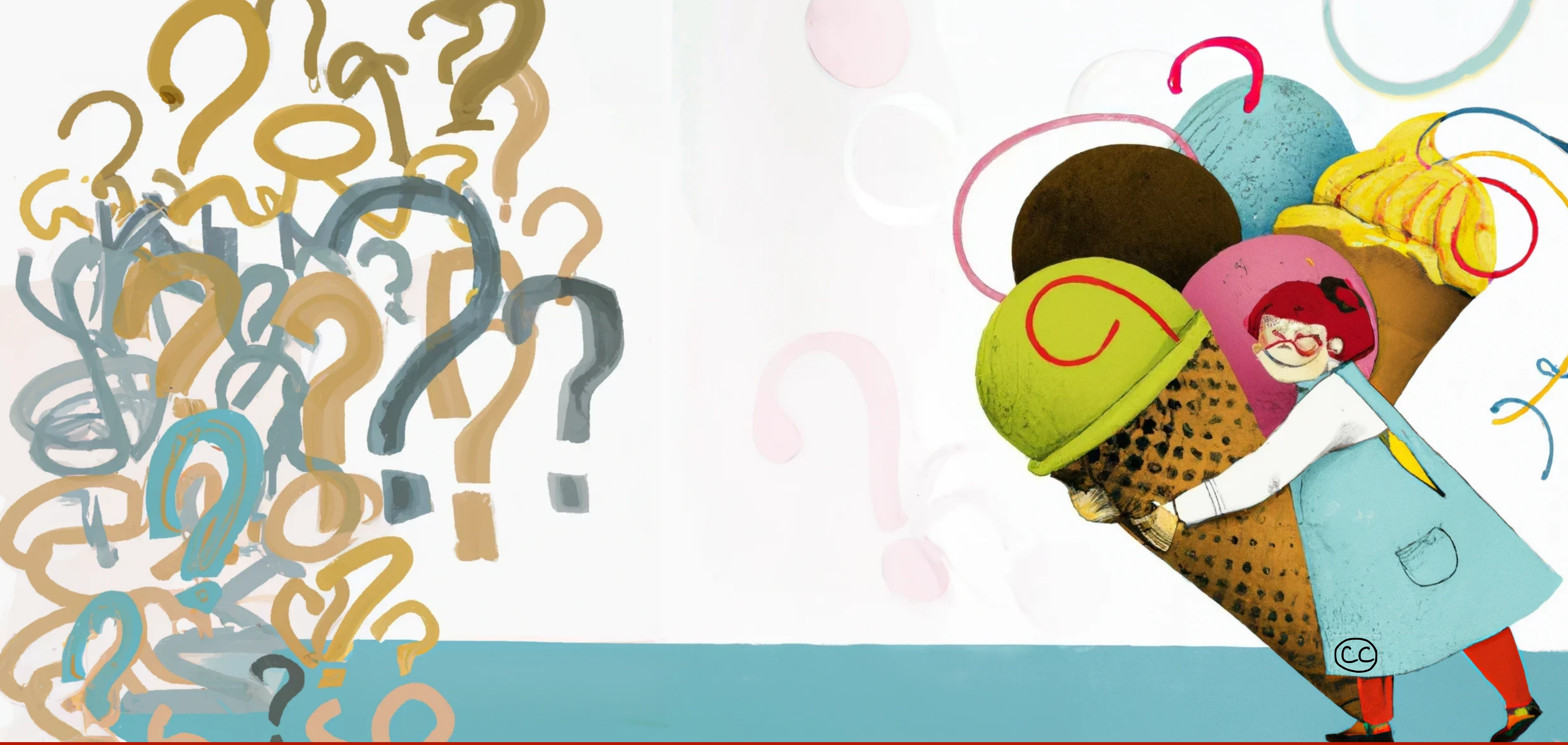


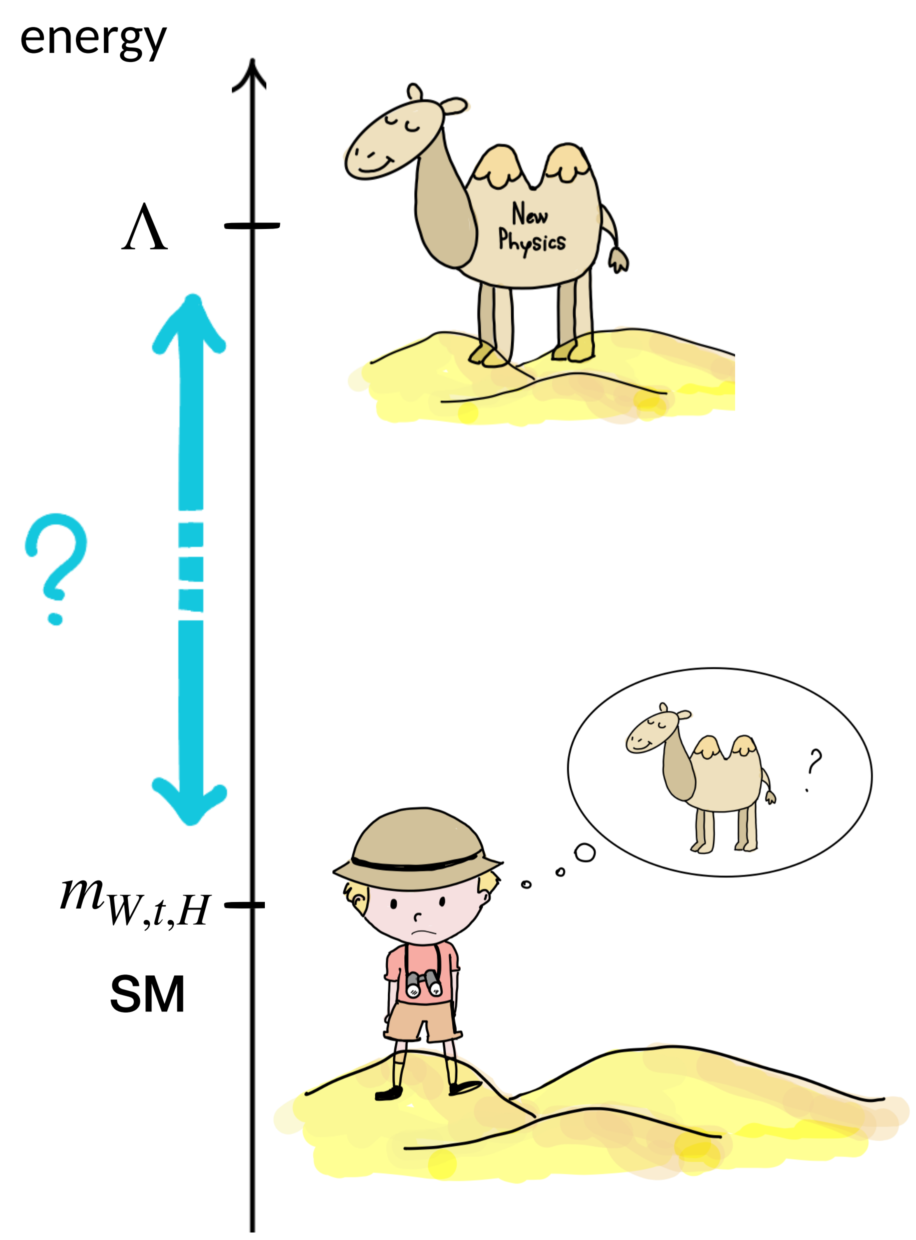
New Physics in the third generation: current status and future prospects

Claudia Cornella (JGU Mainz)

based on 2311.00020 and work in progress with L. Allwicher, G. Isidori, and B. Stefanek

The scale of New Physics

We have many reasons to think that the SM must be extended at higher energies. But **how high**?



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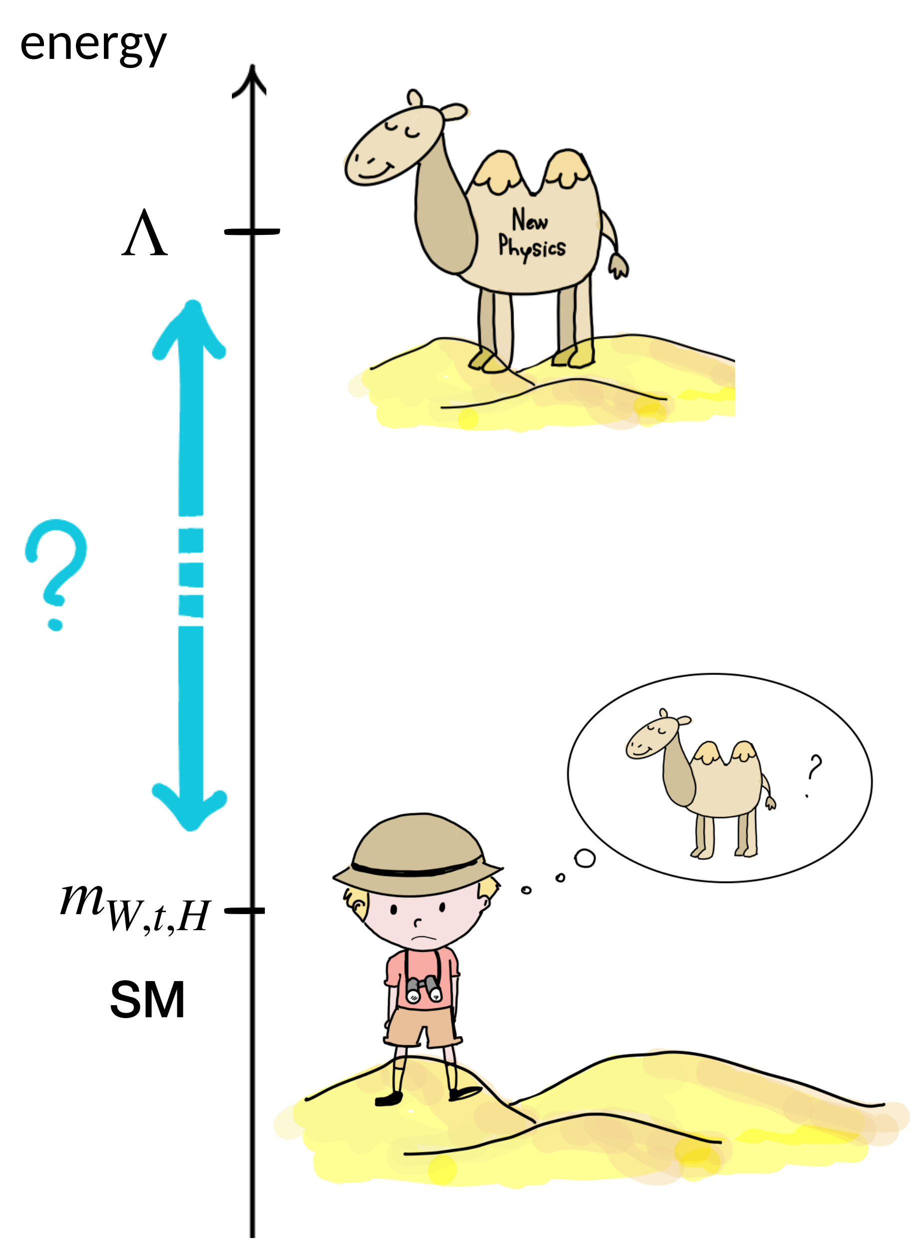
With data we place constraints on the coefficients of SMEFT operators, and interpret them as constraints on the NP scale.



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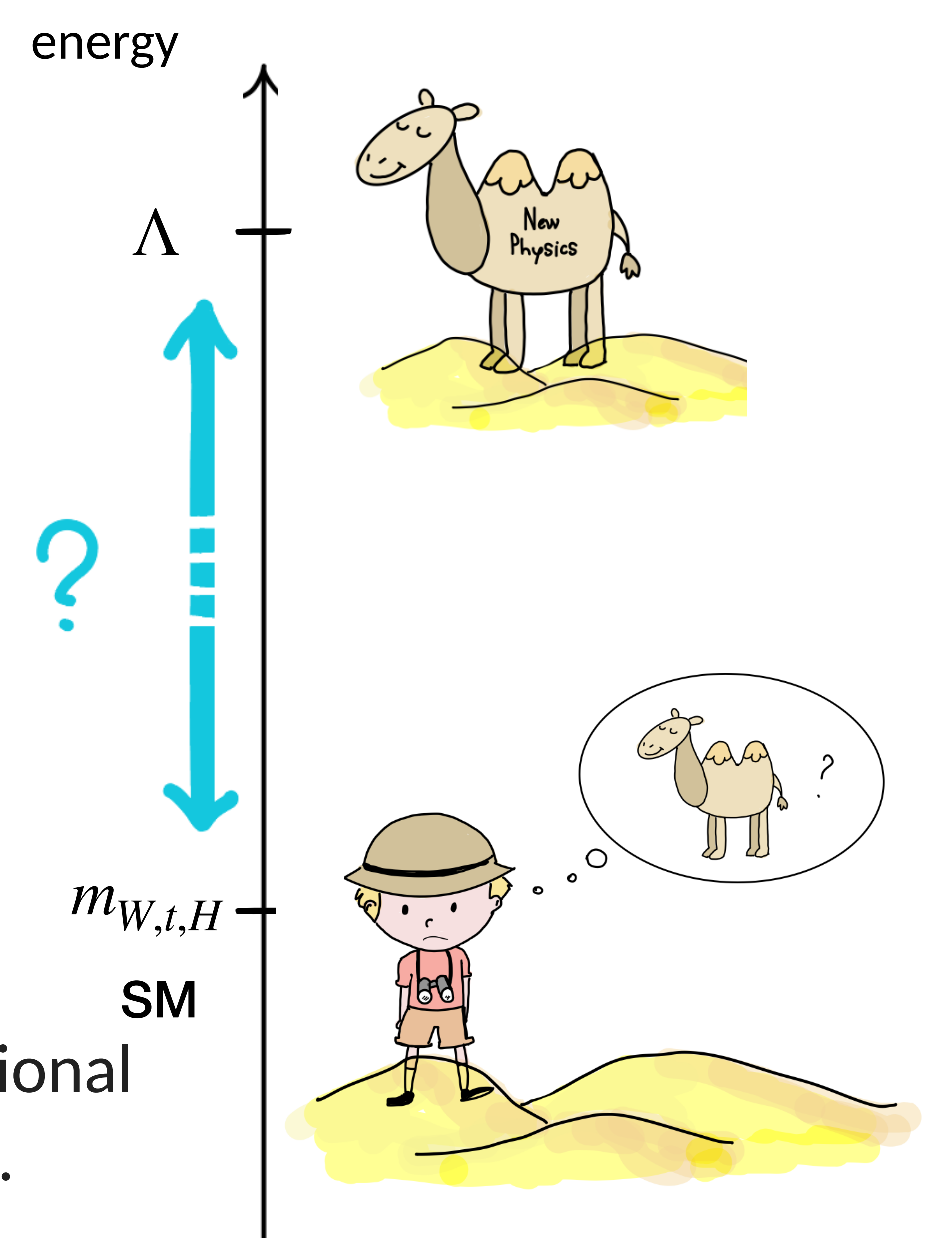
However, interpreting these constraints without additional assumptions can lead to overly pessimistic estimates…



The scale of New Physics: an example from the past

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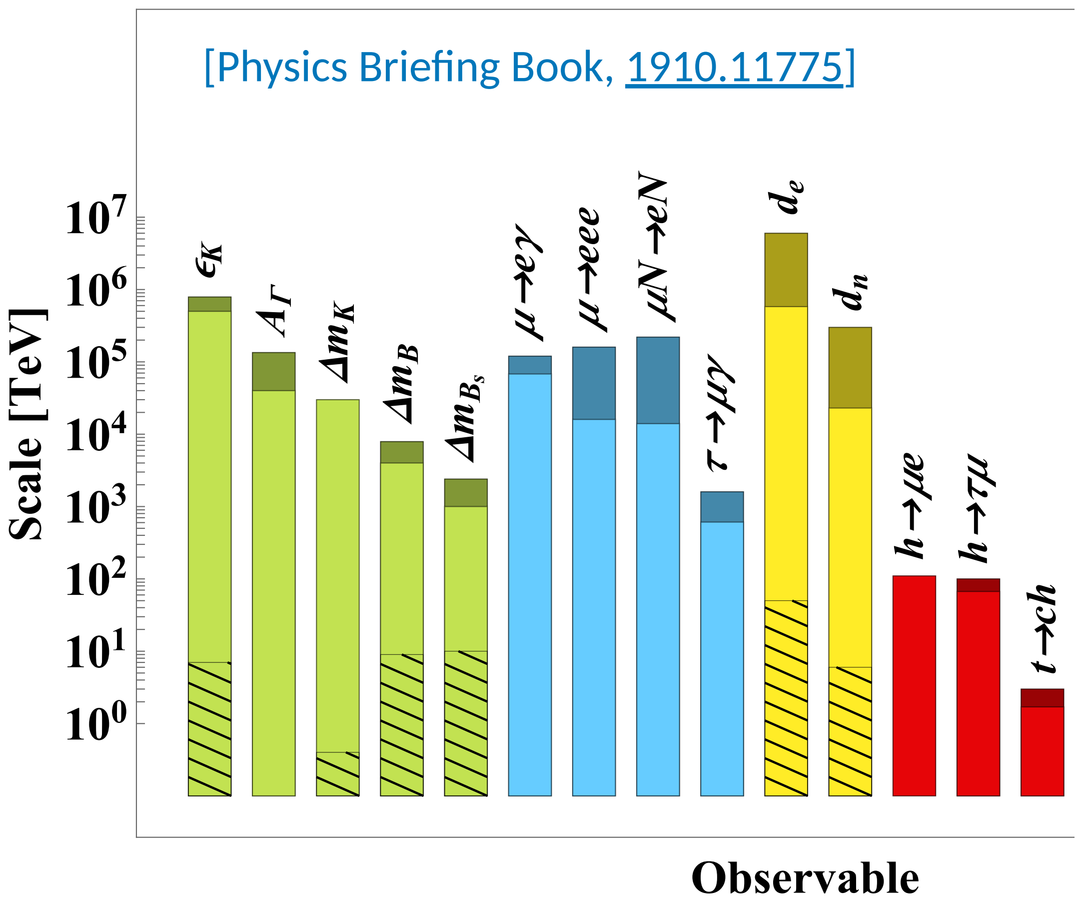
Now we know that the real characteristic scale of this interaction was much lower:

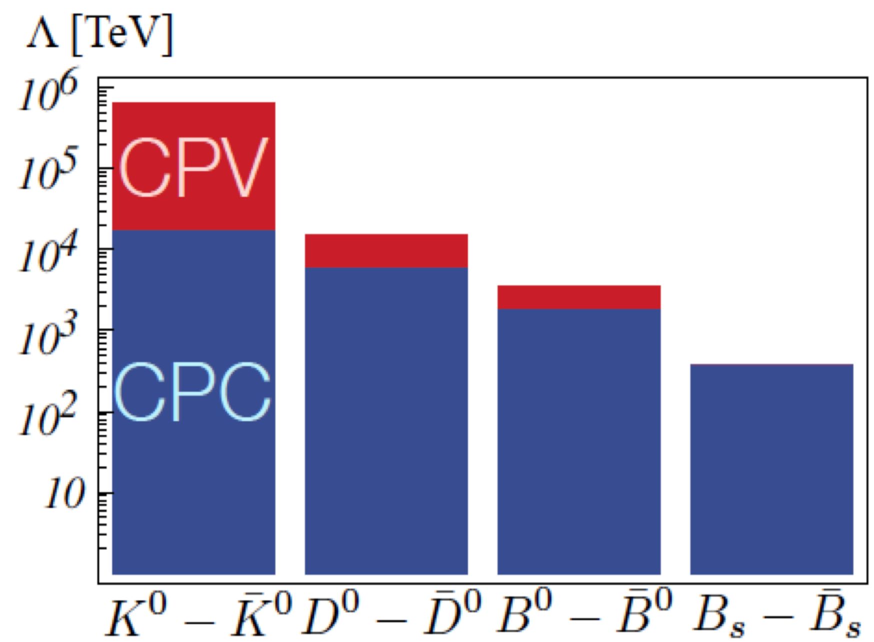
$$\frac{1}{\Lambda_{\rm CP}^2} \sim \frac{(G_F m_t V_{ts} V_{td})^2}{4\pi^2}$$

The scale of New Physics

Similar caution is needed when interpreting SMEFT bounds.

