The Flavor Path to New Physics

$b \to s\nu\bar{\nu}$ & related modes

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October 6, 2025 || KEK

Key questions

Questions I'd like to discuss:

- What does current data tell us about the flavor of physics beyond the SM? Connection to the SM flavor puzzle?
- Which role does $b \to s\nu\bar{\nu}$ play in shaping this picture? What's its interplay with other processes, e.g. with other flavor changing transitions ($s \to d\nu\bar{\nu}$, $b \to s\tau\tau\ldots$)?
- How will this change in the future, with existing and future facilities?

Caveats:

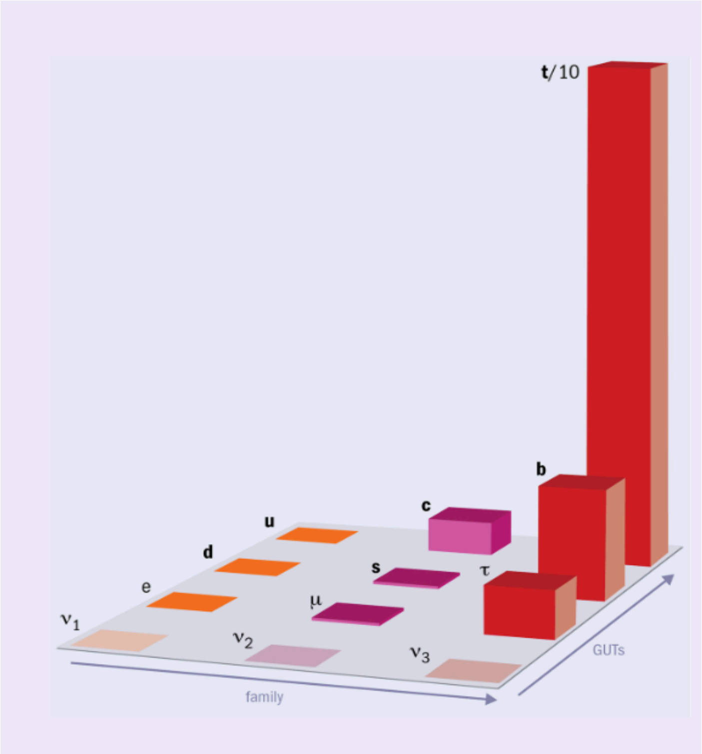
- Some overlap with other theory talks
- Not covered here:
  - light new physics scenarios
  - SM prediction challenges in $b \to s\nu\bar{\nu}$

Flavor in the Standard Model: puzzling aspects

SM flavor puzzle = a series of puzzling observations

3 copies x species, identical from the point of view of gauge interactions, yet seen very differently by the Higgs
[and by BSM giving mass to neutrinos]

- 12 orders of magnitude from neutrinos to the top mass
- pronounced mass hierarchies for charged fermions
- mixing looks very different in lepton vs quark sector



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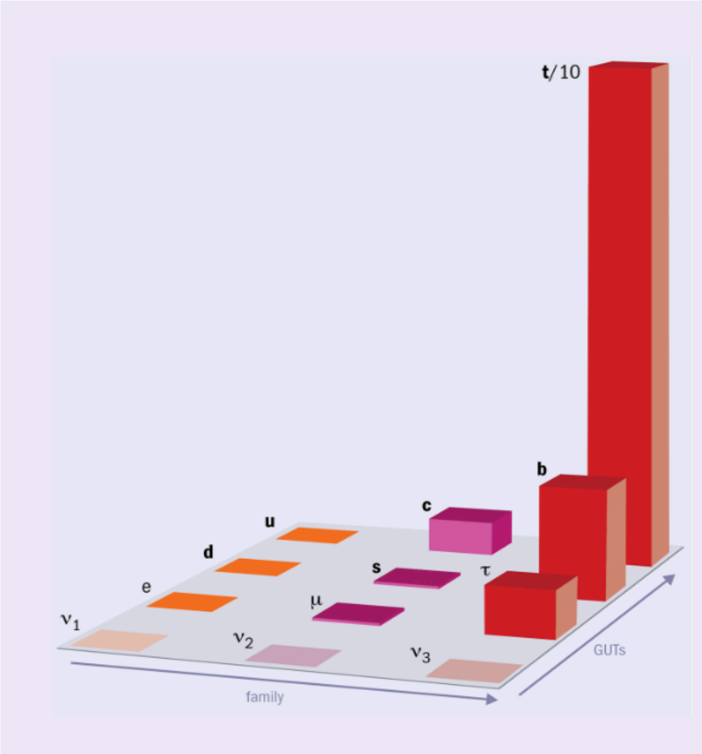


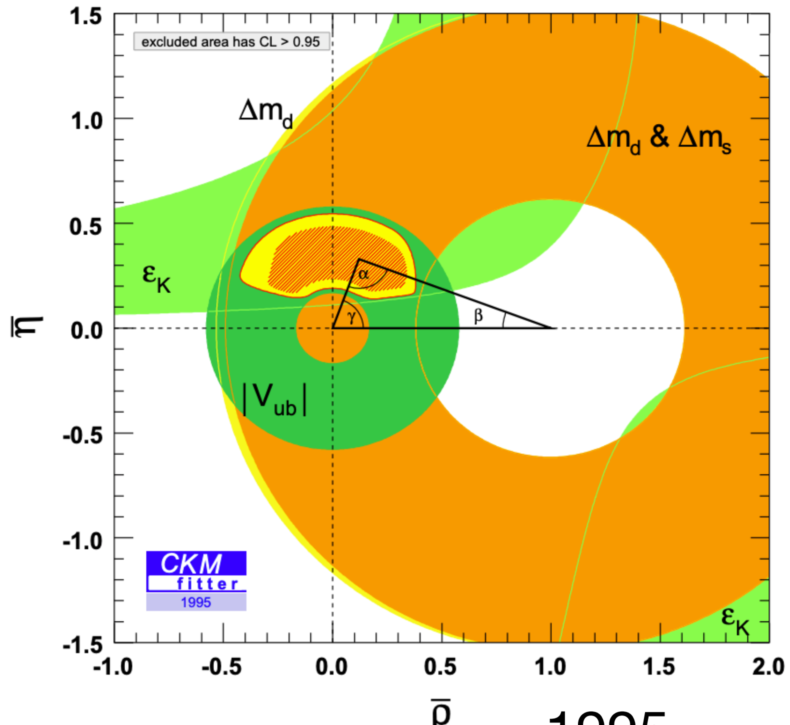
No explanation in the SM: just free parameters "fixed" via measurements. T*echnically natural,* yet suggestive of an organising principle (necessarily) *beyond* the SM.

- Many ideas: Froggatt-Nielsen, Randall-Sundrum, GUTs, Flavor deconstruction…
- Not pointing to specific scales unless linked to other "problems" (hierarchy/gauge coupling unification)

Flavor in the Standard Model: strong predictions

Despite its mysterious origin, the flavor structure of the SM leads to a set of remarkably **successful predictions**:

- absence of charged lepton flavor violation [up to small mν effects]
- lepton flavor universality [up to ml effects]
- suppression of flavor changing neutral currents [GIM + loop]
- unitarity of the CKM



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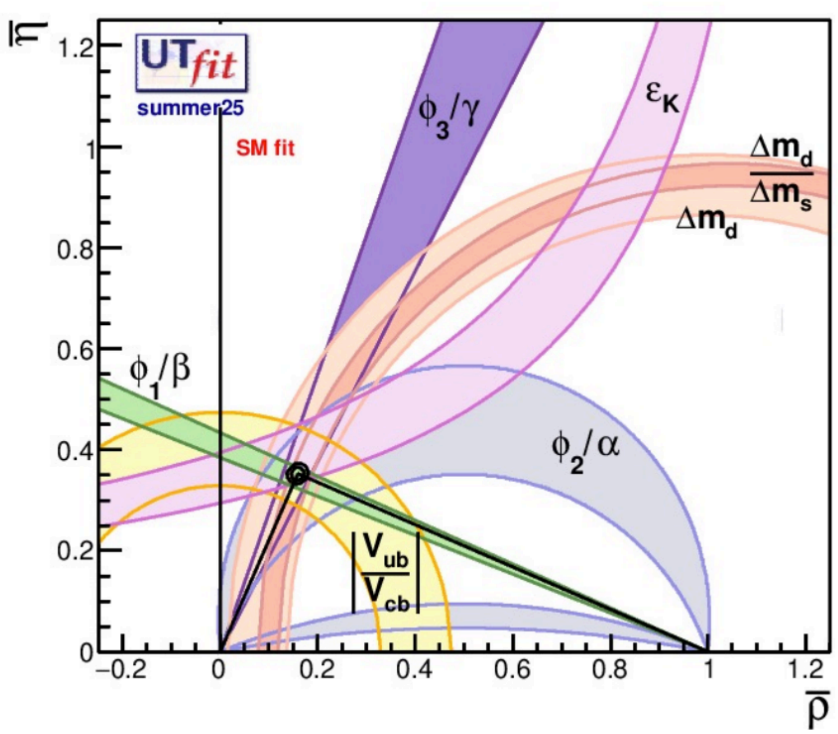

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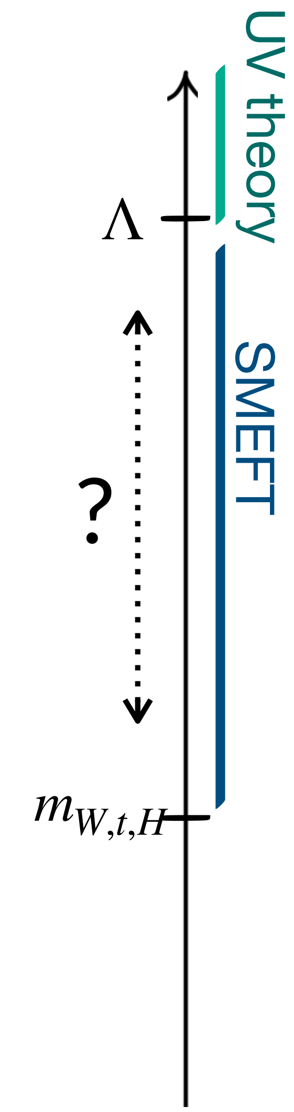
…all expression of the SM matter content and the resulting accidental symmetries.

The scale of New Physics, from theory

We have many more reasons beyond the flavor puzzle to know that BSM exists — yet the absence of direct hints suggests a mass gap. How large? **What is the scale of NP?**



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Top-down considerations

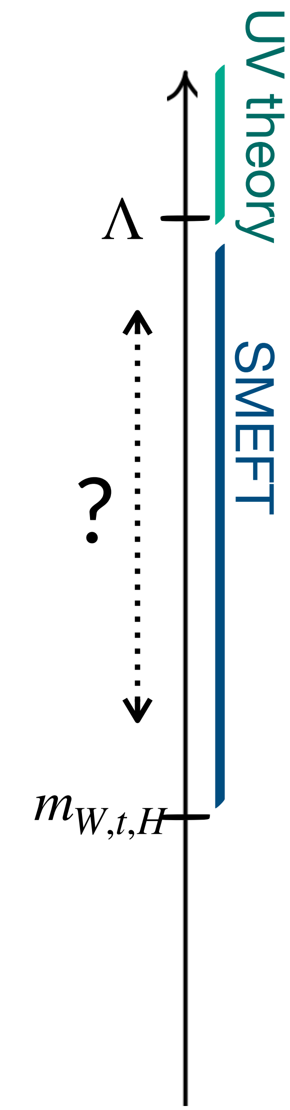
- the main hint for a “low” Λ is a “natural” solution to the hierarchy problem

  Any heavy BSM coupled to the Higgs destabilises m_h

  ⇒Need some NP coupled to Higgs & top at $\Lambda \sim$ TeV to stabilise it.

  In general, these solutions modify the Yukawa sector: necessarily connected to flavor.

- Other challenges (dark matter, dark energy, inflation…) are more difficult to link to a Λ accessible by colliders — *Exception*: the WIMP miracle



The scale of New Physics, from data

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Bottom-up considerations

- Indirect searches at $E \ll \Lambda$ can pinpoint Λ far beyond directly accessible scales

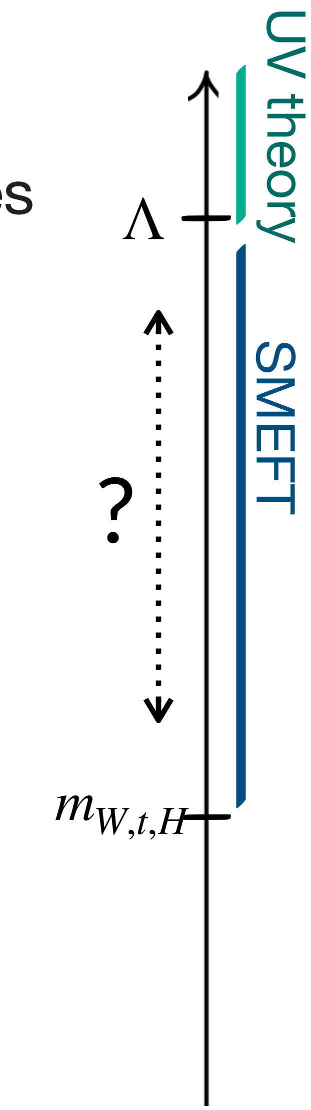
  many historical precedents: m_c from K mixing, m_t from EWPOs

- best performed with processes that we can predict and measure precisely
  - null tests proton decay (~~U(1)$_B$~~), $0\nu\beta\beta$ (~~U(1)$_L$~~), $\mu \to e\gamma$ ((~~U(1)$_{Li}$~~), LFUV
  - flavor-changing transitions
  - EWPOs

- likely where we'll see the biggest experimental progress in the next 50 yrs

  @ existing & planned facilities: (HL-)LHC, KEK, PSI, JPARC…

  @ a future Tera Z factory



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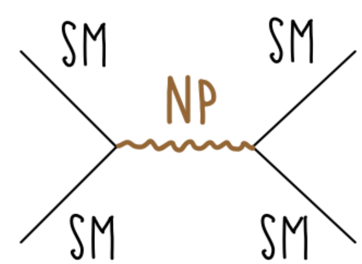
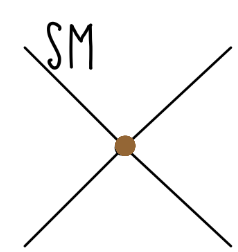
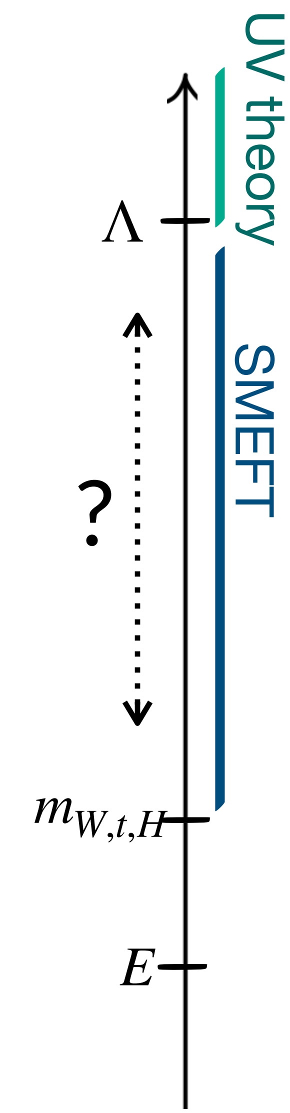
- If NP is much heavier than the scale we're probing, we can describe its effects "model independently" with an effective field theory



$$\sim \frac{g^2}{E^2-\Lambda^2}$$



$$-\frac{g^2}{\Lambda^2}\left[1+\mathcal{O}\left(\frac{E^2}{\Lambda^2}\right)\right]$$



$$\mathscr{L}_{\text{SMEFT}} \supset \frac{1}{\Lambda^2}\sum_{i=1}^{N_6} C_i^{(6)} O_i^{(6)} + \mathcal{O}\left(\frac{E^3}{\Lambda^3}\right)$$

