{c|c} 0 & LQ \\ \hline LQ & \end{array}\right] + \left[\begin{array}{c|c} \frac{1}{3} & 0 \\ \hline 0 & -1 \end{array}\right]$$

B-L generator

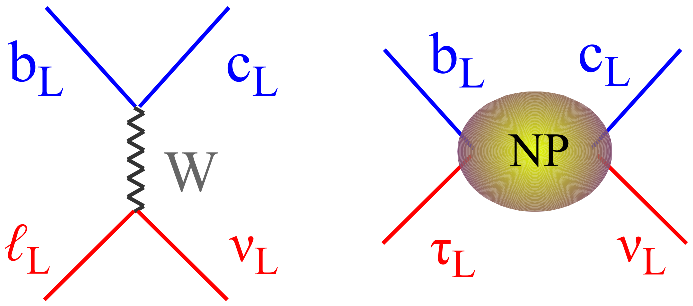
A brief look to current data & future prospects

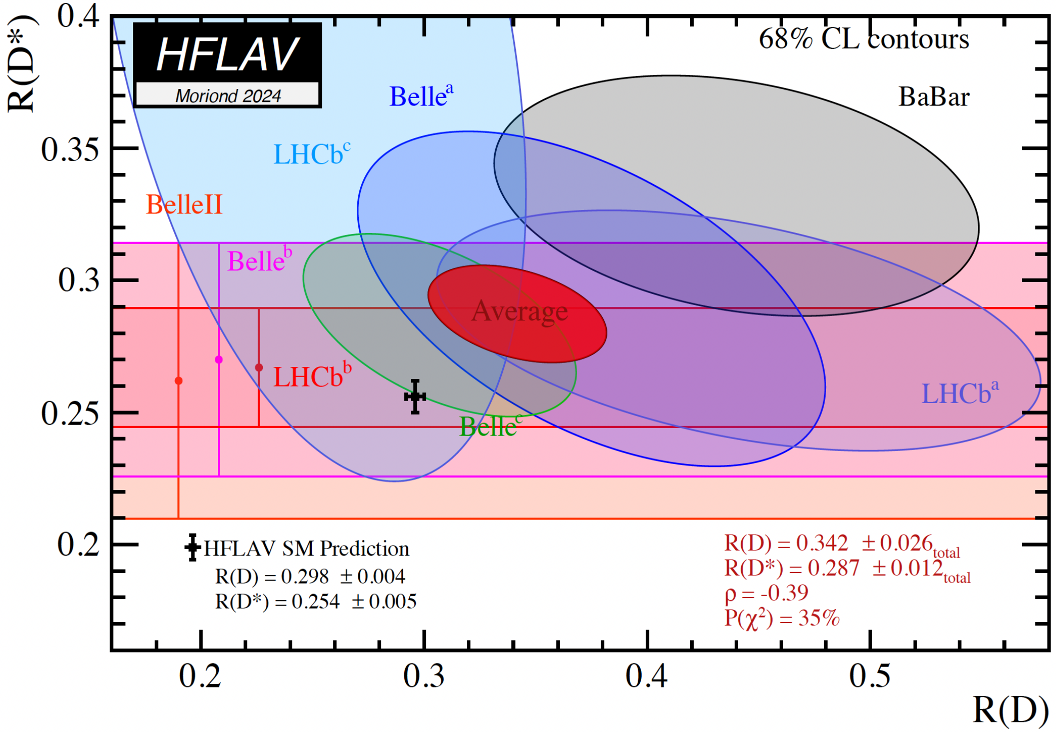
The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements (*with different degree of model-dependence*)