With O(1) NP couplings, bounds on flavor-violating operators point to huge scales:





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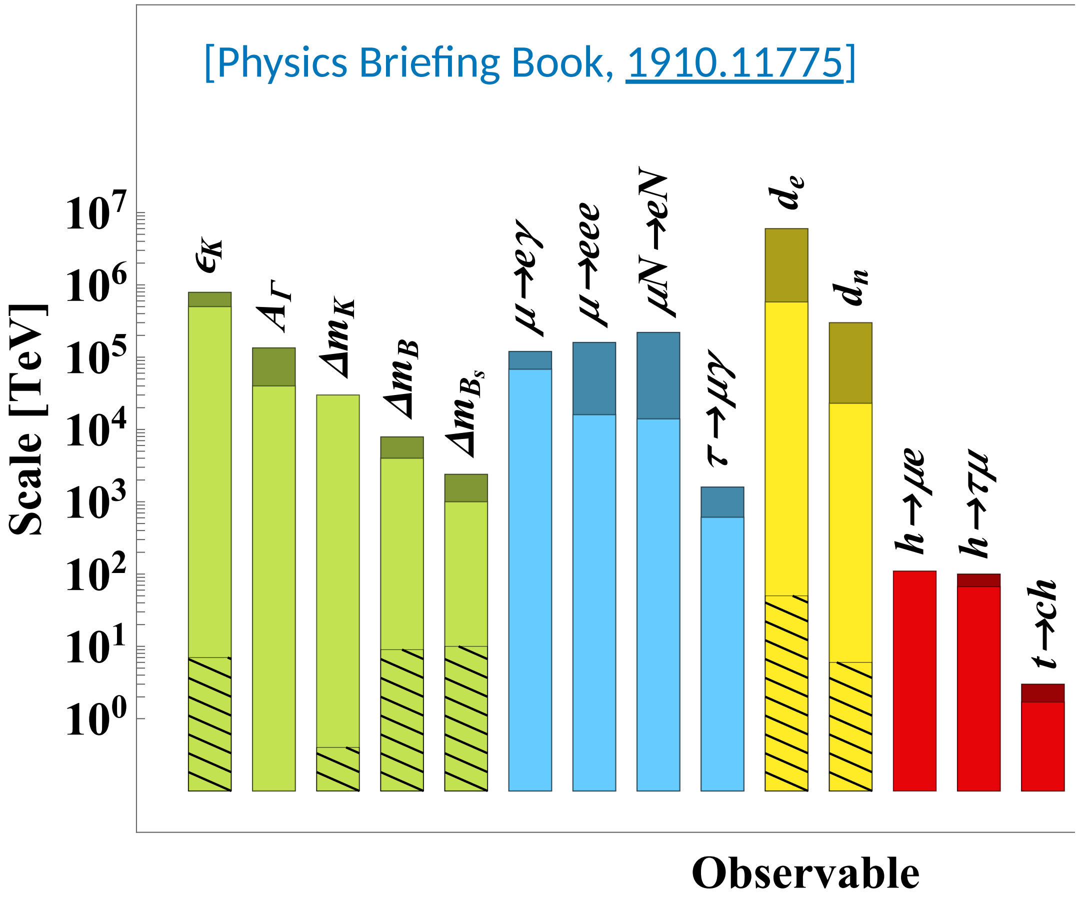

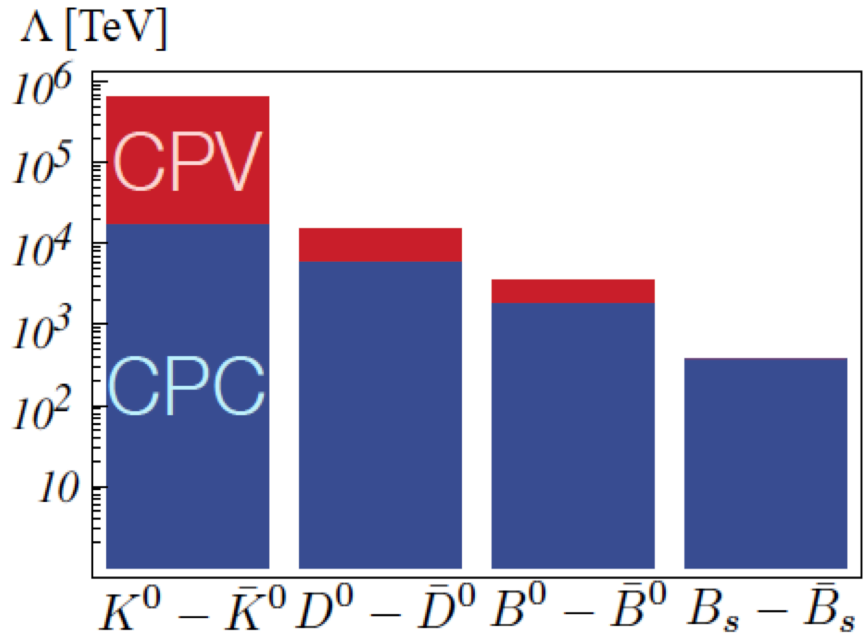

…but in realistic models these couplings can be suppressed, and give much looser constraints!

Making **educated assumptions about the NP structure** and translating them into selection rules in the SMEFT can provide a more informative interpretation of bounds!

Goal and outline

Here: focus on **models where NP predominantly couples to the third generation**.

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Outline

- Introduction of the flavor symmetry characterising these models, $U(2)^5$.
- SMEFT + $U(2)^5$
- Bounds on the $U(2)^5$ - symmetric SMEFT
- Same, but for NP coupling mostly to the 3rd generation.
- Future projections.

The SM flavor puzzle and U(2) symmetry

Models where NP couples mostly to the **3rd family** are well-motivated theoretically: the 3rd generation plays a special role in two long-standing problems of the SM, the **hierarchy problem** and the **flavor puzzle**.

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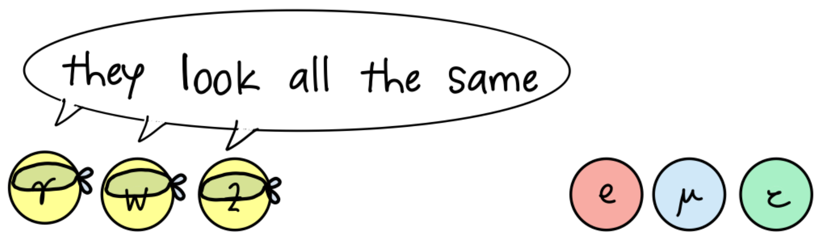

$$\mathcal{G}_F = U(3)^5 \equiv U(3)_q \times U(3)_u \times U(3)_d \times U(3)_\ell \times U(3)_e$$

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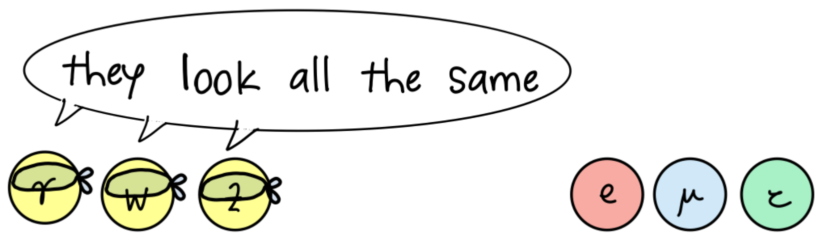

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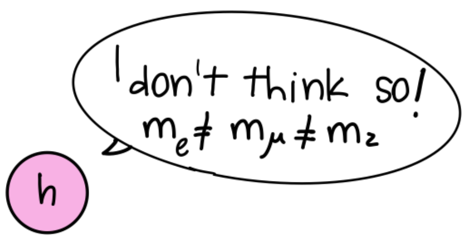
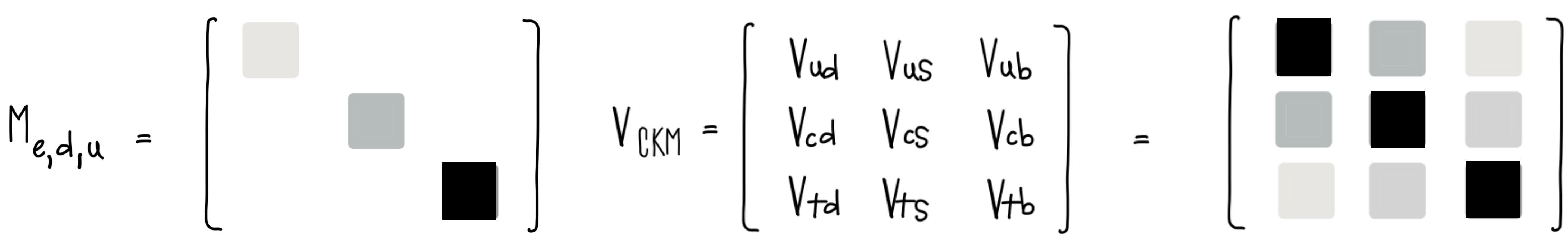


Yukawa interactions **break** this symmetry in a specific way:



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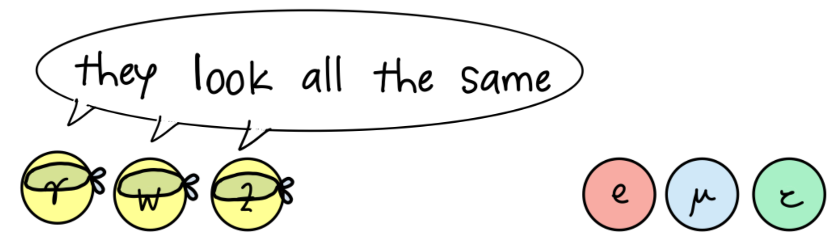

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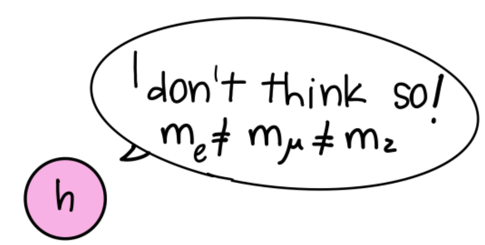
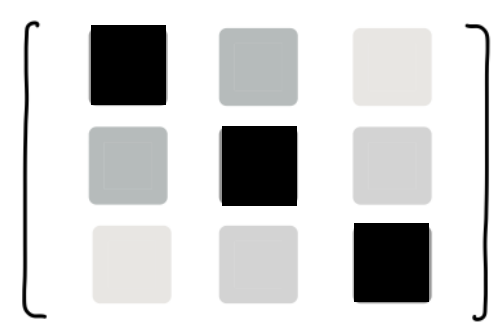


$M_{e,d,u}$ =

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} =$$



$$U^5(3) \to U(2)^5 \equiv U(2)_q \times U(2)_u \times U(2)_d \times U(2)_\ell \times U(2)_e \qquad \psi = (\boxed{\psi_1 \; \psi_2} \; \psi_3)$$

[Barbieri et al. 2022, Isidori,Straub 2012]

The New Physics flavor puzzle

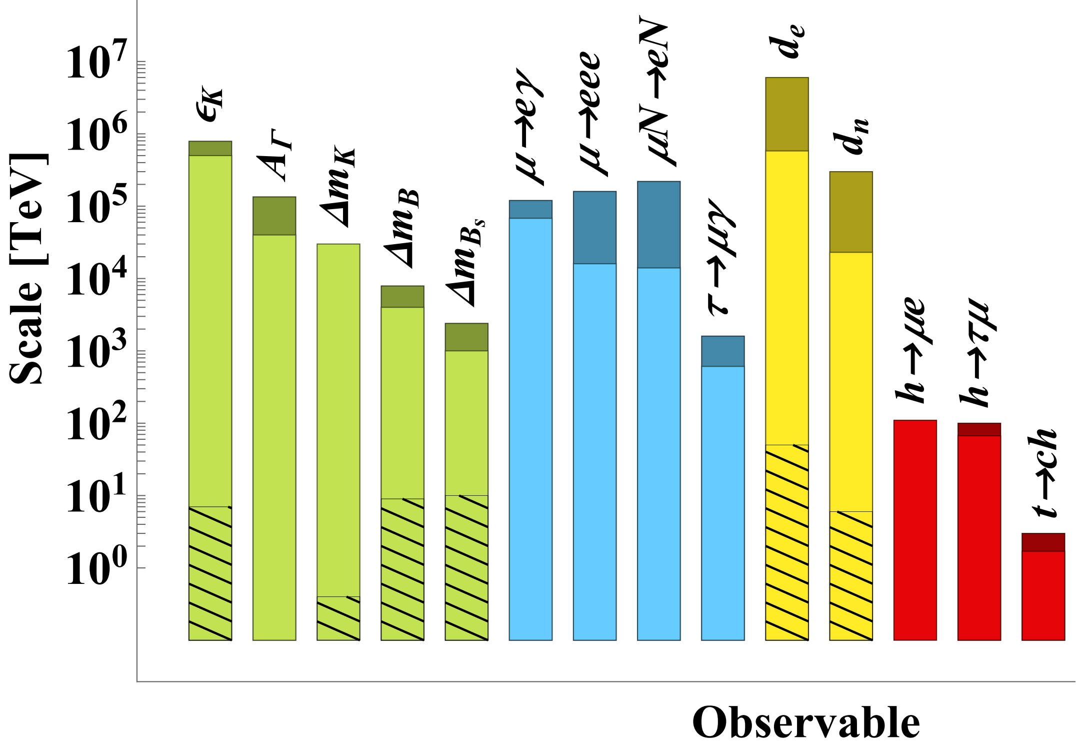
The NP flavor puzzle:

Flavor is just an accidental symmetry: nothing forbids it to be badly violated in the UV. Then why don't we observe sizeable non-standard flavor-violating effects?

Either because the scale of these interaction is astronomically high.....

Or because the couplings of these operators are small.

[Physics Briefing Book 2020, 1910.11775]



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Or because the couplings of these operators are small.

In either case, the only **unambiguous** message of these bounds is that **there is no large breaking of U(2)⁵ at nearby scales**.

U(2)⁵ is a good symmetry also of the SMEFT!

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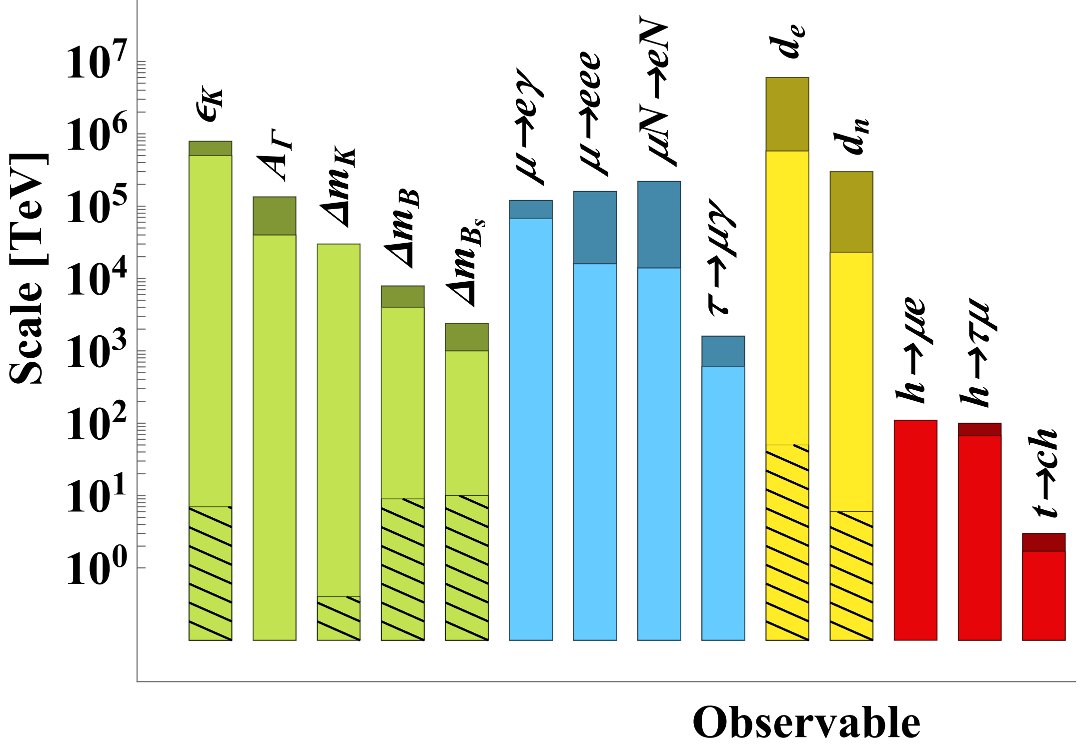

$U(2)^5$ vs MFV

Previously, the way to allow for TeV NP while protecting it from flavor bounds was to assume **Minimal Flavor Violation**.

- Yukawas are the only sources of G_f=$U(3)^5$ breaking also beyond the SM.
- by construction, MFV gives little to no effect in flavor-changing processes.
- MFV describes (perturbations around) **flavor-universal NP** 1 = 2 = 3

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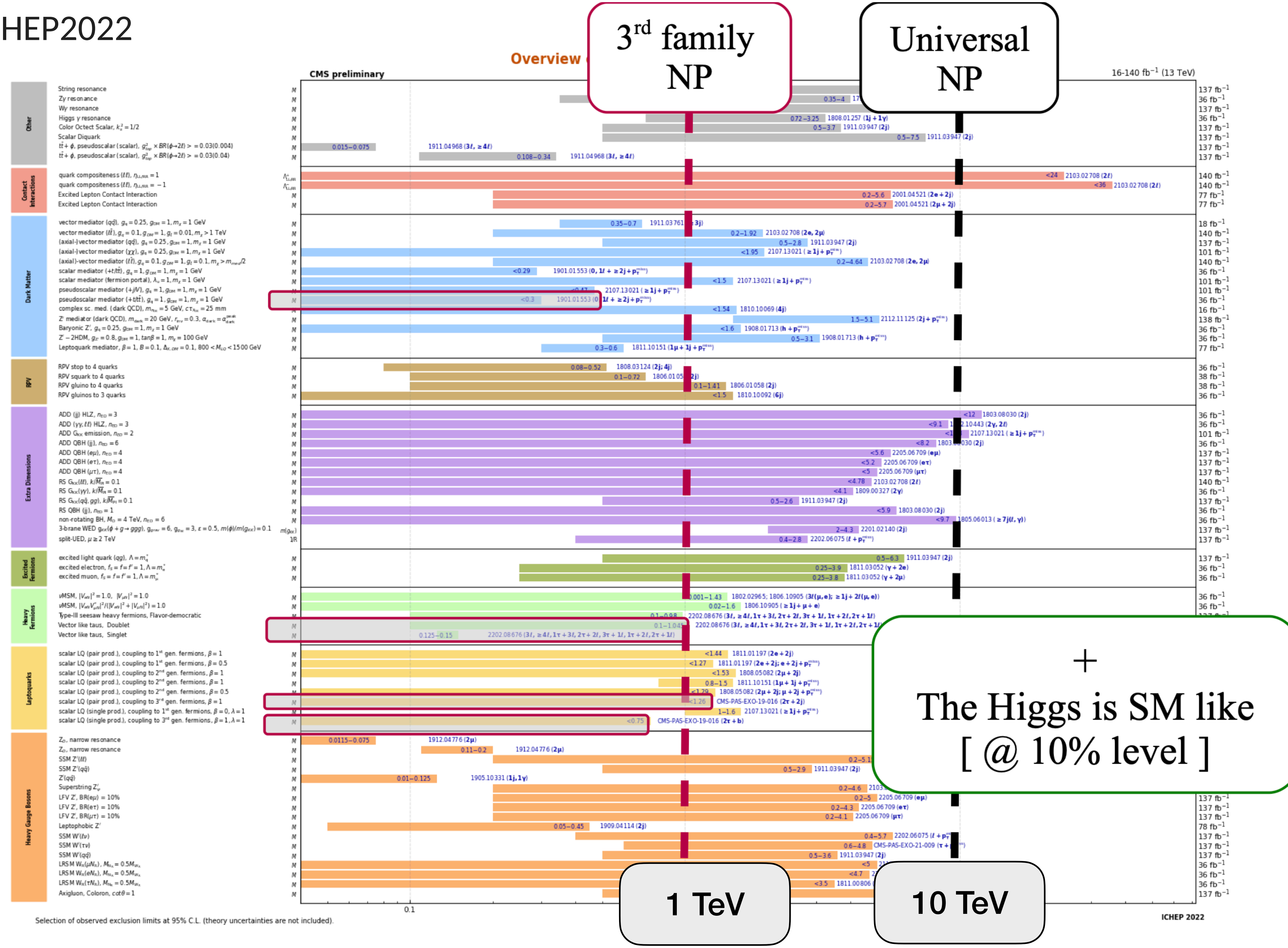
And now LHC data push the scale of MFV NP to scales $\gtrsim$ 10 TeV!

