Impact of flavour on Higgs/EW/top

David Marzocca

INFN Trieste

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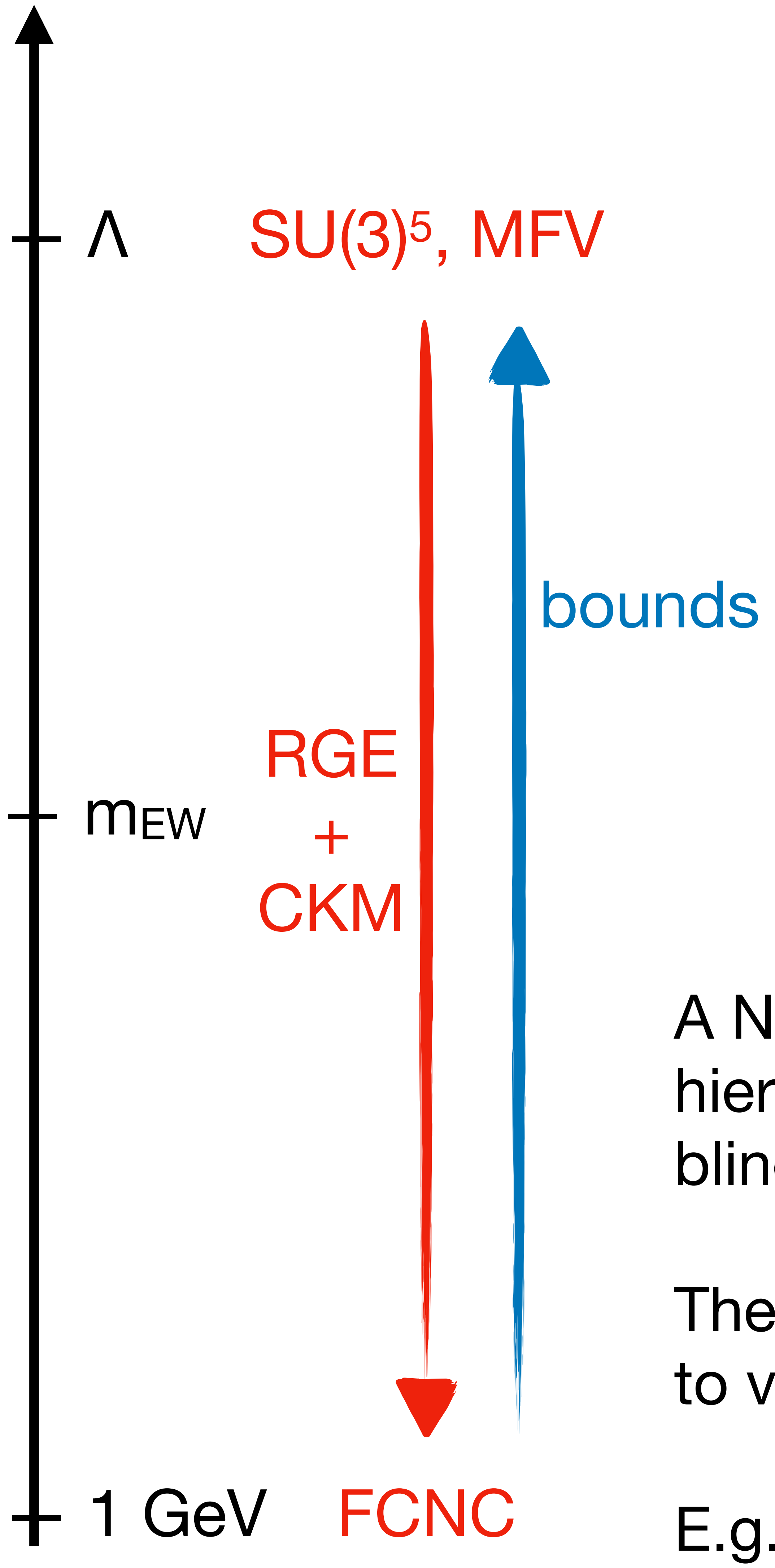
Heavy flavour aspects in EFT fits [LHC EFT WG]

1) Flavor bounds on flavor-blind NP



Assume NP at the UV scale is flavor-blind (or flavor-minimal)

Evolve the EFT coefficients to the low-energy scale:
due to operator mixing and the non-trivial CKM and Yukawas,
flavor-violating low-energy operators are induced.

These generate constraints on the flavor-blind UV coefficients.

Motivation

A NP sector mainly related to the hierarchy problem prefers a flavor-blind structure to avoid bounds.

The SM flavor puzzle is postponed to very high energies.

E.g. Composite Higgs, cMSSM, …

> Main effects of NP are in the EW/Higgs sector (+top)
“*Universal New Physics*” scenarios

> Still, flavor bounds often are very constraining, pushing NP to high scales.

No signals of this class from experiments, so far.

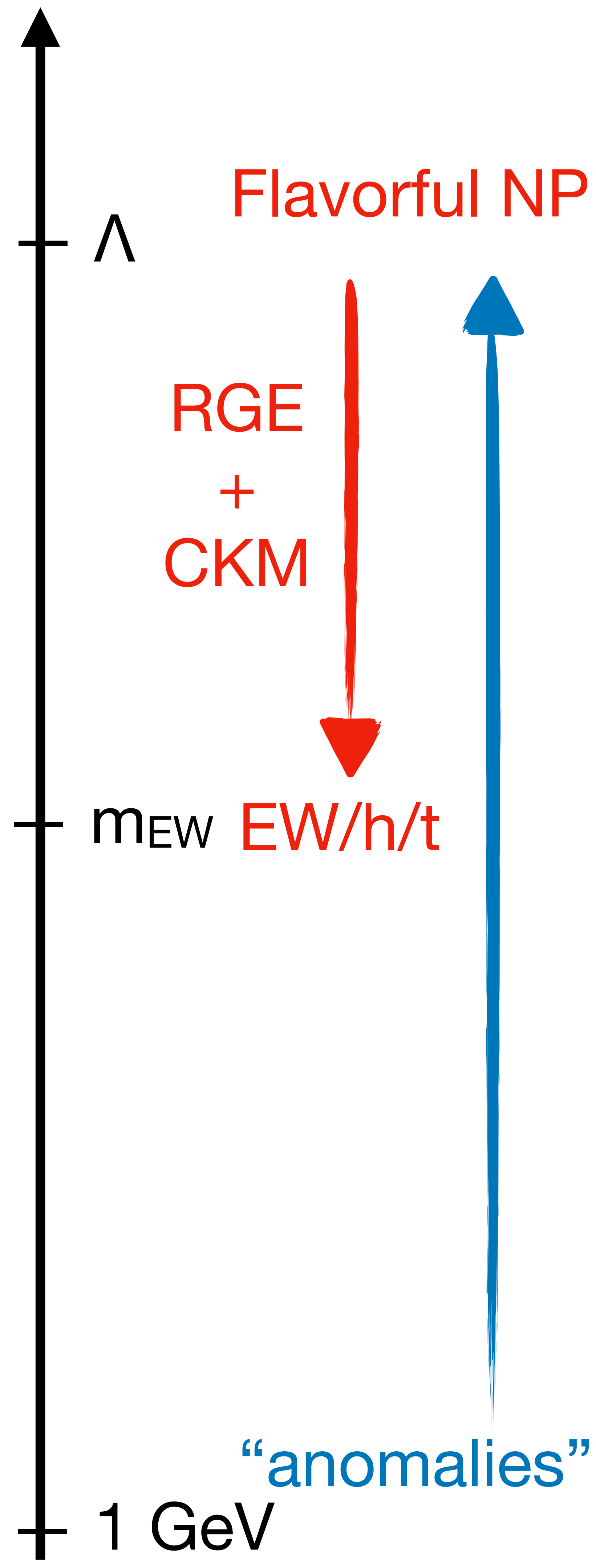
2) EW/Higgs/top from flavourful NP

Mainly driven by experimental results

Relax the strong assumption about the flavor blindness of NP.

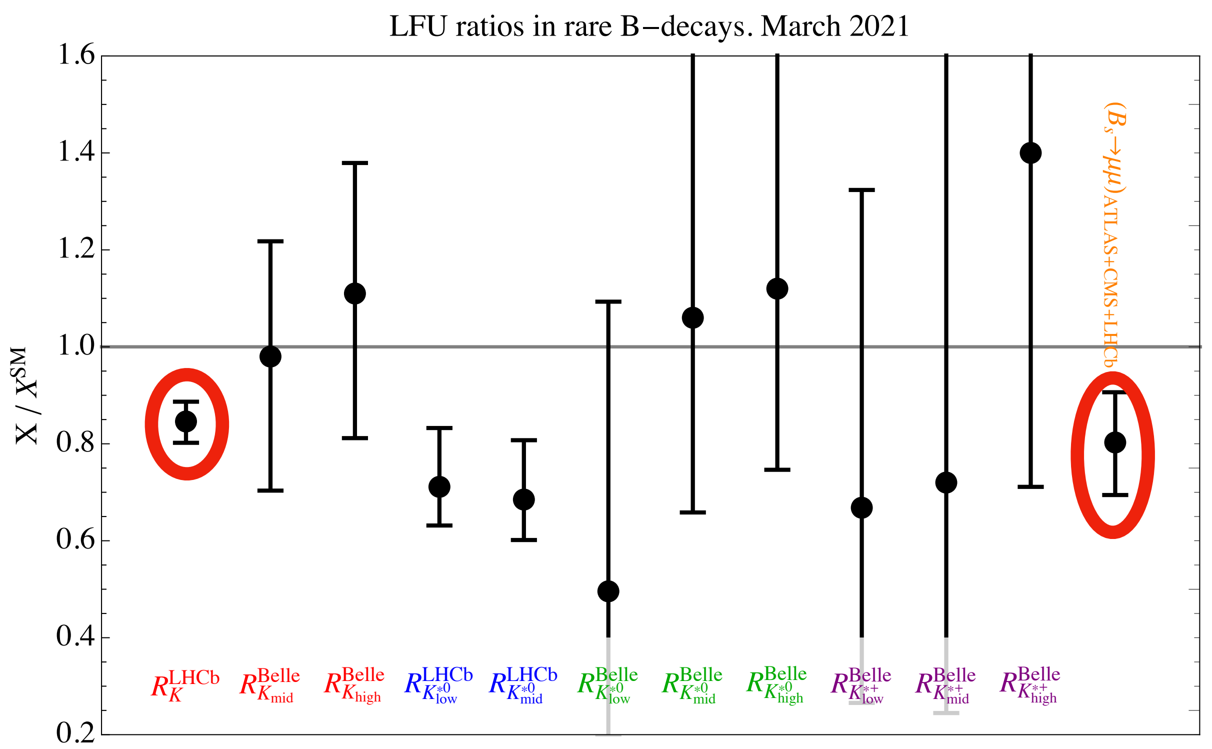
Assume some flavourful NP at the high scale, perhaps more directly linked to the flavor problem.