E.g.: I) Lepton universality violations in $b \to c\tau\nu$ decays

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

$$X = \text{D or D*}$$





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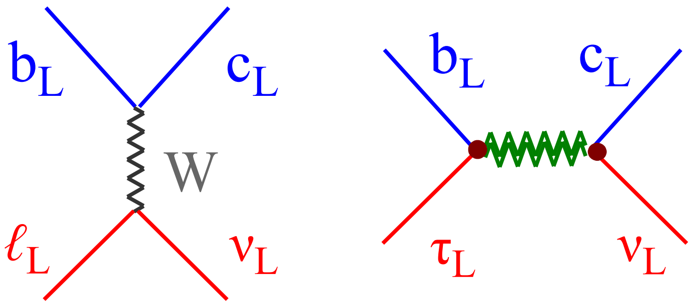
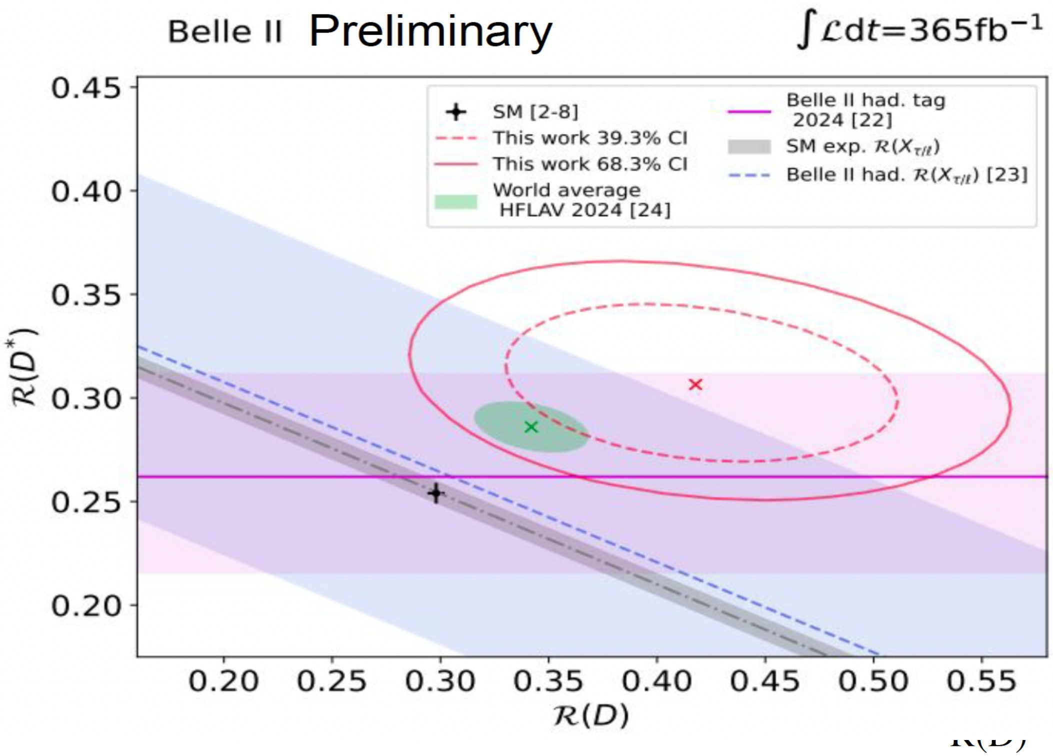


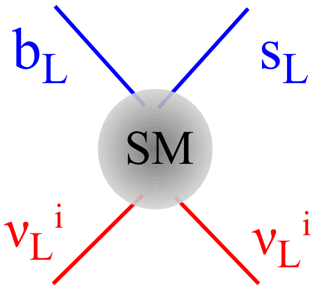


→ *The vector LQ of 3rd gen. quark-lepton unification is an ideal candidate to describe current data*

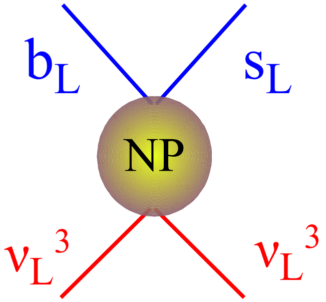
▶ *A brief look to current data & future prospects*

The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements (*with different degree of model-dependence*)

E.g.: II) Deviations from SM in b→sνν rates [3rd gen. ν in the final state]