By contrast, **$U(2)^5$** describes **flavor non-universal NP**, placing a clear distinction between light and heavy generations.

Different NP couplings for light families make it possible to suppress couplings to valence quarks and relax direct search bounds!

Status of high-energy searches

@ICHEP2022



Flavor non-universal interactions

These considerations translate into model-building ideas!

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- The 3 families are *not* identical up to very high energies.

  Multiscale picture: non-universal interactions acting on the i-th family switch on at $\Lambda_1 \gg \Lambda_2 \gg \Lambda_3 \gg m_W$

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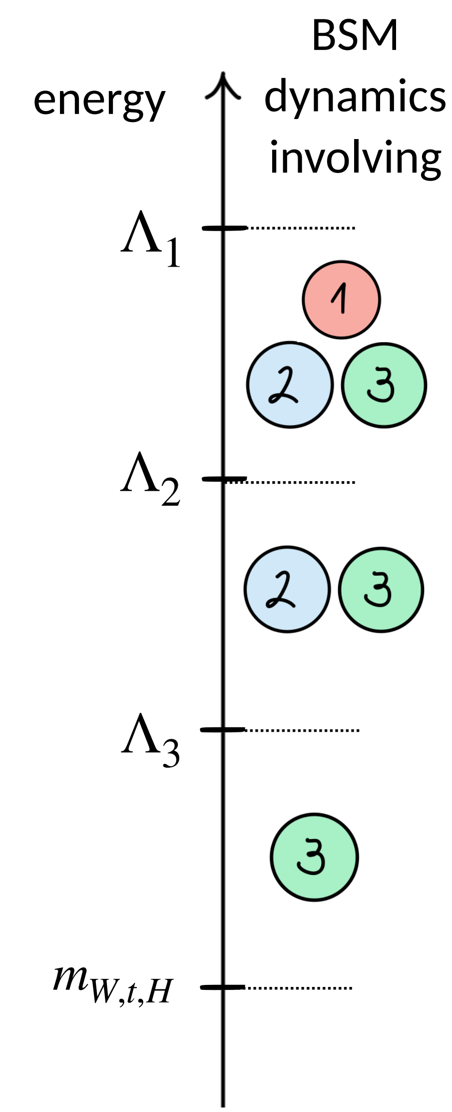

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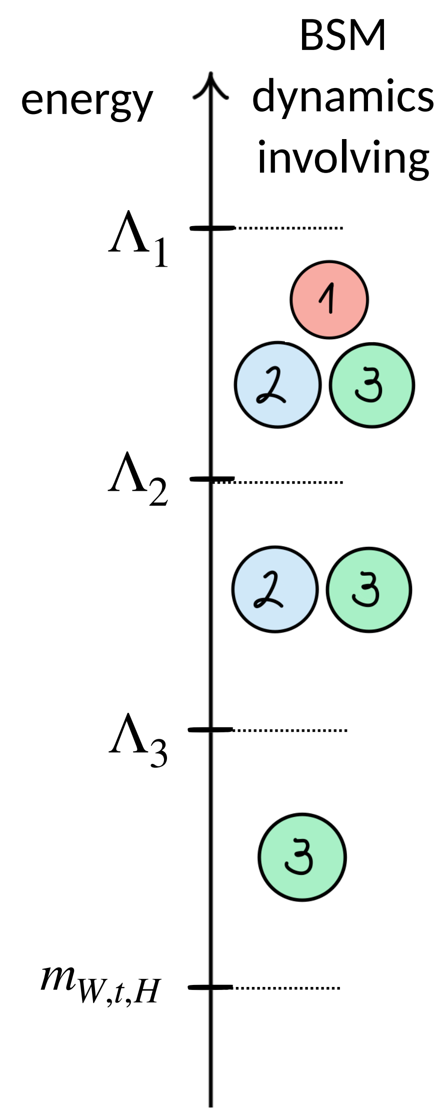

"deconstructed" gauge group

$$G_3 \times G_{12} \rightarrow G_{\text{universal}}$$

acts on 3rd fam. & Higgs

acts on light fam.

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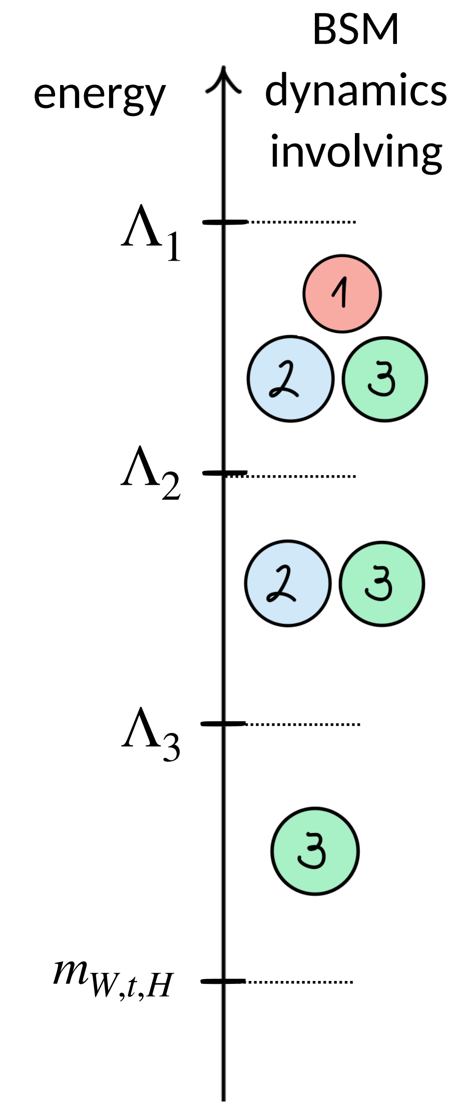
How low?



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The U(2) symmetric SMEFT

$U(2)^5$ is an **efficient organising principle**:

- SMEFT with 3 generations has 1350 + 1149 = 2499 independent WCs at dim-6.
- In the exact $U(2)^5$ limit, this is reduced to 124 + 23 = 147 independent WCs.
  Here we focus on the CP-conserving case.

Operators	$U(2)^5$ [terms summed up to different orders]													
	Exact		$\mathcal{O}(V^1)$		$\mathcal{O}(V^2)$		$\mathcal{O}(V^1,\Delta^1)$		$\mathcal{O}(V^2,\Delta^1)$		$\mathcal{O}(V^2,\Delta^1 V^1)$		$\mathcal{O}(V^3,\Delta^1 V^1)$	
Class 1–4	9	6	9	6	9	6	9	6	9	6	9	6	9	6
$\psi^2 H^3$	3	3	6	6	6	6	9	9	9	9	12	12	12	12
$\psi^2 XH$	8	8	16	16	16	16	24	24	24	24	32	32	32	32
$\psi^2 H^2 D$	15	1	19	5	23	5	19	5	23	5	28	10	28	10
$(\bar{L}L)(\bar{L}L)$	23	–	40	17	67	24	40	17	67	24	67	24	74	31
$(\bar{R}R)(\bar{R}R)$	29	–	29	–	29	–	29	–	29	–	53	24	53	24
$(\bar{L}L)(\bar{R}R)$	32	–	48	16	64	16	53	21	69	21	90	42	90	42
$(\bar{L}R)(\bar{R}L)$	1	1	3	3	4	4	5	5	6	6	10	10	10	10
$(\bar{L}R)(\bar{L}R)$	4	4	12	12	16	16	24	24	28	28	48	48	48	48
total:	124	23	182	81	234	93	212	111	264	123	349	208	356	215

Table 6: Number of independent operators in the SMEFT assuming a minimally broken $U(2)^5$ symmetry, including breaking terms up to $\mathcal{O}(V^3,\Delta^1 V^1)$. Notations as in Table 1.

[D. A. Faroughy, G. Isidori, F. Wilsch, K. Yamamoto, arXiv:2005.05366]

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An example:

$$Q_{He}^{[ij]} = (H^\dagger i D_\mu H)(\bar{e}_i \gamma^\mu e_j)$$

SMEFT

6 independent structures

$U(2)^5$ - symmetric SMEFT

only 2 independent structures

$$Q_{He}^{[33]} = (H^\dagger i D_\mu H)(\bar{e}_3 \gamma^\mu e_3)\,,$$
$$Q_{He}^{[ii]} = (H^\dagger i D_\mu H) \sum_{i=1,2} (\bar{e}_i \gamma^\mu e_i)$$

The flavor rotation

What is the **third generation** in the SMEFT?

Non-trivial to define for the LH quark doublet because of the CKM misalignment!

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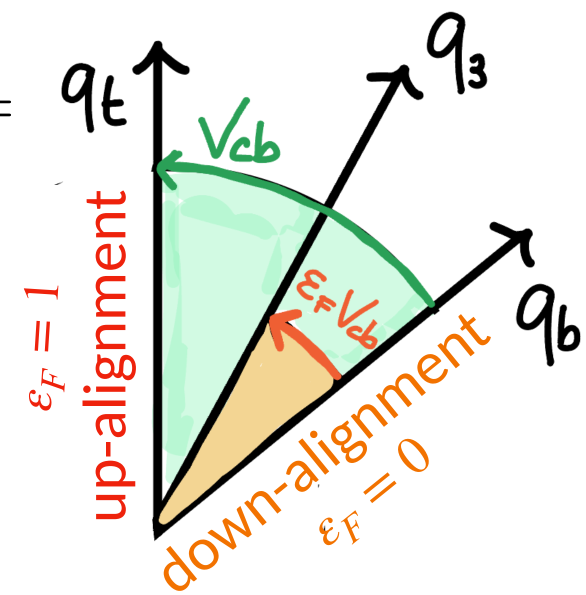
Non-trivial to define for the LH quark doublet because of the CKM misalignment!

In the interaction basis where the dim-6 SMEFT operators are U(2)^5 symmetric, the 3rd generation quark doublet is somewhere **in-between** the down-aligned and the up-aligned case.

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



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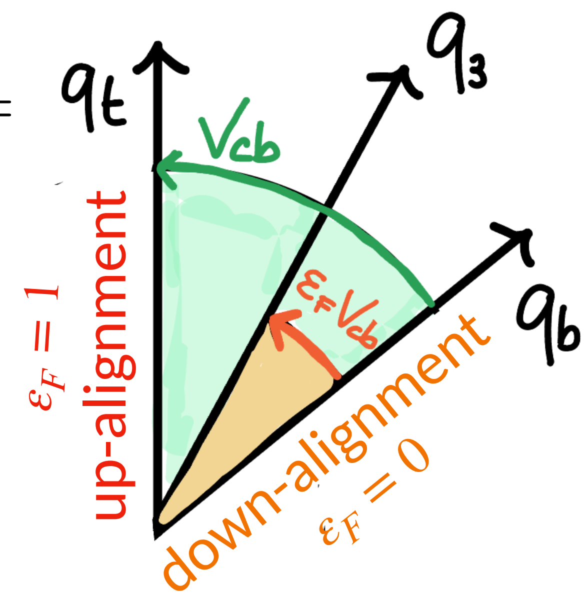

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In the spirit of minimally-broken U(2)^5, we describe this **misalignment** in terms of a single **angle** in the 2-3 sector, $\theta \sim V_{cb}\, \boldsymbol{\varepsilon_F}$.

Observables

EWPO

- W-pole observables [V. Bresó-Pla, A. Falkowski, M. González-Alonso, 2103.12074]
- Z-pole observables [L. Allwicher, G. Isidori, J. M. Lizana, N. Selimovic, B.Stefanek, 2302.11584]
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Flavor

- $\Delta F = 1$ ($B \to X_s \gamma, B \to K\nu\bar{\nu}, K \to \pi\nu\bar{\nu}, B \to K^{(*)}\mu^+\mu^-, B_{s,d} \to \mu^+\mu^-$)
- $\Delta F = 2$ ($B_{s,d}$ - mixing, K- mixing, D - mixing)
- Charged-current $b \to c, u$ transitions ($R_D, R_{D*}, B_{u,c} \to \tau\nu$)

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Collider

- LHC Drell-Yan $pp \to \ell\ell$ and mono-lepton $pp \to \ell\nu$ [L. Allwicher, D. A. Faroughy, F. Jaffredo, O. Sumensari, F. Wilsch, 2207.10756]
- LHC 4-quark observables
- LEP 4-lepton $ee \to \ell\ell$ [Ethier, Magni, Maltoni, Mantani, Nocera, Rojo, Slade, Vryonidou, Zhang, 2105.00006]

HighPT

Analysis strategy

- Run all WCs to a reference scale Λ = 3 TeV.
- For LEFT running, LEFT-SMEFT matching and SMEFT running we use DSixTools, which allows us to work analytically in the WCs also beyond leading log.
- Once all observables have been expressed in terms of SMEFT WCs at the hight scale, we impose the $U(2)^5$ symmetry.
- We construct the combined likelihood from collider, EW, and flavour observables as a function of the 124 WCs of the $U(2)^5$-symmetric (and CP conserving) SMEFT, and switch them on one at a time to get lower bound on the NP scale.

Results

Strong **complementarity** between 3 sectors.

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coeff.	$\Lambda_{\text{flav.}}^{\text{down}}$	$\Lambda_{\text{flav.}}^{\text{up}}$	Λ_{EW}	$\Lambda_{\text{coll.}}$
$\mathcal{C}_{H\ell}^{(1)[33]}$	0.1	0.1	4.4	1.6
$\mathcal{C}_{H\ell}^{(1)[ii]}$	0.7	0.7	7.6	3.
$\mathcal{C}_{H\ell}^{(3)[33]}$	0.7	0.7	4.5	1.7
$\mathcal{C}_{H\ell}^{(3)[ii]}$	0.7	0.7	7.7	3.8
$\mathcal{C}_{He}^{[33]}$	-	-	3.8	1.5
$\mathcal{C}_{He}^{[ii]}$	0.9	0.9	6.6	2.7
$\mathcal{C}_{\ell q}^{(3)[3333]}$	0.7	1.5	1.4	1.
$\mathcal{C}_{\ell q}^{(3)[ii33]}$	0.7	5.1	2.4	1.5
$\mathcal{C}_{\ell q}^{(3)[33ii]}$	0.1	1.4	2.	8.6
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  Operators with 3rd-family fermions get milder bounds, ~ 1 TeV.

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- Down alignment can relax these bounds down to ~ few TeV.

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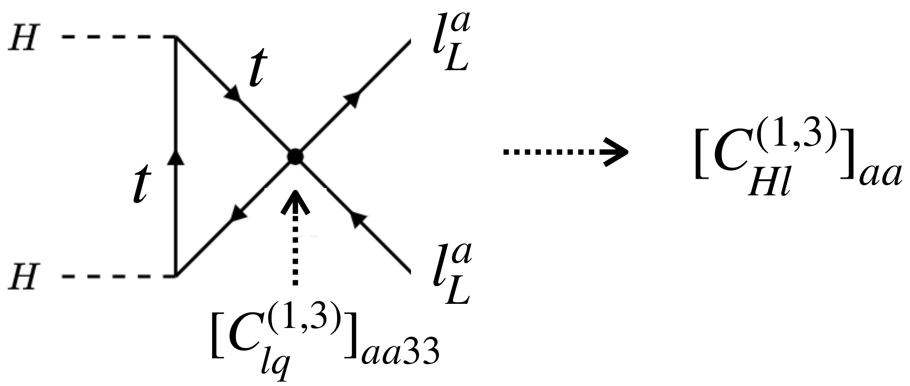

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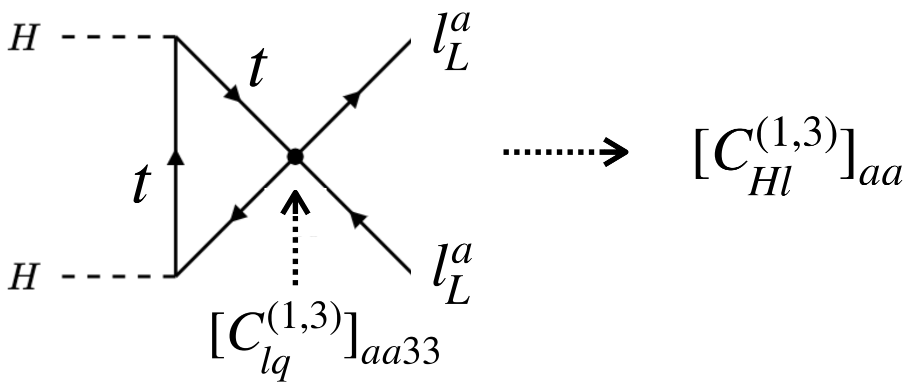

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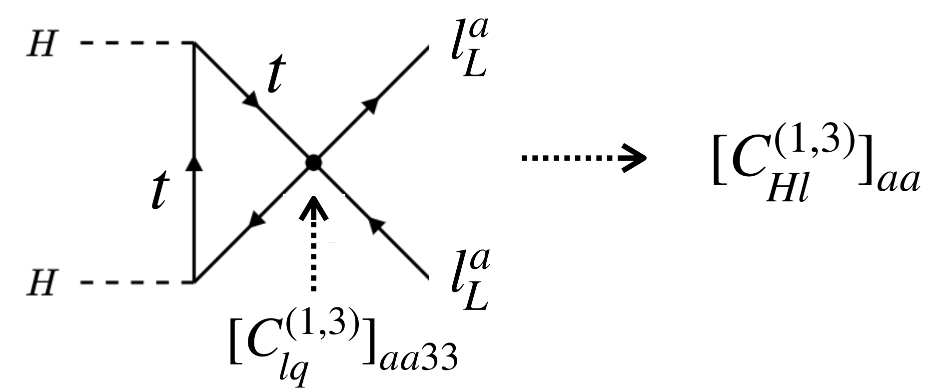

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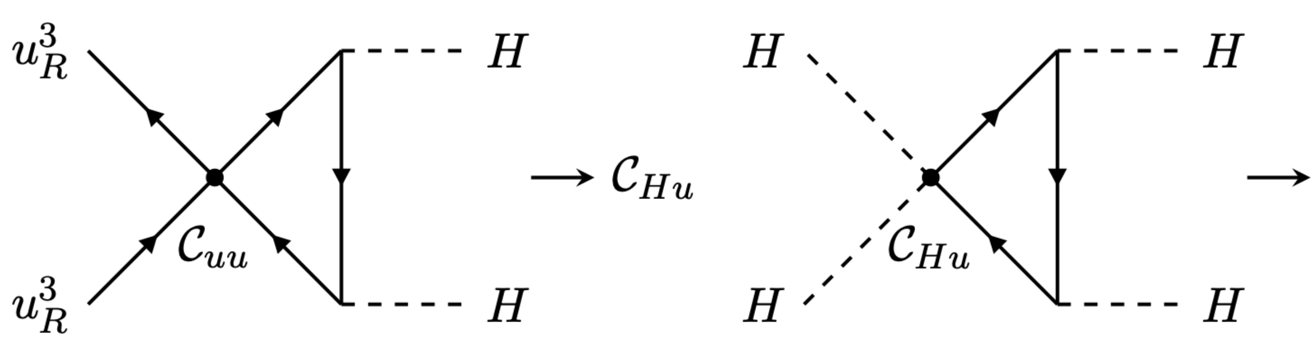
  Example: $[O_{uu}]_{3333}$ enters the EW fit only at NLL by mixing with O_{HD}



$$\rightarrow \quad [\mathcal{C}_{HD}]^{\rm NLL} \approx \frac{4N_c^2\, y_t^4}{(16\pi^2)^2}\, \mathcal{C}_{uu} \log^2\left(\frac{\mu^2}{\Lambda_{\rm NP}^2}\right)$$

The hypothesis of NP in the 3rd generation

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Can we make the bounds on ALL other operators compatible with 1.5 TeV for reasonable values for the suppression factors ε_q, ε_l, and ε_H?