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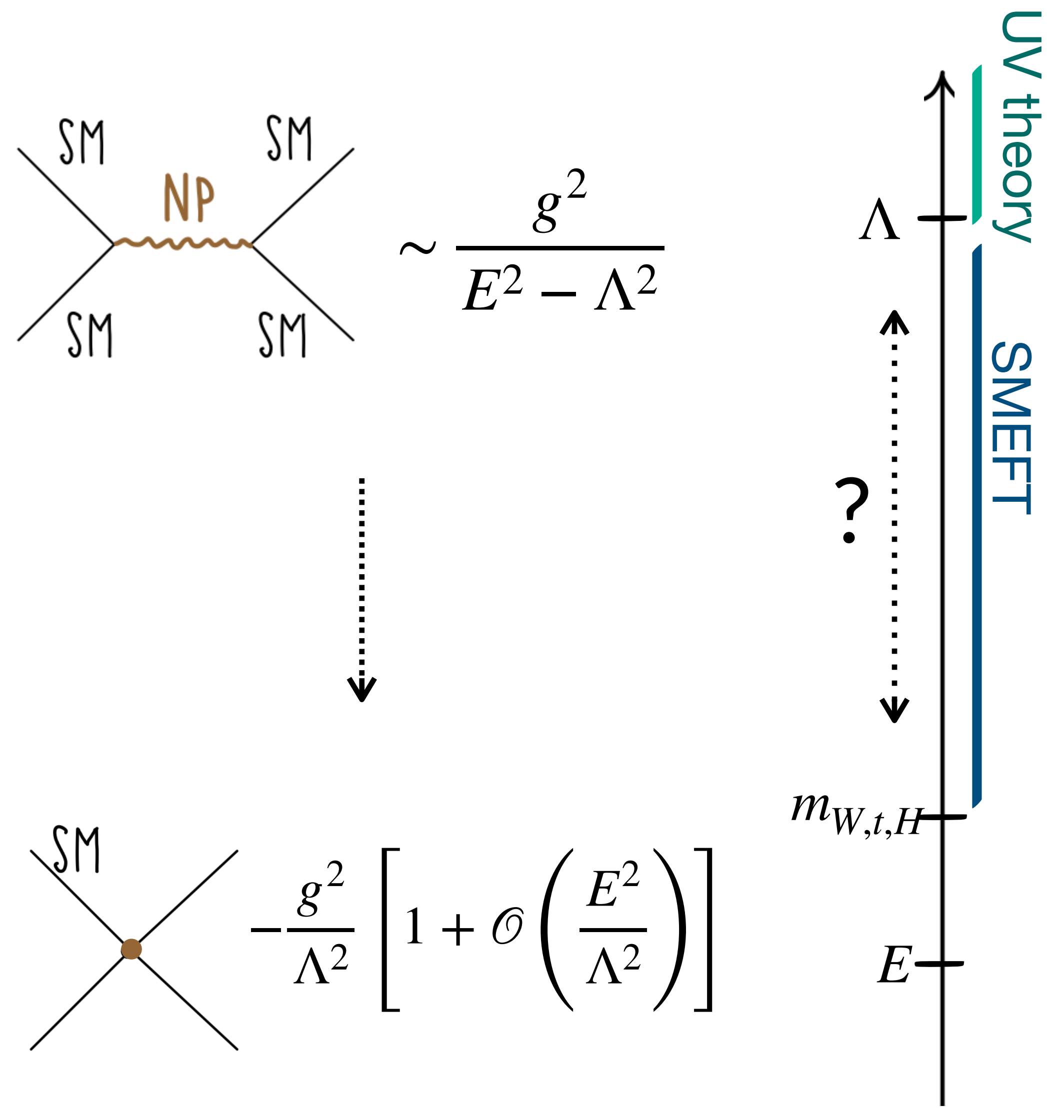
- EFTs translate data → info on heavy NP:
  - use data (EWPOs, flavor, collider) to constrain WCs
  - constraints interpreted as bounds on an *effective* NP scale
    $$\Lambda^i_{\rm eff} = \frac{\Lambda}{\sqrt{C_i}} \sim \frac{M}{g}$$
  - *absolute* scale Λ depends on assumptions on NP couplings!



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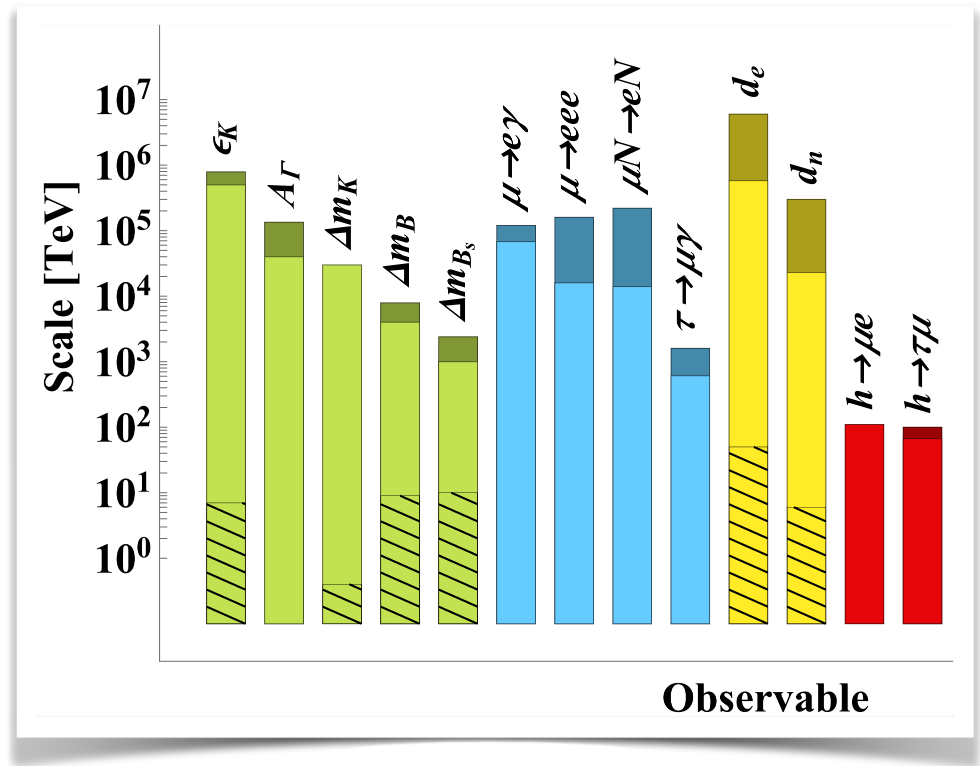
On the importance of flavor assumptions

When looking at flavor data through this EFT lens, we encounters the well-known

new physics flavor puzzle

= nothing forbids bad violations of the SM accidental symmetries, yet we don't see any

$$\Lambda_{\rm eff}^{\rm FV} \gtrsim 10^{4-6}\,{\rm TeV}$$



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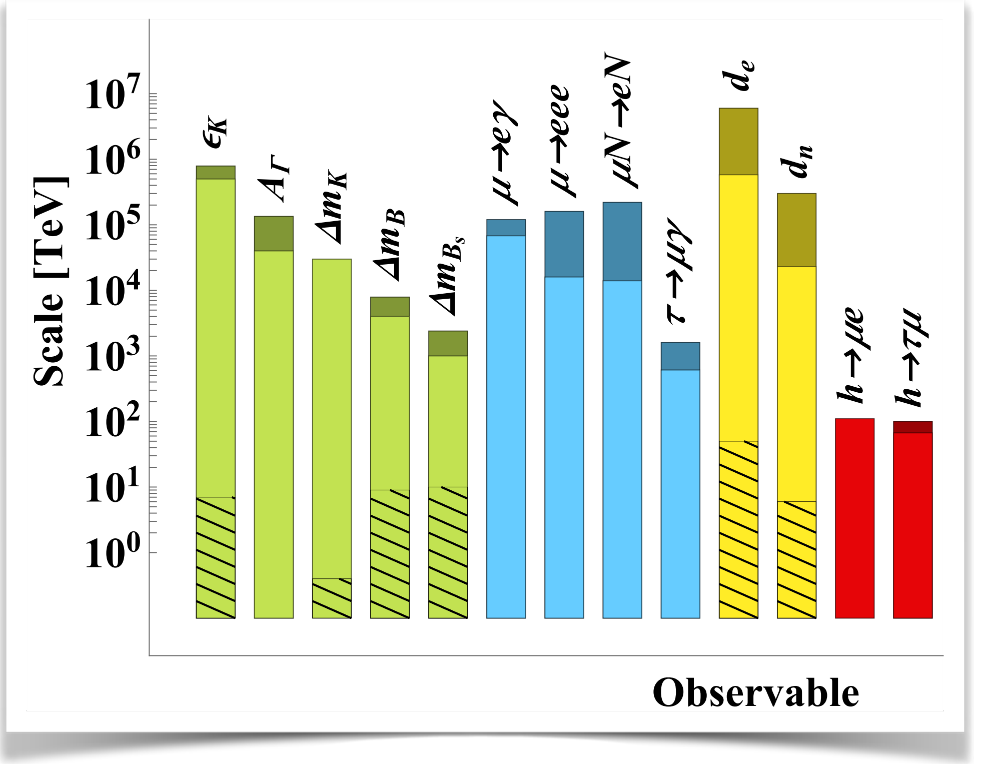

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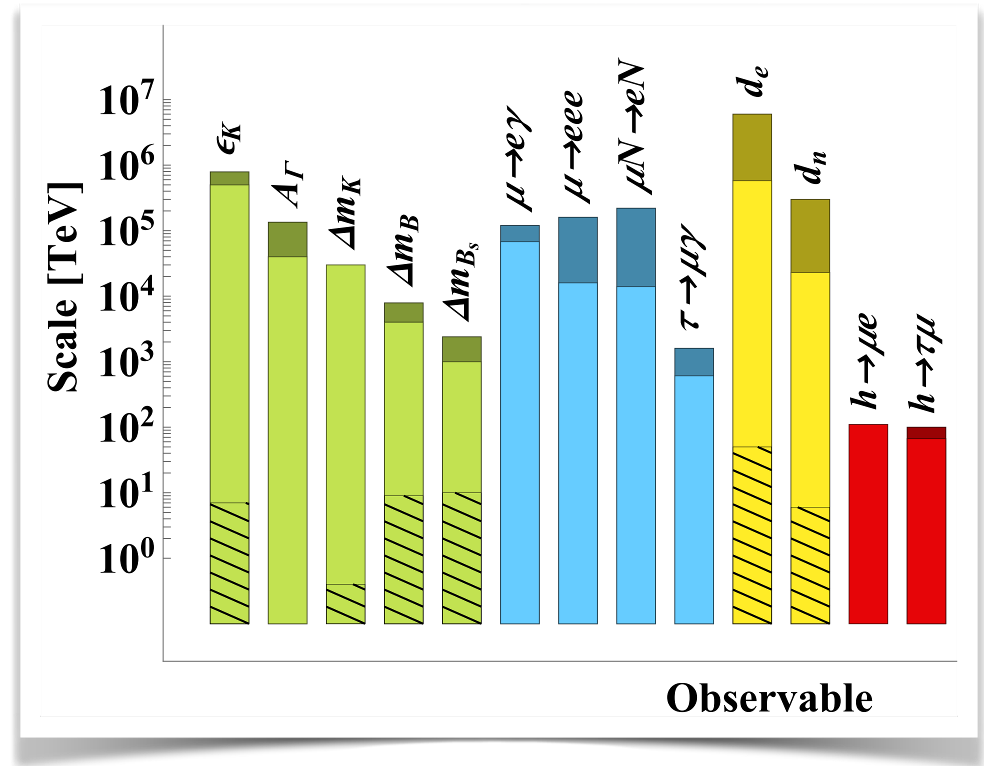

Two options:

New physics is anarchic:

$$C_{\rm FC} \sim \mathcal{O}(1) \;\Rightarrow\; \Lambda = \Lambda_{\rm eff}$$

- Very heavy, hence untestable
- Higgs stabilised in some other way [relaxion, landscape..?]
- unclear how flavor patterns could arise

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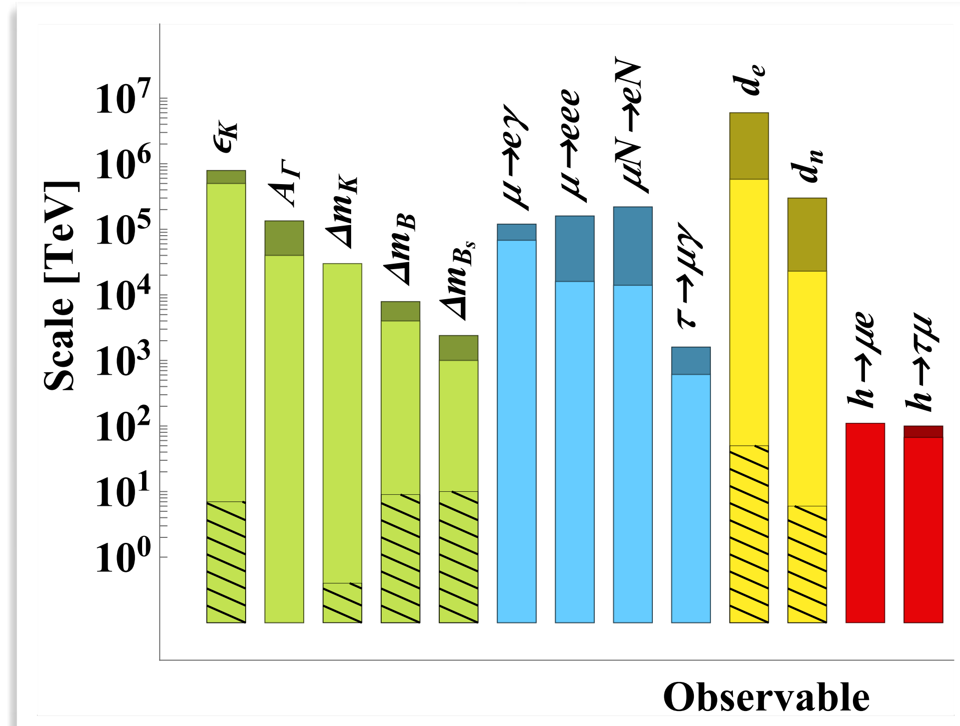

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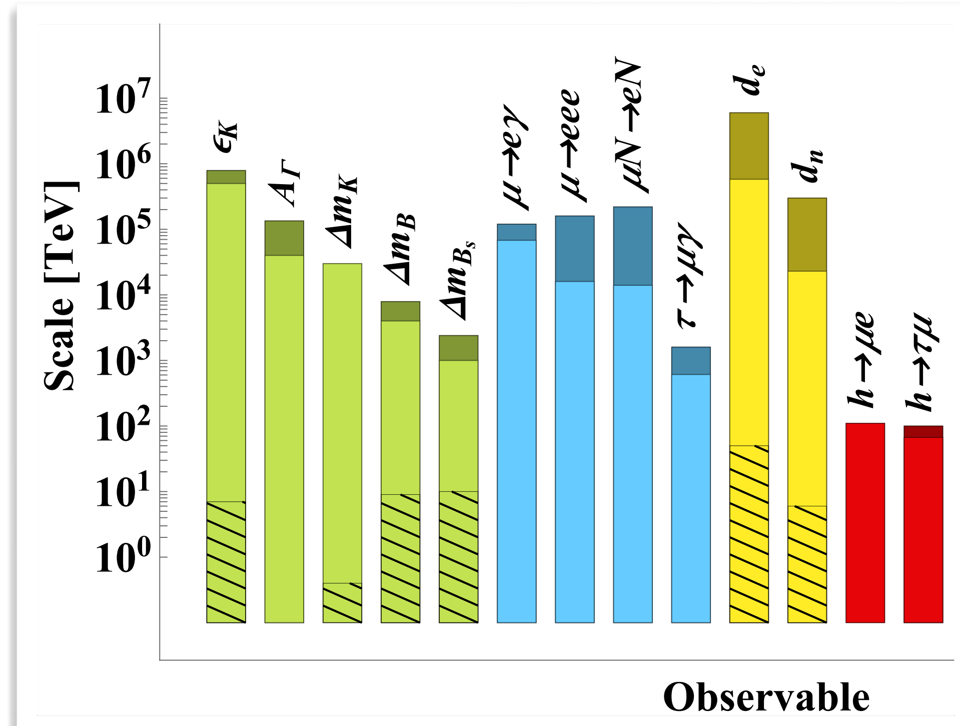

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Which one?