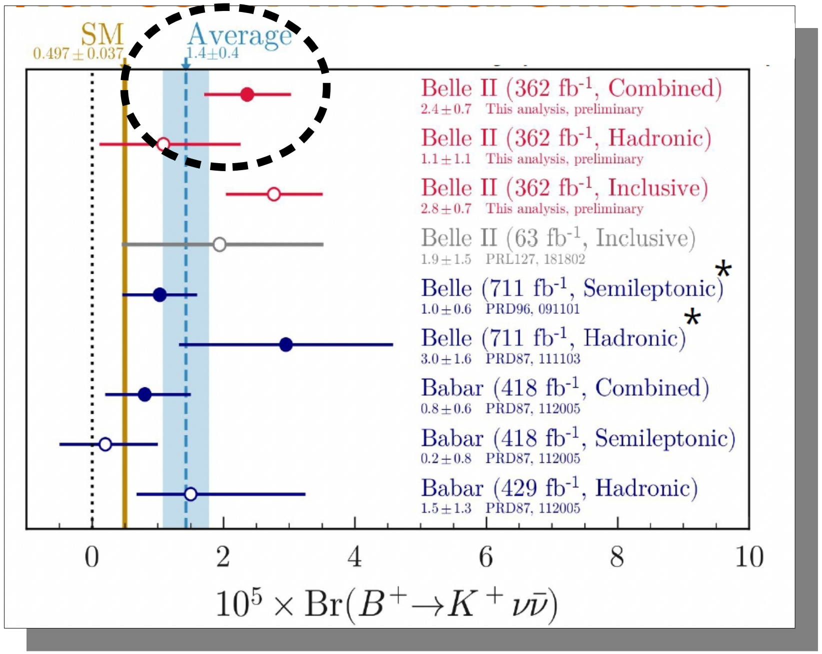
identical for all
neutrino species



relevant only for
3rd gen. neutrinos

Unambiguous prediction of O(50%) enhancement of B(B→Kνν) in the model with vector LQ – given excess in R(D).

Fuentes-Martin, GI, Konig, Selimovic, '20

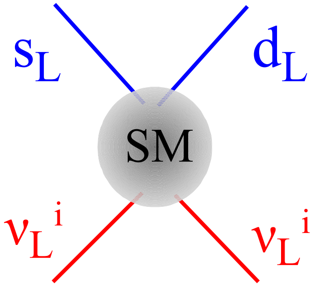


Belle-II '2023

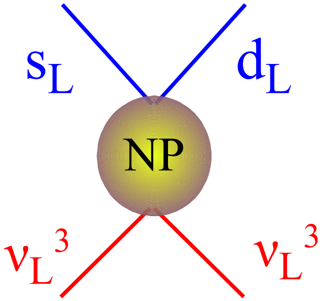
A brief look to current data & future prospects

The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements (*with different degree of model-dependence*)