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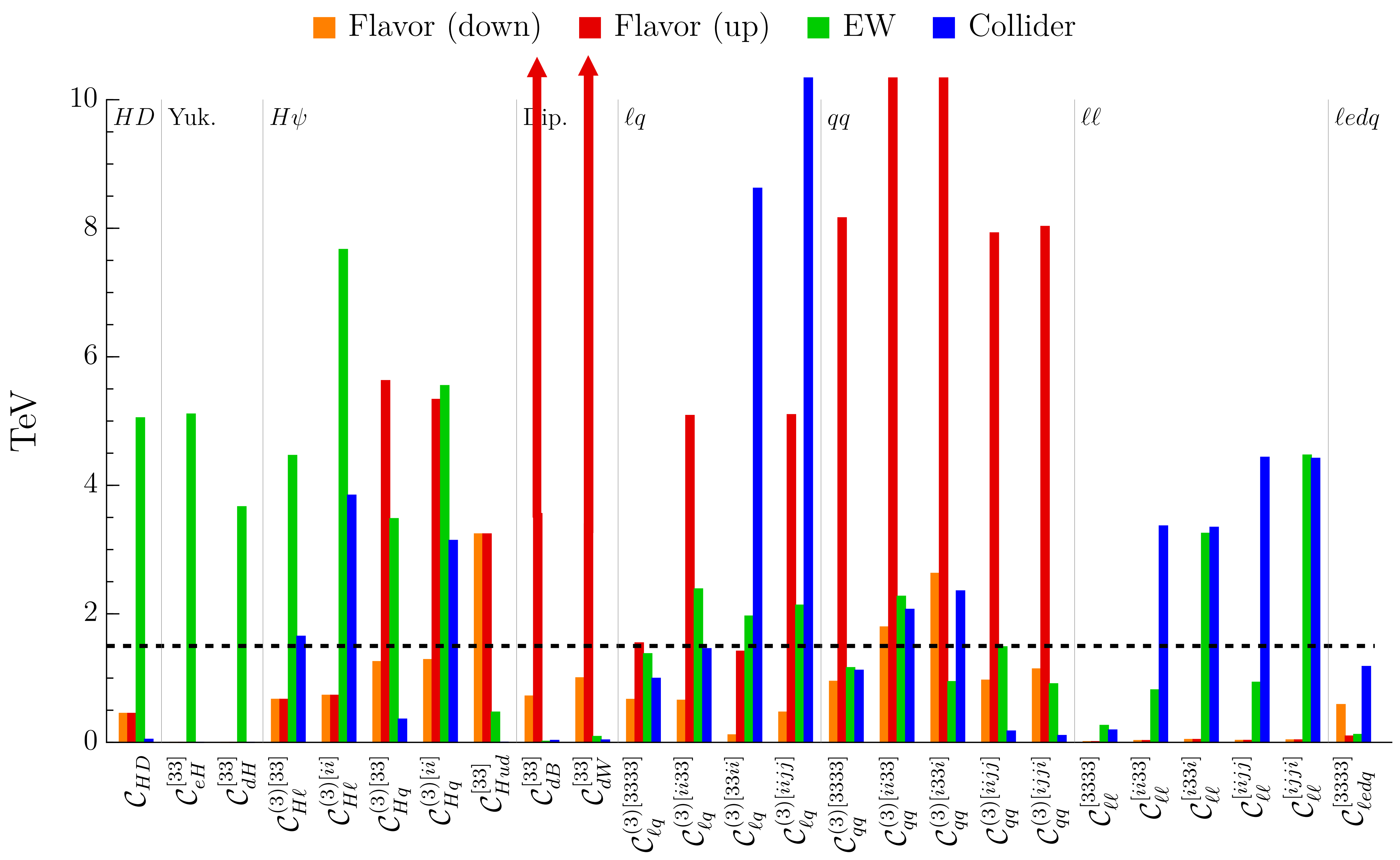

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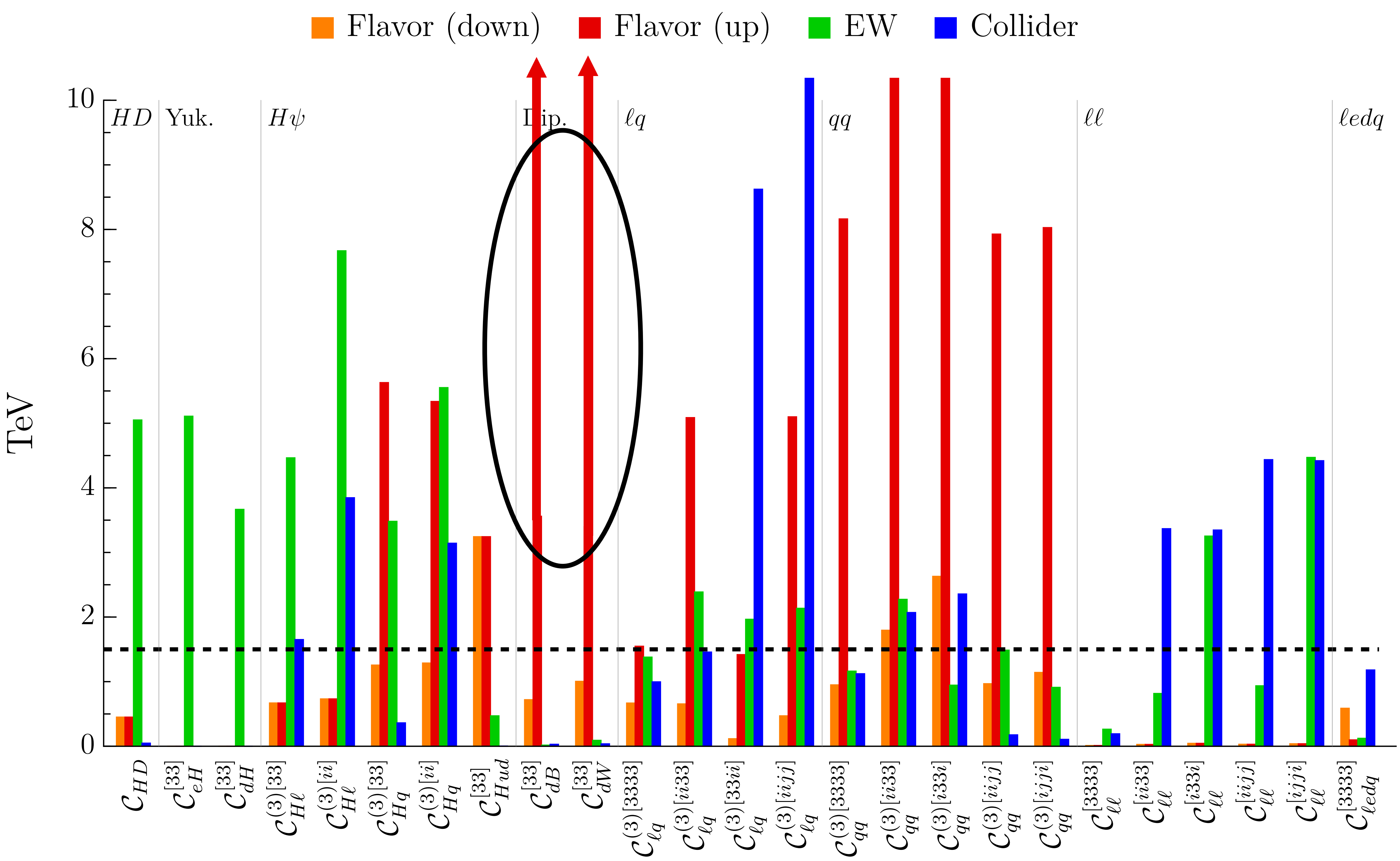

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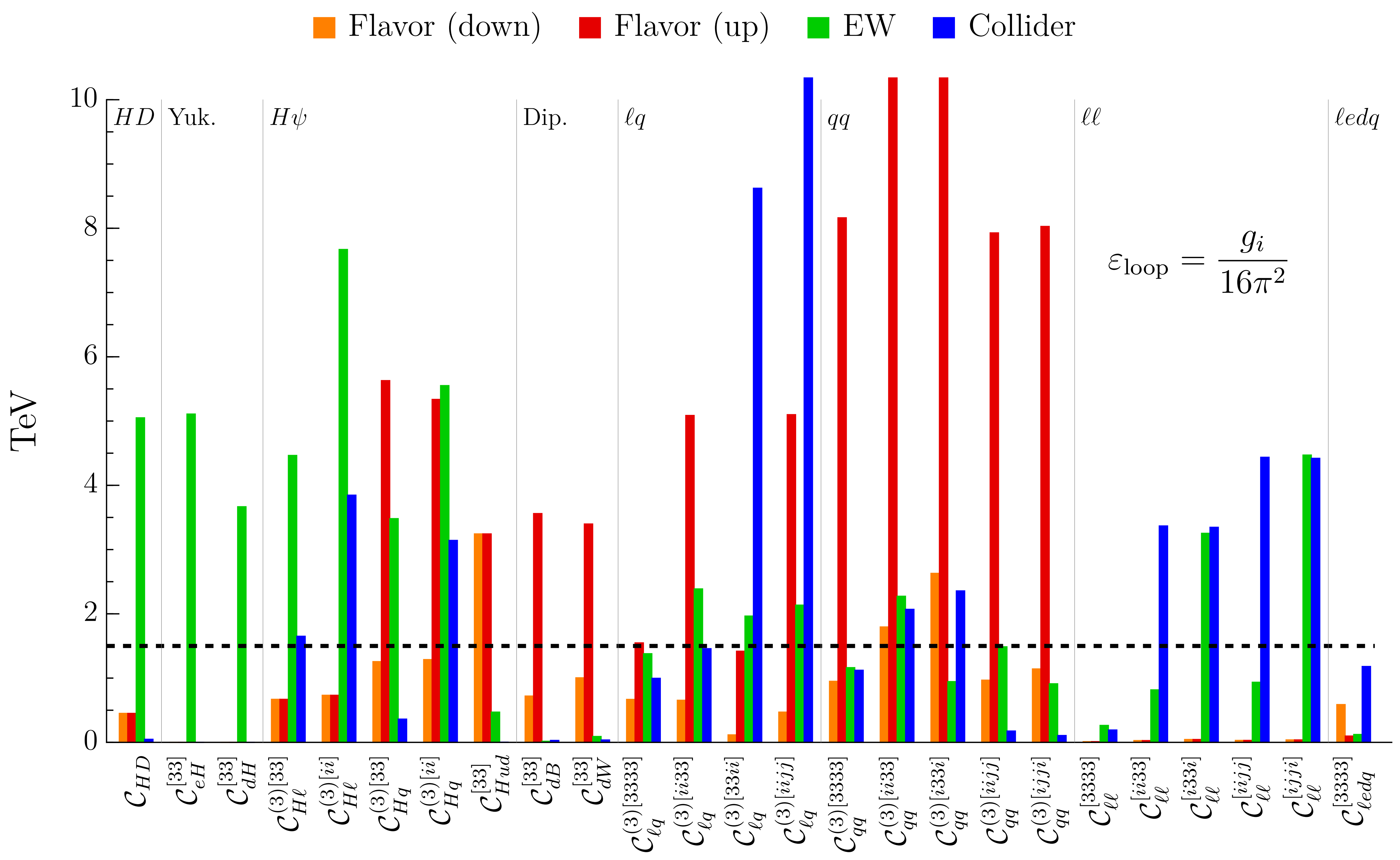

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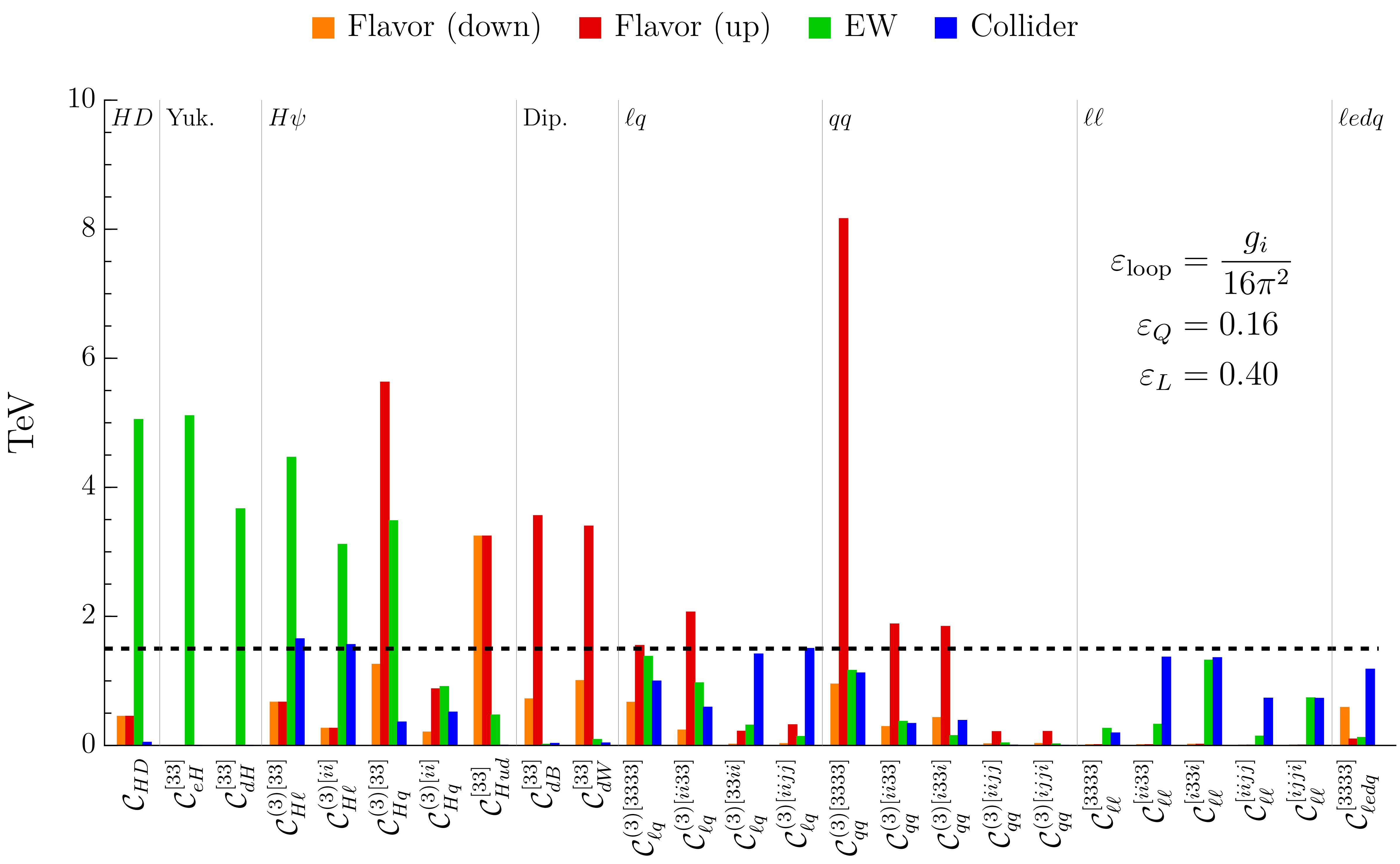

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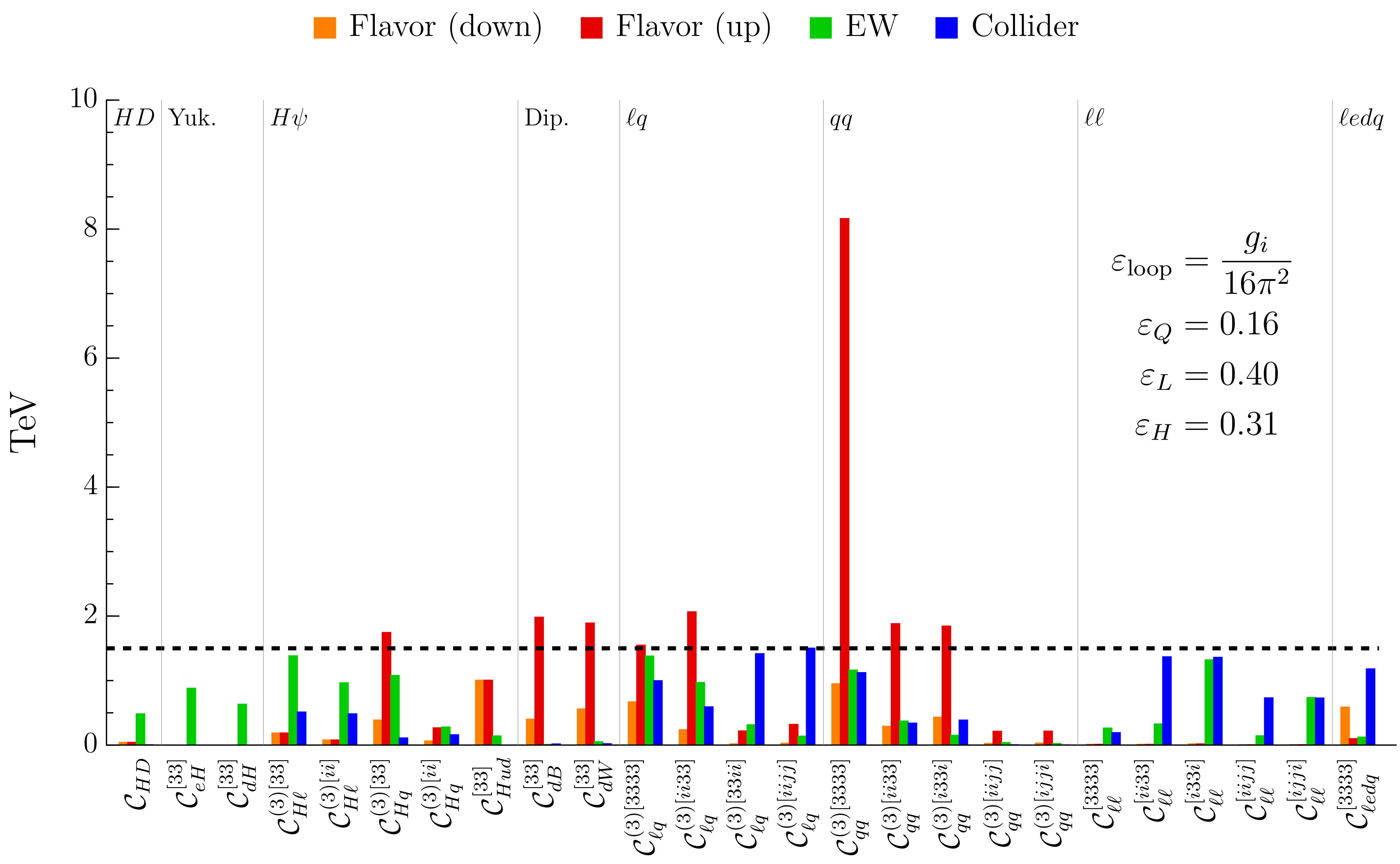