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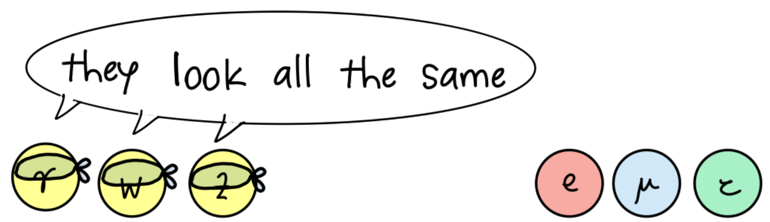

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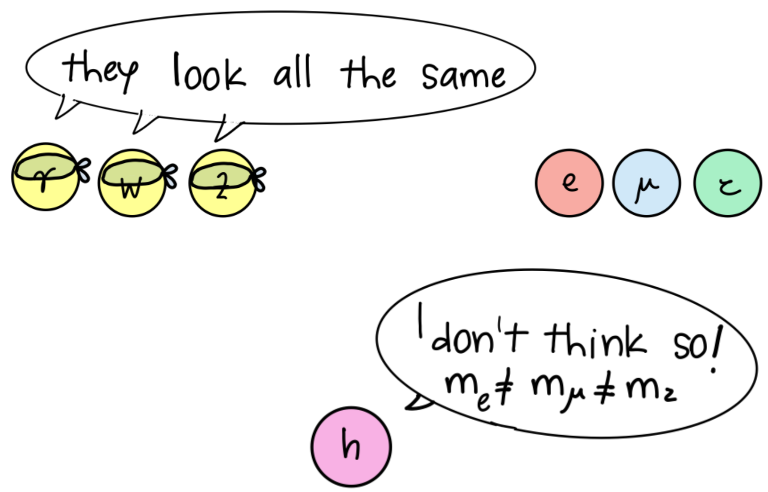
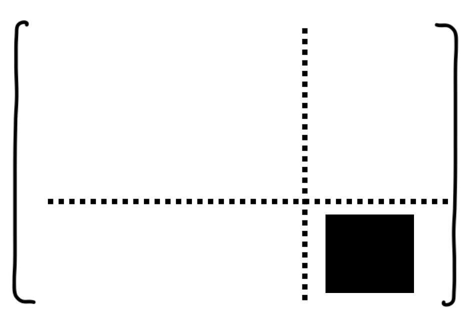


….broken by Yukawa interactions to an *approximate* $U(2)^5$.
— *approximate,* because it needs to be broken to reproduce light quark masses and CKM.

U(2) exact

$Y_{u,d}$ =



only $m_{b,t} \neq 0$, CKM = 1

"Minimal" breaking

$Y_{u,d}$ =

$V_q \sim 2_q \sim \epsilon_F \begin{pmatrix} V_{td} \\ V_{ts} \end{pmatrix}$

$\Delta_{u,d} \sim (\bar{2}_{d,u}, 2_q) \sim y_{c,s}$

only two "free" params: ϵ_F, ϕ_q

[non minimal options also possible]

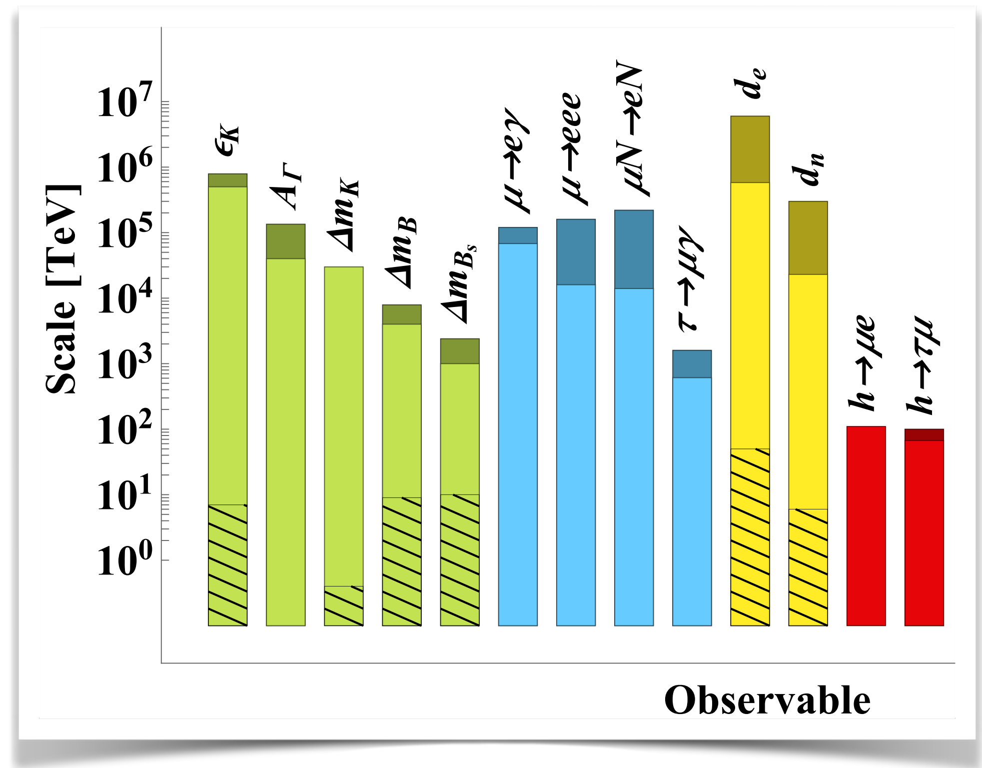
Using the SM accidental symmetries as a guidance

This symmetry seems to hold also beyond the SM — at least if NP is not too far.

In other words, the only unambiguous message of flavor bounds is that

if there is NP "close by" (< 10^4 TeV), it must respect a U(2)-like structure

…which in turn is suggestive of the idea that this symmetry might have a more "fundamental" origin.



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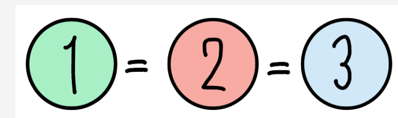

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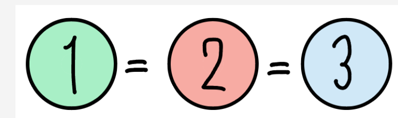
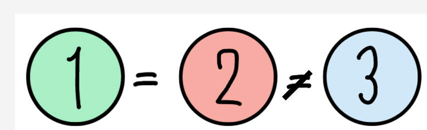


Non-universal (3rd family) New Physics



Approximate Flavor Symmetries in the SM and Beyond

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MFV-like ("universal") New Physics $1 = 2 = 3$

- w/o additional assumptions, $U(2)^n \approx$ MFV:
  - Yukawas *only* sources of flavor violation.
  - describes approximately flavor-universal NP

- CKM-like suppression of FCNCs, but unsuppressed valence-quark couplings

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Non-universal (3rd family) New Physics ① = ② ≠ ③

- $U(2)^n$ can host NP coupling dominantly to the 3rd family
- theoretical motivation: possible link to flavor puzzle (and hierarchy problem)
  [as of today, natural solutions to the hierarchy problem require flavor-non-universal NP]
- valence-quark couplings suppressed $\Rightarrow$ high pT bounds relax to $\Lambda \gtrsim O(1)$ TeV

Adding flavor to the SMEFT: $U(2)^5$

To study these scenarios” agnostically, **impose $U(2)^5$ in the SMEFT**.

It’s an efficient organising principle

- the SMEFT has 1350 (w/o CPV) + 1149 (w CPV) = 2499 WCs at d=6.
- In the *exact* $U(2)^5$ limit, this reduces to 124 + 23 = 147 WCs
- breaking terms can be incorporated systematically order by order

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Example $[Q_{Hq}^{(1)}]_{ij} = (H i \overleftrightarrow{D}_\mu H)(\bar{q}_i \gamma^\mu q_j)$

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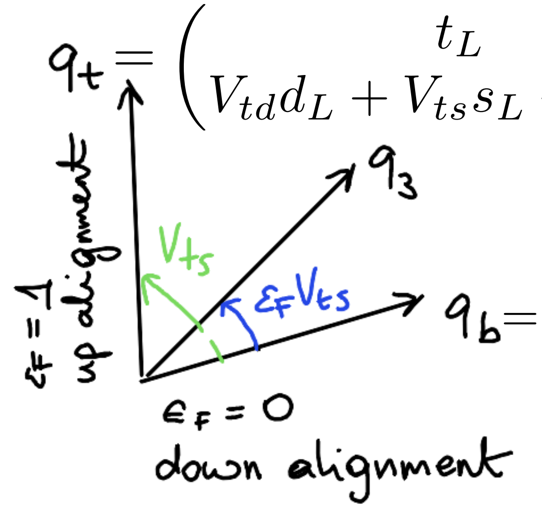
Caveat: need to define flavor basis

- q_3 is in general neither down- nor up-aligned
- misalignment described by V_q



$$q_t = \begin{pmatrix} t_L \\ V_{td} d_L + V_{ts} s_L + V_{tb} b_L \end{pmatrix}$$

$$q_b = \begin{pmatrix} V_{ub}^* u_L + V_{cb}^* c_L + V_{tb}^* t_L \\ b_L \end{pmatrix}$$

Adding flavor to the SMEFT: some comments

Why using flavor assumptions in the SMEFT? Don't we lose agnosticity? Yes, but…

- the SMEFT is *not* a model, and fully general != informative
- realistic models populate only some directions → new correlations & stronger bounds
- postulating a flavor structure = studying a *class* of NP models

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Including flavor data in SMEFT analyses is challenging

- For EW and collider data, exact flavor symmetries [hence CKM = 1] are enough

- Flavor data requires the inclusion of breaking terms:
  - "mandatory" breakings to reproduce masses + CKM
  - additional non-standard sources of breaking, to be constrained from data

- Ongoing, non-trivial effort [Aoude, Hurth, Renner, Shepherd 2003.05432 Bruggisser, van Dyk, Westhoff 2212.02532 Grundwald, Hiller, Kröninger, Nollen 2304.12837 Allwicher, CC, Isidori, Stefanek 2311.00020 Bartocci, Biekötter, Hurth 2311.04963…]

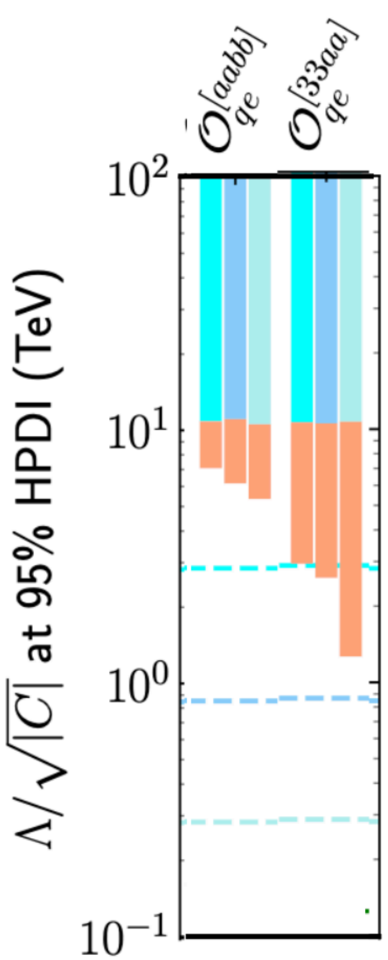
  First global SMEFT fit with $U(2)^5$ and real CKM [de Blas, Goncalves, Miralles, Reina, Silvestrini, Valli 2507.06191]

The role of flavor data: complementarity

Flavour measurements play a crucial role in constraining flavor-conserving new interactions*, **complementary** to EW and high pT

[*= overall scale & suppression of light fam. couplings]

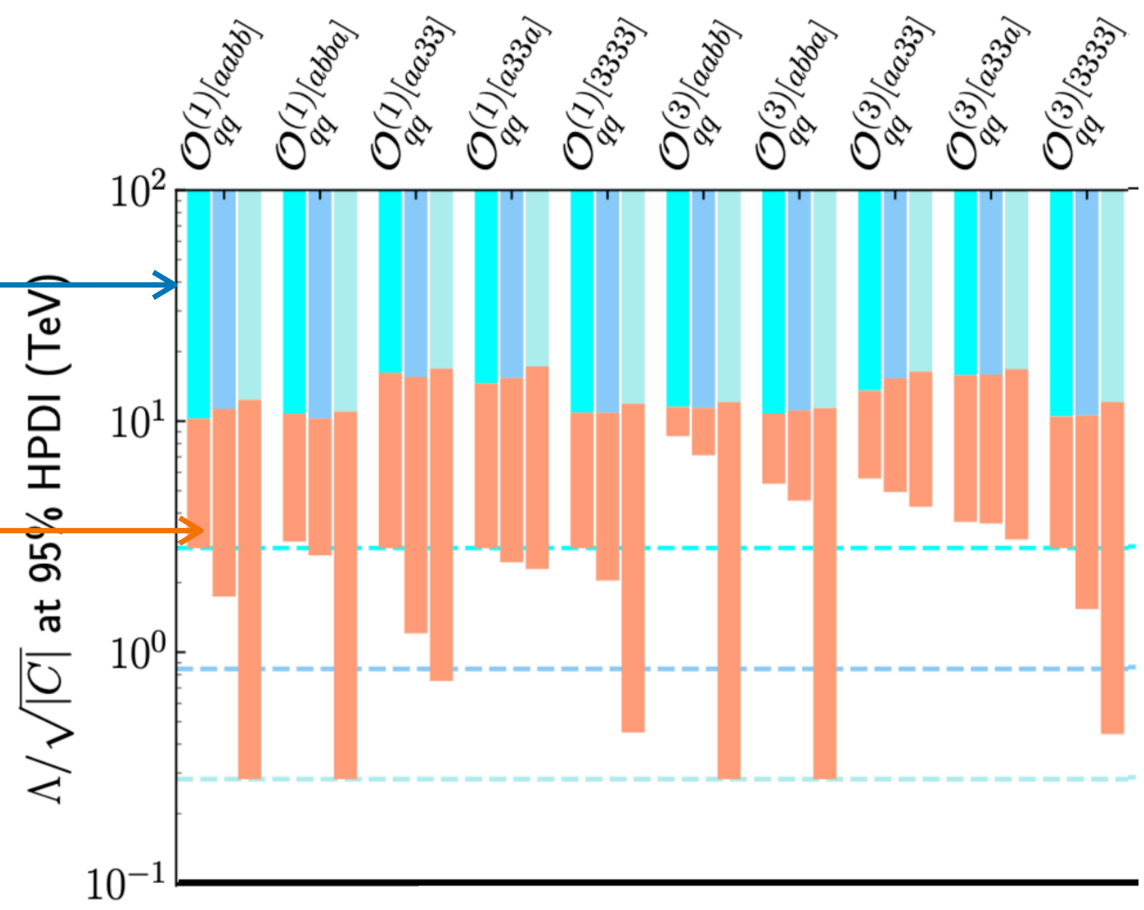
Examples: $B_s \to \mu^+\mu^-$ *for lepton-quark ops*



Full fit

W/o flavor observables

meson mixing for 4-quark ops.