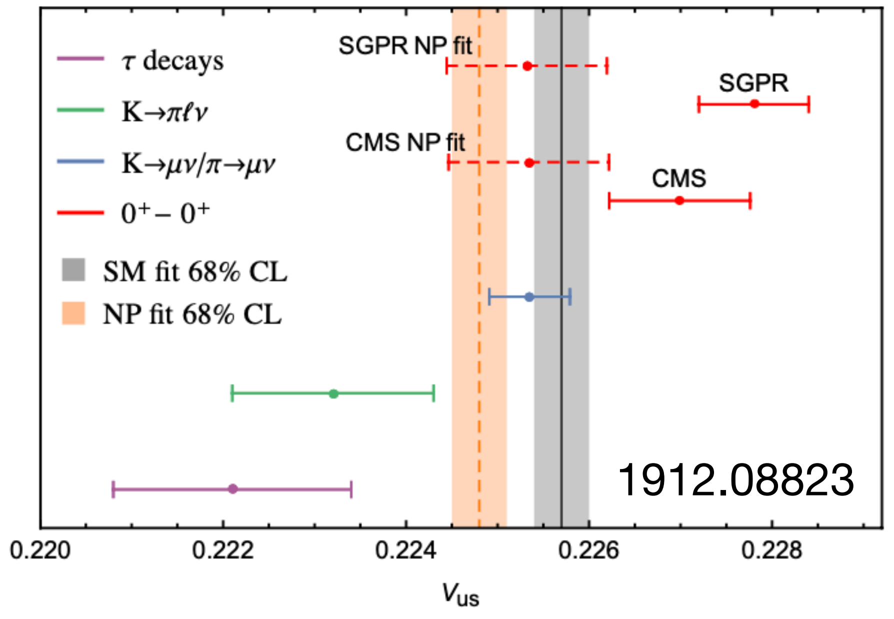
EFT fits should be performed with a general flavor structure.

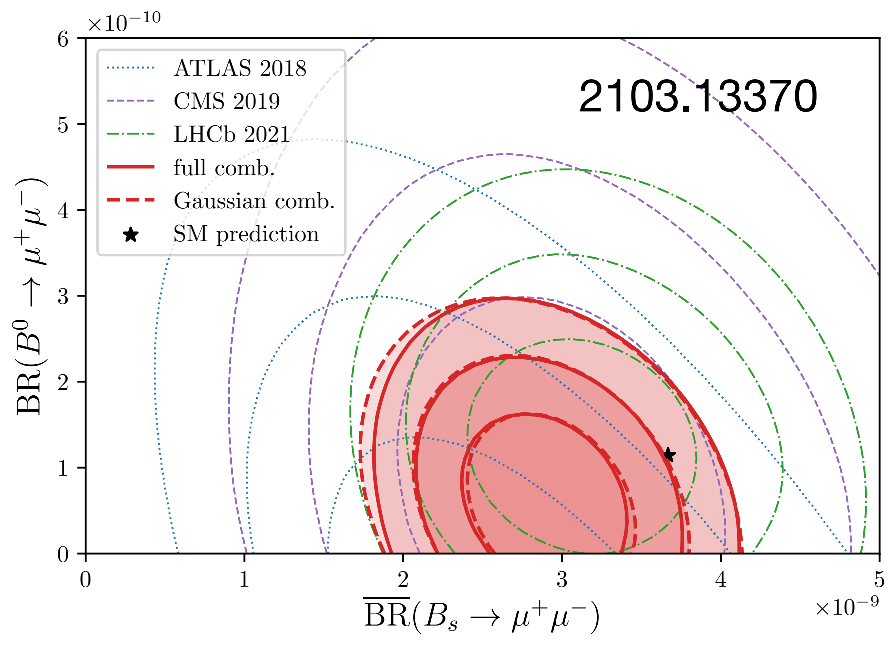


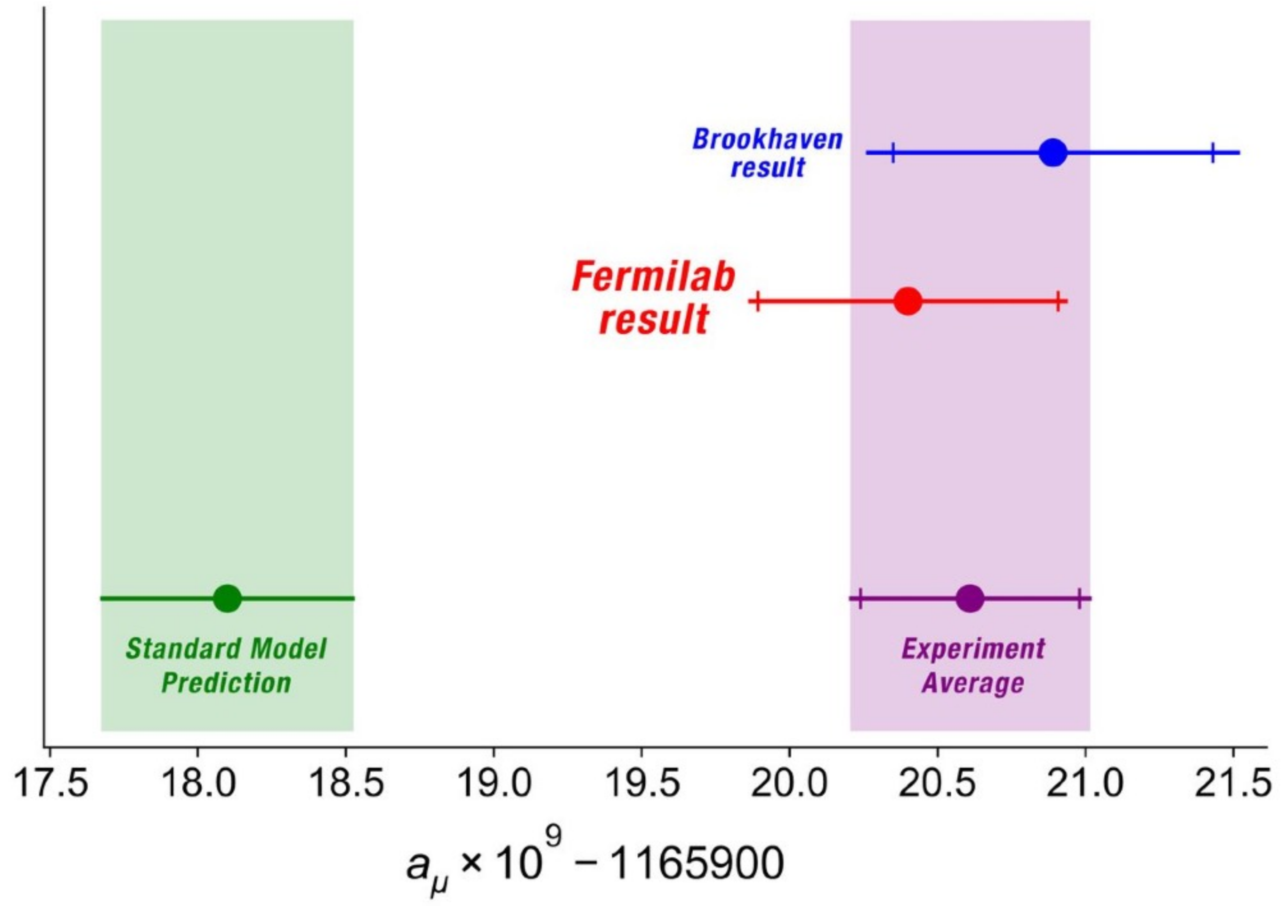
… could it be we are onto something here?

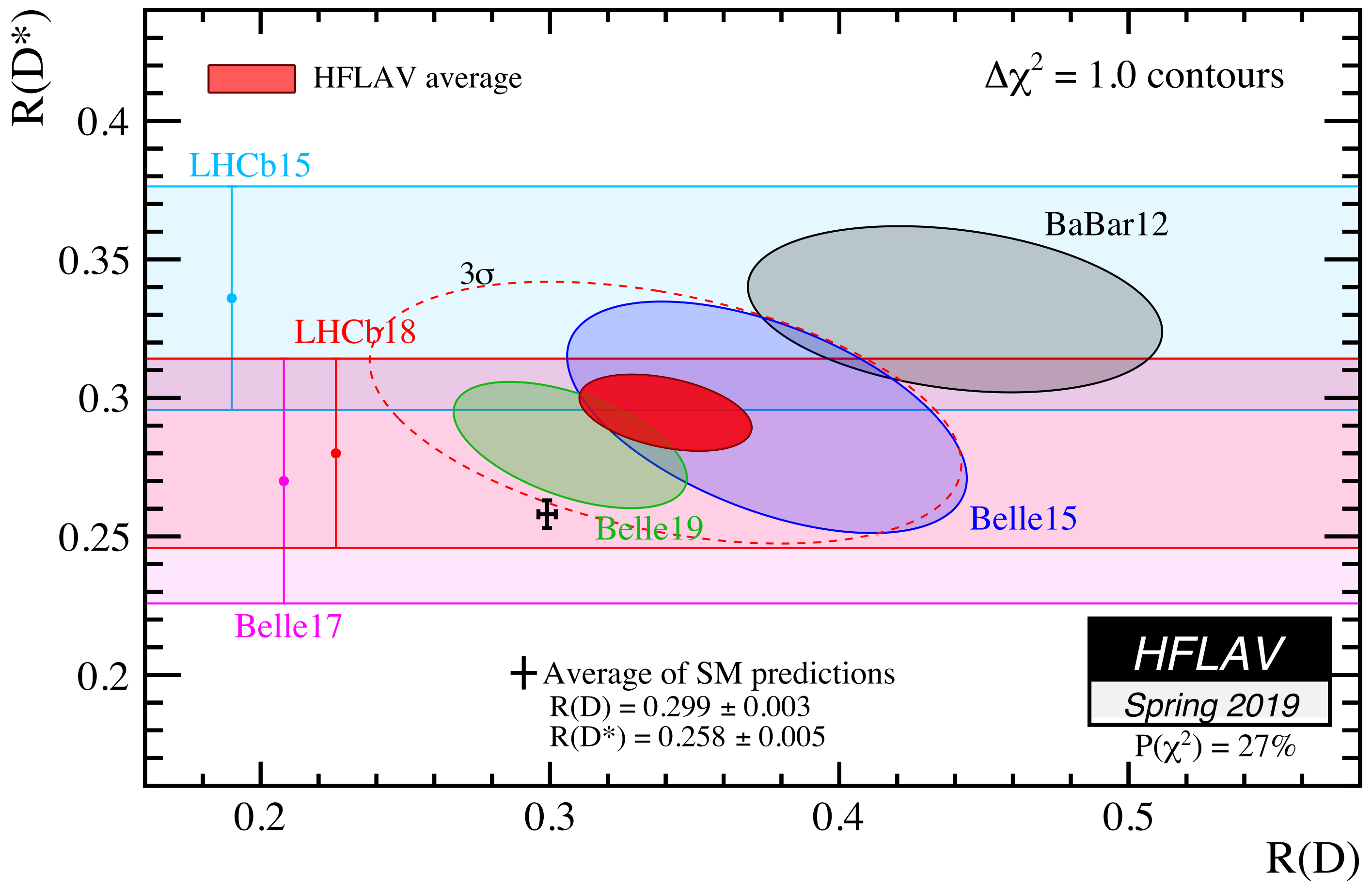
What is the impact on EW/Higgs/top from the NP required to fit these?