E.g.: II) Deviations from SM in b→sνν rates… & s→dνν rates

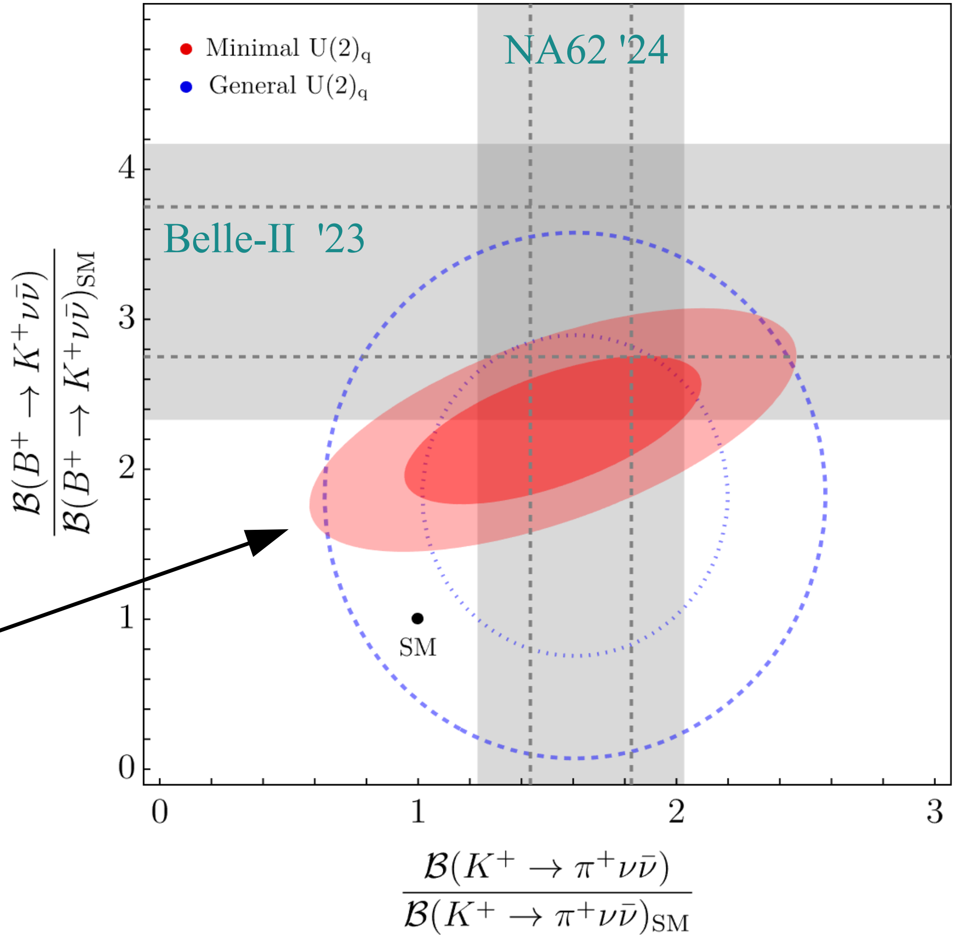


identical for all neutrino species



relevant only for 3rd gen. neutrinos

Close correlation of non-standard effects in B(B→Kνν) & B(K→πνν)



Bordone *et al.* '24

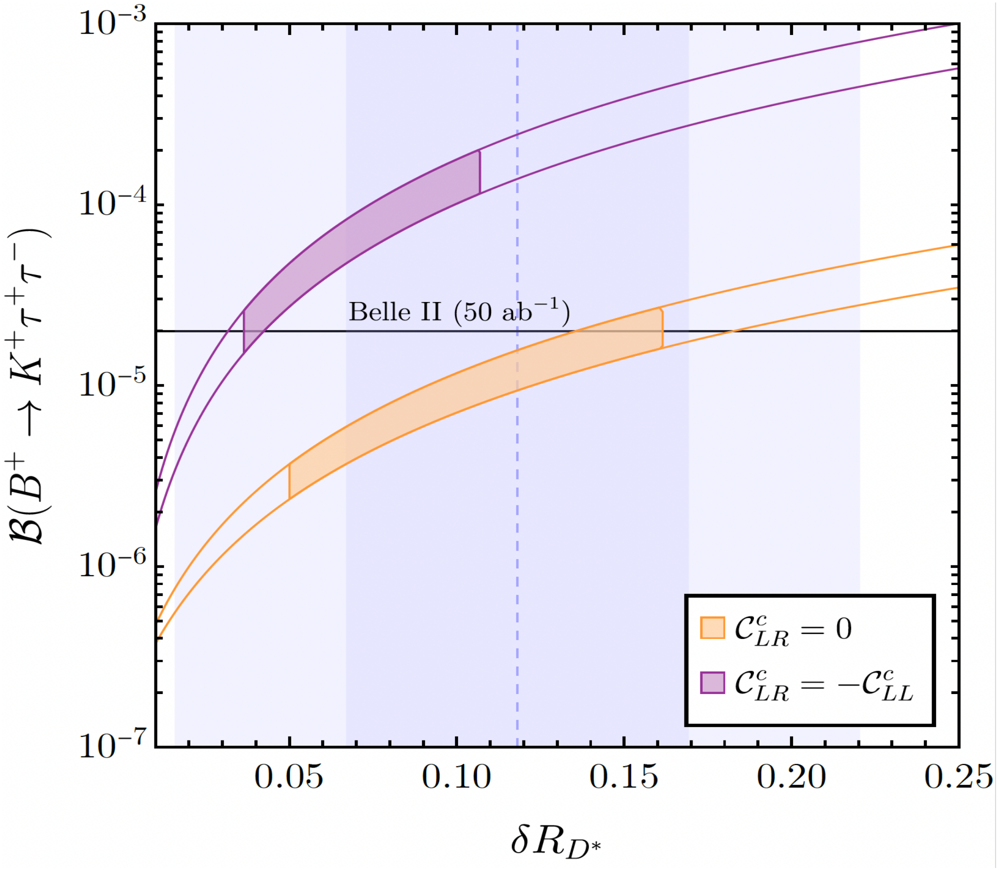
A brief look to current data & future prospects