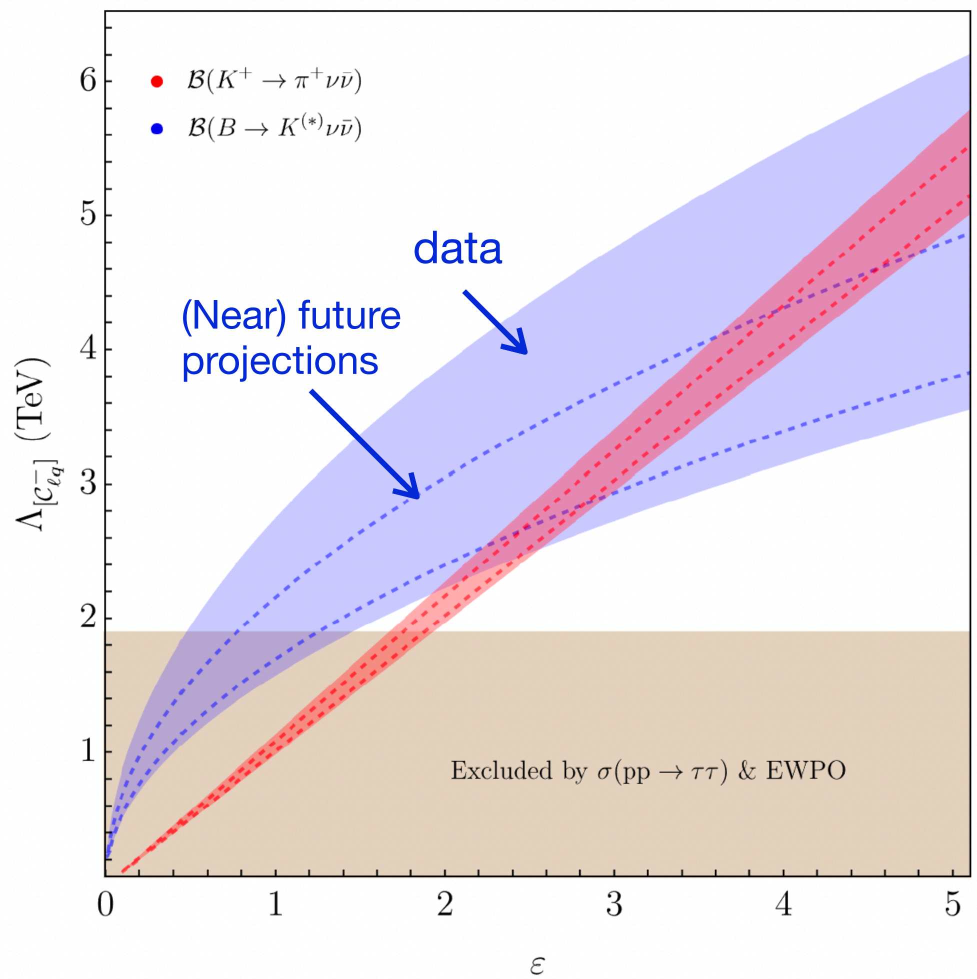
[de Blas, Goncalves, Miralles, Reina, Silvestrini, Valli 2507.06191]

The role of flavor data: unicity

but flavor also provides **unique** info on the NP flavor structure by constraining genuinely flavor violating interactions

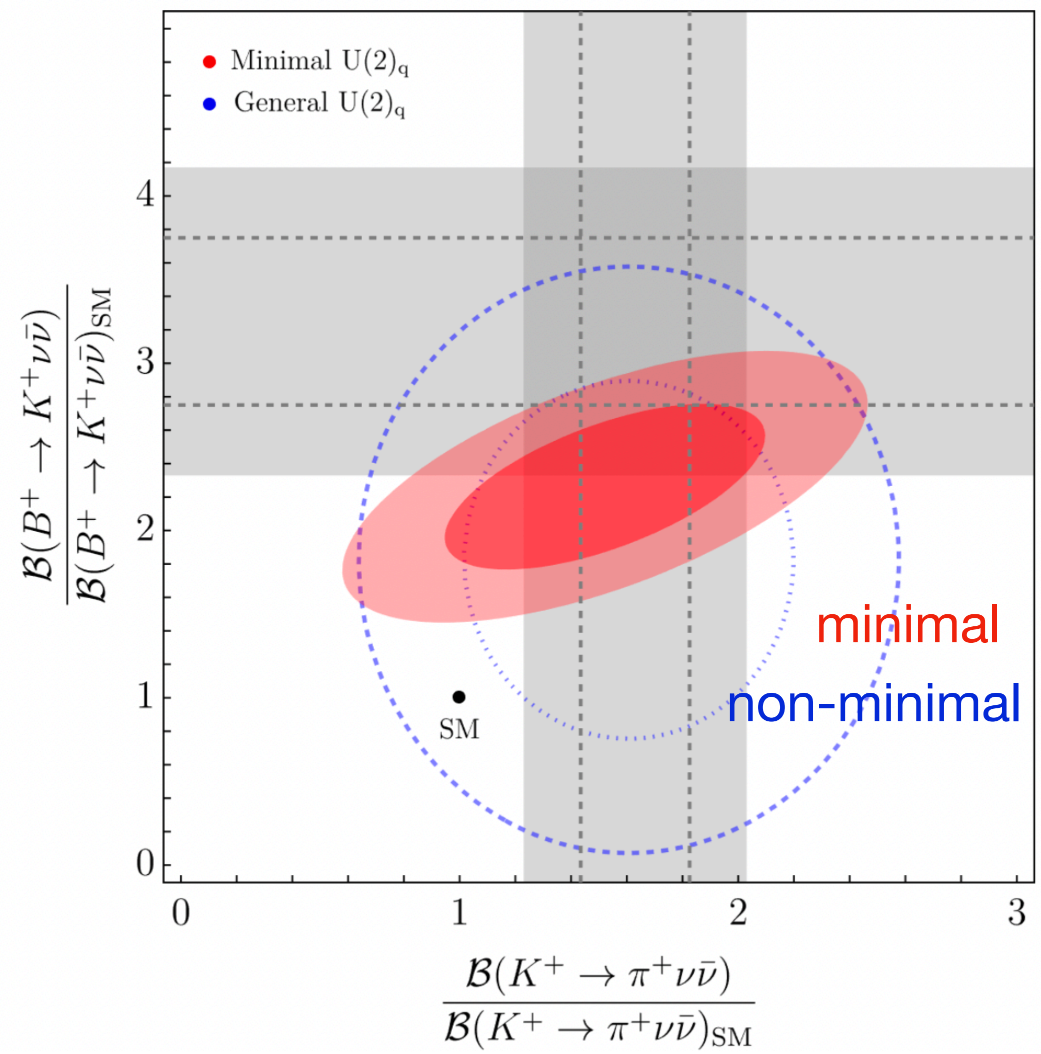
determine size of breaking terms

[those not already fixed by masses & CKM]



e.g. leading $U(2)_q$ breaking can be determined by comparing b→s vs s→d

discriminate between ≠ breaking patterns via characteristic correlations



[Allwicher, Bordone, Isidori, Piazza, Stanzione, 2410.21444]

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As an example, two predictions of the “minimal” breaking ansatz for down-type FCNCs:

NP in $b \to s$ fixes NP in $b \to d$

NP in $s \to d$ is related to NP in $b \to s, d$

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As an example, two predictions of the "minimal" breaking ansatz for down-type FCNCs:

NP in $b \to s$ fixes NP in $b \to d$

- $$\frac{b \to sX}{b \to dX} = \left.\frac{b \to sX}{b \to dX}\right|_{\rm SM} = \frac{V_{td}}{V_{ts}}, \qquad X = \ell^-\ell^+, \nu\bar{\nu}$$
- possible clean tests: $\dfrac{\mathscr{B}(B_s \to \mu\mu)}{\mathscr{B}(B_d \to \mu\mu)}, \quad \dfrac{\mathscr{B}(B \to K\bar{\nu}\nu)}{\mathscr{B}(B \to \pi\bar{\nu}\nu)}$

NP in $s \to d$ is related to NP in $b \to s, d$

The role of flavor data: unicity

Indeed, different breaking patterns yield different correlations among FC processes.

As an example, two predictions of the "minimal" breaking ansatz for down-type FCNCs:

NP in $b \to s$ fixes NP in $b \to d$

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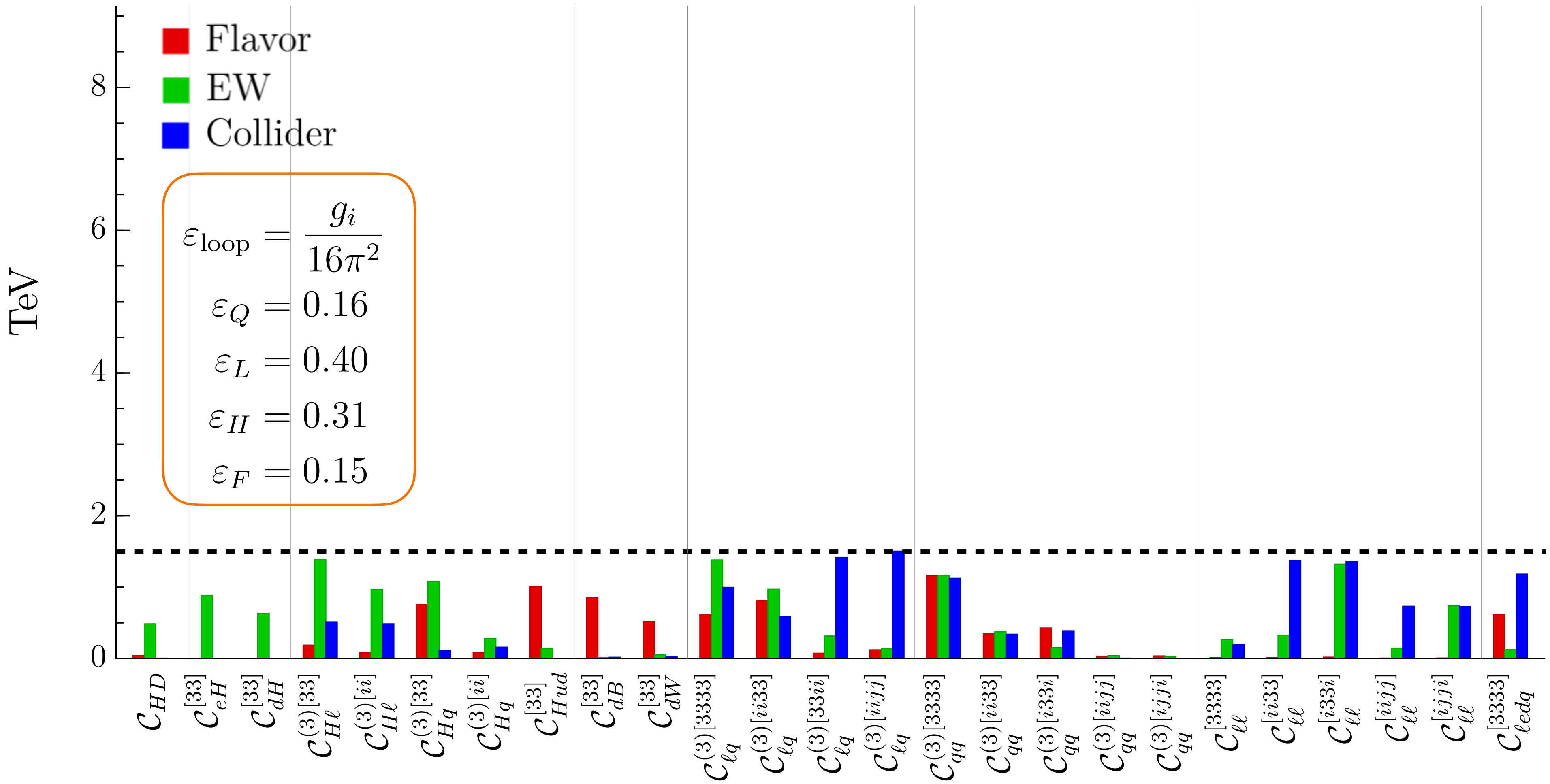
NP in $s \to d$ is related to NP in $b \to s, d$

- $s \to d$ feels subleading breaking terms — the connection becomes 1:1 only with additional hypotheses [e.g: "rank 1": NP coupled only to 3rd family]
- only clean test is comparing dineutrino modes: $\mathcal{B}(K \to \pi\bar{\nu}\nu)$ vs $\mathcal{B}(B \to K\bar{\nu}\nu)$ [both charged & neutral modes]

SMEFT Bounds on Third Family New Physics

Single operator analysis in **SMEFT + minimally broken U(2)^5**

[= no sources of quark FV apart from the minimal ones required for the CKM, V_q, $\Delta_{u,d}$]



[Allwicher, CC, Isidori, Stefanek, 2311.00020]

(*) Minimal suppression of NP couplings to light families, Higgs & orientation in flavor space fixed by high-PT, EW and flavor data, respectively.

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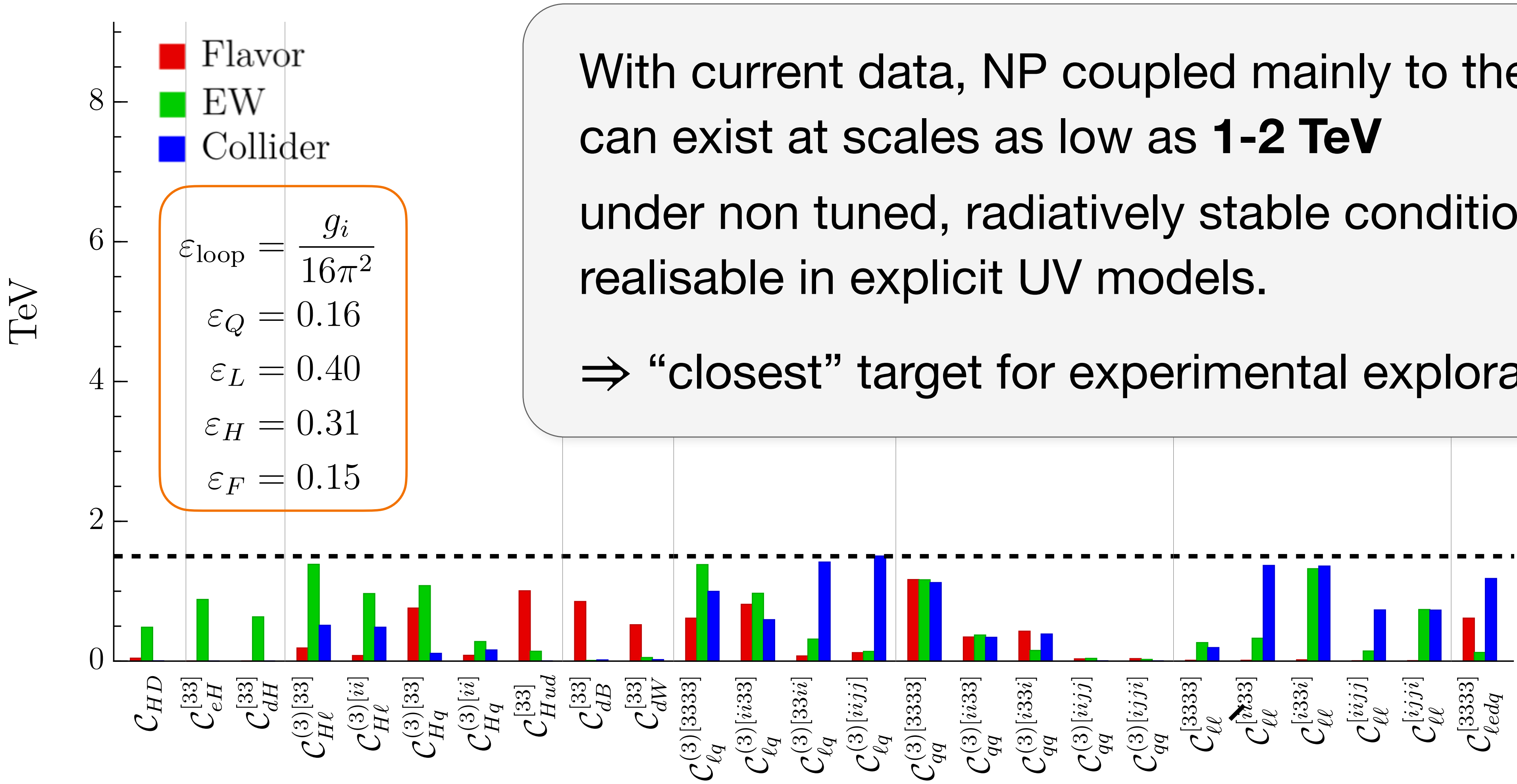


With current data, NP coupled mainly to the 3rd family can exist at scales as low as **1-2 TeV**
under non tuned, radiatively stable conditions that are realisable in explicit UV models.

