

Constraints on top quark interactions from global analyses

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Based on

- JHEP 12 (2023) 129, 2310.00047
with F. Garosi, D. Marzocca and A. Stanzione
- 2409.00218 with H. Gisbert and L. Vale Silva



Starting point

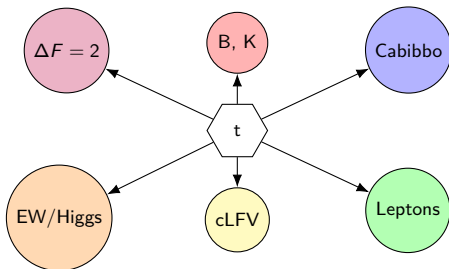
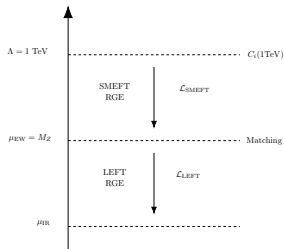
- BSM exists. Hopefully found in the next scale jump...
- Plausible scenario: new physics mainly couples to the top quark
- Assume that mostly top quark operators are induced at the TeV

Semi-leptonic		Four quarks	
$\mathcal{O}_{lq}^{(1),\alpha\beta}$	$(\bar{l}^\alpha \gamma_\mu l^\beta)(\bar{q}^3 \gamma^\mu q^3)$	$\mathcal{O}_{qq}^{(1)}$	$(\bar{q}^3 \gamma^\mu q^3)(\bar{q}^3 \gamma_\mu q^3)$
$\mathcal{O}_{lq}^{(3),\alpha\beta}$	$(\bar{l}^\alpha \gamma_\mu \tau^a l^\beta)(\bar{q}^3 \gamma^\mu \tau^a q^3)$	$\mathcal{O}_{qq}^{(3)}$	$(\bar{q}^3 \gamma^\mu \tau^a q^3)(\bar{q}^3 \gamma_\mu \tau^a q^3)$
$\mathcal{O}_{lu}^{\alpha\beta}$	$(\bar{l}^\alpha \gamma_\mu l^\beta)(\bar{u}^3 \gamma^\mu u^3)$	\mathcal{O}_{uu}	$(\bar{u}^3 \gamma^\mu u^3)(\bar{u}^3 \gamma_\mu u^3)$
$\mathcal{O}_{qe}^{\alpha\beta}$	$(\bar{q}^3 \gamma^\mu q^3)(\bar{e}^\alpha \gamma_\mu e^\beta)$	$\mathcal{O}_{qu}^{(1)}$	$(\bar{q}^3 \gamma^\mu q^3)(\bar{u}^3 \gamma_\mu u^3)$
$\mathcal{O}_{eu}^{\alpha\beta}$	$(\bar{e}^\alpha \gamma^\mu e^\beta)(\bar{u}^3 \gamma_\mu u^3)$	$\mathcal{O}_{qu}^{(8)}$	$(\bar{q}^3 \gamma^\mu T^A q^3)(\bar{u}^3 \gamma_\mu T^A u^3)$
$\mathcal{O}_{lequ}^{(1),\alpha\beta}$	$(\bar{l}^\alpha e^\beta)\epsilon(\bar{q}^3 u^3)$	Higgs-Top	
$\mathcal{O}_{lequ}^{(3),\alpha\beta}$	$(\bar{l}^\alpha \sigma_{\mu\nu} e^\beta)\epsilon(\bar{q}^3 \sigma^{\mu\nu} u^3)$	$\mathcal{O}_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}^3 \gamma^\mu q^3)$
Dipoles		$\mathcal{O}_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^a H)(\bar{q}^3 \gamma^\mu \tau^a q^3)$
\mathcal{O}_{uG}	$(\bar{q}^3 \sigma^{\mu\nu} T^A u^3)\tilde{H}G_{\mu\nu}^A$	\mathcal{O}_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}^3 \gamma^\mu u^3)$
\mathcal{O}_{uW}	$(\bar{q}^3 \sigma^{\mu\nu} u^3)\tau^a \tilde{H}W_{\mu\nu}^a$	\mathcal{O}_{uH}	$(H^\dagger H)(\bar{q}^3 u^3 \tilde{H})$
\mathcal{O}_{uB}	$(\bar{q}^3 \sigma^{\mu\nu} u^3)\tilde{H}B_{\mu\nu}$		