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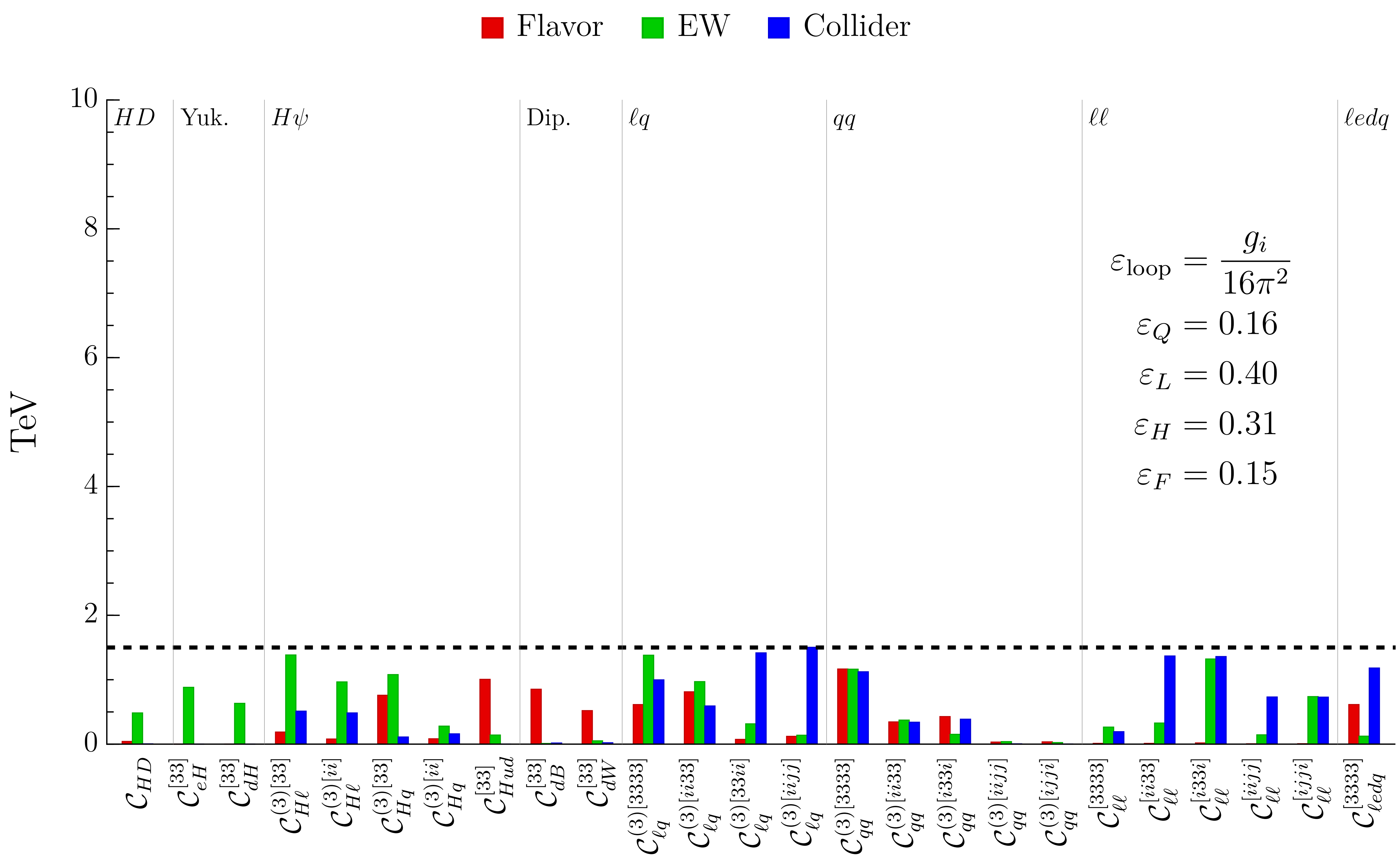

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New Physics mainly coupled to the 3rd generation compatible with all current data can exist at scales as low as 1.5 TeV under these conditions:

$$\varepsilon_q \leq 0.16\,, \qquad \varepsilon_l \leq 0.40\,, \qquad \varepsilon_H \leq 0.31\,, \qquad \varepsilon_F \leq 0.15$$

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…How would these bounds look like with a future tera Z machine, like FCC-ee?

Projections for FCC-ee

The expected improvements for Z- and W-pole observables, Higgs and tau decays are available from the literature.

[J. De Blas, G. Durieux, C.Grojean, J.Gu and A. Paul, 1907.04311, A. Blondel and P. Janot, 2106.13885, Snowmass 2203.06520]

Tera Z- pole run: **10^5 more Z bosons than LEP**, so statistics can improve by up to a factor 300.

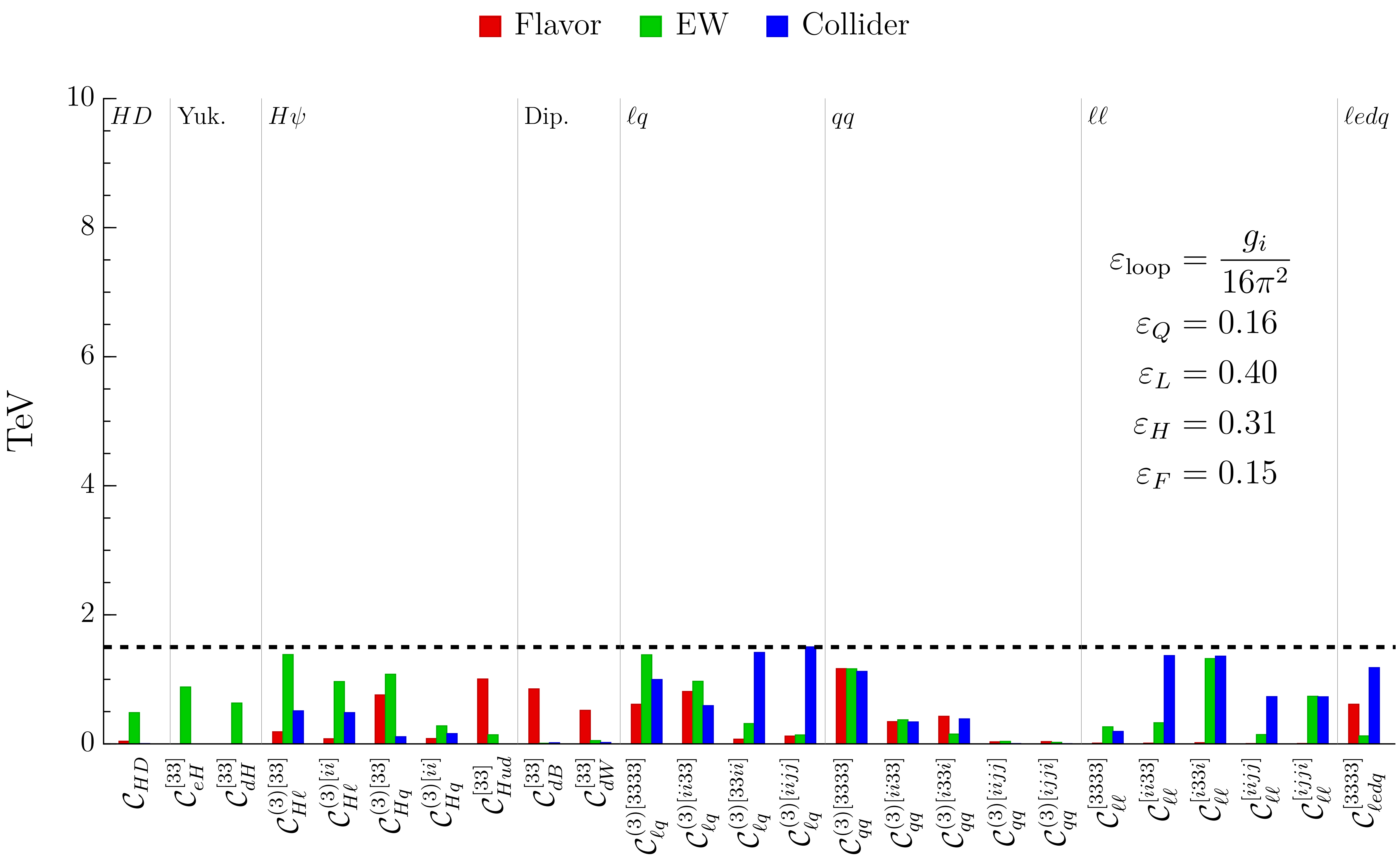
In practice, leptonic (hadronic) obs. improve by a factor 10-100 (10).

To build a projected EW likelihood for FCC-ee:

- Exp. values set to the SM
- error reduction as tabulated in the literature

Observable	Proj. Error Reduction
Γ_Z	23
σ^0_{had}	7.4
R_b	10.2
R_c	11.6
$A^{0,b}_{\text{FB}}$	15.5
$A^{0,c}_{\text{FB}}$	15.4
A_b	7.13
A_c	5.05
R_e	8.03
R_μ	31.8
R_τ	21.7
$A^{0,e}_{\text{FB}}$	30.8
$A^{0,\mu}_{\text{FB}}$	26.7
$A^{0,\tau}_{\text{FB}}$	21
A^{**}_e	130
A^{**}_μ	680
A^{**}_τ	340

FCC and 3rd generation NP



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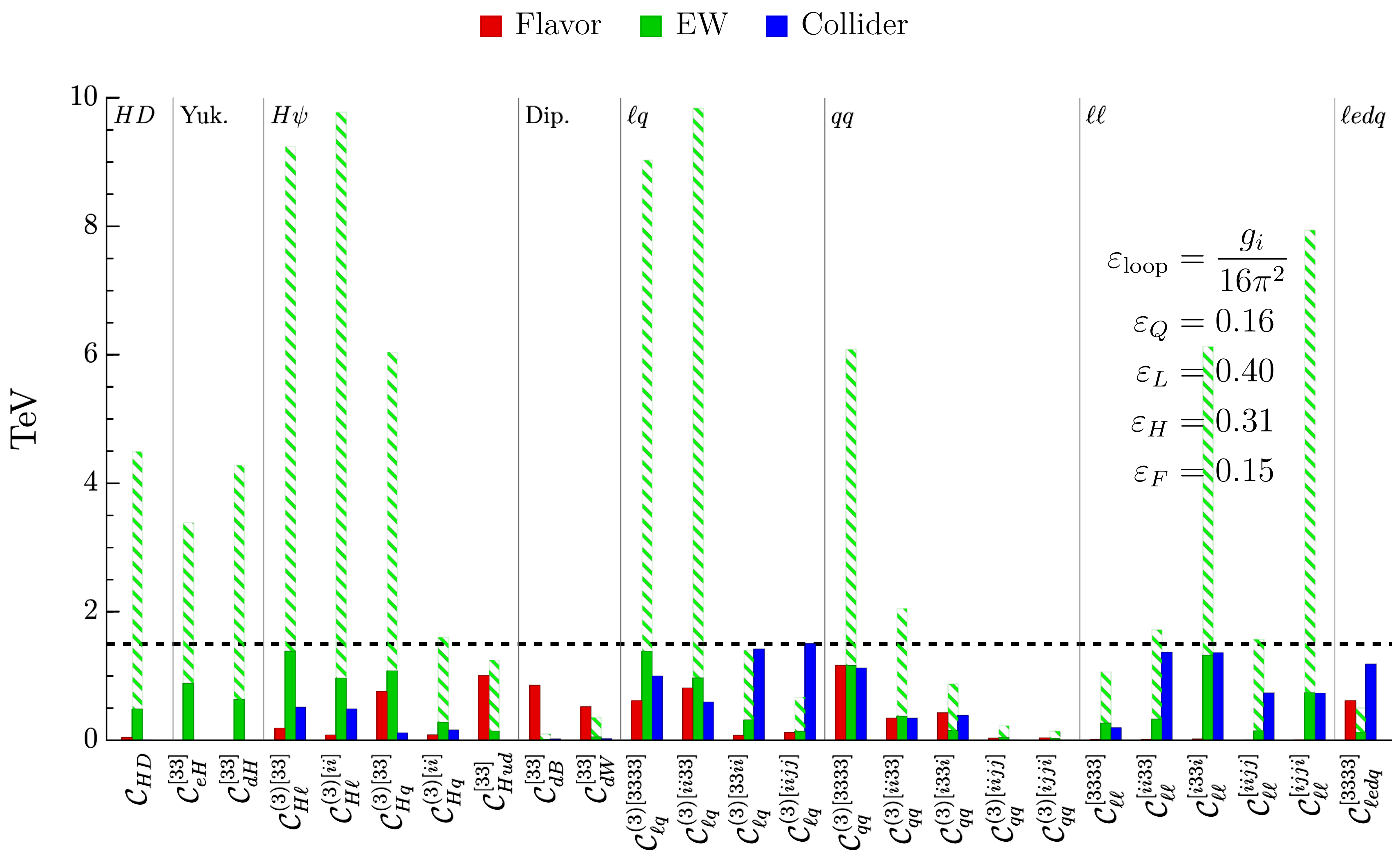

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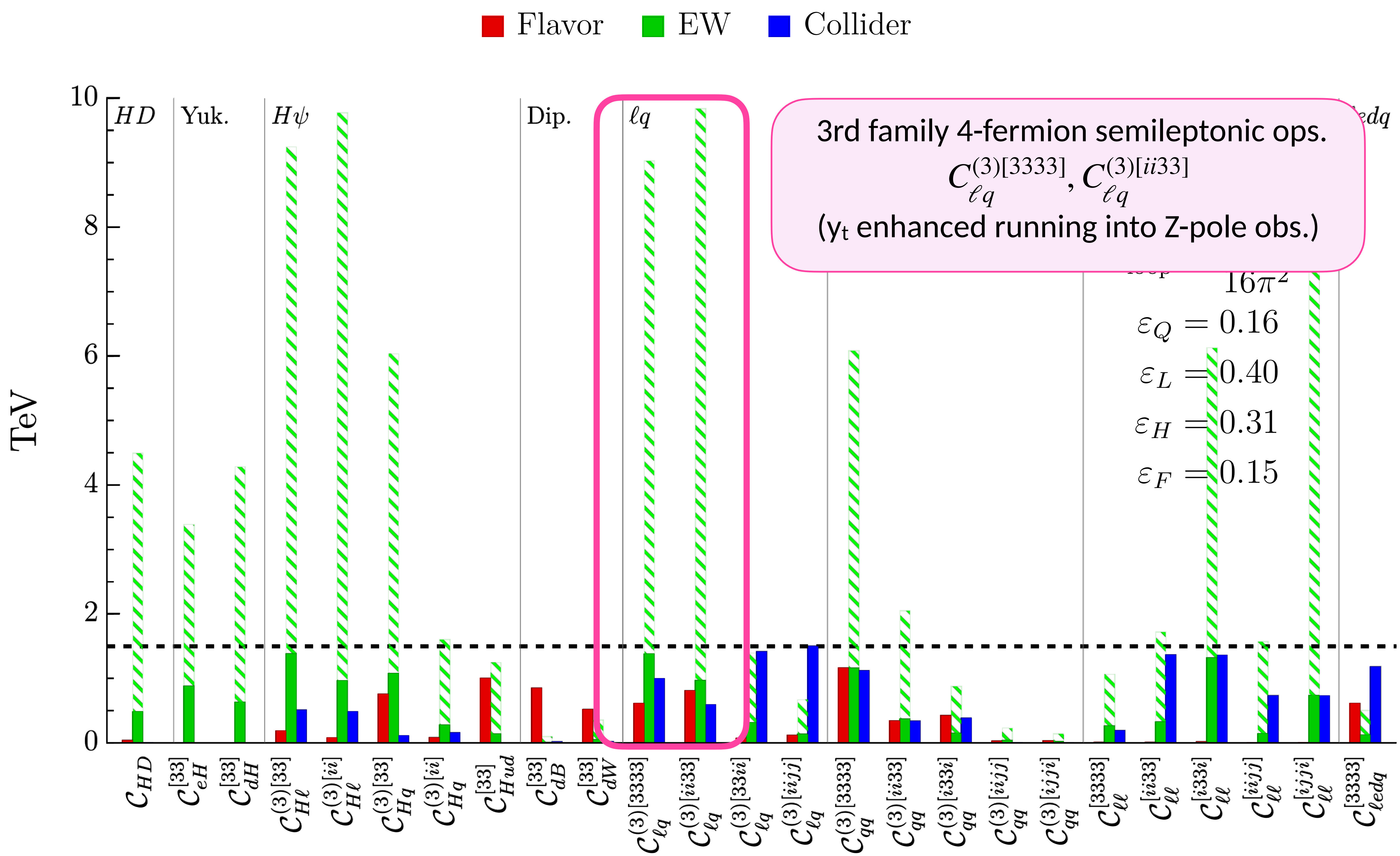

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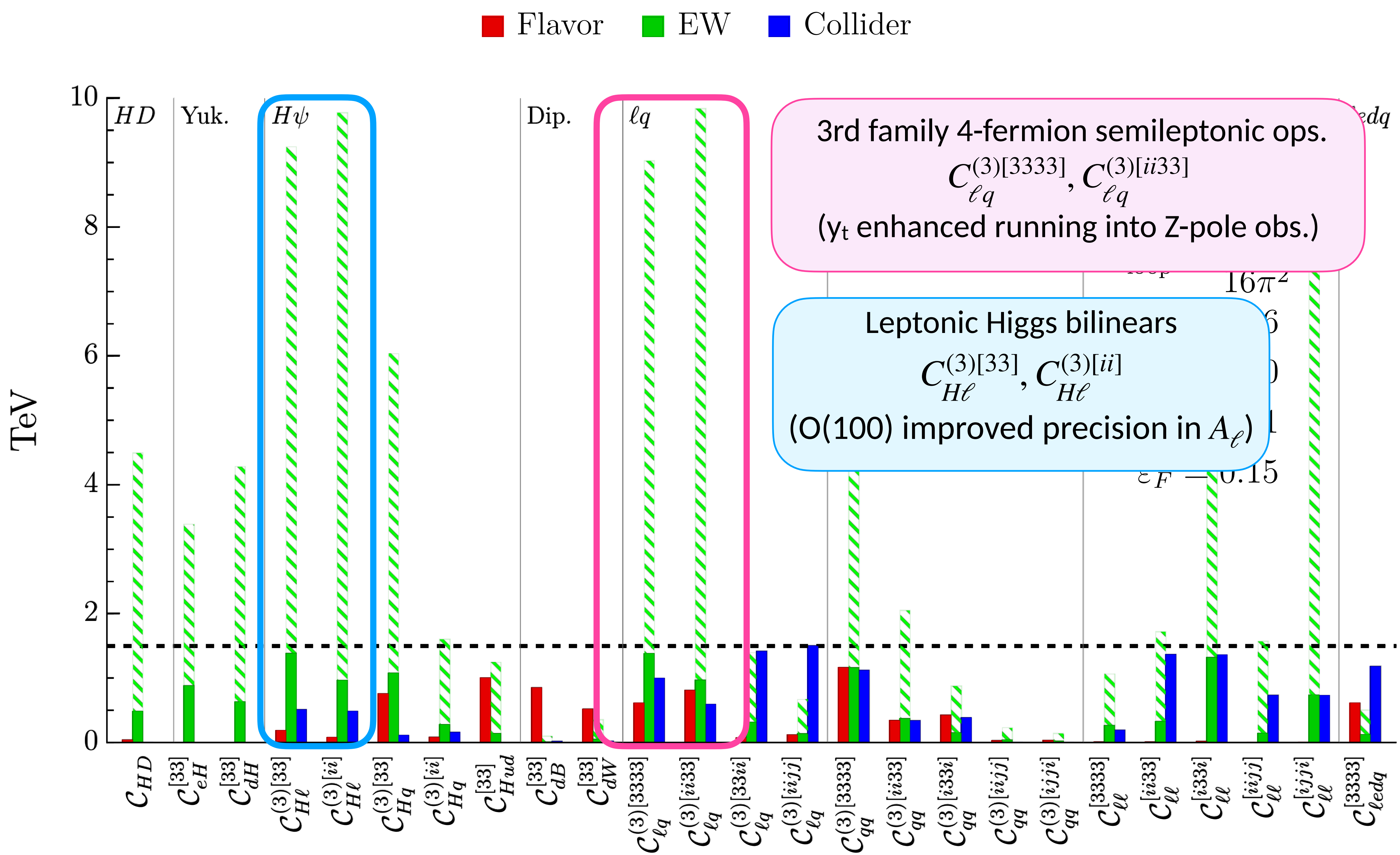