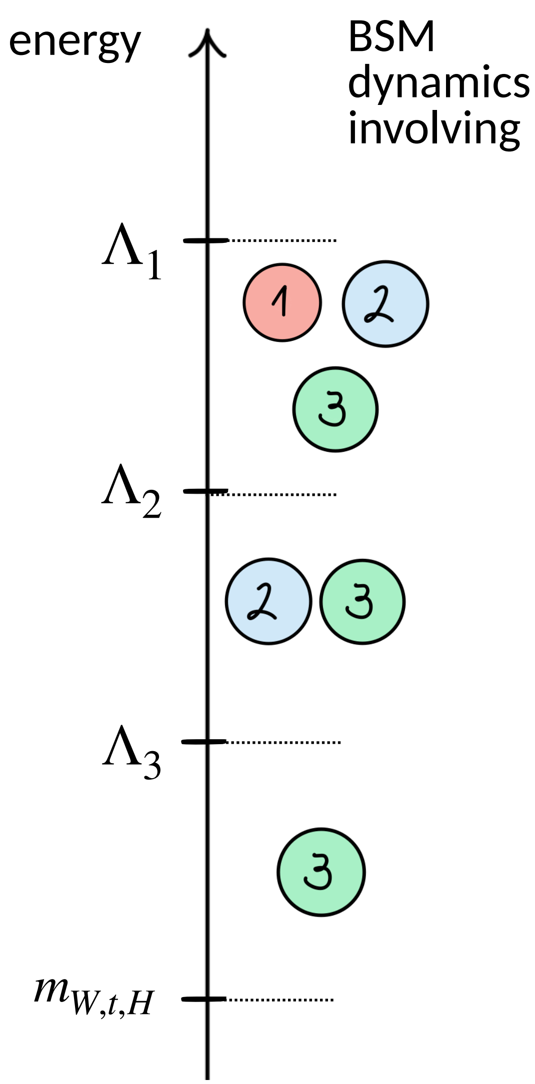
⇒ "closest" target for experimental exploration

[Allwicher, CC, Isidori, Stefanek, 2311.00020]

(*) Minimal suppression of NP couplings to light families, Higgs & orientation in flavor space fixed by high-PT, EW and flavor data, respectively.

Aside: Model building for Third Family New Physics

Key idea: The U(2) symmetry in the Yukawas and in the new physics couplings has the same dynamical origin & is a remnant of a fundamental difference



At high energies, the 3 **families** are **intrinsically different** objects.

Non-universal forces acting on the i-th SM family have characteristic scales $\Lambda_1 \gg \Lambda_2 \gg \Lambda_3 \gg m_W$.

The flavor universality of SM gauge interactions is an accidental low-energy property.

Around Λ_3, Yukawas & NP couplings have an approximate U(2) symmetry: largest entries in the 3rd family.

Aside: Model building for Third Family New Physics

Key idea: The U(2) symmetry in the Yukawas and in the new physics couplings has the same dynamical origin & is a remnant of a fundamental difference

- Explicit realisation via **flavor deconstruction** of the SM gauge group:

$$G = G_{3,\text{SM}} \times G_{12,\text{SM}} \xrightarrow{\Lambda_3} G_{\text{SM}}$$

acts on 3rd fam. & Higgs — acts on light families

Many examples for G have been studied:

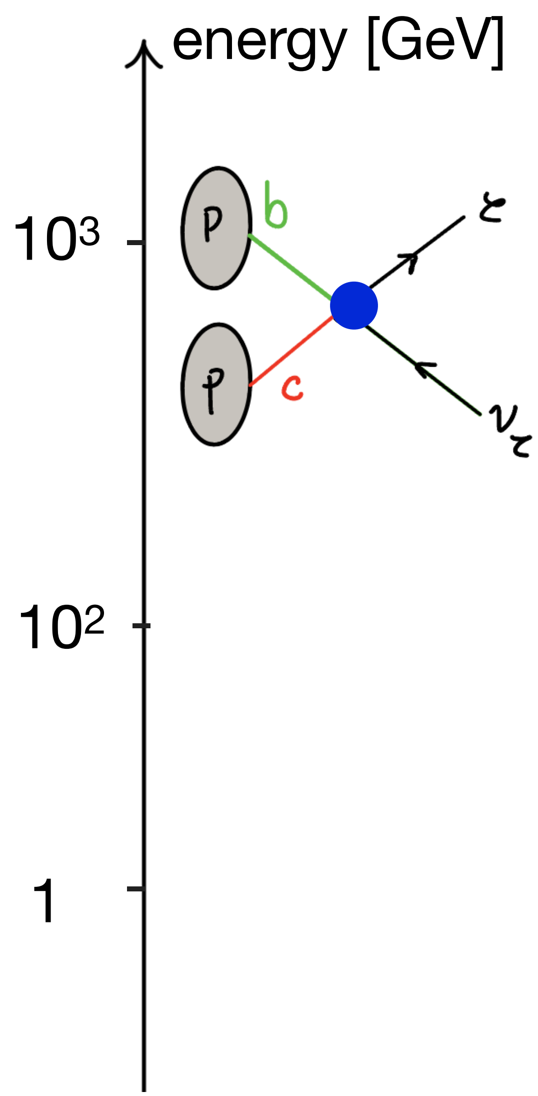
$SU(4)_3 \times SU(3)_{12} \times SU(2)_L \times U(1)'_Y$

$SU(3) \times SU(2)_{L,3} \times SU(2)_{L,12} \times U(1)_Y$

$SU(3) \times SU(2)_L \times U(1)_{Y,3} \times U(1)_{Y,12}$

  - built-in $U(2)^5$ in the gauge sector; only $y_3 \neq 0$
  - SSB to SM generates new gauge bosons with $M \sim \mathcal{O}(\Lambda_3)$ coupled mostly to the 3rd family — rich phenomenology for $\Lambda_3 \sim$ TeV
  - same breaking of $U(2)^5$ generates light Yukawas and couplings of the new gauge bosons to light families

High-energy signatures of 3rd family new physics



LHC searches [&] [See talks by T.Vazquez & M. Martinez]

- largest effects in 3rd-family processes:
  - lepton sector: $pp \to t\bar{t},\, pp \to b\bar{b} \ldots$
  - quark sector: $pp \to \tau\tau,\, pp \to \tau\nu$
  - also LFU, e.g. comparing $pp \to \tau\tau$ to $pp \to \mu\mu$

- energy enhancement in tails helps overcome pdf suppression of heavy flavours in the proton

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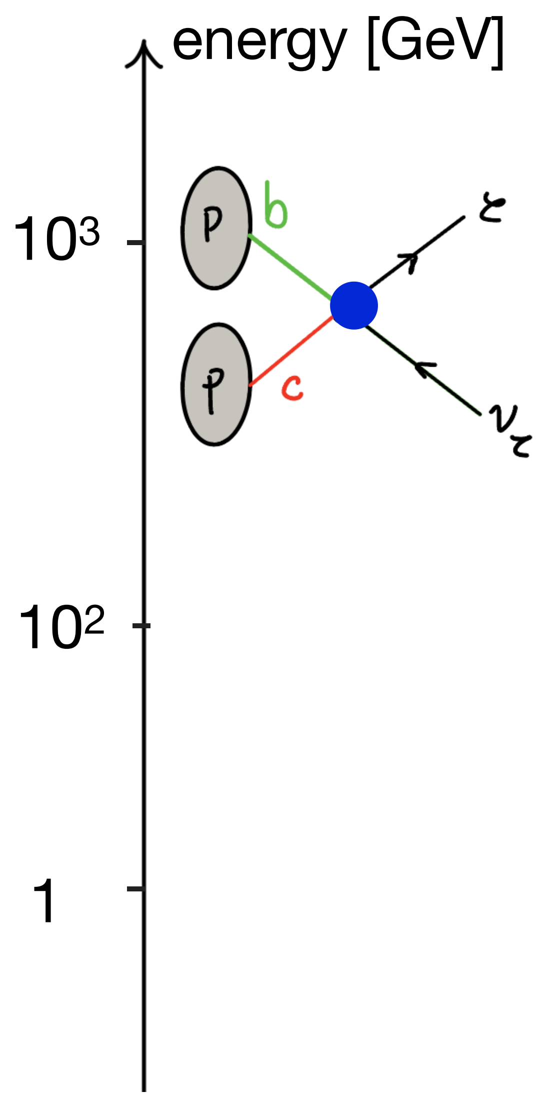

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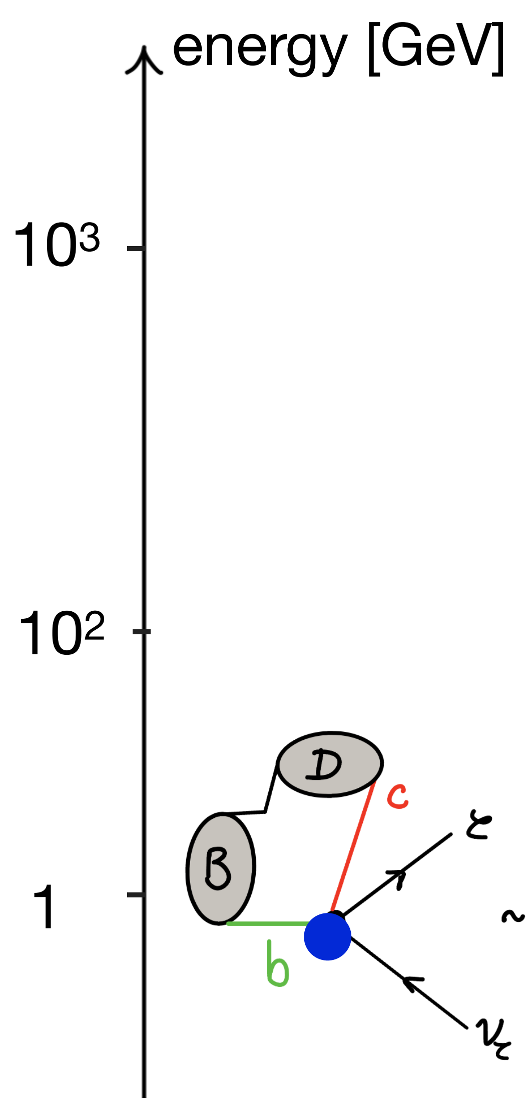
- energy enhancement in tails helps overcome pdf suppression of heavy flavours in the proton

Status and prospects

- currently, LHC probes scales ~ 1 TeV
- HL-LHC: improvement in WCs bounds range from 20% to 4 x for semileptonic operators (factor 2x in the scale)

Low-energy signatures of 3rd family new physics



Flavor-changing low-energy probes

- Leading effects in 3 → light transitions: B physics

  e.g. semileptonic 3→2 transitions: $b \to s(d)\ell\ell^{(\prime)},\ b \to s(d)\nu\nu$

  largest effects expected for $\tau\,,\nu_\tau$. $b \to c(u)\ell\nu$

- Subleading, correlated effects in 2→1 transitions: K physics

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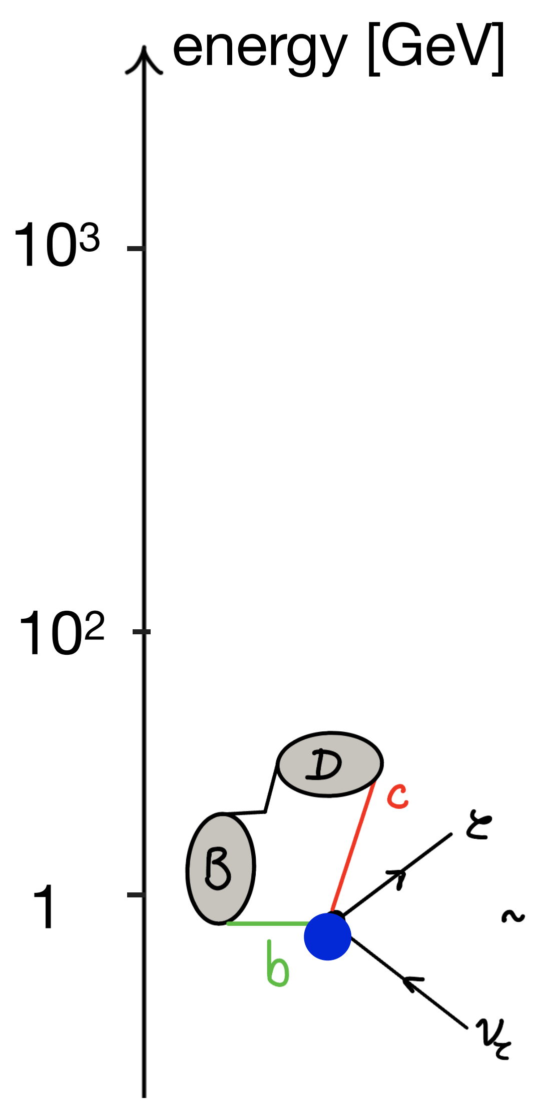

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- Subleading, correlated effects in 2→1 transitions: K physics

Status & prospects in B physics

- In the next 15 years, LHCb & Belle II should collect ~100x the B mesons they have now.

  This means:
  - CKM matrix elements <1%
  - LFU ratios in SL decays to O(1%) level
  - observe CPV in B_s
  - measure CPV in charm precisely

  Important progress: B_s and D mixing are already leading constraints on flavored heavy NP!

FCNCs with Taus

Probing $b \to s\tau\tau$ directly is experimentally very challenging.