- Otherwise (yet setting $q^i = (u_L^i, V_{ij}d_L^j)$) model independent

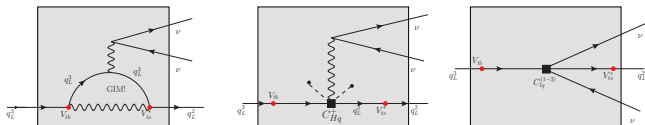
Overview of low-energy sectors

- Quark flavor rotation induce some low-energy processes even at tree level (suppressed by CKM angles)
- Radiative corrections induced by tops are leading in some cases. Use **DsixTools** [Eur.Phys.J.C 81 \(2021\) 2](#)

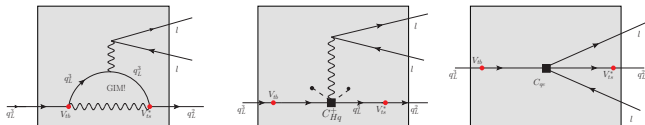


B and K physics. Examples

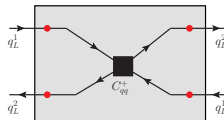
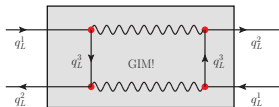
- $R_{K^{(*)}}^\nu, K \rightarrow \pi \nu \bar{\nu}$



- $B \rightarrow K^{(*)} \ell_\alpha \ell_\beta, B_{s,d} \rightarrow \ell_\alpha \ell_\beta, K \rightarrow \pi \ell_\alpha \ell_\beta, K \rightarrow \ell_\alpha \ell_\beta, R_{K^{(*)}}$



$\Delta F = 2$. Examples

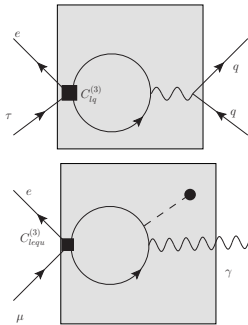
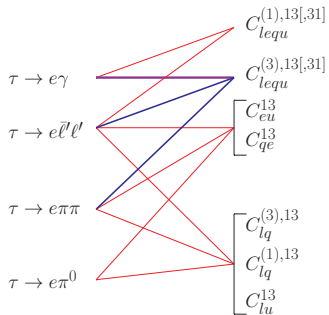


Observable	Experimental value	SM prediction
ϵ_K	$(2.228 \pm 0.011) \times 10^{-3}$	$(2.14 \pm 0.12) \times 10^{-3}$
ΔM_s	$(17.765 \pm 0.006) \text{ ps}^{-1}$	$(17.35 \pm 0.94) \text{ ps}^{-1}$
ΔM_d	$(0.5065 \pm 0.0019) \text{ ps}^{-1}$	$(0.502 \pm 0.031) \text{ ps}^{-1}$

Use [JHEP 12 \(2020\) 187](#)

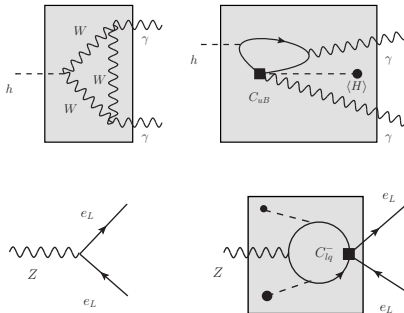
Charged Lepton Flavor-Violating decay modes