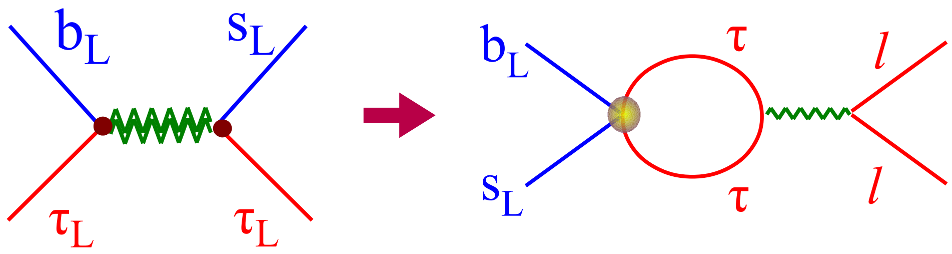
The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements (*with different degree of model-dependence*)

E.g.: III) Potential large enhancement of b→sττ rates

b→sττ are affected by the LQ already at the tree-level (contrary b→sνν)

- huge effect compared to SM in b→sττ (consitent with data)
- O(10%) effect in b→sll via RGE effects (*could explain current tenisons…*)

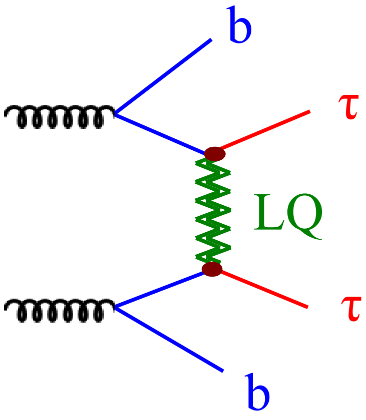




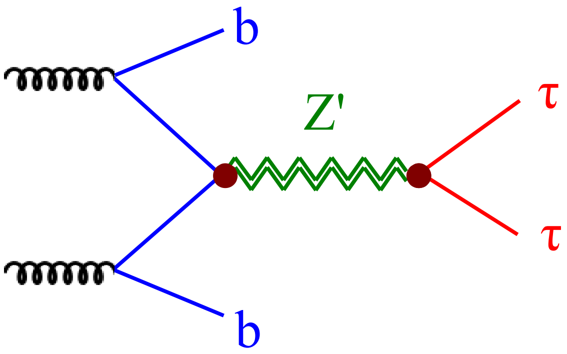
A brief look to current data & future prospects

The idea of flavor non-universal interactions – with a 1st layer of new physics already at the TeV scale – has several interesting implications for various low-energy measurements & collider observables

E.g.: IV) pp → $\tau\bar{\tau}$ (+ b-jets)