Recently, several remarkable results:

[★ =new world best]

- $\boldsymbol{B^+ \to K^+\tau^+\tau^-}$

  [CKM2025] Belle [711 fb-1] incl. tagging + Belle II [365 fb-1]: BR< 8.7 x 10^{-4} at 90% C.L [★]

- $\boldsymbol{B^0 \to K^{*0}\tau^+\tau^-}$

  [CKM2025] Belle II [365 fb-1]: BR < 1.8 x 10^{-3} at 90% CL

- other:

  [2024] bound on C_{9_τ} from $\tau^+\tau^-$ rescattering in $B^0 \to K^{*0}\mu^+\mu^-$ competitive with direct

  [CKM2025] LHCb [5.4 fb-1]: searches for $B^0 \to K^+\pi^-\tau^+\tau^-$ & $B^0 \to K^+K^-\tau^+\tau^-$ translate in BR < O(10^{-4}) on $B^0 \to K^{*0}\tau^+\tau^-$ and $B_s \to \phi\tau^+\tau^-$ [★]

Limit: even with full LHCb and Belle II datasets, bounds likely to exceed SM (~10^{-7}) by $10^{2\text{-}3}$.

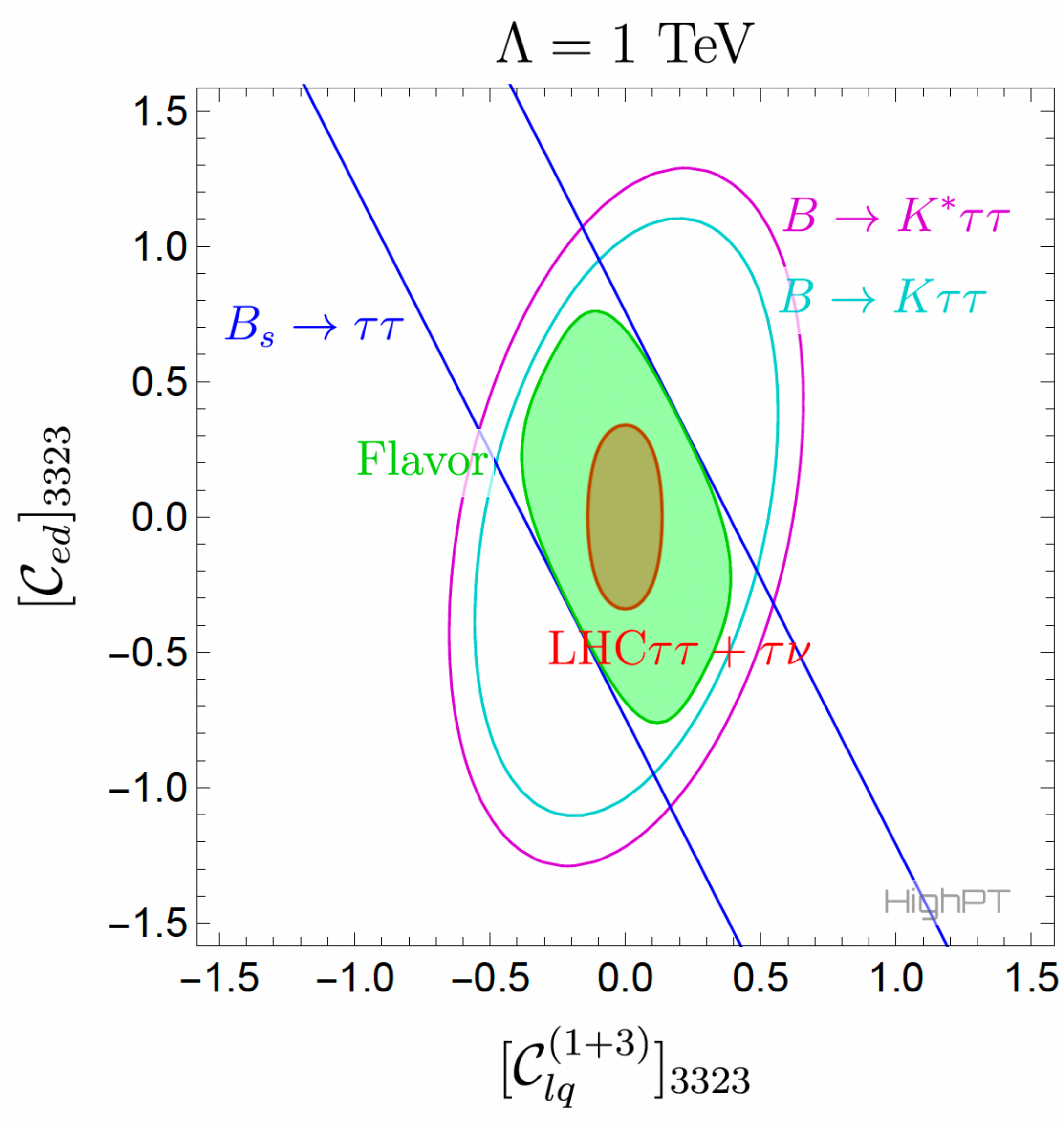
⇒ Will need Tera-Z to go beyond!

FCNCs with Taus

Still, we start being sensitive to scenarios with large NP couplings to 3rd family

Complementary with dilepton tails at the LHC! [though not as powerful just yet]

[see e.g. Faroughy, Greljio, Kamenik, 1609.07138
Greljo, Marzocca. 1704.09015
Allwicher, Faroughy, Jaffredo, Sumensari, Wilsch 2207.10714 …]



FCNCs with Neutrinos

Currently the only measured FCNCs sensitive to NP interacting with 3rd family leptons are the **dineutrino** modes $b \to s\nu\bar{\nu}$ and $s \to d\nu\bar{\nu}$.

- **Very precise SM prediction:**
  - advantage wrt to dilepton modes: no "charm loop" effects (ν don't couple to γ)
  - theory uncertainty dominated by V_{cb} (&form factors for $B \to K/\pi$).
  - not yet a showstopper, but solving the Vcb puzzle + lattice improvements will be important to exploit future exp. precision

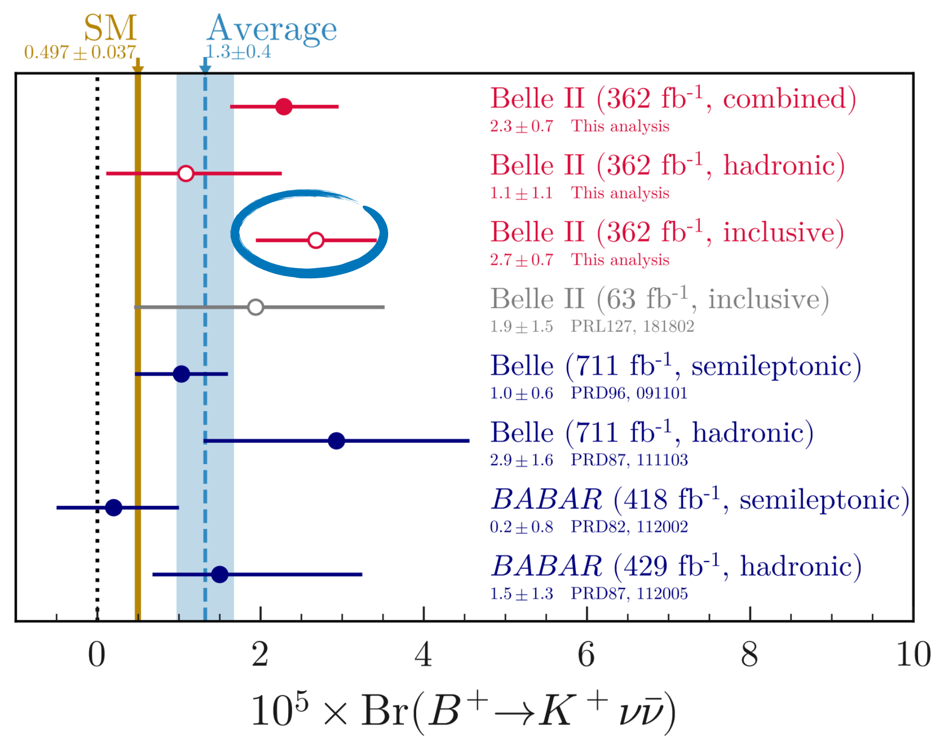
- **Powerful tests** of **NP flavor structure:**
  - all sensitive to leading $U(2)_q$ breaking
  - s →d sensitive also to subleading $U(2)_q$, $U(2)_d$ spurions

FCNCs with Neutrinos

Snapshot of the experimental situation [much more in the dedicated talks!]

$b \to s\nu\bar{\nu}$

- Belle II [2023]: first evidence for $B^+ \to K^+\nu\bar{\nu}$;
- combined result ~2σ above SM (Λ_{eff} ~ 6 TeV)
- Target: 10% precision @ Belle II
- work ongoing on $K^{*0,+}$ and K_S



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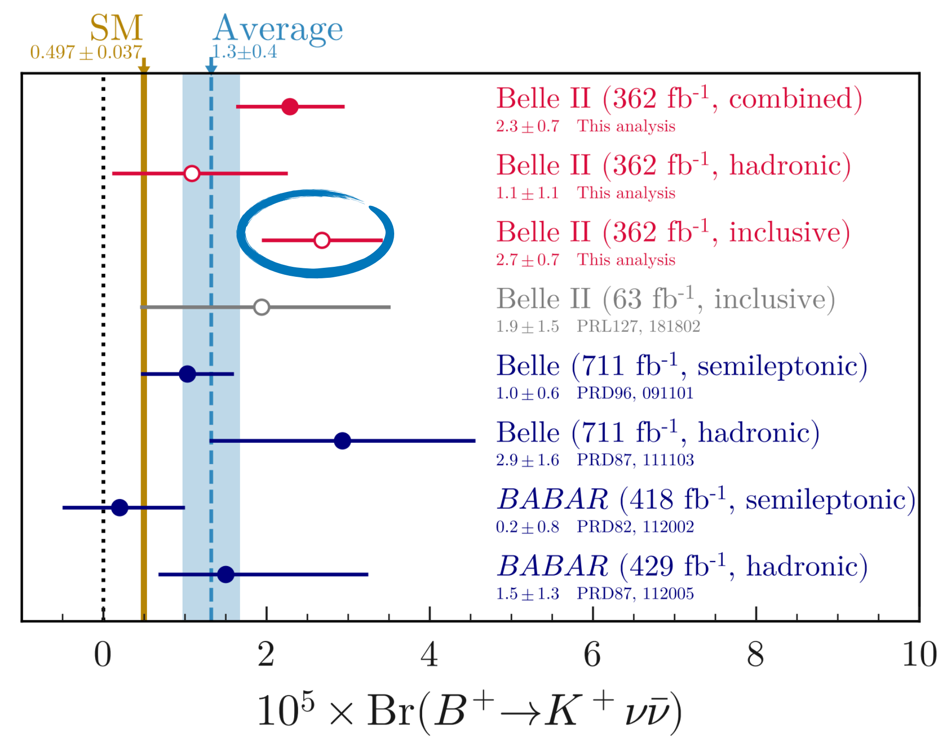
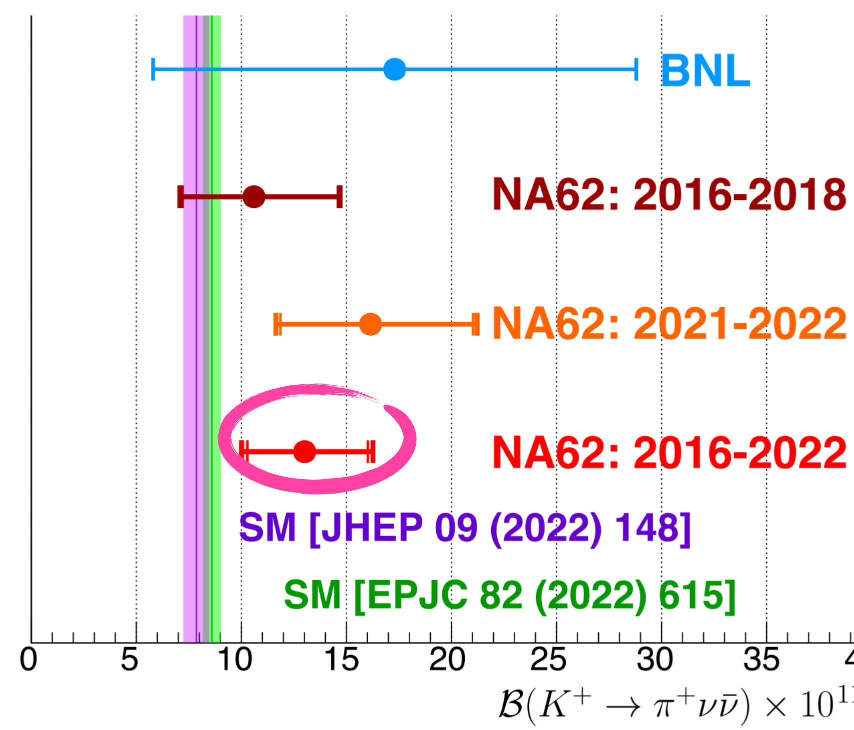


$s \to d\nu\bar{\nu}$

- Na62 [2024]: first evidence for $K^+ \to \pi^+\nu\bar{\nu}$
- combined result ~2σ above SM (Λ_{eff} ~ 80 TeV)
- Target: 15% precision @Na62 (5% @HIKE†)
- $K_L \to \pi^0\nu\bar{\nu}$: BR_{SM}~ O(10^{-11}), BR_{exp} < O(10^{-9}) [KOTO], atm not competitive with charged mode for NP searches

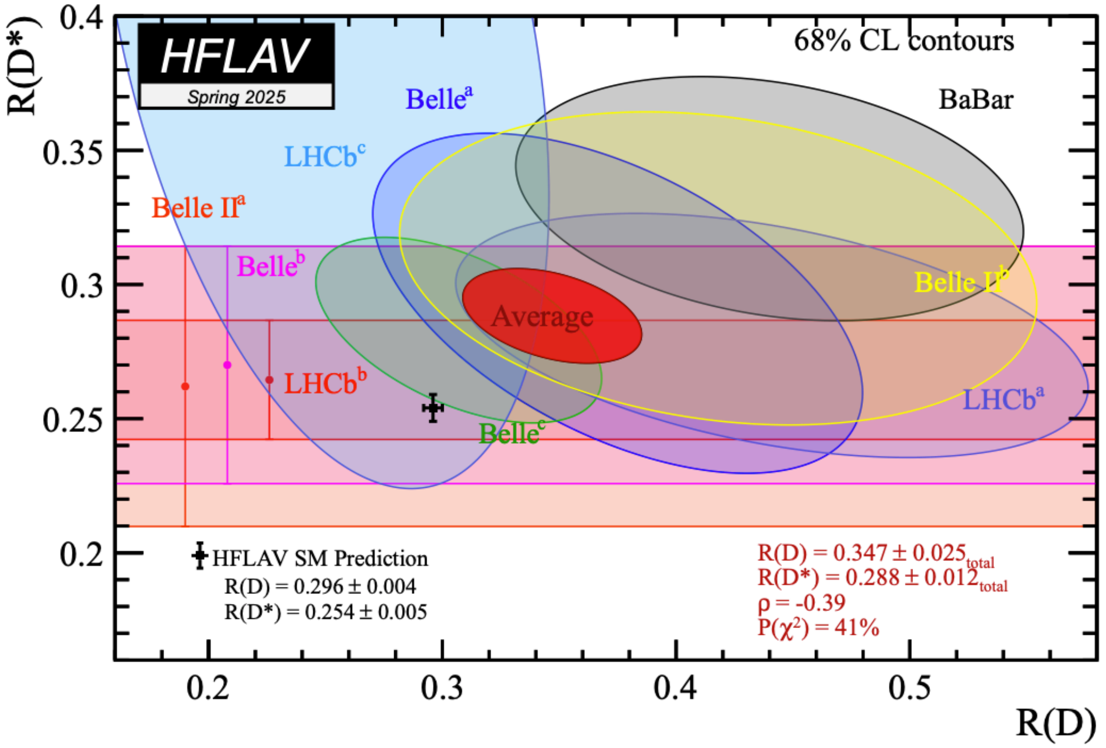


LFUV in $b \to c\ell\nu$

[*w/o the Belle II measurement presented @CKM2025 by I. Tsaklidis, 1.3σ from the HFLAV average displayed here]