1) Flavor bounds on flavor-blind NP

aTGC from B and Kaon physics

Bobeth and Haisch 1503.04829

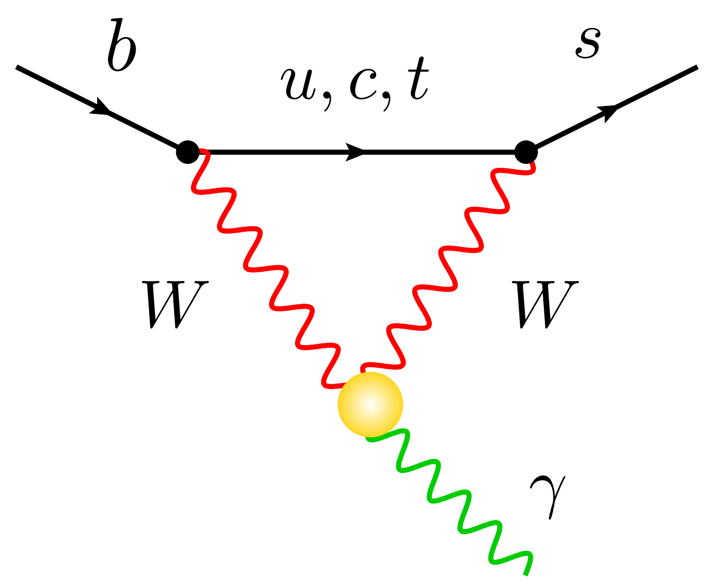
Assuming at Λ one only has:

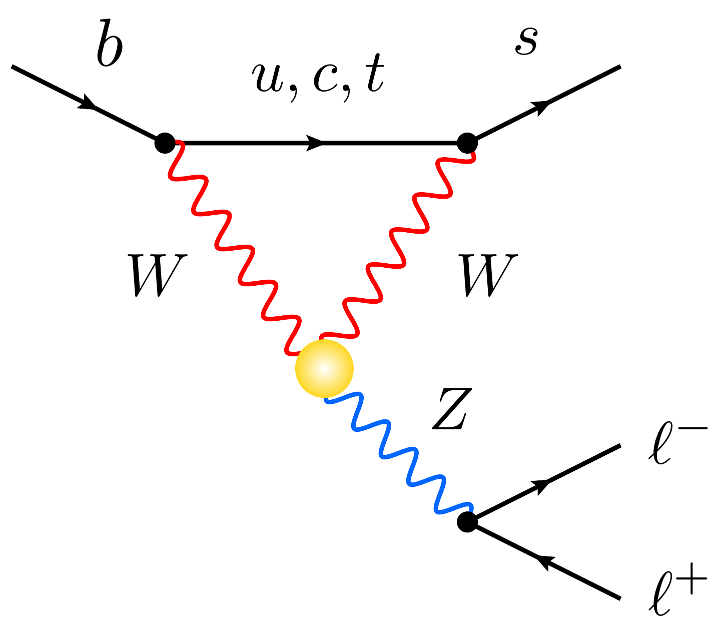
$$\mathcal{L}_{\text{TGC}} = \sum_{i=\phi B,\phi W,3W} \frac{C_i}{\Lambda^2} O_i$$

$$O_{\phi B} = (D_\mu \phi)^\dagger \hat{B}^{\mu\nu} (D_\nu \phi)$$

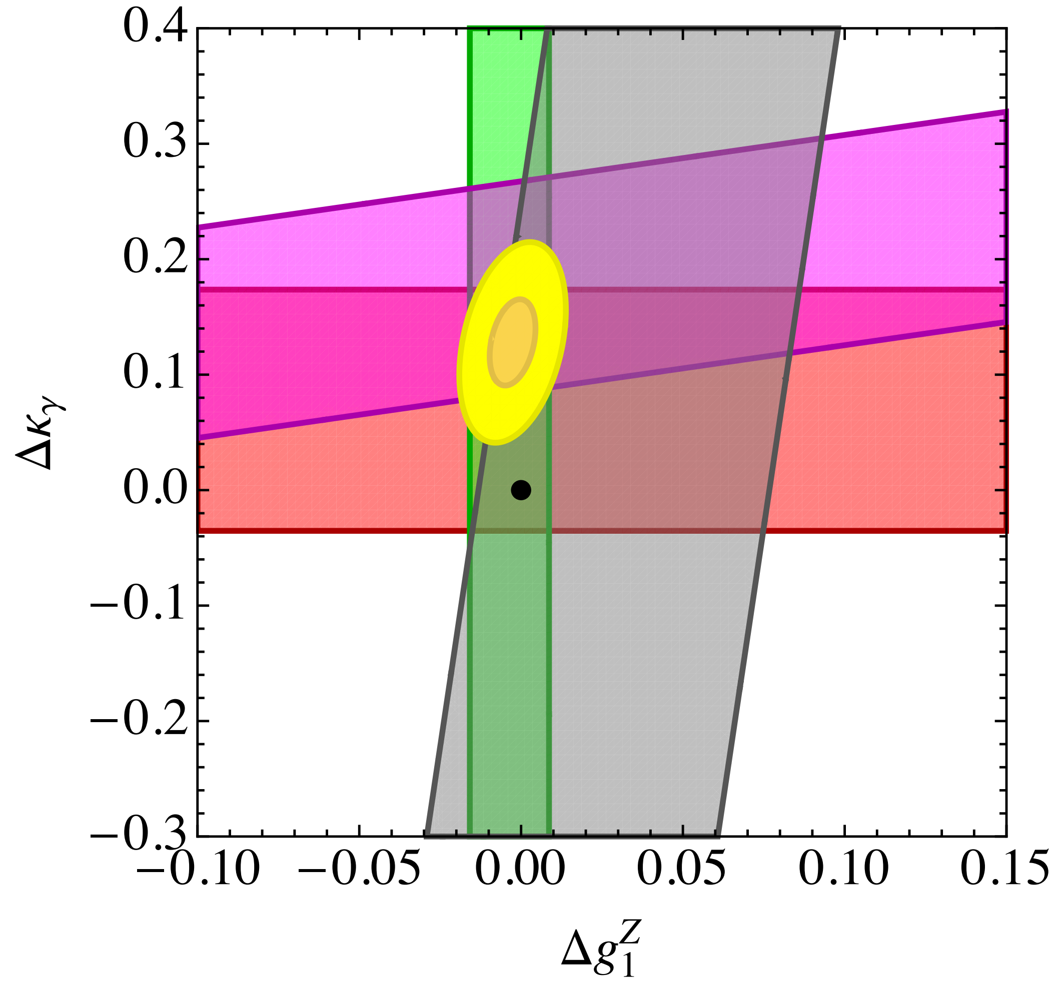
$$O_{\phi W} = (D_\mu \phi)^\dagger \hat{W}^{\mu\nu} (D_\nu \phi)$$

$$O_{3W} = \text{Tr}\left(\hat{W}_{\mu\nu} \hat{W}^{\nu\rho} \hat{W}_\rho{}^\mu\right)$$

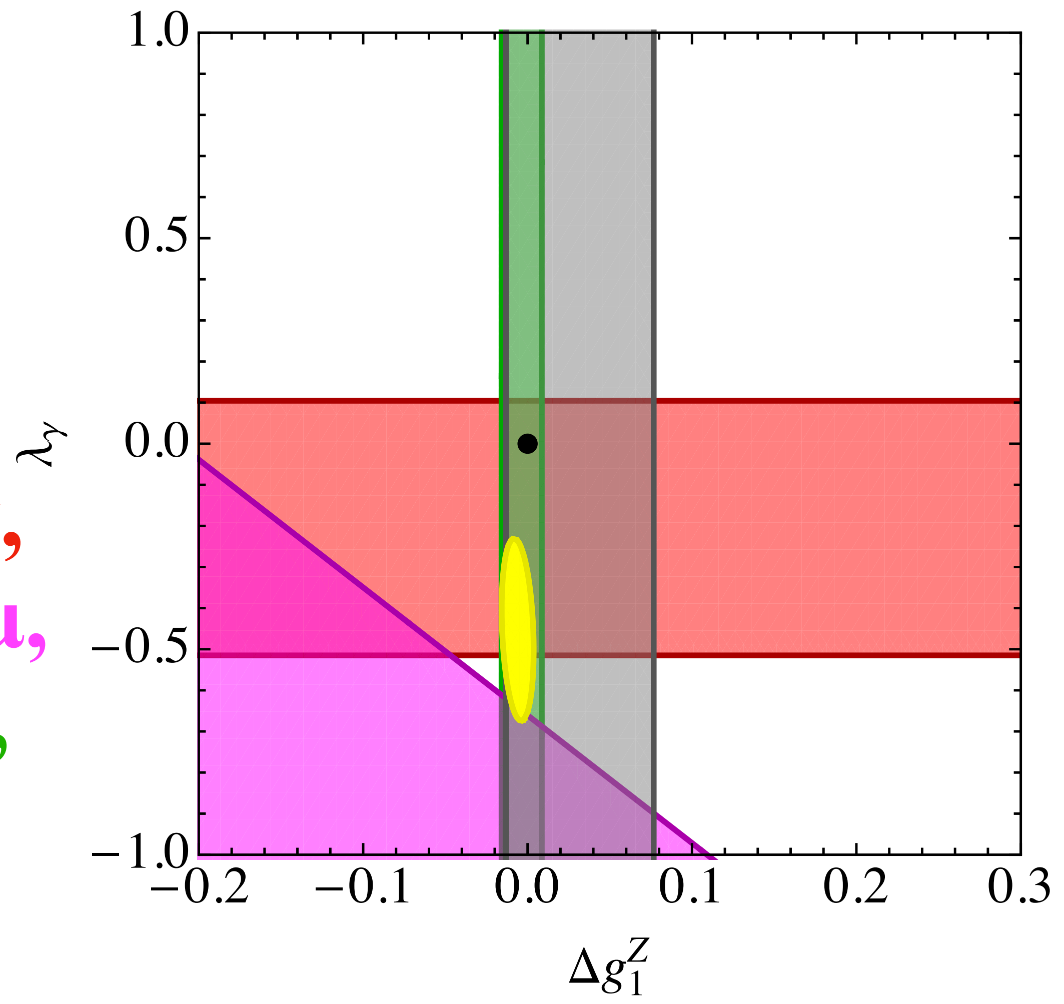




strictly LFU



B → X_s γ,
B → K*μμ,
B_s → μμ,
Z → bb



From LEP-II:

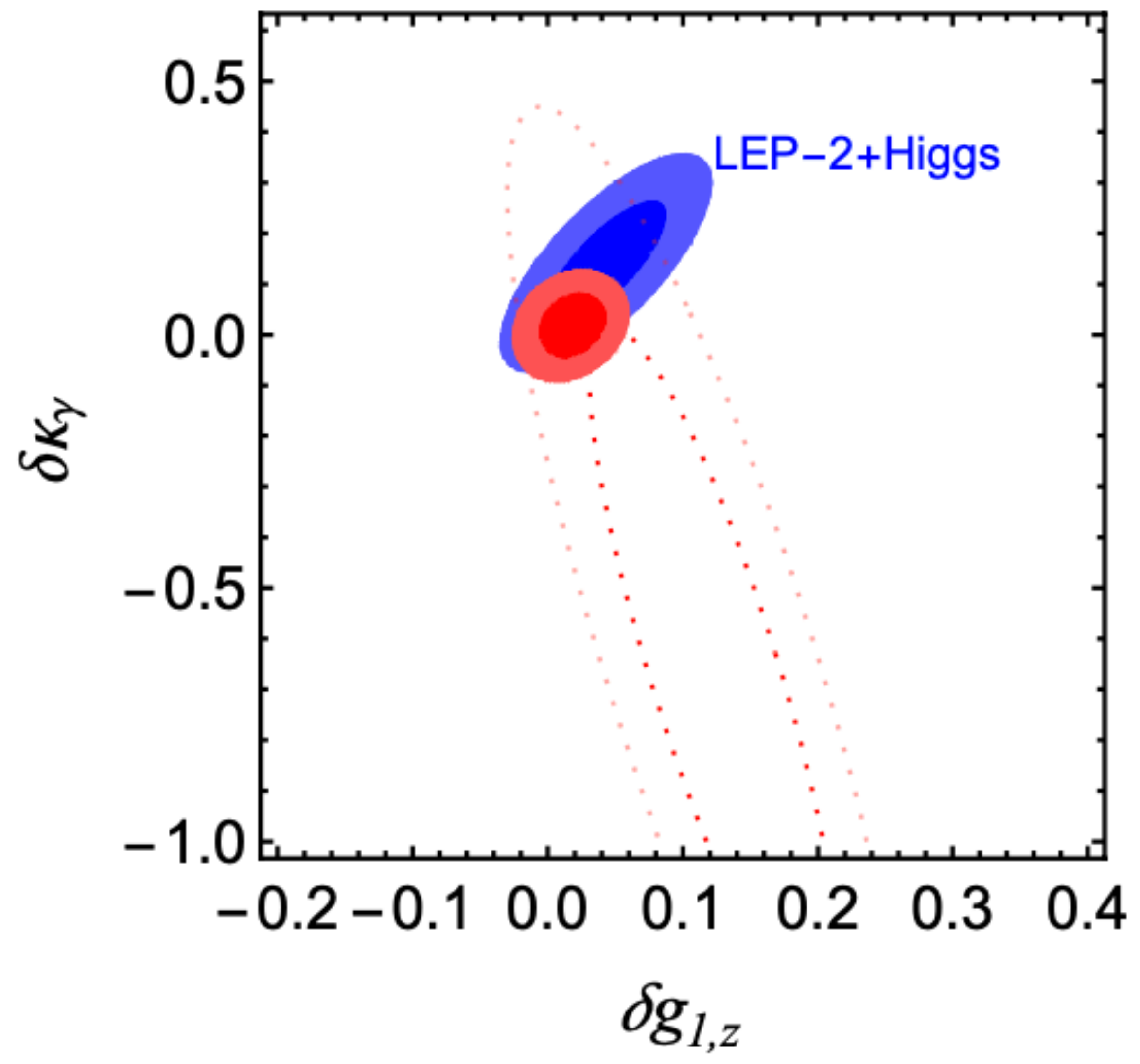
$$\Delta g_1^Z = -0.06 \pm 0.03$$

$$\Delta \kappa_\gamma = 0.06 \pm 0.04.$$

$$\lambda_\gamma = 0.00 \pm 0.07$$

From LEP-II + LHC:

Falkowski, Gonzalez-Alonso, Greljo, DM, Son 1609.06312



Ztt from rare meson decays

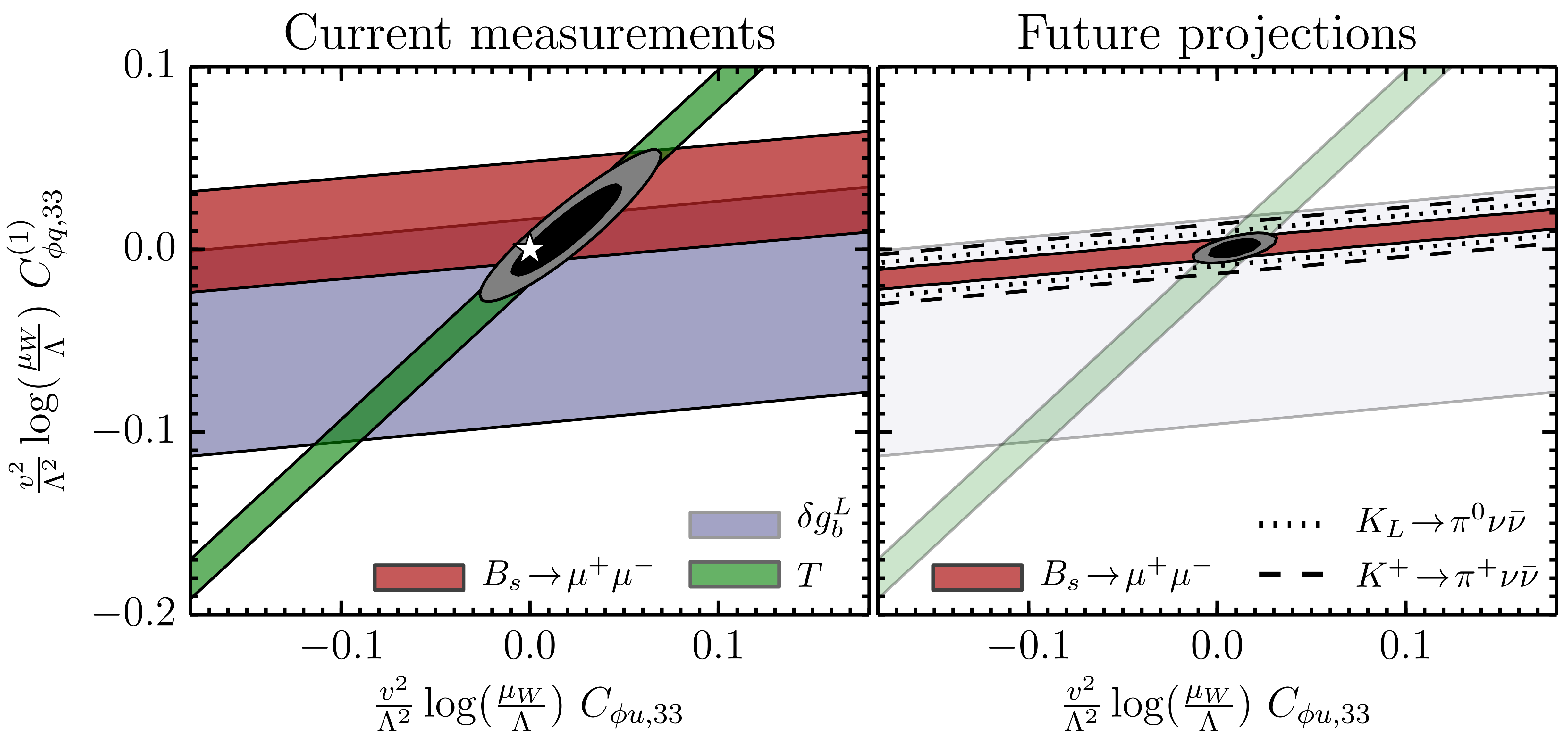
Brod, Greljo, Stamou, Uttayarat 1408.0792

Assuming at Λ one only has (up-basis):

$$Q^{(3)}_{\phi q,33} \equiv (\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)(\bar{Q}_{L,3}\gamma^\mu \sigma^a Q_{L,3})\,,$$
$$Q^{(1)}_{\phi q,33} \equiv (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{Q}_{L,3}\gamma^\mu Q_{L,3})\,,$$
$$Q_{\phi u,33} \equiv (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{t}_R\gamma^\mu t_R)\,.$$

To avoid tree-level down-type FCNC and Zbb:

$$C^{(3)}_{\phi q,33} + C^{(1)}_{\phi q,33} = 0$$



LFU semileptonic operators are induced by RGE:

$$C^{(3)}_{lq}(\mu_W) = C^{(3)}_{lq}(\Lambda) + \frac{1}{3}C^{(3)}_{\phi q,33}(\Lambda)\frac{g_2^2}{16\pi^2}\log\frac{\mu_W}{\Lambda}$$

$$C^{(1)}_{lq}(\mu_W) = C^{(1)}_{lq}(\Lambda) - \frac{1}{3}C^{(1)}_{\phi q,33}(\Lambda)\frac{g_1^2}{16\pi^2}\log\frac{\mu_W}{\Lambda}$$

$$16\pi^2\mu\frac{d}{d\mu}C_{\phi D} = \frac{8}{3}g_1^2\left(C^{(1)}_{\phi q,33} + 2C_{\phi u,33}\right) + 24y_t^2\left(C^{(1)}_{\phi q,33} - C_{\phi u,33}\right)$$

The effect comes from modification of Ztt, same for B ($\delta Y^{\rm NP}$) and K ($\delta X^{\rm NP}$) decays:

$$\delta Y^{\rm NP} = \delta X^{\rm NP} = \frac{x_t}{8}\left(C_{\phi u} - \frac{12+8x_t}{x_t}C^{(1)}_{\phi q,33}\right)\frac{v^2}{\Lambda^2}\log\frac{\mu_W}{\Lambda}$$

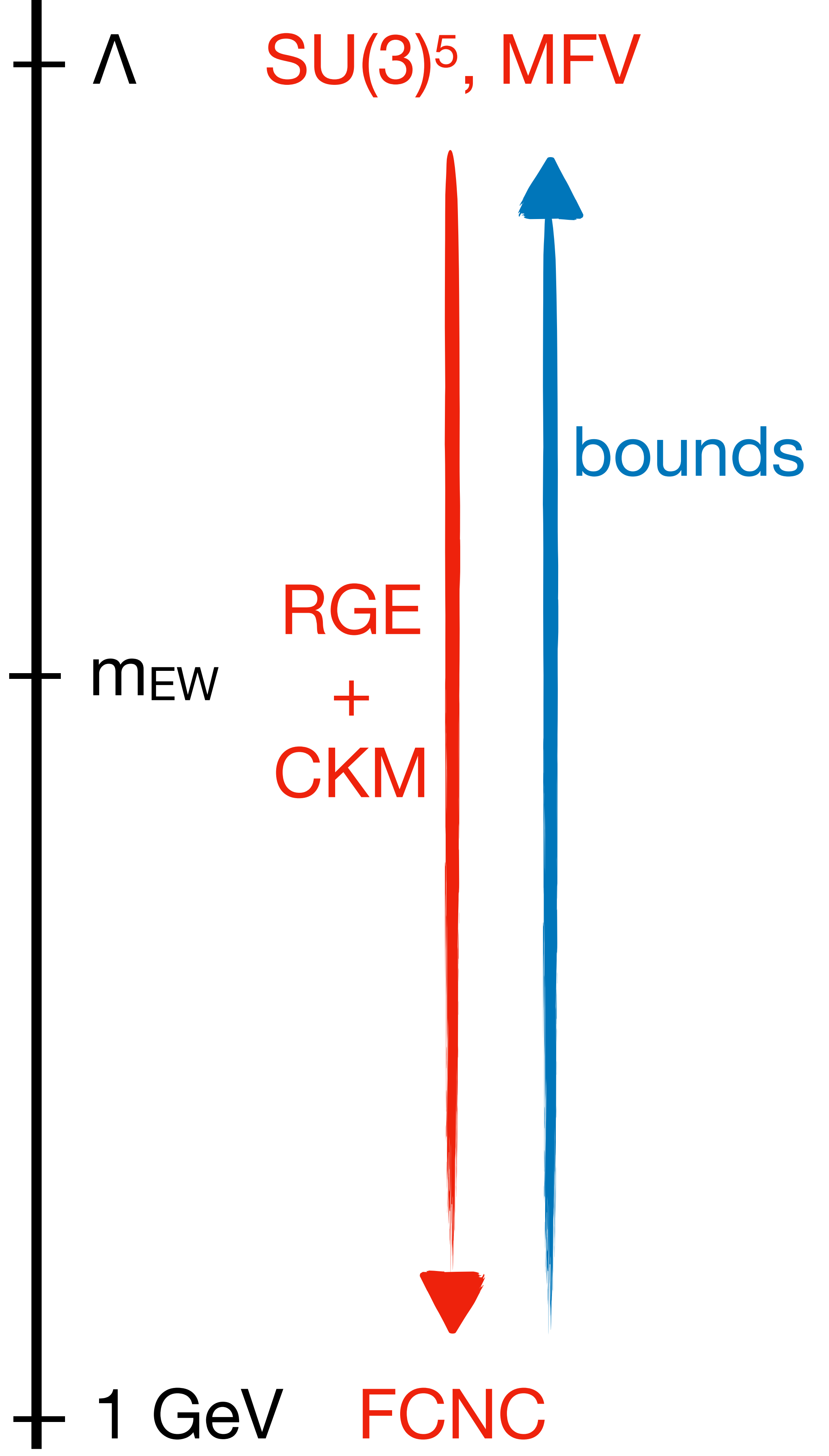
Bounds much stronger than future prospects from tt̄Z production or t → c Z