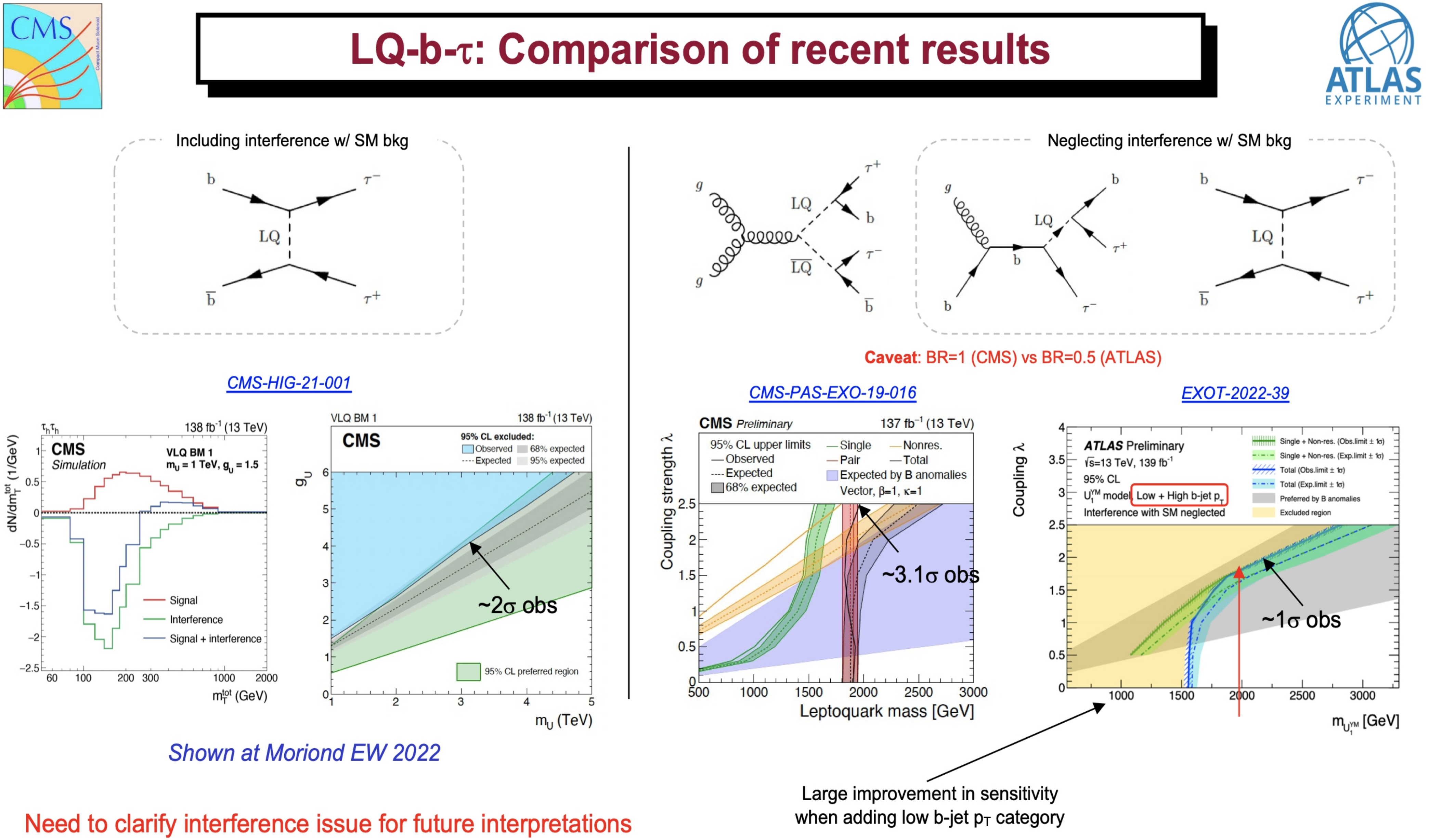


and / or



A brief look to current data & future prospects

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

CMS-PAS-EXO-19-016

EXOT-2022-39

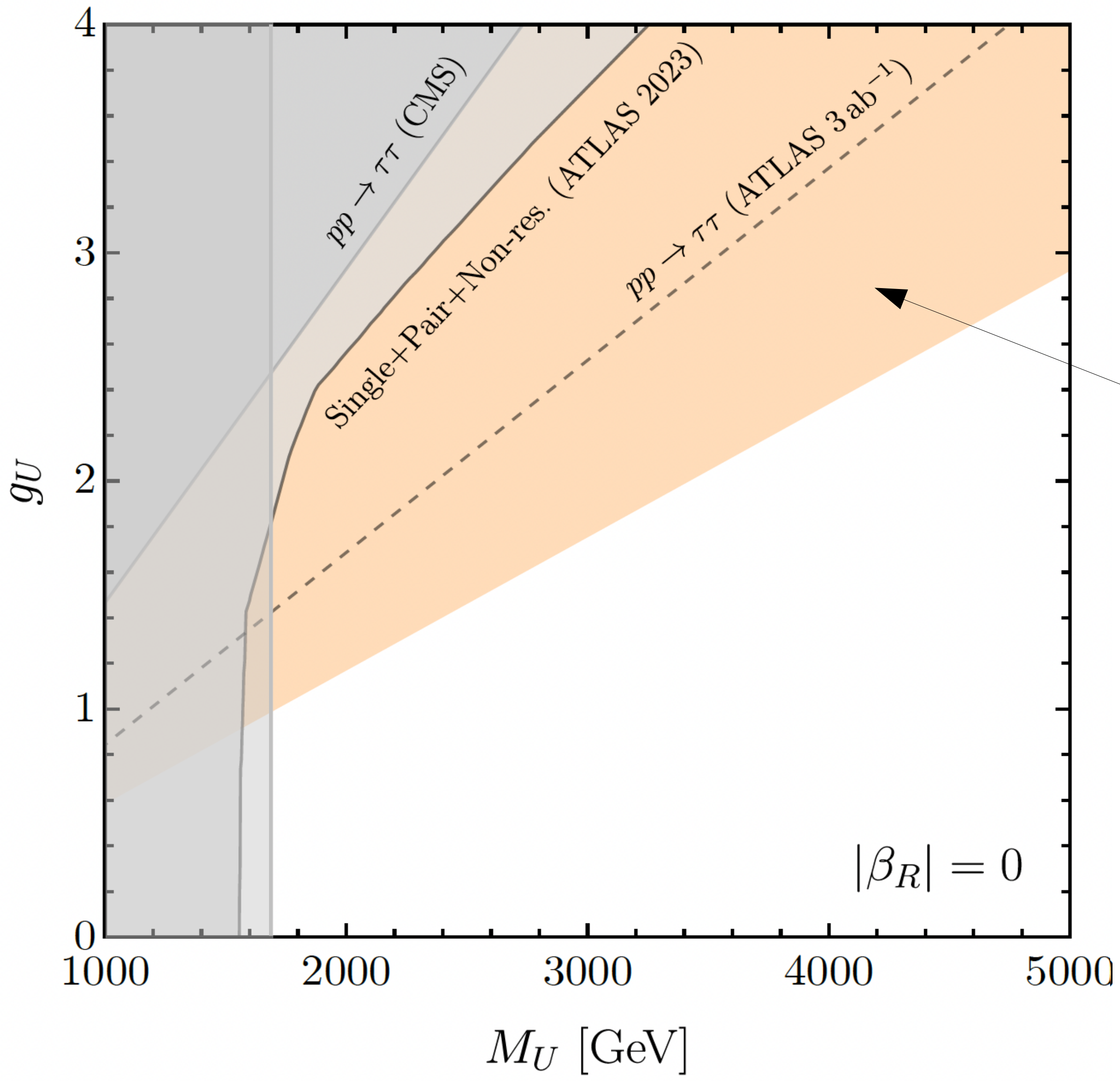
Shown at Moriond EW 2022

Need to clarify interference issue for future interpretations

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

A brief look to current data & future prospects

Leptoquark search in pp → $\tau\overline{\tau}$ (+ b-jets)



Updated preferred region by b → c low-energy data

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 renewed perspective toward the EW hierarchy problem (and the absence of direct signals of NP so far).

- The model-building efforts along this direction, initially triggered by the B anomalies, are still very motivated.

- If these ideas corrects, new non-standard effects should emerge soon both at low and at high energies → very interesting opportunities for near-future exp. in flavor physics (key role for Belle-II & LHCb-II)