15-year old tension far from being settled:

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



~ 10% enhancement due to excess in τ mode combined* ~**3.8σ** above SM (**$\Lambda_{\rm eff}$ ~ O(1) TeV**)

- SM well under control
- Two recent results [2025]: Belle II semil. & hadronic tag
- target for 2040: 1% @ Belle II [50ab^{-1}], 3% @ LHCb[300fb^{-1}]

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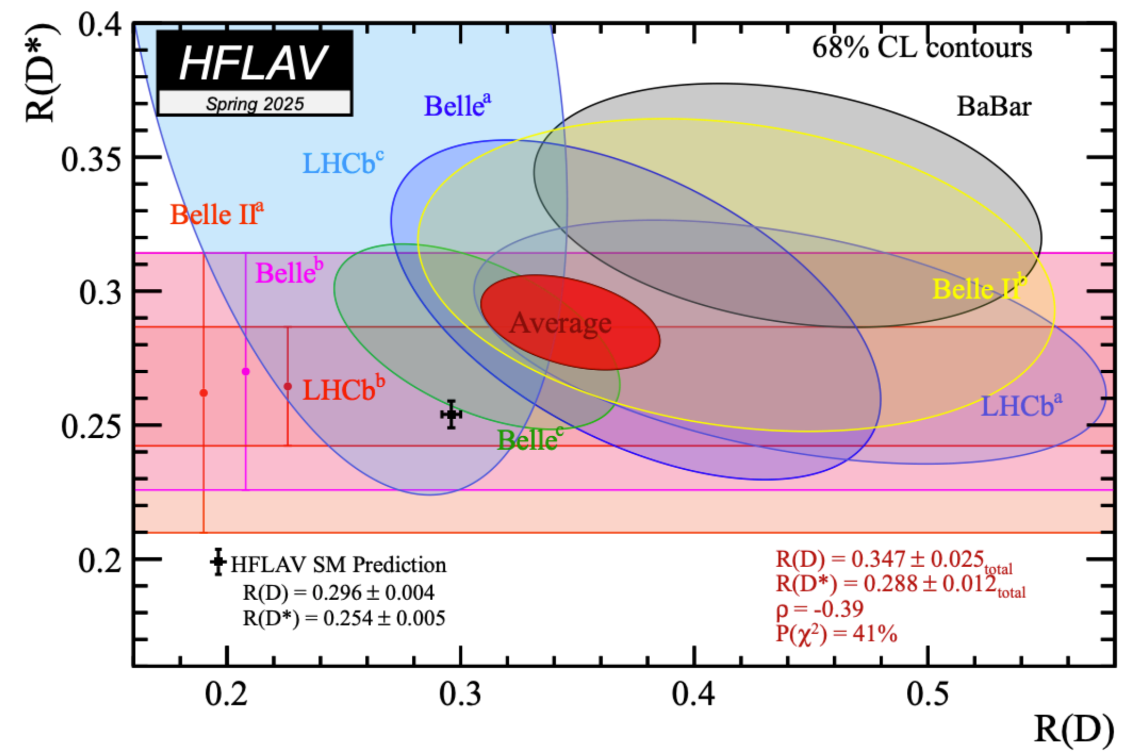

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If due to new physics, expect correlated excesses at low and high energies:

- $B \to K\tau\tau$, $B_s \to \tau\tau$ ~O(100) x SM
- distortion of tails in pp → ττ, pp → τ + E_{miss}
  ATLAS/CMS already constrain a relevant portion of parameter space
- …plus many more more “model dependent” signatures, incl. enhancement of $b \to s\nu\bar{\nu}$

Implications of a NP interpretation of $b \to s\nu\bar{\nu}$ data

IF the $b \to s\nu\bar{\nu}$ excess is due to [heavy] new physics

[Allwicher, Becirevic, Piazza, Rosauro-Alcaraz, Sumensari, 2309.02246; Bause, Gisbert Hiller 2309.00075; Allwicher, CC, Isidori, Stefanek, 2311.00020; Marzocca, Nardecchia, Stanzione, Toni 2404.06533; Allwicher, Bordone, Isidori, Piazza, Stanzione, 2410.21444]

- $\Lambda_{\text{eff}} \sim$ 6-7 TeV
- should be ν_τ to avoid constraints from $B_s \to \mu^+\mu^-$ & $R_{K^{(*)}}$

  ⇒ by $SU(2)_L$ invariance, unavoidable contribution* to $b \to s\tau\tau$ (& $b \to s\mu\mu, ee$ via RGE)

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  ⇒ leptoquarks favoured

  ⇒ same NP would contribute to $R_{D^{(*)}}$ *

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- at the level of explicit models, Z' solutions are generally in tension with B_s mixing

  ⇒ leptoquarks favoured

  ⇒ same NP would contribute to $R_{D^{(*)}}$ *

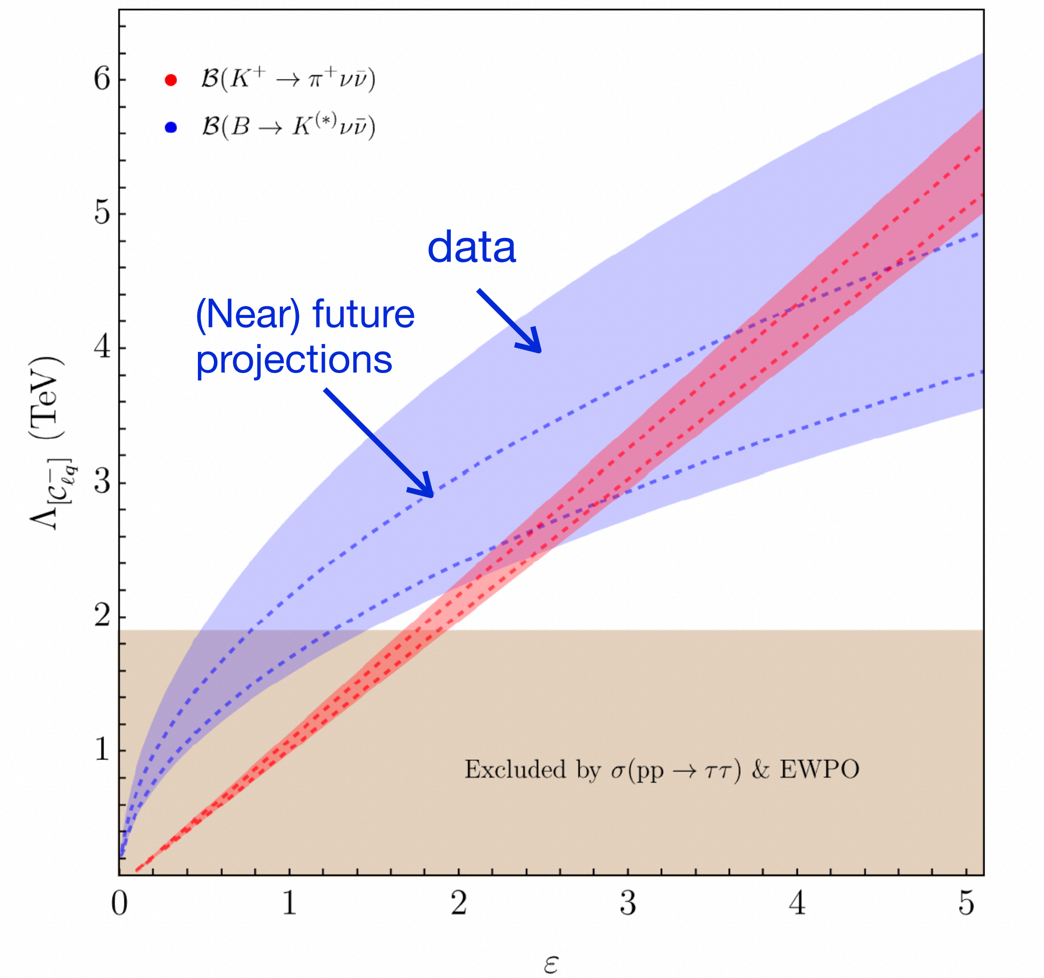
- If the underlying flavor structure is U(2)-like

  ⇒ expect correlated effects in $s \to d\nu\nu$, $b \to d\nu\nu$ (+ $\tau\tau$ modes)

Currently, excesses in $b \to s\nu\bar{\nu}$, $s \to d\nu\nu$ & $R_{D^{(*)}}$ are reconcilable with U(2)-like structure and absolute scale $\Lambda \sim \mathcal{O}(1\,\text{TeV})$ [works at the EFT level, less trivial in explicit modes]

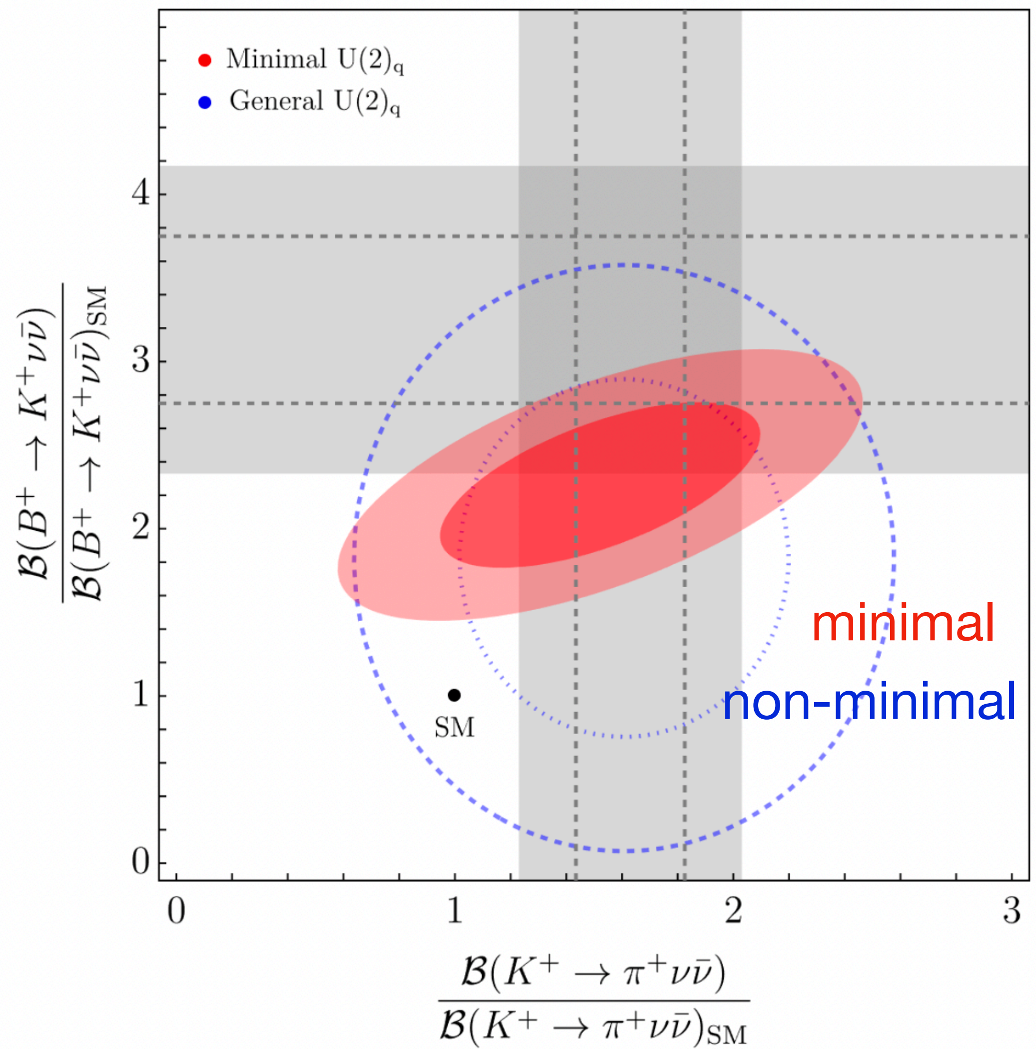
Implications of a NP interpretation of $b \to s\nu\bar{\nu}$ data

determine size of breaking terms
[those not already fixed by masses & CKM]



e.g. leading U(2)$_q$ breaking can be determined by comparing b→s vs s→d

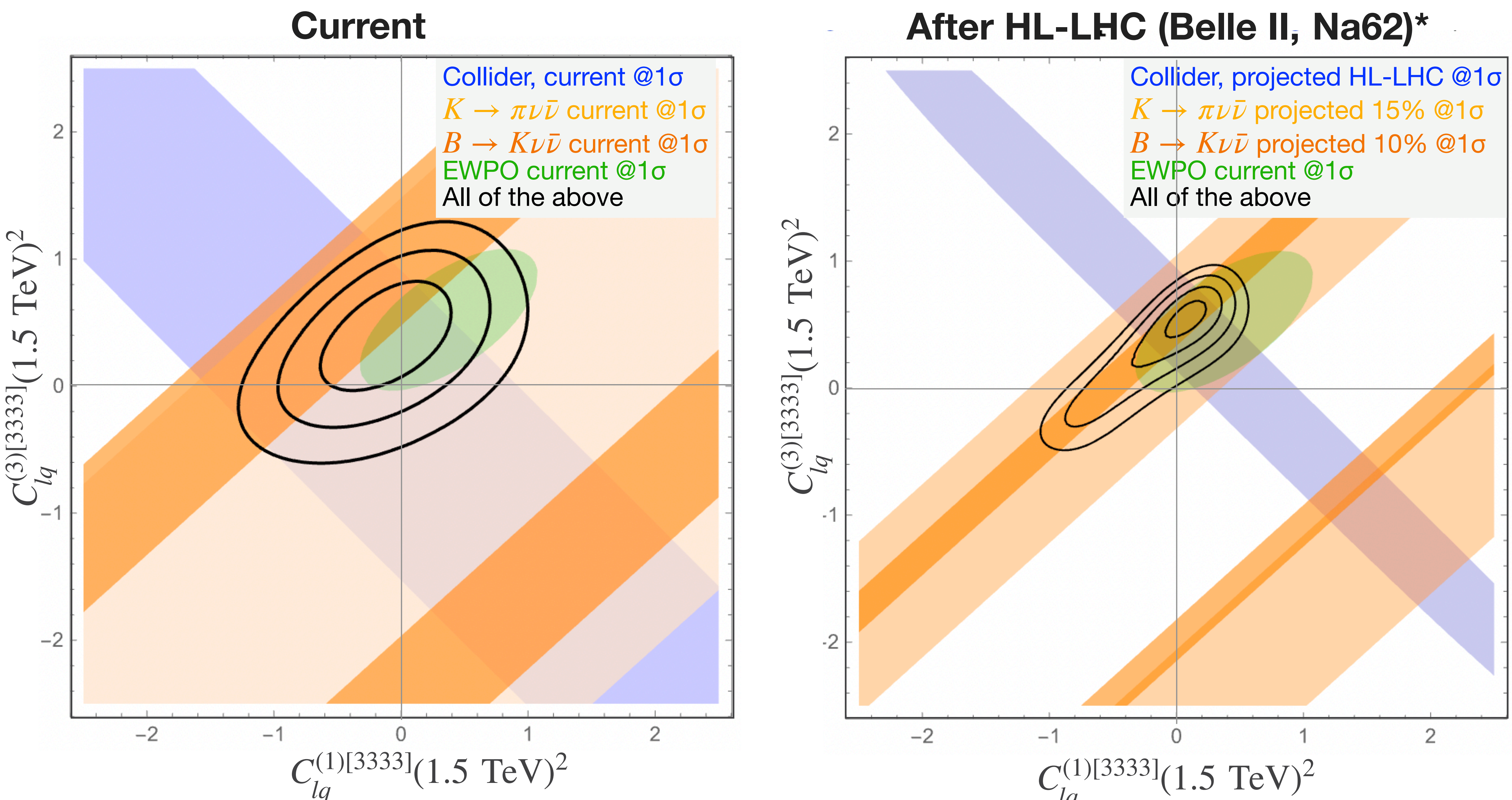
discriminate between ≠ breaking patterns via characteristic correlations



[Allwicher, Bordone, Isidori, Piazza, Stanzione, 2410.21444]

Implications of a NP interpretation of $b \to s\nu\bar{\nu}$ data

Combining $\nu\bar{\nu}$ data with EW precision and collider:



[*assuming current BFP]

Setup: analysis with $C_{\ell q}^{(3)[3333]}$, $C_{\ell q}^{(1)[3333]}$, ϵ_F

[Plots from Allwicher, CC, Isidori, Stefanek, 2311.00020 updated with more recent data]

Why Tera-Z can help probe Flavored New Physics

Looking into the future, a Tera-Z facility can help test flavoured NP via the *combination* of its EW precision & flavor program. How?