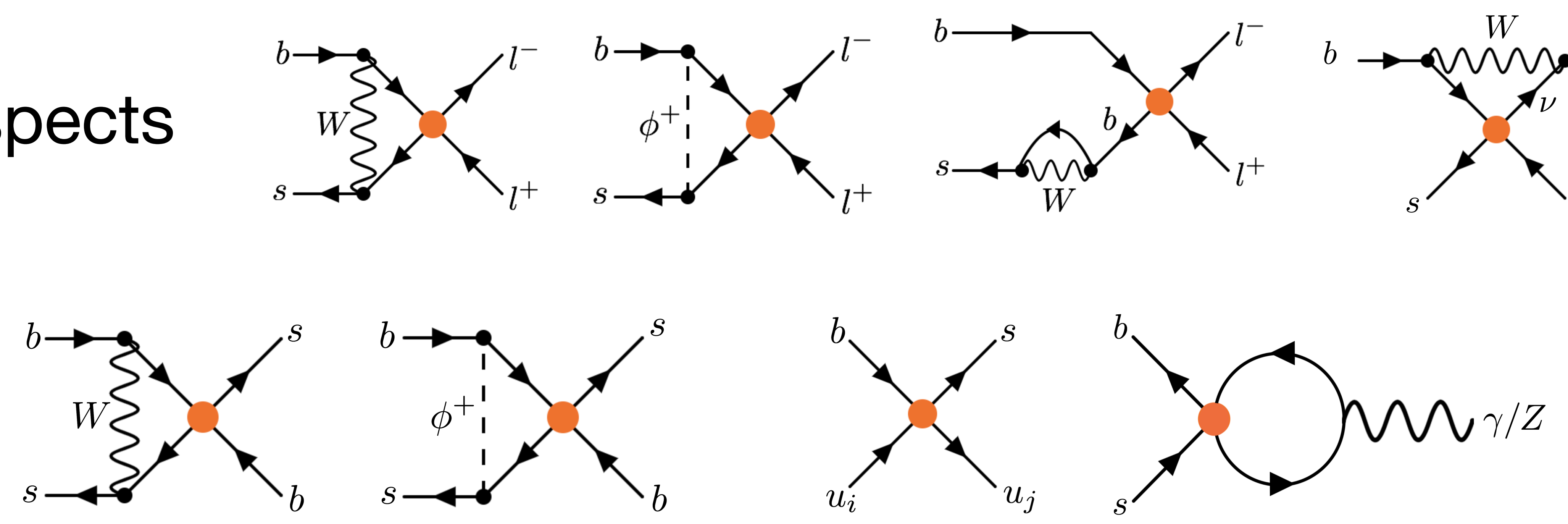
$$\mathrm{Br}(t\to cZ) \simeq \frac{\lambda^4 v^4}{\Lambda^4}\left[\left(C^{(3)}_{\phi q,33} - C^{(1)}_{\phi q,33}\right)^2 + C^2_{\phi u,33}\right] < 0.05\%$$

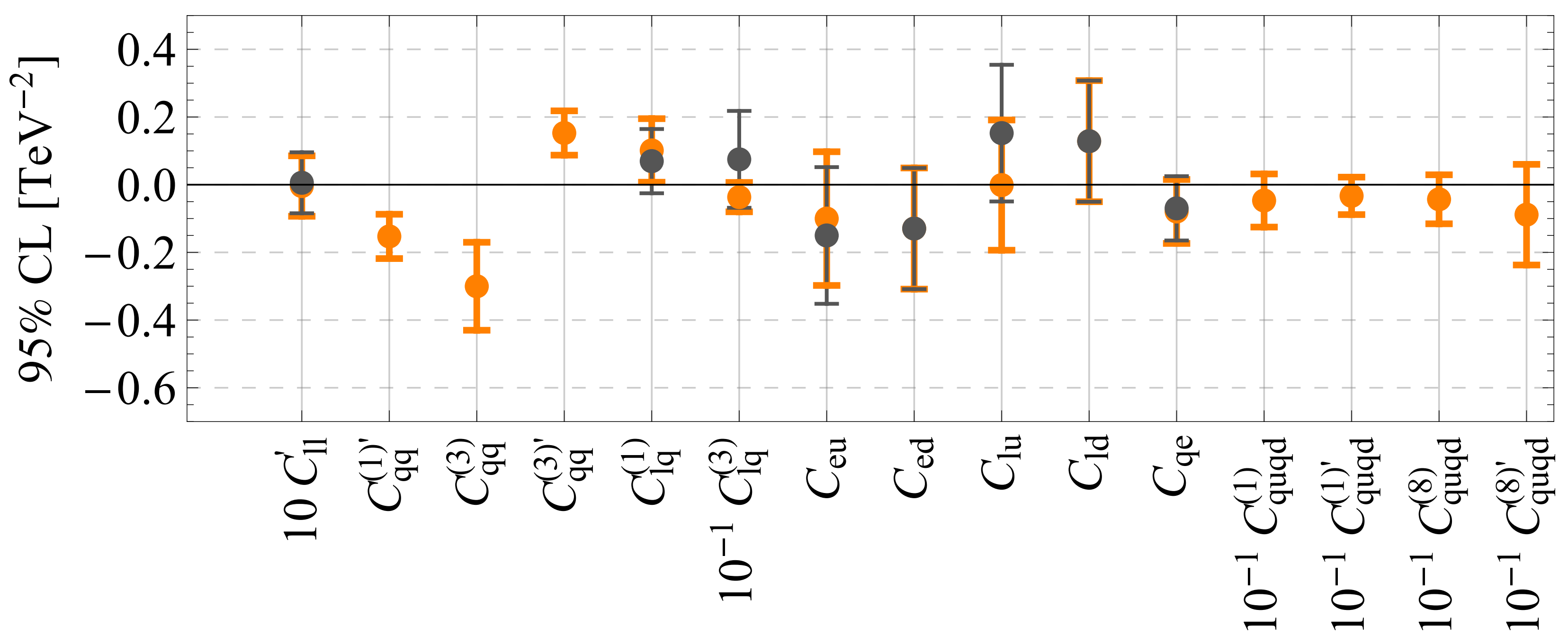
Flavor data for SU(3)⁵ or MFV SMEFT

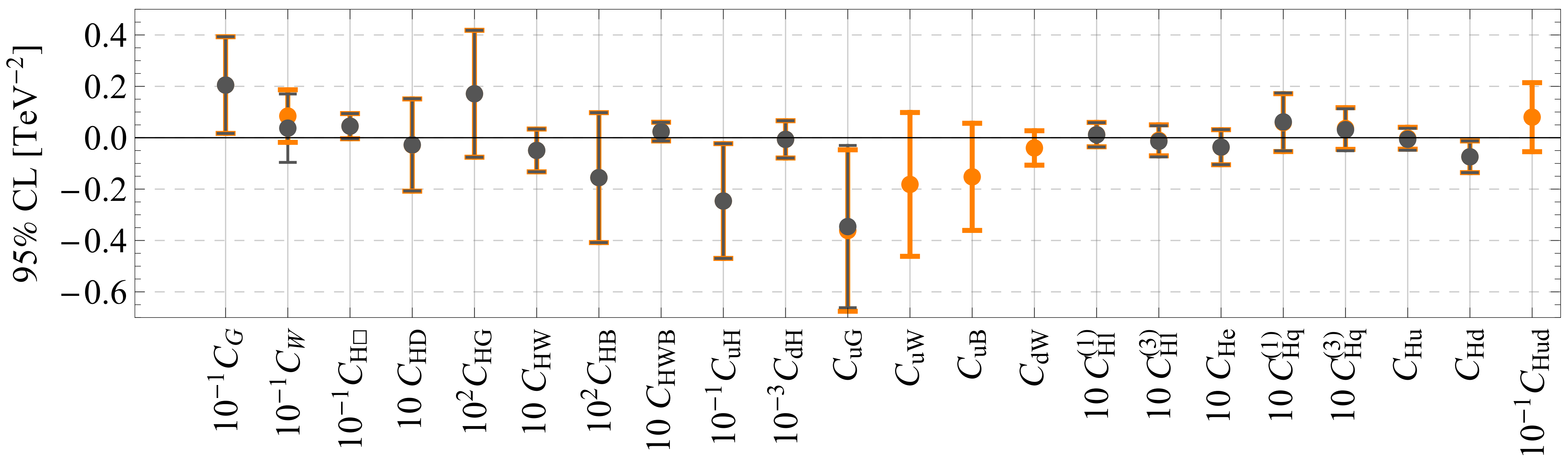
Aoude, Hurth, Renner, Shepherd 1903.00500 (tree + 1-loop matching to LEFT [Dekens, Stoffer 1908.05295]), 2003.05432 (fit)

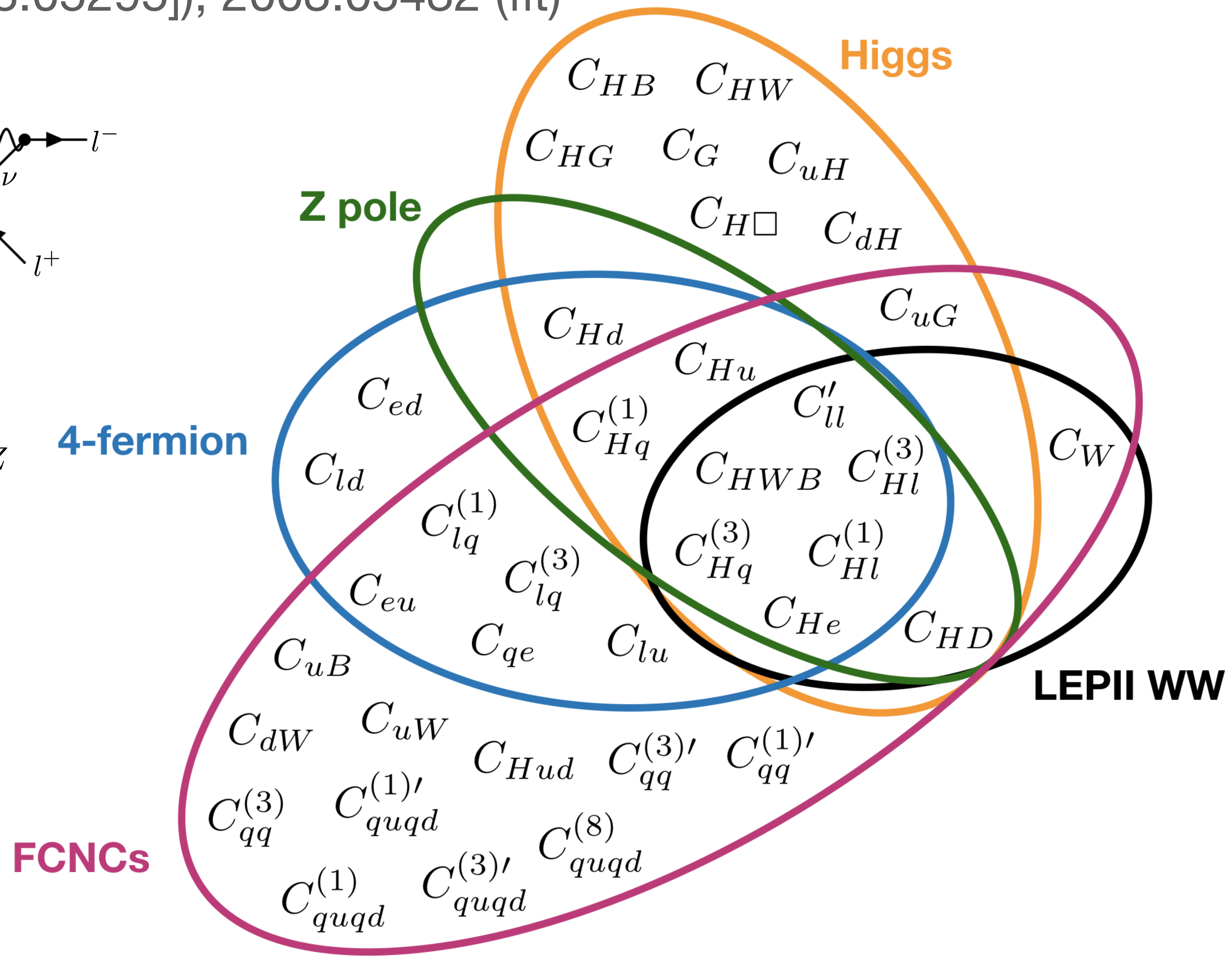
Assume SMEFT at Λ respects
(in the up basis)