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Leptonic Higgs bilinears

$C_{H\ell}^{(3)[33]}, C_{H\ell}^{(3)[ii]}$

(O(100) improved precision in A_ℓ)

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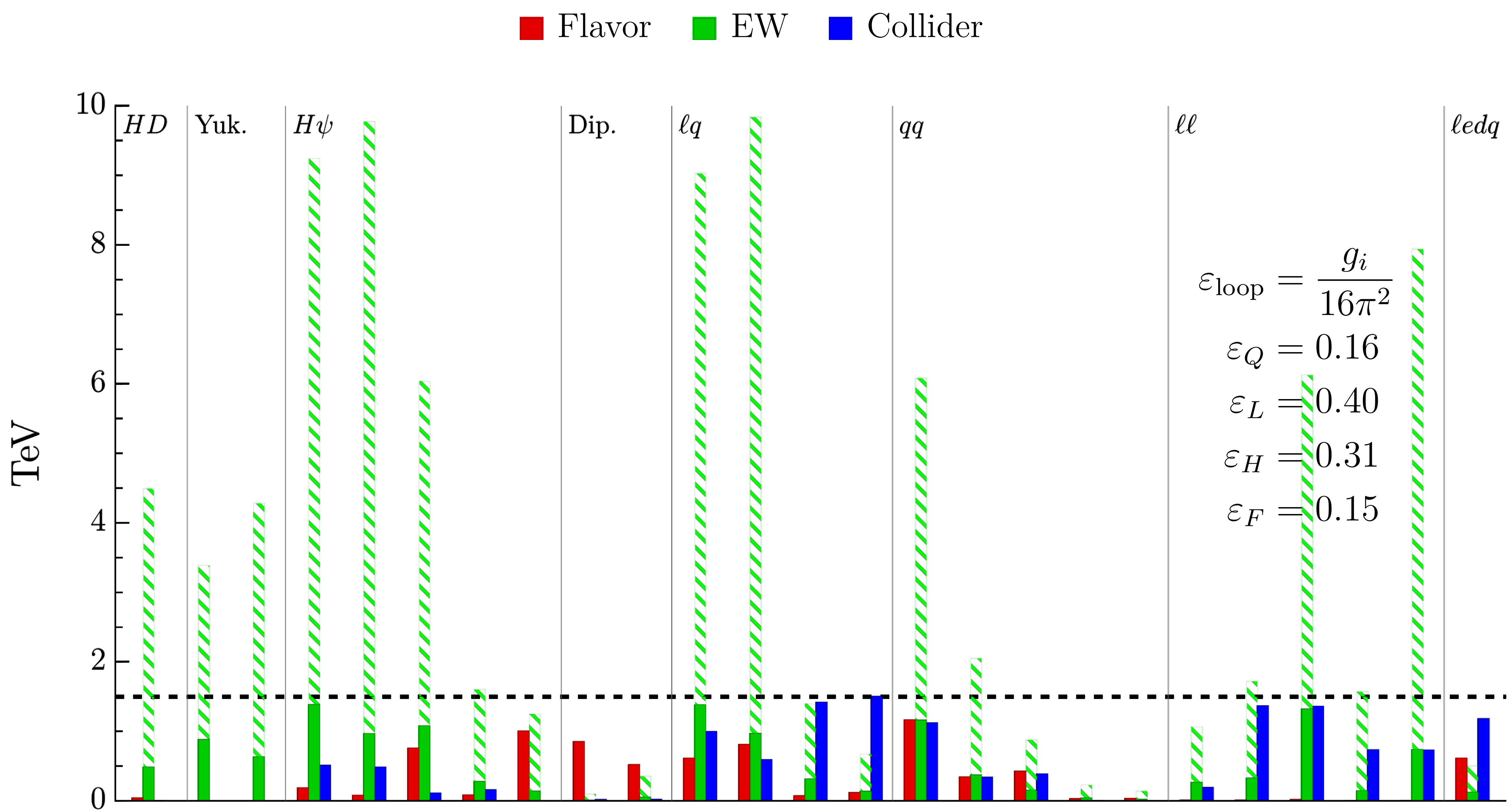

FCC-ee could probe third-generation New Physics up to ~ 10 TeV!

Rare decays and 3rd generation NP

More short-term, improvements in flavor and collider observables can help us probe this scenario. Consider the **rare decays** $B \to K\nu\bar{\nu}$ and $K \to \pi\nu\bar{\nu}$.

$$\frac{\mathcal{B}(B^+ \to K^+\nu\bar{\nu})_{\rm exp}}{\mathcal{B}(B^+ \to K^+\nu\bar{\nu})_{\rm SM}} = 2.8 \pm 0.8\,, \qquad \frac{\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm exp}}{\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\rm SM}} = 1.23 \pm 0.39$$

[Exp: combination from Belle II @EPS 2023]

~3σ tension with the SM

[Exp: NA62 2021; SM: Buras et al. 2015]

Compatible with the SM at 1σ

- theoretically clean
- significant improvements expected in the next years:
  Belle II will measure $B \to K\nu\bar{\nu}$ @ 1%, and NA62(HIKE) $K \to \pi\nu\bar{\nu}$ @ 15%(5%)

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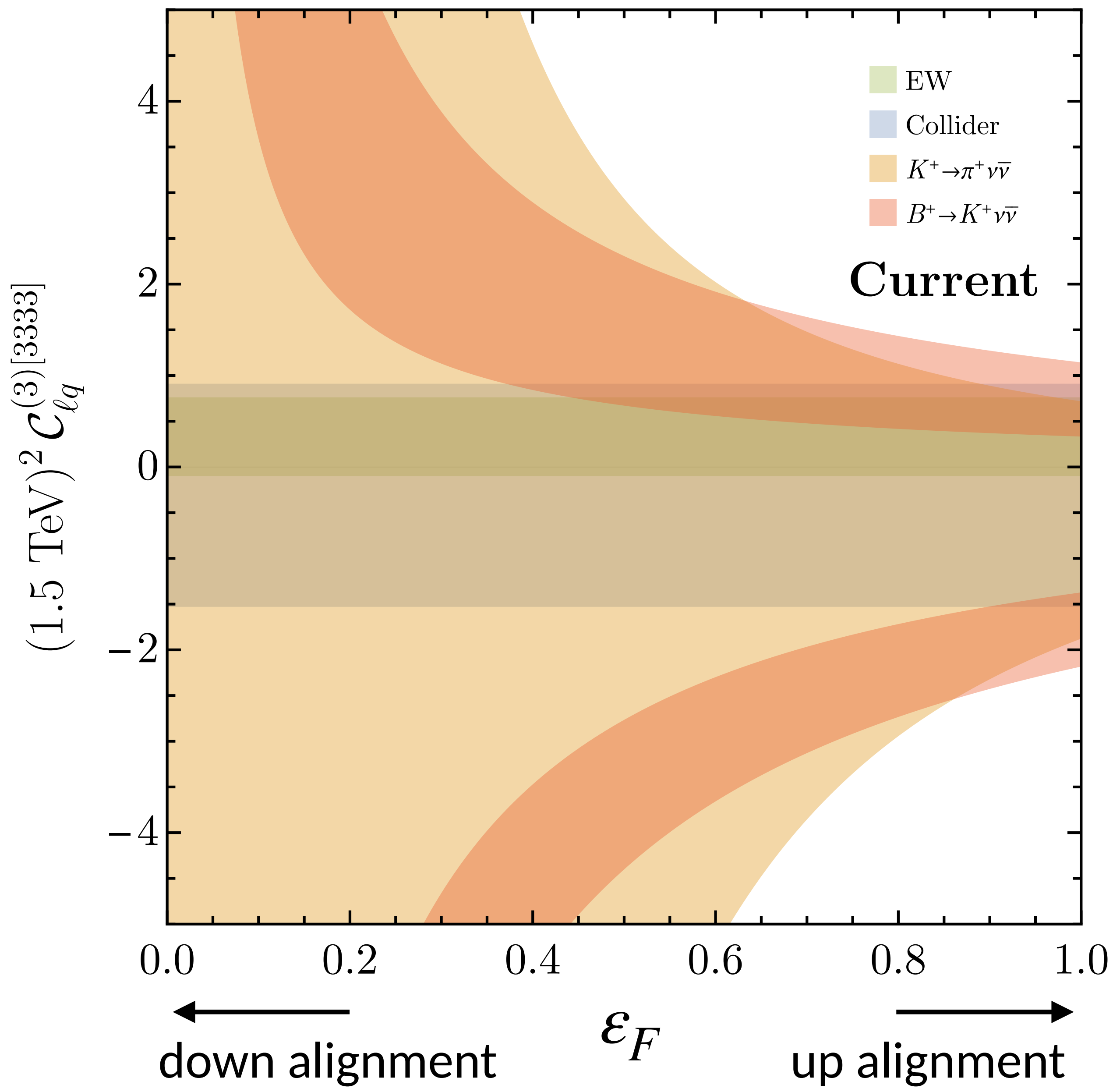
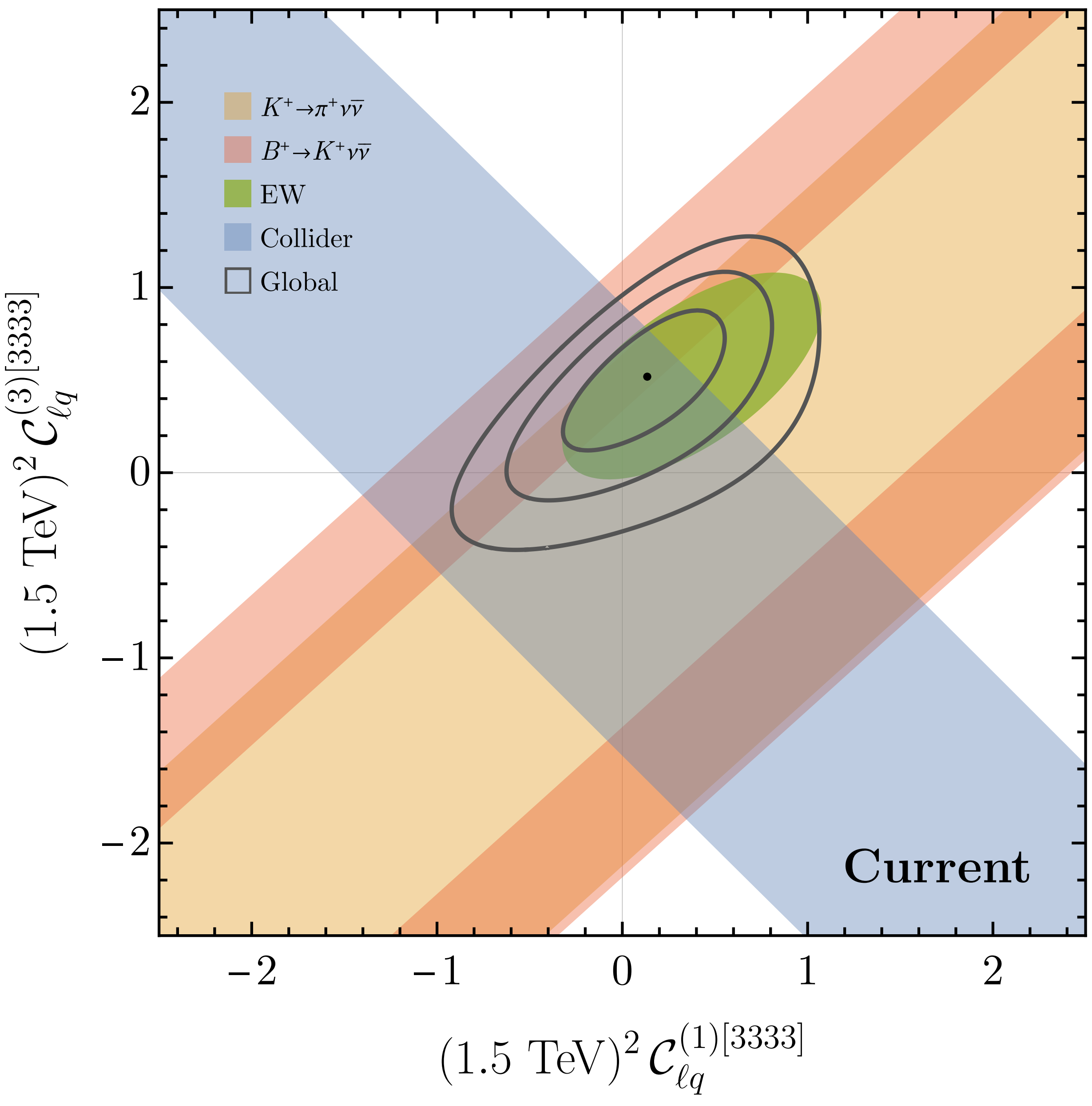
- scale differently with the alignment parameter ε_F