- $\mu \rightarrow e$. A few modes, extremely stringent
- $\tau \rightarrow \ell$. Many modes. Not so precise
- Top-philic + LFV? $\rightarrow \bar{\ell}\ell'\bar{t}t$



EW/Higgs

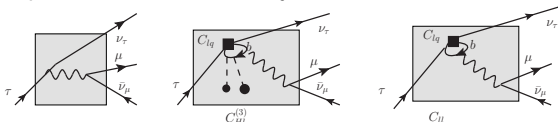
Include EWPOs, such as Z pole observable and $H \rightarrow \gamma\gamma$



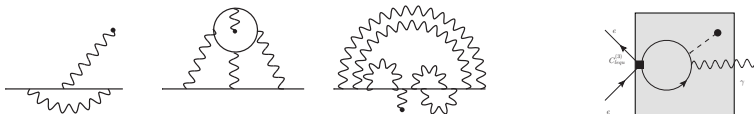
Global likelihood from (updated) [JHEP 04 \(2020\) 066](#)

Leptons

- Lepton Flavor Universality



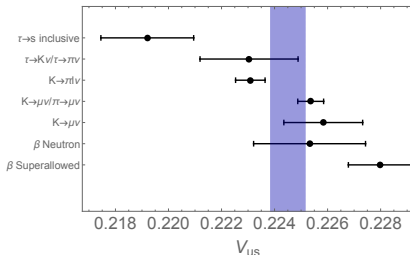
- Magnetic moments



Observable	Experimental value HFLAV	
	$\ell = e$	$\ell = \mu$
$g_\tau / g_\ell - 1$	$(2.7 \pm 1.4) \times 10^{-3}$	$(0.9 \pm 1.4) \times 10^{-3}$
Δa_ℓ	$(2.8 \pm 7.4) \times 10^{-13}$	$(20.0 \pm 8.4) \times 10^{-10}$

Cabibbo angle

- $\pi \rightarrow l\nu$, $K \rightarrow l\nu$, $K \rightarrow \pi l\nu$, $\tau \rightarrow \nu H$, $\mathcal{N} \rightarrow \mathcal{N}' e\nu$, $n \rightarrow pe\nu$
- Related by unitarity $|V_{ud}|^2 + |V_{us}|^2 = 1$ v_{ub} has a negligible effect.



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- Most interesting effect in our set-up: modify apparent V_{ud}^β (paradoxically changing muon vertex)

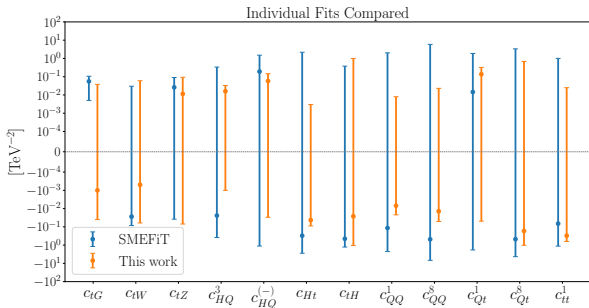
One parameter fits

- Useful to compare experimental reach, scale tested
- If Wilson is induced in a model, where to look at first?

Wilson	Global fit [TeV^{-2}]	Dominant
$C_{qq}^{(+)}$	$(-1.9 \pm 2.3) \times 10^{-3}$	ΔM_s
$C_{qq}^{(-)}$	$(-2.0 \pm 1.0) \times 10^{-1}$	$B_s \rightarrow \mu\mu$
$C_{qu}^{(1)}$	$(1.3 \pm 1.0) \times 10^{-1}$	ΔM_s
$C_{qu}^{(8)}$	$(-1.7 \pm 4.4) \times 10^{-1}$	ΔM_s
C_{uu}	$(-3.0 \pm 1.7) \times 10^{-1}$	$\delta g_{L,11}^{Ze}$
$C_{Hq}^{(+)}$	$(18.7 \pm 8.8) \times 10^{-3}$	$B_s \rightarrow \mu\mu$
$C_{Hq}^{(-)}$	$(5.8 \pm 4.5) \times 10^{-2}$	$\delta g_{L,11}^{Ze}$
C_{Hu}	$(-4.3 \pm 2.3) \times 10^{-2}$	$\delta g_{L,11}^{Ze}$
C_{uB}	$(-0.6 \pm 2.0) \times 10^{-2}$	$c_{\gamma\gamma}$
C_{uG}	$(-0.1 \pm 2.0) \times 10^{-2}$	c_{gg}
C_{uH}	$(-0.3 \pm 5.2) \times 10^{-1}$	$C_{uH,33}$
C_{uW}	$(-0.1 \pm 3.1) \times 10^{-2}$	$c_{\gamma\gamma}$