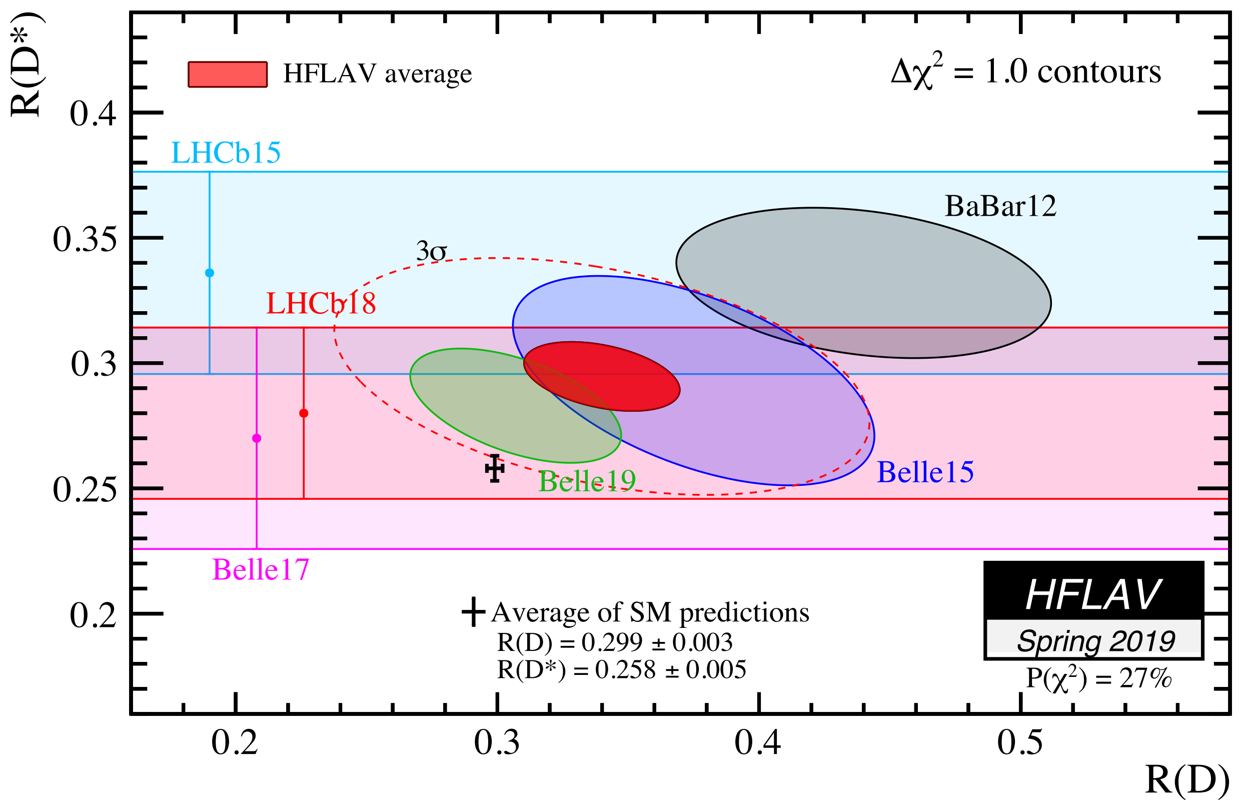


Without flavor data

With flavor data

2) EW/Higgs/top from flavourful NP

Zℓℓ from R(D$^{(*)}$)



Assuming at Λ one only has:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{v^2}\lambda^q_{ij}\lambda^\ell_{\alpha\beta}\left[C_T\,(\bar{Q}^i_L\gamma_\mu\sigma^a Q^j_L)(\bar{L}^\alpha_L\gamma^\mu\sigma^a L^\beta_L) + C_S\,(\bar{Q}^i_L\gamma_\mu Q^j_L)(\bar{L}^\alpha_L\gamma^\mu L^\beta_L)\right]$$

$$\lambda^q_{bb} = \lambda^\ell_{\tau\tau} = 1$$

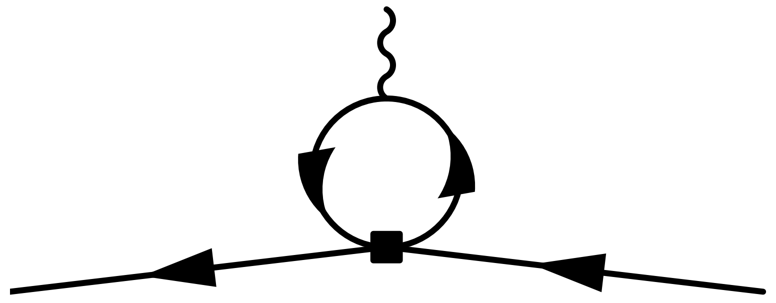
[Buttazzo, Greljo, Isidori, DM 1706.07808]

$$R^{\tau\ell}_{D^{(*)}} \approx 1 + 2C_T\left(1 - \lambda^q_{sb}\frac{V^*_{tb}}{V^*_{ts}}\right) = 1.141 \pm 0.038$$

Requires $C_S \sim C_T$ to suppress B → K* νν.

A too large value of $C_{S,T}$ is excluded by 1-loop contribution to Z → ττ, νν via RGE-mixing:

Feruglio, Paradisi, Pattori 1606.00524, 1705.00929



$$\delta g^Z_{\tau_L} = \frac{1}{16\pi^2}\left(3y_t^2(C_T - C_S)L_t - g^2 C_T L_z - \frac{g_1^2}{3}C_S L_z\right) \approx -0.043C_S + 0.033C_T\,,$$

$$\delta g^Z_{\nu L} = \frac{1}{16\pi^2}\left(3y_t^2(-C_T - C_S)L_t + g^2 C_T L_z - \frac{g_1^2}{3}C_S L_z\right) \approx -0.043C_S - 0.033C_T$$

per-mille constraints by LEP-I

$$L_{t,z} = \log\Lambda/m_{t,z}$$

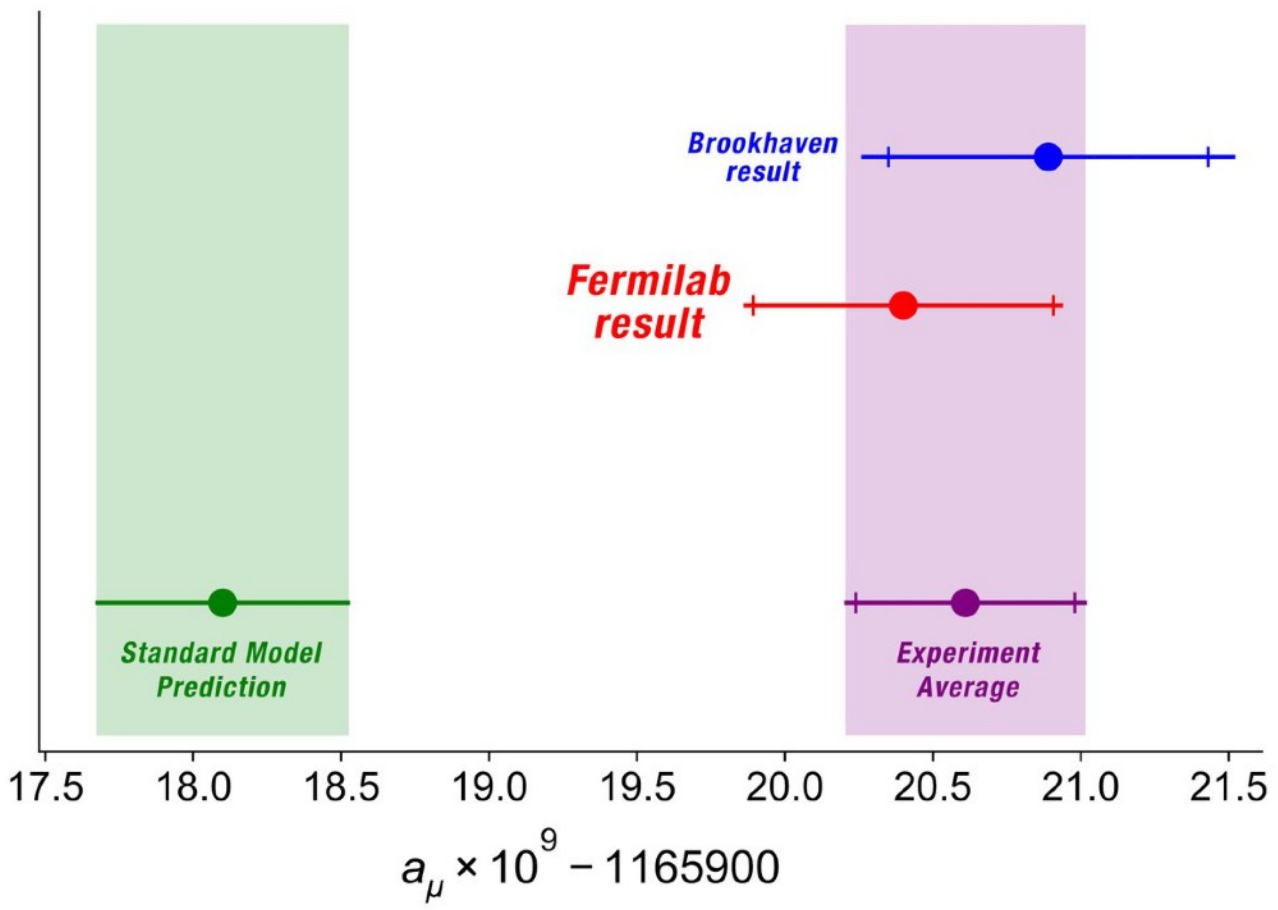
This effect is not described by the oblique parameters S&T >> The flavourful LEP fit is required.