Rare decays and 3rd generation NP: current data





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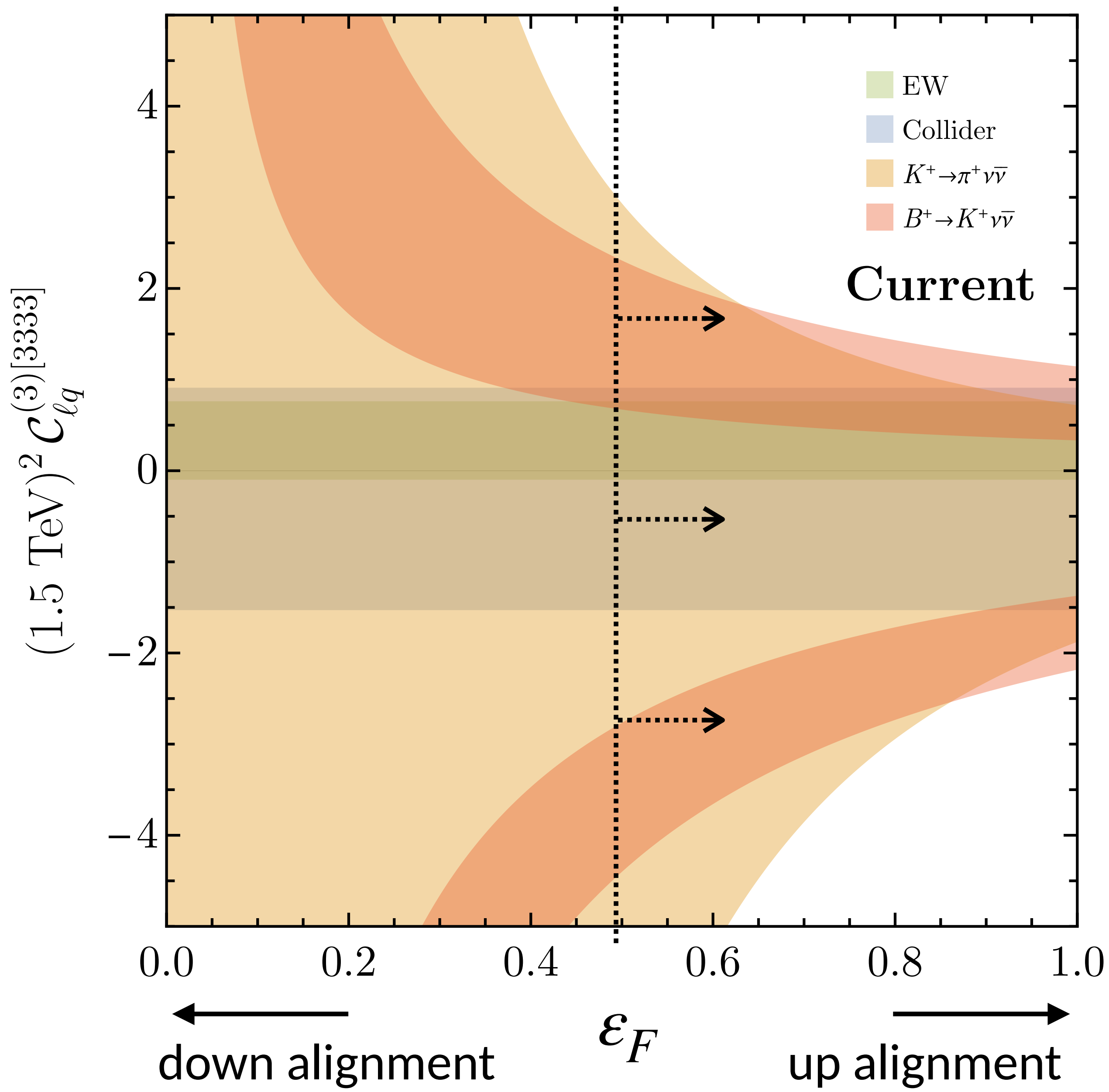
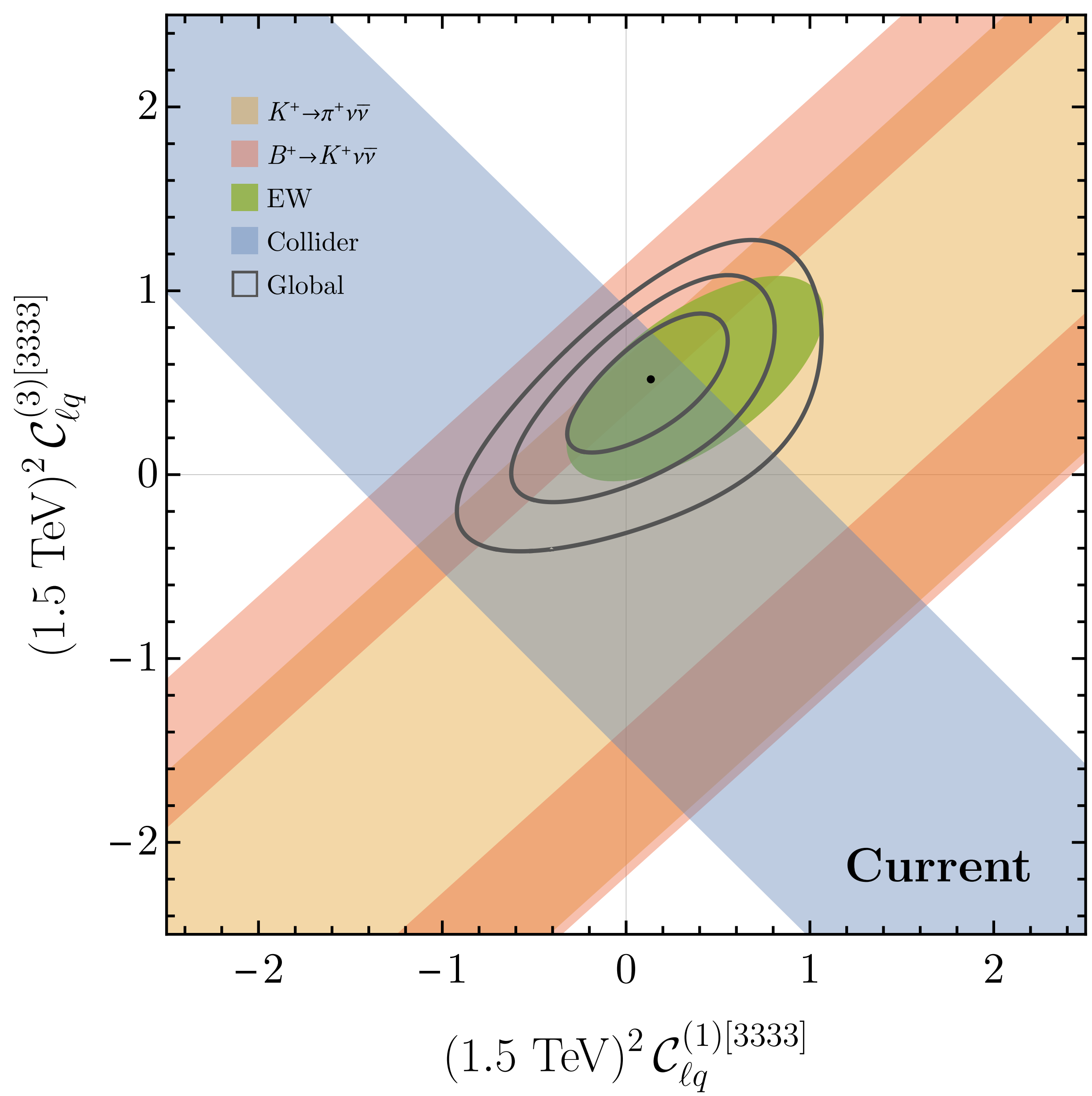
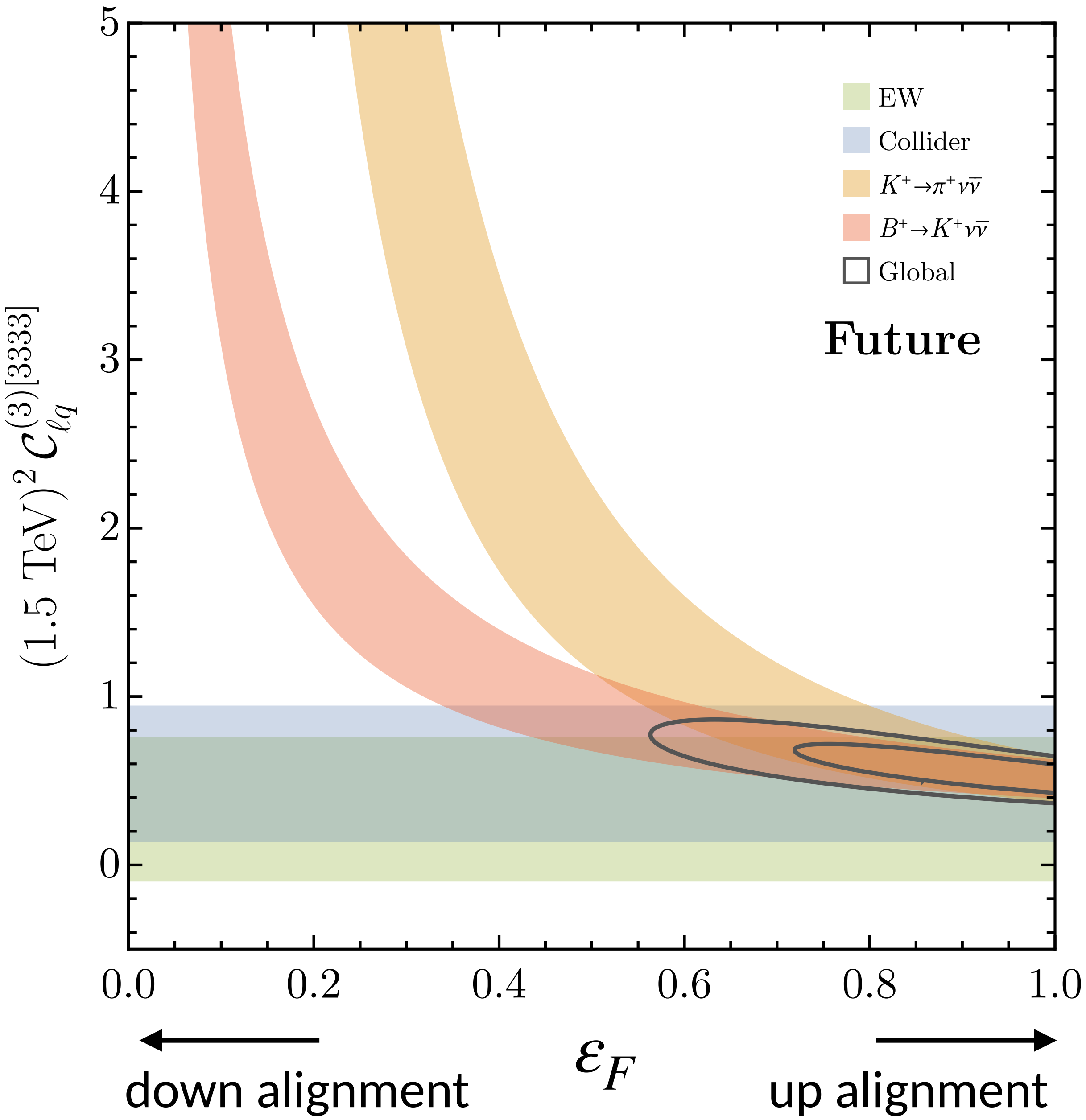
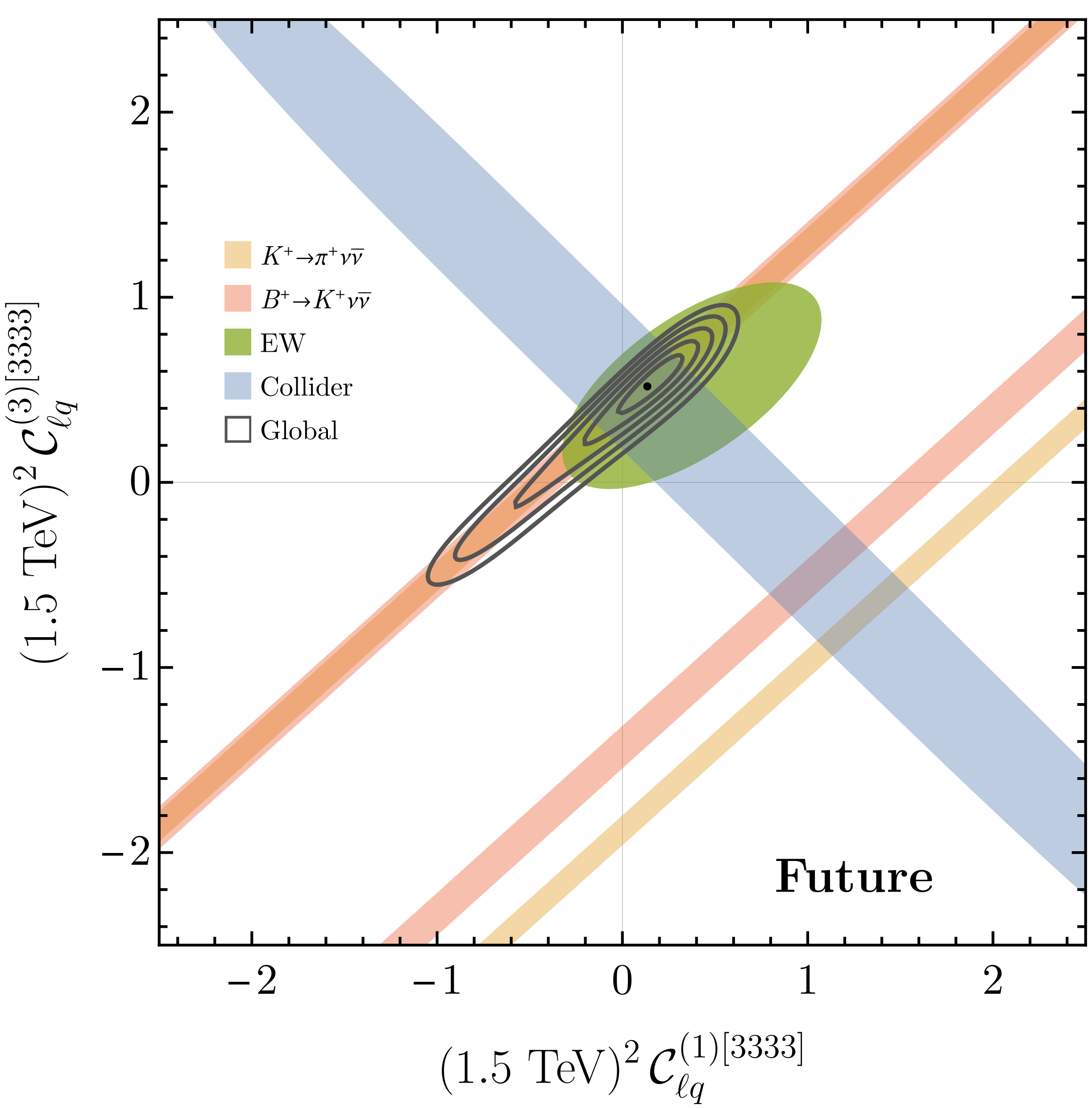




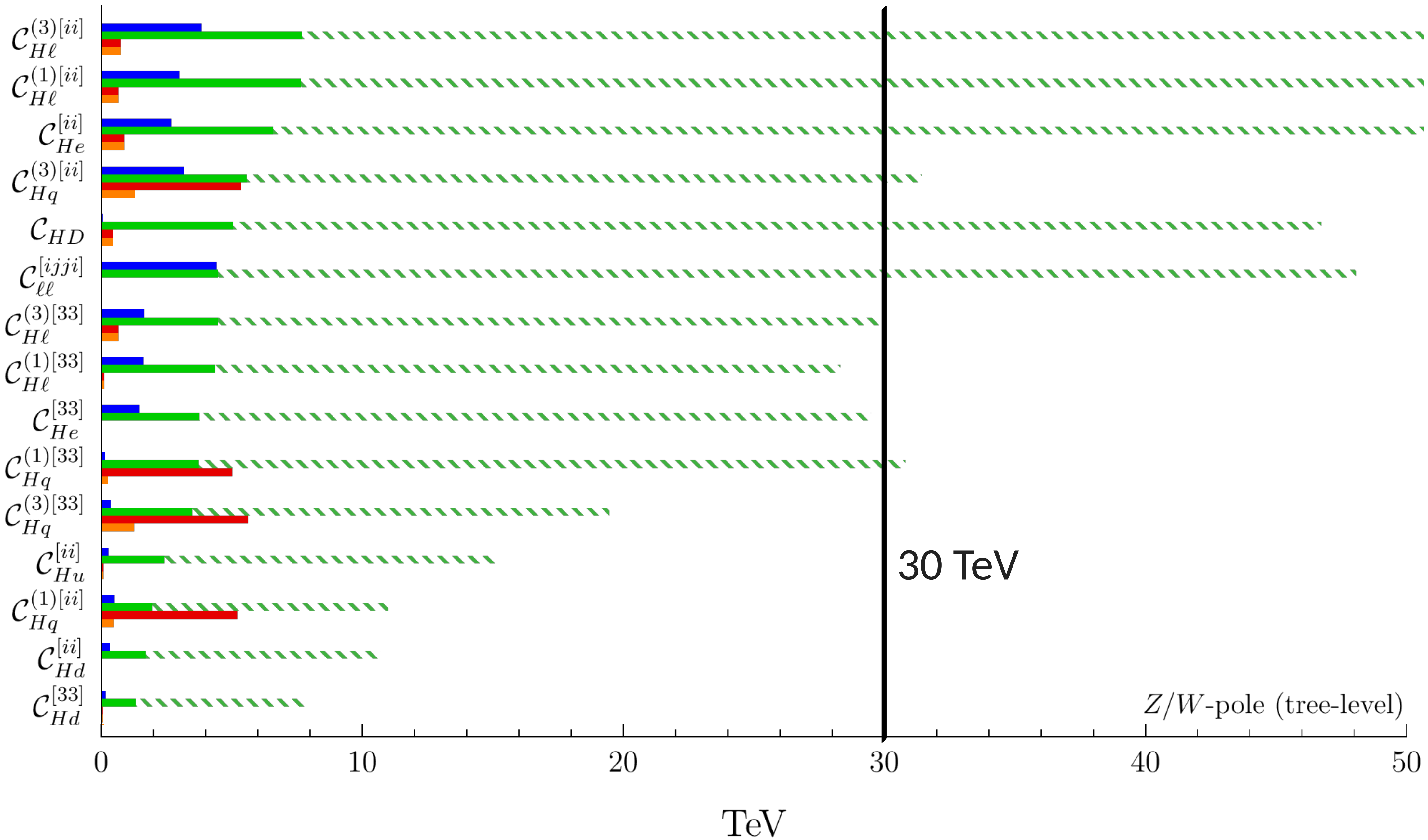
Rare decays and 3rd generation NP: projections





FCC-ee for "generic" U(2) NP (no suppression factors)

- Operators entering Z-pole observables at tree-level get bounds of 30-50 TeV



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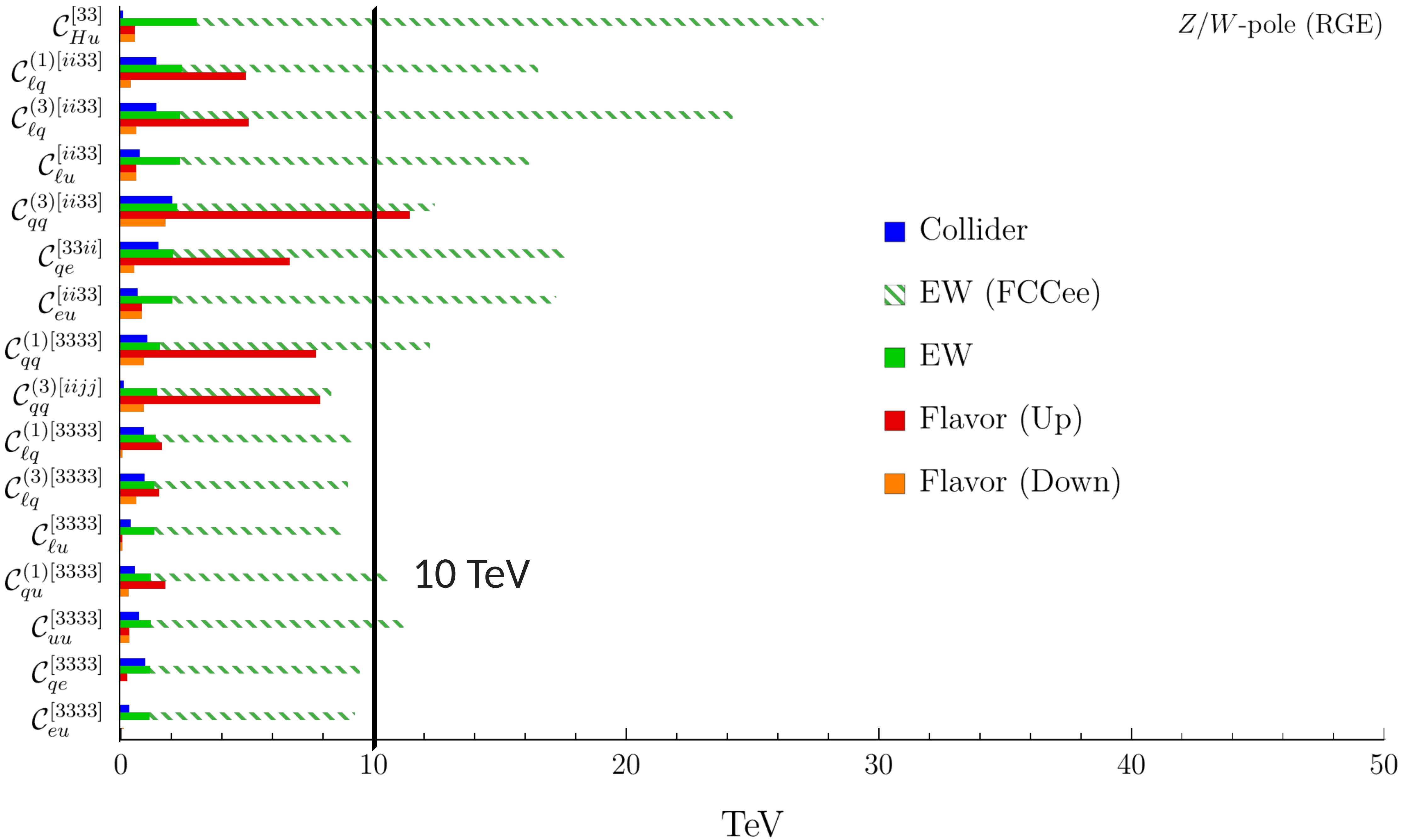

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Two comments:

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FCC-ee can push most of the existing bounds on NP from the EW sector by one order of magnitude!

Conclusions

We investigated NP scenarios characterized by a $U(2)^5$ symmetry acting on the light families. We included EW, flavor, and collider data, and accounted for RG effects.

Our main focus was **NP coupled mostly to the 3rd generation**, because of its strong theoretical motivation.

1. **How low** can the energy **scale of new physics** be for these class of models, and which conditions make this possible?
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1. **How low** can the energy **scale of new physics** be for these class of models, and which conditions make this possible?
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1. **NP in the 3rd family is compatible with a scale as low as 1.5 TeV** under simple, non-tuned assumptions. Well-motivated NP models can be nearby!
2. **Precision flavor measurement** can help probe this scenario. For example, the rare decays $B \to K\nu\bar{\nu}$ and $K \to \pi\nu\bar{\nu}$ can help determine the orientation of the 3rd family in flavor space.

   A future tera-Z machine like **FCC-ee** can probe third-generation NP up to **10 TeV**.