One parameter fits: comparison with direct bounds

- Use SMEFiT [JHEP 11 \(2021\) 089](#)



- Indirect bounds typically stronger or at least complementary

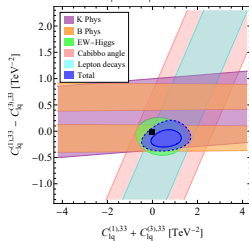
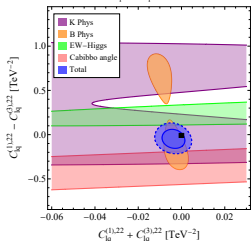
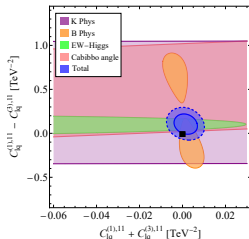
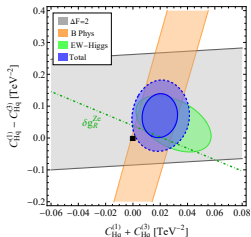
One parameter fits

Wilson	Global fit [TeV^{-2}]	Dominant
$C_{lq}^{(+),11}$	$(2.4 \pm 3.5) \times 10^{-3}$	R_K
$C_{lq}^{(+),22}$	$(-4.0 \pm 3.4) \times 10^{-3}$	R_K
$C_{lq}^{(+),33}$	$(7.2 \pm 4.4) \times 10^{-1}$	g_τ / g_i
$C_{lq}^{(-),11}$	$(10.9 \pm 7.6) \times 10^{-2}$	$R_{K(*)}^\nu$
$C_{lq}^{(-),22}$	$(-6.0 \pm 7.0) \times 10^{-2}$	$R_{K(*)}^\nu$
$C_{lq}^{(-),33}$	$(-1.8 \pm 1.0) \times 10^{-1}$	$R_{K(*)}^\nu$
C_{lu}^{11}	$(-1.7 \pm 7.0) \times 10^{-2}$	$\delta g_{L,11}^{Ze}$
C_{lu}^{22}	$(-4.3 \pm 1.8) \times 10^{-1}$	$\delta g_{L,22}^{Ze}, R_K$
C_{lu}^{33}	$(0.5 \pm 2.4) \times 10^{-1}$	$\Delta g_{L,33}^{Ze}$
C_{qe}^{11}	$(-0.7 \pm 3.9) \times 10^{-2}$	R_{K^*}
C_{qe}^{22}	$(12.1 \pm 9.2) \times 10^{-3}$	$B_s \rightarrow \mu\mu$
C_{qe}^{33}	$(2.2 \pm 2.4) \times 10^{-1}$	$\delta g_{R,33}^{Ze}$