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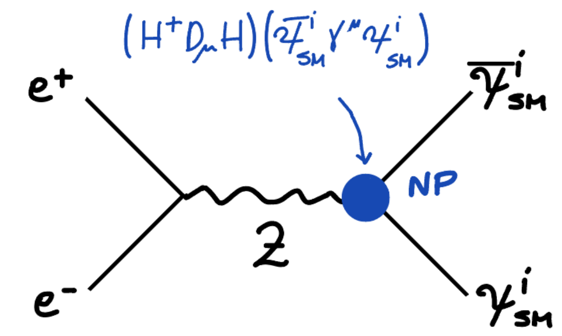
EW precision

- 3rd fam. NP is "protected" against direct searches at the LHC & flavor, but *not* protected vs EWPT - "*everything runs into EW*"
- At a Z factory, we can use the flavor blindness of SM gauge interactions to probe NP coupled to any generation via EWPT
  ⇒ EWPT are powerful probes of flavor non-universal NP



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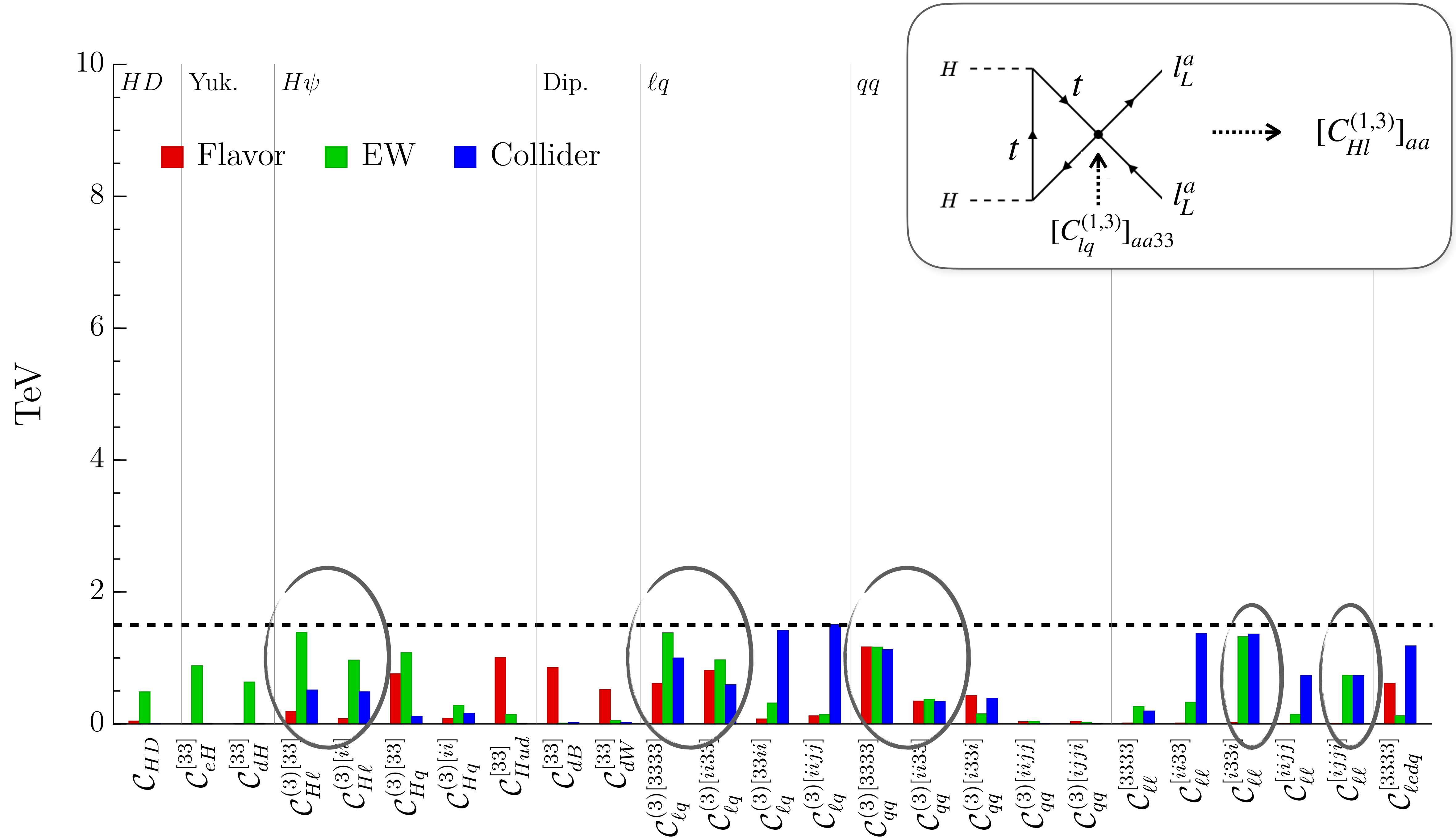
Even now LEP bounds have a strength comparable to current direct searches for operators involving mostly the 3rd generation:

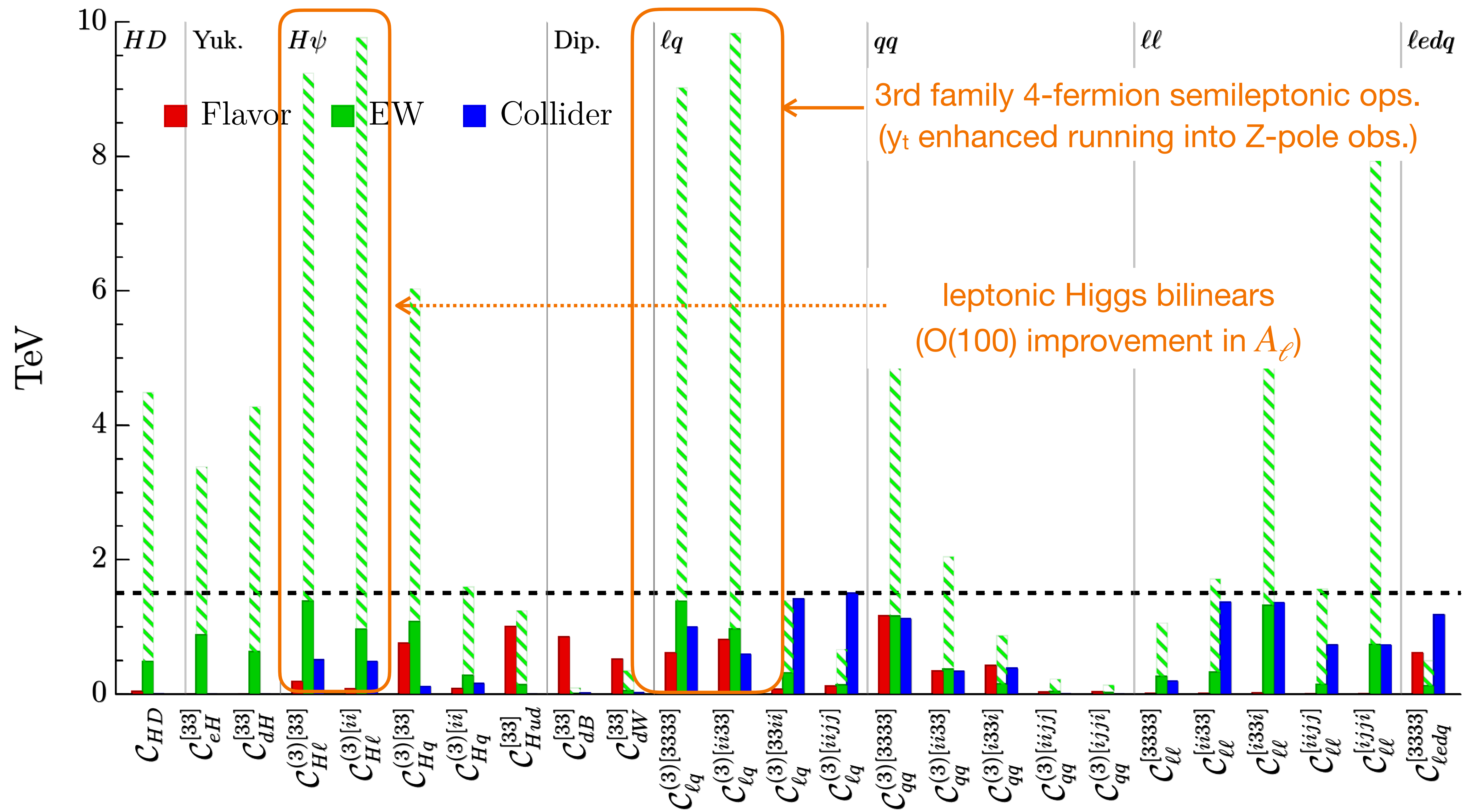


Why Tera-Z can help probe Flavored New Physics

....with $\approx 10^5$ more Z bosons than LEP,

A tera-Z machine in its Z-pole run could probe 3rd-family NP up to ~ 10 TeV!

[And flavor universal NP up to much higher scales, O(30-50 TeV]



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Looking into the future, a Tera-Z facility can help test flavoured NP via the *combination* of its EW precision & flavor program. How?

Flavor

- combines the best features of pp colliders and B factories
  high statistics, "closed" kinematics, high boost of b and τ, access to all b hadrons
- precise measurements of $b \to s\tau\tau$ & $b \to s\nu\nu$, incl. $b \to d$ counterpart
- test LFU in $\boldsymbol{\tau}$ decays @ $O(10^{-4})$
- dedicated studies with detector simulation (IDEA baseline) + background modelling available for a few channels, many more under development

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  Beyond Belle II: Pushing Precision to O(1%)
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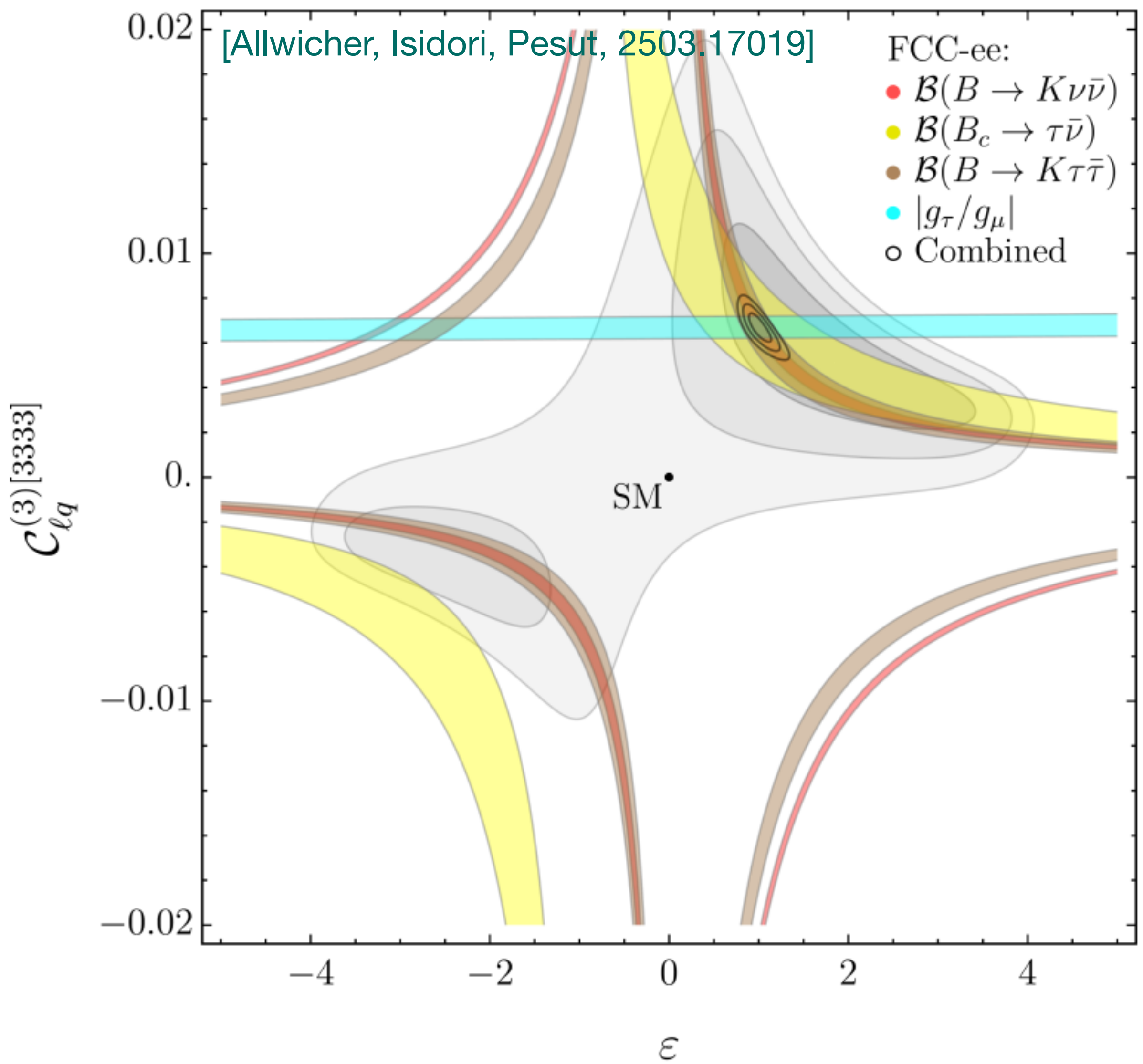
Flavor

Example: determination of alignment of NP in flavor space [ϵ_F = leading U(2)q breaking]



- current data (gray): main sensitivity to ϵ_F from $B \to K\nu\bar{\nu}$ & $K \to \pi\nu\bar{\nu}$, subleading $R_{D^{(*)}}$
- with FCC-ee (flavor), two "new" hyperbolae: $B \to K\tau\bar{\tau}$ & $B_c \to \tau\nu$

[setup as before: analysis with $C_{\ell q}^{(3)[3333]}$, $C_{\ell q}^{(1)[3333]}$, ϵ_F]

Conclusions

NP with flavor protection can exist at the TeV if coupled dominantly to the 3rd family.

Many signatures to look for at existing experiments:

- direct 3rd family searches
- precision measurements in B & K decays

These are the best path to discovery until the next collider.

In this context, dineutrino modes provide privileged test of the flavor structure of NP (alignment in flavor space, info on non minimal breaking patterns).
Should the mild excess solidify, it would imply a plethora of signatures.

Looking forward, a tera-Z machine is ideal in testing “flavored” NP scenarios

- unprecedentedly precise EWPT that cannot be bypassed by flavor symmetries
- major advancements incl. access to new channels