E.g. Efrat et al. 1503.07872

h→ μμ from (g-2)$_\mu$

$$\Delta a_\mu = \frac{4 m_\mu}{e}\, \mathrm{Re}\left[L_{e\gamma}(m_\mu)\right]_{\mu\mu}$$

$$[O_{e\gamma}]_{\alpha\beta} = \bar{e}_L^{\alpha}\, \sigma^{\mu\nu}\, e_R^{\beta}\, F_{\mu\nu}$$



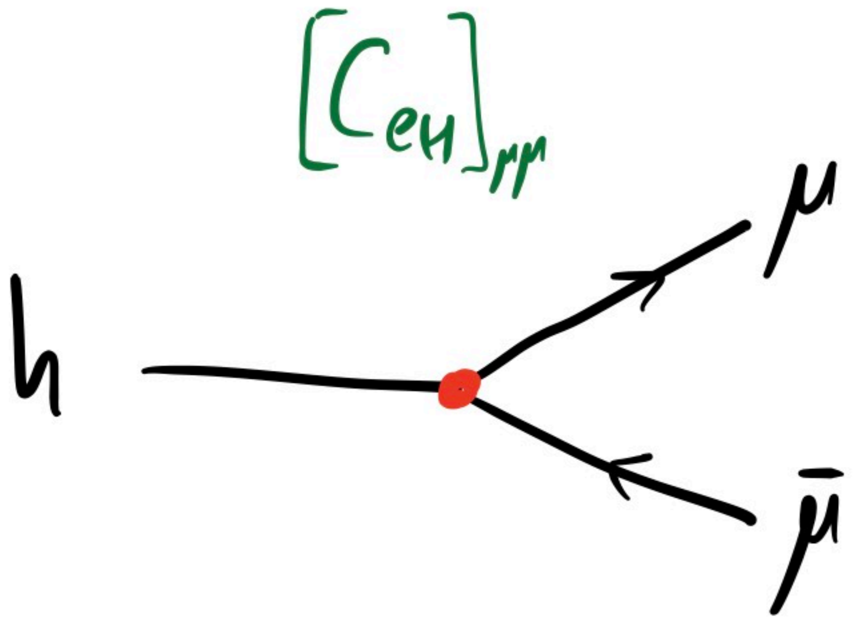
Assuming at Λ one has:

$$[L_{e\gamma}(\mu_{ew})]_{\mu\mu} = -\frac{e N_c m_t}{6\pi^2}\left[C^{(3)}_{lequ}(\Lambda)\right]_{\mu\mu tt} \log\frac{\Lambda^2}{m_t^2}$$

To fit the deviation (I put Λ=2TeV in the log):

$$C^{(3)}_{lequ}(2\,\mathrm{TeV}) \approx -\frac{1}{(83\,\mathrm{TeV})^2}$$

mt-enhanced effect in h→μμ:



$$[C_{eH}(m_h)]_{\mu\mu} = -\frac{y_t^3 N_c}{4\pi^2}\left[C^{(1)}_{lequ}(\Lambda)\right]_{\mu\mu tt} \log\frac{\Lambda^2}{m_h^2}$$

The **two** possible tree-level mediators for $C_{lequ}^{(3)}$,
$S_1 \sim (\bar{3}, 1, 1/3)$ and $S_2 \sim (3, 2, 7/6)$,
generate both operators, e.g. for S_1:

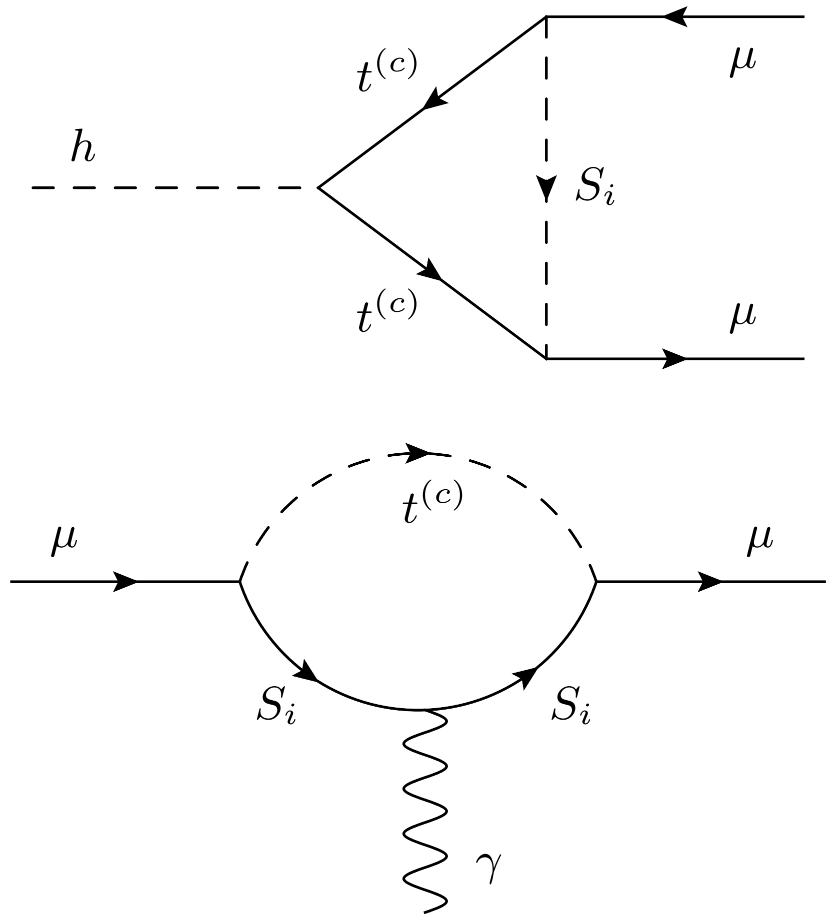
de Blas et al. 1711.10391

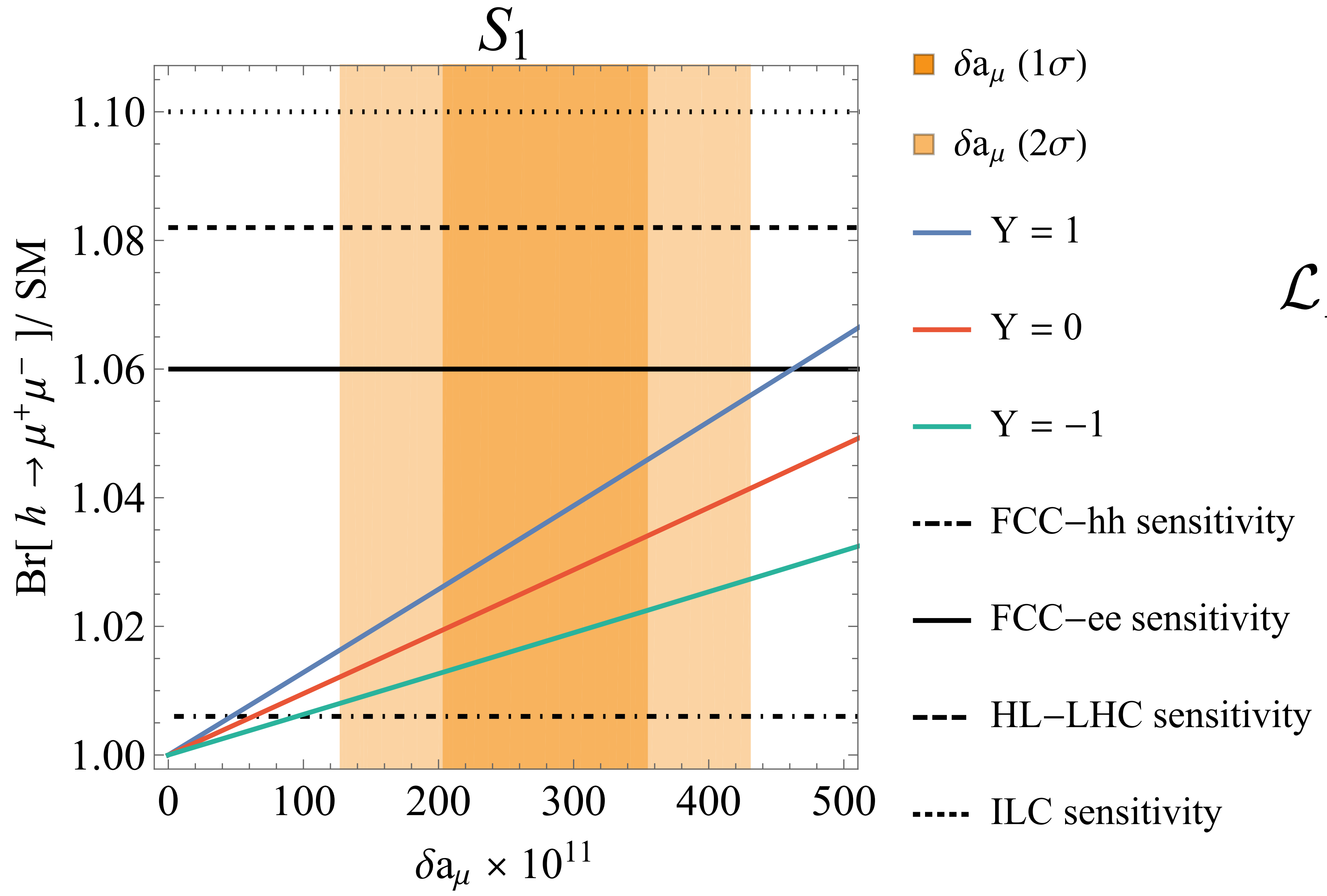
$$[C^{(1)}_{lequ}]_{\mu\mu tt} = -4\,[C^{(3)}_{lequ}]_{\mu\mu tt} = \frac{\lambda^{1R}_{t\mu}\,\lambda^{1L*}_{t\mu}}{2 M_1^2}$$

N.B.: in the model, the complete 1-loop expressions are required for such an analysis.

h→ μμ from (g-2)$_\mu$

Crivellin, Muller, Saturnino 2008.02643



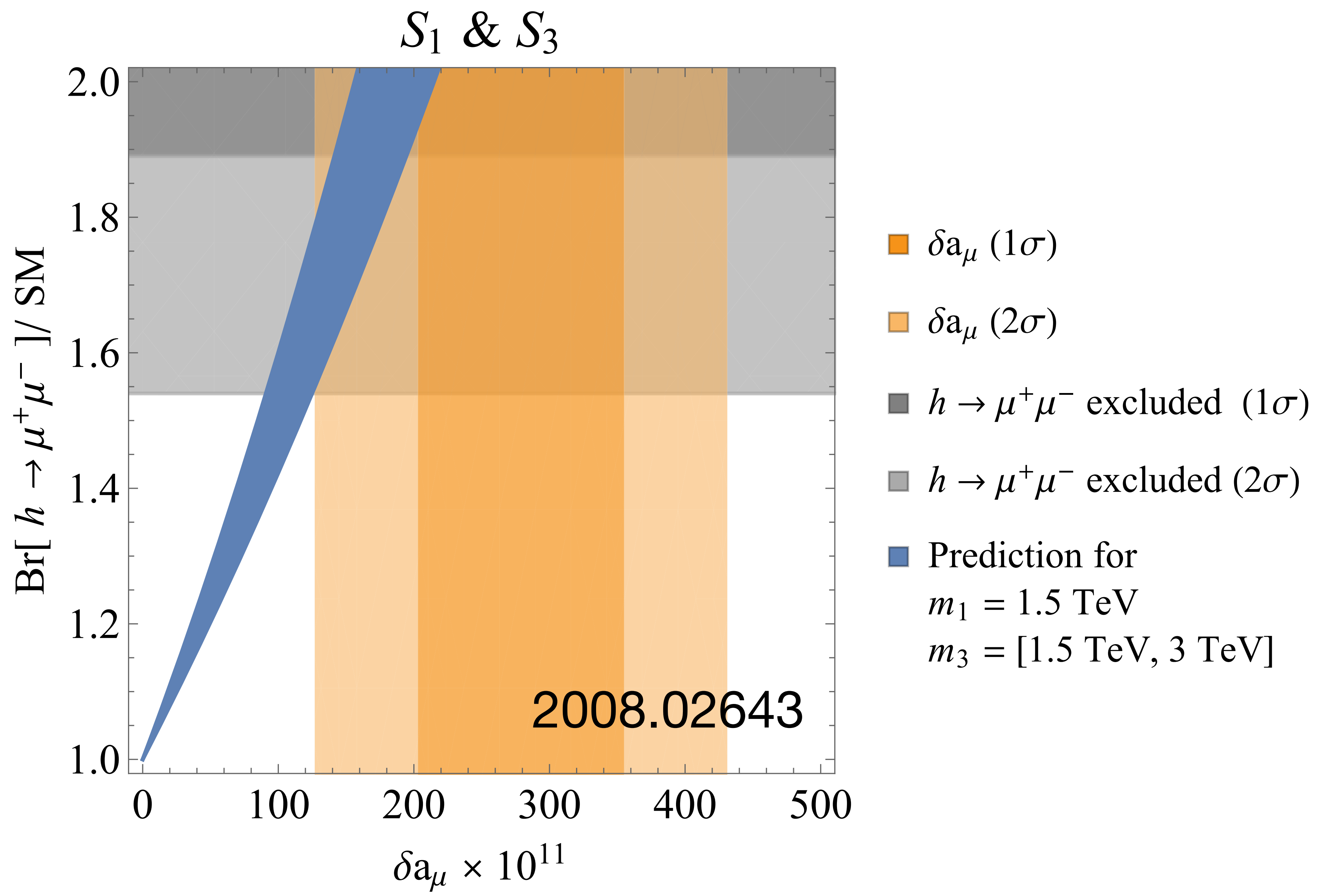


$$\mathcal{L}_H = -\sum_{k=1}^{3}(m_k^2 + Y_k H^\dagger H) S_k^\dagger S_k$$

only few % effect.