Wilson	Global fit [TeV^{-2}]	Dominant
C_{eu}^{11}	$(5.0 \pm 8.1) \times 10^{-2}$	$\Delta g_{R,11}^{Ze}$
C_{eu}^{22}	$(4.8 \pm 2.1) \times 10^{-1}$	$\Delta g_{R,22}^{Ze}$
C_{eu}^{33}	$(-2.3 \pm 2.5) \times 10^{-1}$	$\Delta g_{R,33}^{Ze}$
$C_{lequ}^{(1),11}$	$(0.4 \pm 1.0) \times 10^{-2}$	$(g-2)_e$
$C_{lequ}^{(1),22}$	$(1.8 \pm 1.6) \times 10^{-2}$	C_{eH22}
$C_{lequ}^{(1),33}$	$(8.0 \pm 9.1) \times 10^{-2}$	C_{eH33}
$C_{lequ}^{(3),11}$	$(-0.6 \pm 1.5) \times 10^{-5}$	$(g-2)_e$
$C_{lequ}^{(3),22}$	$(-19.3 \pm 8.1) \times 10^{-5}$	$(g-2)_\mu$
$C_{lequ}^{(3),33}$	$(-7.0 \pm 7.8) \times 10^{-1}$	C_{eH33}

Two parameter fits

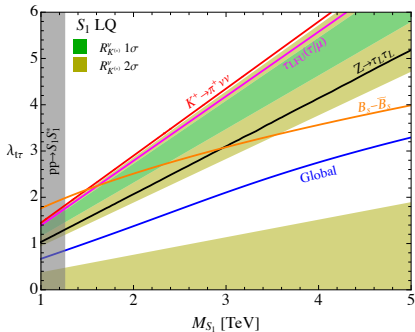
Some insight on the interplay between coefficients/sectors



Applications to UV model I: tau-philic S_1

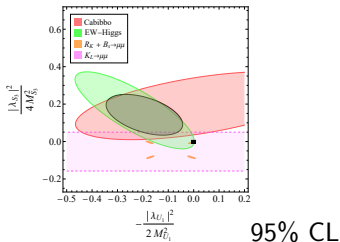
- $S_1 \sim (\bar{\mathbf{3}}, \mathbf{1})_{+1/3}$
- $\mathcal{L} \supset \lambda_{t\tau} \bar{q}_3^c i \sigma_2 l_3 S_1 + \text{h.c.}$,

- $C_{lq}^{(1),33} = -C_{lq}^{(3),33} = \frac{|\lambda_{t\tau}|^2}{4M_{S_1}^2}$, $C_{qq}^{(1)} = C_{qq}^{(3)} = -\frac{|\lambda_{t\tau}|^4}{256\pi^2 M_{S_1}^2}$



Applications to UV models II: Cabibbo anomalies

- Assume Cabibbo tensions were new physics hints. Can they (at least partially) be accommodated in top-philic set-up?
- $[C_{lq}^{(3),22}]^{\text{Cabibbo}} = (0.19 \pm 0.06) \text{ TeV}^{-2}$. Dominated by Δ_{CKM}
- Accommodate EW fit (cure G_μ vs G_F and beware of δg_L^{Ze})
 $[C_{lq}^{(3),11}] = [C_{lq}^{(1),11}] (\sim U_1)$, $C_{lq}^{(1),22} \approx 3C_{lq}^{(3),22} (\sim S_3)$



- Killed B/K physics unless top-philic condition in down-quark basis

Baryon Number Violation in top operators?

- Direct searches can test potential BNV in the top-quark sector

PHYSICAL REVIEW LETTERS **132**, 241802 (2024)

Search for Baryon Number Violation in Top Quark Production and Decay Using Proton-Proton Collisions at $\sqrt{s}=13$ TeV

A. Hayrapetyan *et al.*^{*}
(CMS Collaboration)


 (Received 28 February 2024; accepted 8 May 2024; published 13 June 2024)

TABLE II. Expected and observed 95% CL upper limits on the BNV effective couplings and top quark BNV branching fractions.

Vertex	C_x	C_x/Λ^2	C_x/Λ^2	B_x [10 ⁻⁶]	B_x [10 ⁻⁶]
		[TeV ⁻²] Exp.	[TeV ⁻²] Obs.	Exp.	Obs.
<i>teud</i>	<i>s</i>	0.055	0.048	0.015	0.011
	<i>t</i>	0.031	0.027	0.005	0.003
<i>tμud</i>	<i>s</i>	0.046	0.036	0.010	0.006
	<i>t</i>	0.025	0.020	0.003	0.002

- Impressive precision, significantly improving previous results
- Interesting test of SM symmetry
- Could we expect a nonzero result in a general BSM scenario?