Back-up slides

Higgs bi-fermion operators

coeff.	$\Lambda^{\rm down}_{\rm flav.}$	$\Lambda^{\rm up}_{\rm flav.}$	$\Lambda_{\rm EW}$	$\Lambda_{\rm coll.}$	$\Lambda^{\rm down}_{\rm all}$	Obs.	$\Lambda^{\rm up}_{\rm all}$	Obs.
$\mathcal{C}^{(1)[33]}_{H\ell}$	0.1	0.1	4.4	1.6	4.3	R_τ	4.3	R_τ
$\mathcal{C}^{(1)[ii]}_{H\ell}$	0.7	0.7	7.6	3.	7.8	$\sigma_{\rm had}$	7.8	$\sigma_{\rm had}$
$\mathcal{C}^{(3)[33]}_{H\ell}$	0.7	0.7	4.5	1.7	4.4	R_τ	4.4	R_τ
$\mathcal{C}^{(3)[ii]}_{H\ell}$	0.7	0.7	7.7	3.8	7.7	$\sigma_{\rm had}$	7.7	$\sigma_{\rm had}$
$\mathcal{C}^{[33]}_{He}$	-	-	3.8	1.5	3.7	R_τ	3.7	R_τ
$\mathcal{C}^{[ii]}_{He}$	0.9	0.9	6.6	2.7	6.7	$\sigma_{\rm had}$	6.7	$\sigma_{\rm had}$
$\mathcal{C}^{(1)[33]}_{Hq}$	0.3	5.	3.7	0.1	3.7	Γ_Z	5.1	$B_s \to \mu\mu$
$\mathcal{C}^{(1)[ii]}_{Hq}$	0.5	5.2	1.9	0.5	2.	R_c	5.4	$B_s \to \mu\mu$
$\mathcal{C}^{(3)[33]}_{Hq}$	1.3	5.6	3.5	0.4	3.4	R_b	5.5	$B_s \to \mu\mu$
$\mathcal{C}^{(3)[ii]}_{Hq}$	1.3	5.3	5.6	3.1	5.7	R_τ	7.7	Γ_Z
$\mathcal{C}^{[33]}_{Hd}$	-	-	1.3	0.2	1.3	R_b	1.3	R_b
$\mathcal{C}^{[ii]}_{Hd}$	-	-	1.7	0.3	1.7	R_τ	1.7	R_τ
$\mathcal{C}^{[33]}_{Hu}$	0.6	0.6	3.	0.1	3.1	$A_b^{\rm FB}$	3.1	$A_b^{\rm FB}$
$\mathcal{C}^{[ii]}_{Hu}$	-	-	2.4	0.3	2.4	R_τ	2.4	R_τ

3H and dipole operators

coeff.	$\Lambda^{\rm down}_{\rm flav.}$	$\Lambda^{\rm up}_{\rm flav.}$	$\Lambda_{\rm EW}$	$\Lambda_{\rm coll.}$	$\Lambda^{\rm down}_{\rm all}$	Obs.	$\Lambda^{\rm up}_{\rm all}$	Obs.
$\mathcal{C}^{[33]}_{eH}$	-	-	5.1	-	5.1	$H \to \tau\tau$	5.1	$H \to \tau\tau$
$\mathcal{C}^{[33]}_{uH}$	-	-	0.2	-	0.2	$H \to \tau\tau$	0.2	$H \to \tau\tau$
$\mathcal{C}^{[33]}_{dH}$	-	-	3.7	-	3.7	$H \to bb$	3.7	$H \to bb$
$\mathcal{C}^{[33]}_{Hud}$	3.2	3.2	0.5	-	3.2	$B \to X_s\gamma$	3.2	$B \to X_s\gamma$
$\mathcal{C}^{[33]}_{eB}$	-	-	0.2	1.2	1.2	$pp \to \tau\tau$	1.2	$pp \to \tau\tau$
$\mathcal{C}^{[33]}_{uB}$	0.7	0.8	2.4	1.9	2.7	$A_b^{\rm FB}$	2.7	$A_b^{\rm FB}$
$\mathcal{C}^{[33]}_{dB}$	15.2	74.8	0.4	0.7	15.2	$B \to X_s\gamma$	74.8	$B \to X_s\gamma$
$\mathcal{C}^{[33]}_{eW}$	-	-	1.	1.9	1.8	$pp \to \tau\nu$	1.8	$pp \to \tau\nu$
$\mathcal{C}^{[33]}_{uW}$	0.5	0.9	2.3	3.6	3.7	QuarkDipoles	3.8	QuarkDipoles
$\mathcal{C}^{[33]}_{dW}$	15.7	53.	1.4	0.6	15.7	$B \to X_s\gamma$	53.	$B \to X_s\gamma$
$\mathcal{C}^{[33]}_{uG}$	0.1	0.3	0.5	2.7	2.7	QuarkDipoles	2.7	QuarkDipoles
$\mathcal{C}^{[33]}_{dG}$	4.	25.5	0.3	-	4.	$B \to X_s\gamma$	25.5	$B \to X_s\gamma$

Scalar and tensor operators

coeff.	$\Lambda_{\rm flav.}^{\rm down}$	$\Lambda_{\rm flav.}^{\rm up}$	$\Lambda_{\rm EW}$	$\Lambda_{\rm coll.}$	$\Lambda_{\rm all}^{\rm down}$	Obs.	$\Lambda_{\rm all}^{\rm up}$	Obs.
$\mathcal{C}_{\ell edq}^{[3333]}$	0.6	-	0.1	1.2	1.1	$pp \to \tau\tau$	1.2	$pp \to \tau\tau$
$\mathcal{C}_{quqd}^{(1)[3333]}$	1.8	5.5	1.7	0.4	2.2	$B \to X_s\gamma$	5.5	$B \to X_s\gamma$
$\mathcal{C}_{quqd}^{(8)[3333]}$	1.	5.1	0.7	0.2	1.	$B \to X_s\gamma$	5.1	$B \to X_s\gamma$
$\mathcal{C}_{\ell equ}^{(1)[3333]}$	-	-	2.1	-	2.1	$H \to \tau\tau$	2.1	$H \to \tau\tau$
$\mathcal{C}_{\ell equ}^{(3)[3333]}$	-	-	0.8	-	0.8	$H \to \tau\tau$	0.8	$H \to \tau\tau$

LLLL vector operators

coeff.	$\Lambda^{\rm down}_{\rm flav.}$	$\Lambda^{\rm up}_{\rm flav.}$	$\Lambda_{\rm EW}$	$\Lambda_{\rm coll.}$	$\Lambda^{\rm down}_{\rm all}$	Obs.	$\Lambda^{\rm up}_{\rm all}$	Obs.
$\mathcal{C}_{\ell\ell}^{[3333]}$	-	-	0.3	0.2	0.3	$\sigma_{\rm had}$	0.3	$\sigma_{\rm had}$
$\mathcal{C}_{\ell\ell}^{[ii33]}$	-	-	0.8	3.4	3.3	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$	3.3	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$
$\mathcal{C}_{\ell\ell}^{[i33i]}$	-	-	3.3	3.3	4.2	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$	4.2	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$
$\mathcal{C}_{\ell\ell}^{[iijj]}$	-	-	0.9	4.4	4.4	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$	4.4	$(e^+e^- \to \mu^+\mu^-)_{\rm FB}$
$\mathcal{C}_{\ell\ell}^{[ijji]}$	-	-	4.5	4.4	4.9	$A_b^{\rm FB}$	4.9	$A_b^{\rm FB}$
$\mathcal{C}_{qq}^{(1)[3333]}$	1.	7.8	1.6	1.1	1.7	Γ_Z	7.6	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(1)[ii33]}$	1.3	11.2	0.9	1.5	1.7	FourQuarksTop	11.3	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(1)[i33i]}$	2.5	11.3	0.7	1.6	2.6	$B_s \to \mu\mu$	11.3	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(1)[iijj]}$	0.9	8.1	0.4	-	0.9	${\rm Im}(C_D)$	8.1	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(1)[ijji]}$	1.1	8.1	0.5	-	1.	${\rm Im}(C_D)$	8.1	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(3)[3333]}$	1.	8.2	1.2	1.1	1.5	m_W	8.2	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(3)[ii33]}$	1.8	11.5	2.3	2.1	3.	R_b	11.3	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(3)[i33i]}$	2.6	11.2	0.9	2.4	3.1	$B_s \to \mu\mu$	11.3	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(3)[iijj]}$	1.	7.9	1.5	0.2	1.5	R_τ	7.9	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{qq}^{(3)[ijji]}$	1.1	8.	0.9	0.1	1.2	$K^+ \to \pi^+\nu\bar\nu$	8.	$\lvert C_{Bs}\rvert$
$\mathcal{C}_{\ell q}^{(1)[3333]}$	0.1	1.7	1.4	1.	1.4	R_τ	1.6	$K^+ \to \pi^+\nu\bar\nu$
$\mathcal{C}_{\ell q}^{(1)[ii33]}$	0.4	5.	2.5	1.5	2.5	$\sigma_{\rm had}$	5.1	$B_s \to \mu\mu$
$\mathcal{C}_{\ell q}^{(1)[33ii]}$	-	1.6	0.3	3.4	3.4	$pp \to \tau\tau$	3.4	$pp \to \tau\tau$
$\mathcal{C}_{\ell q}^{(1)[iijj]}$	0.5	5.	0.5	5.4	5.4	$pp \to \mu\mu$	5.6	$pp \to \mu\mu$
$\mathcal{C}_{\ell q}^{(3)[3333]}$	0.7	1.5	1.4	1.	1.6	R_τ	1.6	$K^+ \to \pi^+\nu\bar\nu$
$\mathcal{C}_{\ell q}^{(3)[ii33]}$	0.7	5.1	2.4	1.5	2.5	$A_b^{\rm FB}$	5.	$B_s \to \mu\mu$
$\mathcal{C}_{\ell q}^{(3)[33ii]}$	0.1	1.4	2.	8.6	8.8	$pp \to \tau\nu$	8.7	$pp \to \tau\nu$
$\mathcal{C}_{\ell q}^{(3)[iijj]}$	0.5	5.1	2.1	22.5	22.5	$pp \to \mu\nu$	23.7	$pp \to \mu\nu$

RRRR vector operators

coeff.	$\Lambda^{\text{down}}_{\text{flav.}}$	$\Lambda^{\text{up}}_{\text{flav.}}$	Λ_{EW}	$\Lambda_{\text{coll.}}$	$\Lambda^{\text{down}}_{\text{all}}$	Obs.	$\Lambda^{\text{up}}_{\text{all}}$	Obs.
$\mathcal{C}_{ee}^{[3333]}$	-	-	0.3	0.2	0.3	R_τ	0.3	R_τ
$\mathcal{C}_{ee}^{[ii33]}$	-	-	0.7	3.2	3.2	$(e^+e^- \to \mu^+\mu^-)_{\text{FB}}$	3.2	$(e^+e^- \to \mu^+\mu^-)_{\text{FB}}$
$\mathcal{C}_{ee}^{[iijj]}$	-	-	0.8	4.2	4.2	$(e^+e^- \to \mu^+\mu^-)_{\text{FB}}$	4.2	$(e^+e^- \to \mu^+\mu^-)_{\text{FB}}$
$\mathcal{C}_{uu}^{[3333]}$	0.4	0.4	1.2	0.8	1.3	A_b^{FB}	1.3	A_b^{FB}
$\mathcal{C}_{uu}^{[ii33]}$	0.1	0.1	1.1	1.3	1.4	FourQuarksTop	1.4	FourQuarksTop
$\mathcal{C}_{uu}^{[i33i]}$	-	-	0.5	1.3	1.4	FourQuarksTop	1.4	FourQuarksTop
$\mathcal{C}_{uu}^{[iijj]}$	-	-	0.3	-	0.3	R_τ	0.3	R_τ
$\mathcal{C}_{uu}^{[ijji]}$	-	-	0.3	-	0.3	R_τ	0.3	R_τ
$\mathcal{C}_{dd}^{[3333]}$	-	-	-	-	-	R_b	-	R_b
$\mathcal{C}_{dd}^{[ii33]}$	-	-	0.1	-	0.1	R_τ	0.1	R_τ
$\mathcal{C}_{dd}^{[i33i]}$	-	-	-	-	-	Γ_Z	-	Γ_Z
$\mathcal{C}_{dd}^{[iijj]}$	-	-	0.2	-	0.2	R_τ	0.2	R_τ
$\mathcal{C}_{dd}^{[ijji]}$	-	-	0.1	-	0.1	R_τ	0.1	R_τ
$\mathcal{C}_{eu}^{[3333]}$	-	-	1.2	0.4	1.2	R_τ	1.2	R_τ
$\mathcal{C}_{eu}^{[ii33]}$	0.9	0.9	2.1	0.7	2.2	σ_{had}	2.2	σ_{had}
$\mathcal{C}_{eu}^{[33ii]}$	-	-	0.3	2.8	2.8	$pp \to \tau\tau$	2.8	$pp \to \tau\tau$
$\mathcal{C}_{eu}^{[iijj]}$	-	-	0.6	7.4	7.4	$pp \to ee$	7.4	$pp \to ee$
$\mathcal{C}_{ed}^{[3333]}$	-	-	0.2	1.	1.	$pp \to \tau\tau$	1.	$pp \to \tau\tau$
$\mathcal{C}_{ed}^{[ii33]}$	-	-	0.3	1.5	1.5	$pp \to \mu\mu$	1.5	$pp \to \mu\mu$
$\mathcal{C}_{ed}^{[33ii]}$	-	-	0.2	2.8	2.8	$pp \to \tau\tau$	2.8	$pp \to \tau\tau$
$\mathcal{C}_{ed}^{[iijj]}$	-	-	0.4	4.4	4.4	$pp \to \mu\mu$	4.4	$pp \to \mu\mu$
$\mathcal{C}_{ud}^{(1)[3333]}$	0.1	0.1	0.4	0.3	0.4	R_b	0.4	R_b
$\mathcal{C}_{ud}^{(1)[ii33]}$	-	-	0.1	-	0.1	R_τ	0.1	R_τ
$\mathcal{C}_{ud}^{(1)[33ii]}$	-	-	0.5	1.2	1.2	FourQuarksTop	1.2	FourQuarksTop
$\mathcal{C}_{ud}^{(1)[iijj]}$	-	-	0.2	-	0.2	R_τ	0.2	R_τ
$\mathcal{C}_{ud}^{(8)[3333]}$	0.1	0.1	-	0.2	0.2	FourQuarksBottom	0.2	FourQuarksBottom
$\mathcal{C}_{ud}^{(8)[ii33]}$	-	-	-	-	-	-	-	-
$\mathcal{C}_{ud}^{(8)[33ii]}$	-	-	0.1	0.7	0.7	FourQuarksTop	0.7	FourQuarksTop
$\mathcal{C}_{ud}^{(8)[iijj]}$	-	-	-	-	-	-	-	-

LLRR vector operators

coeff.	$\Lambda^{down}_{flav.}$	$\Lambda^{up}_{flav.}$	Λ_{EW}	$\Lambda_{coll.}$	Λ^{down}_{all}	Obs.	Λ^{up}_{all}	Obs.
$\mathcal{C}_{\ell e}^{[3333]}$	-	-	0.2	0.1	0.2	A_τ	0.2	A_τ
$\mathcal{C}_{\ell e}^{[ii33]}$	-	-	0.4	2.	1.9	$(e^+e^- \to \mu^+\mu^-)_{FB}$	1.9	$(e^+e^- \to \mu^+\mu^-)_{FB}$
$\mathcal{C}_{\ell e}^{[33ii]}$	-	-	0.3	1.9	2.	$(e^+e^- \to \mu^+\mu^-)_{FB}$	2.	$(e^+e^- \to \mu^+\mu^-)_{FB}$
$\mathcal{C}_{\ell e}^{[iijj]}$	-	-	0.5	3.8	3.8	$(e^+e^- \to \mu^+\mu^-)_{FB}$	3.8	$(e^+e^- \to \mu^+\mu^-)_{FB}$
$\mathcal{C}_{\ell u}^{[3333]}$	0.1	0.1	1.4	0.4	1.3	R_τ	1.3	R_τ
$\mathcal{C}_{\ell u}^{[ii33]}$	0.7	0.7	2.4	0.8	2.3	σ_{had}	2.3	σ_{had}
$\mathcal{C}_{\ell u}^{[33ii]}$	-							
$\mathcal{C}_{\ell u}^{[iijj]}$	-							
$\mathcal{C}_{\ell d}^{[3333]}$	-							
$\mathcal{C}_{\ell d}^{[ii33]}$	-							
$\mathcal{C}_{\ell d}^{[33ii]}$	-							
$\mathcal{C}_{\ell d}^{[iijj]}$	-							
$\mathcal{C}_{qe}^{[3333]}$	-	0						
$\mathcal{C}_{qe}^{[33ii]}$	0.6	6						
$\mathcal{C}_{qe}^{[ii33]}$	-	0						
$\mathcal{C}_{qe}^{[iijj]}$	-							
$\mathcal{C}_{qu}^{(1)[3333]}$	0.3	1						
$\mathcal{C}_{qu}^{(1)[ii33]}$	0.3	1						
$\mathcal{C}_{qu}^{(1)[33ii]}$	-	0						
$\mathcal{C}_{qu}^{(1)[iijj]}$	-	0						
$\mathcal{C}_{qu}^{(8)[3333]}$	0.2	0						
$\mathcal{C}_{qu}^{(8)[ii33]}$	0.3	0						
$\mathcal{C}_{qu}^{(8)[33ii]}$	-	0						
$\mathcal{C}_{qu}^{(8)[iijj]}$	-	0						
$\mathcal{C}_{qd}^{(1)[3333]}$	0.2	0						
$\mathcal{C}_{qd}^{(1)[ii33]}$	-	0						
$\mathcal{C}_{qd}^{(1)[33ii]}$	-	0						
$\mathcal{C}_{qd}^{(1)[iijj]}$	-	0						
$\mathcal{C}_{qd}^{(8)[3333]}$	-							
$\mathcal{C}_{qd}^{(8)[ii33]}$	0.1	-	-	-	0.1	$B \to X_s\gamma$	-	$B \to X_s\gamma$
$\mathcal{C}_{qd}^{(8)[33ii]}$	-	-	0.1	0.7	0.7	FourQuarksTop	0.7	FourQuarksTop
$\mathcal{C}_{qd}^{(8)[iijj]}$	-	-	-	-	-	R_τ	-	$\lvert C_{Bs}\rvert$

coeff.	$\Lambda^{down}_{flav.}$	$\Lambda^{up}_{flav.}$	Λ_{EW}	$\Lambda_{coll.}$	Λ^{down}_{all}	Obs.
$\mathcal{C}_{H}$	-	-	-	-	-	-
$\mathcal{C}_{H\Box}$	0.2	0.2	0.6	0.1	0.6	A_b^{FB}
$\mathcal{C}_{HD}$	0.5	0.5	5.1	-	5.	A_b^{FB}
$\mathcal{C}_{HG}$	0.8	0.8	0.4	-	0.9	$B \to X_s\gamma$
$\mathcal{C}_{HB}$	0.5	0.5	0.9	-	0.9	A_b^{FB}
$\mathcal{C}_{HW}$	0.7	0.7	0.9	-	1.	A_b^{FB}
$\mathcal{C}_{HWB}$	1.	1.	9.	-	9.	A_b^{FB}
$\mathcal{C}_{G}$	1.1	1.1	0.1	-	1.1	$B \to X_s\gamma$
$\mathcal{C}_{W}$	0.3	0.3	0.9	-	0.9	A_b^{FB}

Bosonic operators

coeff.	$\Lambda^{\rm down}_{\rm flav.}$	$\Lambda^{\rm up}_{\rm flav.}$	$\Lambda_{\rm EW}$	$\Lambda_{\rm coll.}$	$\Lambda^{\rm down}_{\rm all}$	Obs.	$\Lambda^{\rm up}_{\rm all}$	Obs.
$\mathcal{C}_H$	-	-	-	-	-	-	-	-
$\mathcal{C}_{H\Box}$	0.2	0.2	0.6	0.1	0.6	$A_b^{\rm FB}$	0.6	$A_b^{\rm FB}$
$\mathcal{C}_{HD}$	0.5	0.5	5.1	-	5.	$A_b^{\rm FB}$	5.	$A_b^{\rm FB}$
$\mathcal{C}_{HG}$	0.8	0.8	0.4	-	0.9	$B \to X_s\gamma$	0.9	$B \to X_s\gamma$
$\mathcal{C}_{HB}$	0.5	0.5	0.9	-	0.9	$A_b^{\rm FB}$	0.9	$A_b^{\rm FB}$
$\mathcal{C}_{HW}$	0.7	0.7	0.9	-	1.	$A_b^{\rm FB}$	1.	$A_b^{\rm FB}$
$\mathcal{C}_{HWB}$	1.	1.	9.	-	9.	$A_b^{\rm FB}$	9.	$A_b^{\rm FB}$
$\mathcal{C}_G$	1.1	1.1	0.1	-	1.1	$B \to X_s\gamma$	1.1	$B \to X_s\gamma$
$\mathcal{C}_W$	0.3	0.3	0.9	-	0.9	$A_b^{\rm FB}$	0.9	$A_b^{\rm FB}$