The effect in h→μμ is larger in a scenario with two leptoquarks, S_1 and S_3, that can mix, and S_1 only couples to RH fermions.

$$\mathcal{L}_H = Y_{13} S_1^\dagger \left(H^\dagger \left(\tau \cdot S_3\right) H\right) + \text{h.c.}$$



Present bound on h→μμ already doesn't allow an explanation for the central value of a_μ in this scenario.

See also Dorsner, Fajfer, Sumensari 1910.03877

Beyond the EFT: h→ γγ, gg and S, T from LQ

Gherardi, DM, Venturini 2008.09548; Crivellin, Muller, Saturnino 2006.10758

B-anomalies and a_μ motivate the scalar LQ pair $S_1 = (\bar{\mathbf{3}}, \mathbf{1}, 1/3)$ $S_3 = (\bar{\mathbf{3}}, \mathbf{3}, 1/3)$

Their potential couplings to the Higgs can be probed by Higgs and EW physics

$$\mathcal{L}_{\rm LQ} = -\lambda_{H1}|H|^2|S_1|^2 - \lambda_{H3}|H|^2|S_3^I|^2 - \left(\lambda_{H13}(H^\dagger\sigma^I H)S_3^{I\dagger}S_1 + \text{h.c.}\right) + \\ -\lambda_{\epsilon H3} i\epsilon^{IJK}(H^\dagger\sigma^I H)S_3^{J\dagger}S_3^K,$$

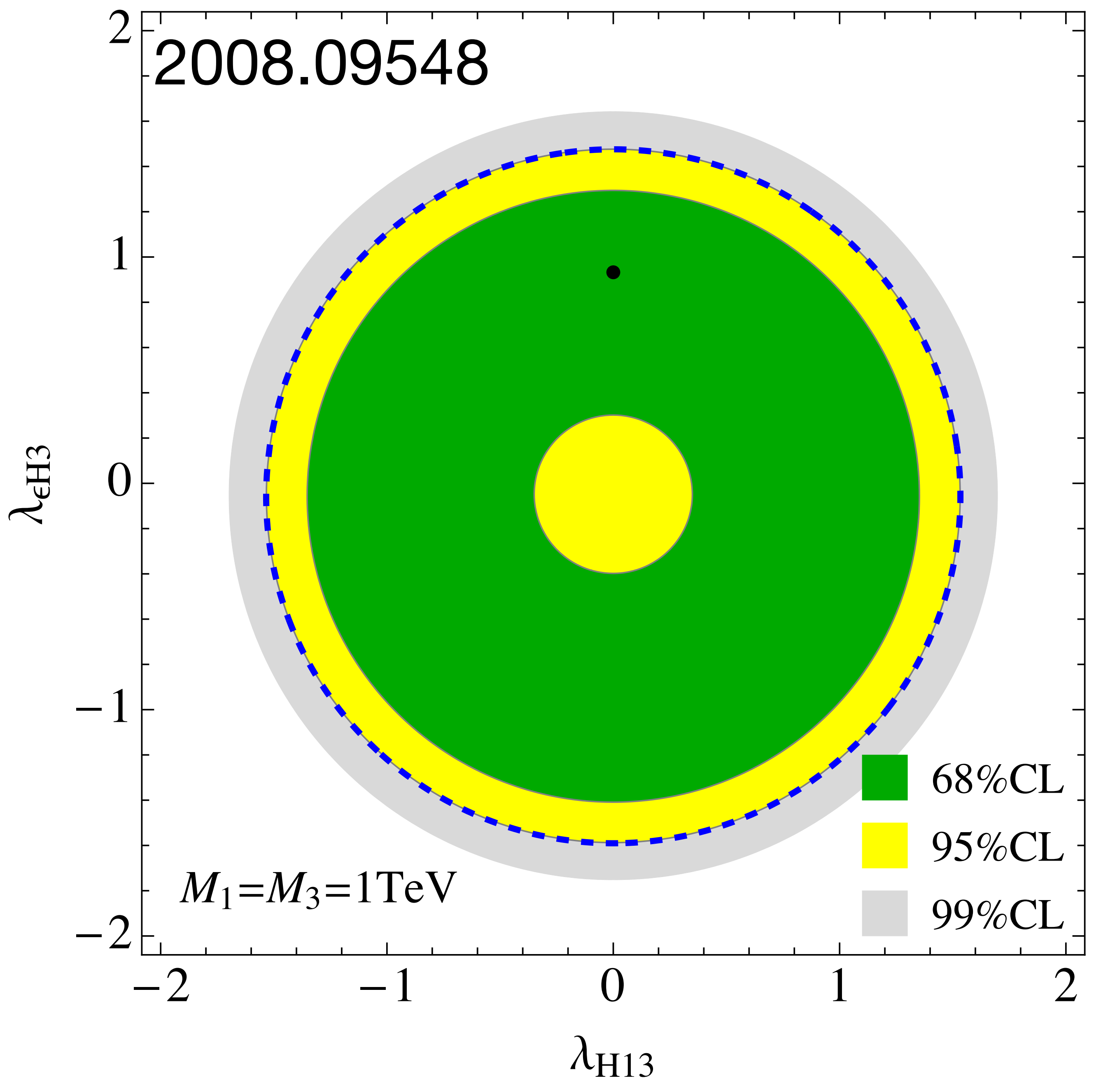
$$\hat{S} = \frac{\alpha}{4s_W^2}S = -\frac{g^2 N_c v^2 Y_{S_3}}{48\pi^2}\frac{\lambda_{\epsilon H3}}{M_3^2} \approx -5.4\times10^{-5}\lambda_{\epsilon H3}/m^2 ,$$

$$\hat{T} = \alpha T = \frac{N_c v^2 \lambda_{\epsilon H3}^2}{48\pi^2 M_3^2} + \frac{N_c v^2}{16\pi^2}|\lambda_{H13}|^2\frac{M_1^4 - M_3^4 - 2M_1^2M_3^2\log M_1^2/M_3^2}{(M_1^2-M_3^2)^3} = \\ \approx 3.8\times10^{-4}\lambda_{\epsilon H3}^2/m^2 + 3.8\times10^{-4}|\lambda_{H13}|^2/m^2 ,$$

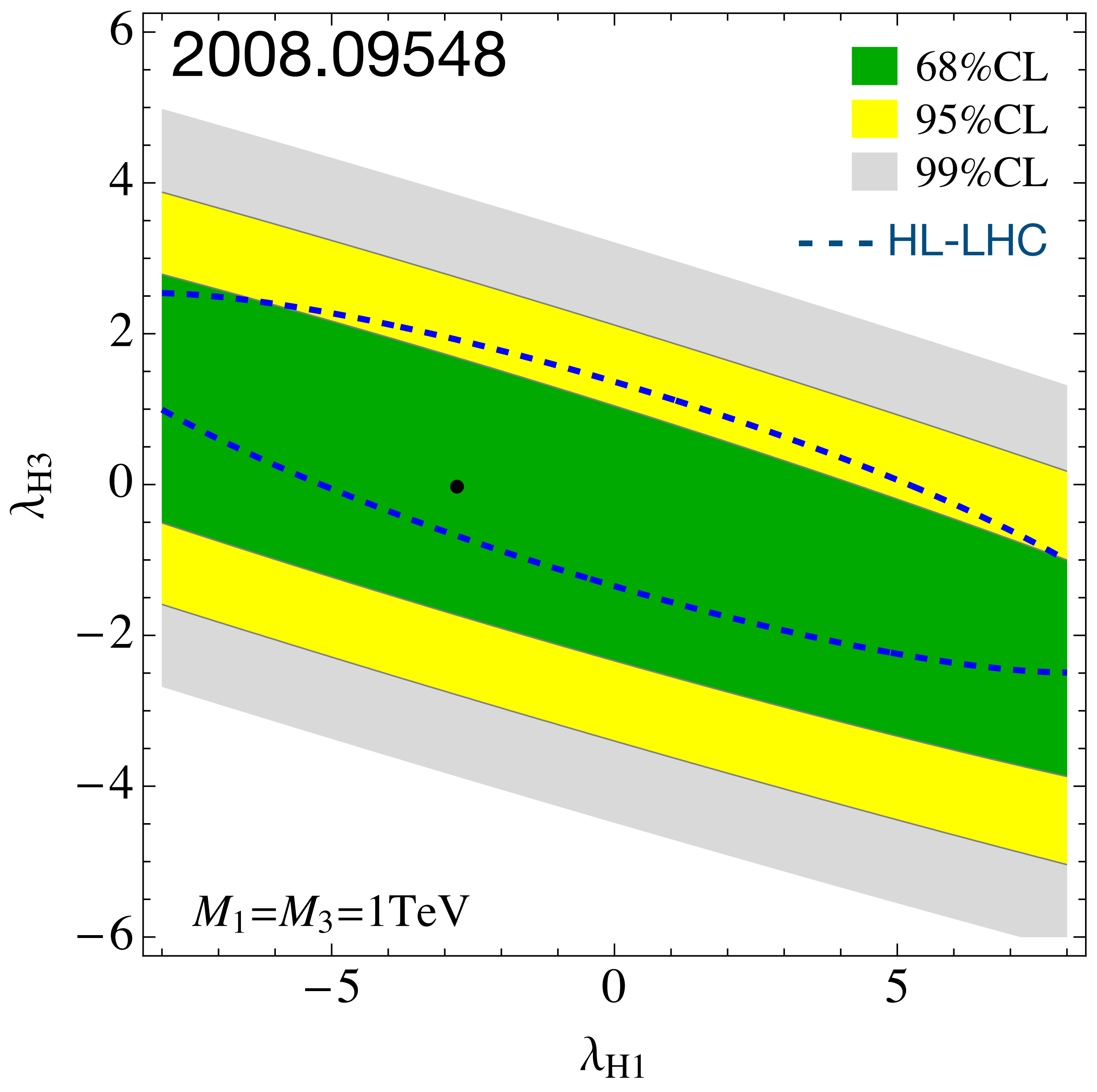
$$\kappa_g - 1 = -(3.51\lambda_{H3} + 1.17\lambda_{H1})\times10^{-2}/m^2 ,$$
$$\kappa_\gamma - 1 = -(2.32\lambda_{H3} + 0.66\lambda_{\epsilon H3} - 0.11\lambda_{H1})\times10^{-2}/m^2 ,$$
$$\kappa_{Z\gamma} - 1 = -(1.89\lambda_{H3} + 0.23\lambda_{\epsilon H3} - 0.033\lambda_{H1})\times10^{-2}/m^2 .$$

$$M_1 = M_3 = m \text{ TeV}.$$

Mainly from $\hat{T}$:



Mainly from Higgs:



Conclusions

Flavor can impact EW/Higgs/top physics in two main ways:

1) Indirect constraints on flavor-less operators in the UV from FCNC via RGE and CKM.

   - In some cases these constraints can be of the same order (or stronger) than direct ones.

2) Flavorful New Physics (e.g. as hinted to by the various *flavor anomalies*) can manifest itself in EW/Higgs observables. This connection can have different degree of "model independence":

   - it might arise already at the EFT level via RGE (e.g. Z couplings from $R(D^{(*)})$),

   - it could be "hinted to" by the EFT, but require a UV completion for a robust evaluation,

   - finally, the connection might arise only when a UV completion is assumed.

To be able to address these cases it is important to perform EFT fits keeping the complete flavor dependence.