Baryon Number Violation in top operators?

- Very stringent bounds on BNV from nucleon decay searches (SK)

Channel	Limit [10^{30} years]
$p \rightarrow \pi^0 e^+$	2.4×10^4
$p \rightarrow \pi^0 \mu^+$	1.6×10^4
$p \rightarrow \pi^+ \bar{\nu}$	3.9×10^2
$p \rightarrow K^0 e^+$	1.0×10^3
$p \rightarrow K^0 \mu^+$	4.5×10^3
$p \rightarrow K^+ \bar{\nu}$	5.9×10^3
$n \rightarrow \pi^- e^+$	5.3×10^3
$n \rightarrow \pi^- \mu^+$	3.5×10^3
$n \rightarrow \pi^0 \bar{\nu}$	1.1×10^3
$n \rightarrow K^0 \bar{\nu}$	1.3×10^2

- Described by the LEFT, where there are no top-quarks
- However top-quark operators at a high scale, say 1 TeV, as any other high-energy effects, do leave an imprint at low energies

Baryon Number Violation in top operators?

- Gauge invariance connects processes with and without tops, e.g.
 $\varepsilon_{\alpha\beta\gamma} d_R^\alpha C u_R^\beta (t_L^\gamma C e_L - b_L^\gamma C \nu_L)$

- Operator basis

$$Q_{prst}^{duq\ell} = \varepsilon_{\alpha\beta\gamma} \varepsilon_{ij} (d_p^\alpha C u_r^\beta) (q_s^{i\gamma} C \ell_t^j) ,$$

$$Q_{prst}^{qqe} = \varepsilon_{\alpha\beta\gamma} \varepsilon_{ij} (q_p^{i\alpha} C q_r^{j\beta}) (u_s^\gamma C e_t) ,$$

$$Q_{prst}^{qqq\ell} = \varepsilon_{\alpha\beta\gamma} \varepsilon_{il} \varepsilon_{jk} (q_p^{i\alpha} C q_r^{j\beta}) (q_s^{k\gamma} C \ell_t^l) ,$$

$$Q_{prst}^{duue} = \varepsilon_{\alpha\beta\gamma} (d_p^\alpha C u_r^\beta) (u_s^\gamma C e_t) .$$

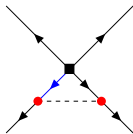
- Nucleon decays mediated by light-quark operators in mass basis, misaligned wrt flavor basis $u_L = U_L^u u'_L$, $d_L = U_L^d d'_L$.

$$Q_{113\ell}^{duq\ell} \supset \varepsilon_{\alpha\beta\gamma} U_{R,11}^u U_{R,11}^d (d_R'^{1\alpha} C u_R'^{1\beta}) \\ \cdot (U_{L,31}^u u_L'^{1\gamma} C e_{L,\ell} - U_{L,31}^d d_L'^{1\gamma} C \nu_{L,\ell})$$

- Cannot simultaneously take $u_L = u'_L$ and $d_L = d'_L$

Baryon Number Violation in top operators?

- One may still take $t_R = t'_R$, e.g. take Y_u diagonal, and try to only generate $\mathcal{O}(t_R)$. **Unstable** under universal/IR radiative corrections
- $Y_u^{\text{diag}}(\Lambda_{UV}) \rightarrow Y_u^{\text{not diag}}(\Lambda_{EW})$. Take $Y_u^{\text{diag}}(\Lambda_{EW})$
- Still **pure SM interactions systematically convert tops into light quarks**, with not enough suppression
- If a top quark operator is generated at a UV scale, light-quark operators are generated at the EW one via SMEFT β functions.

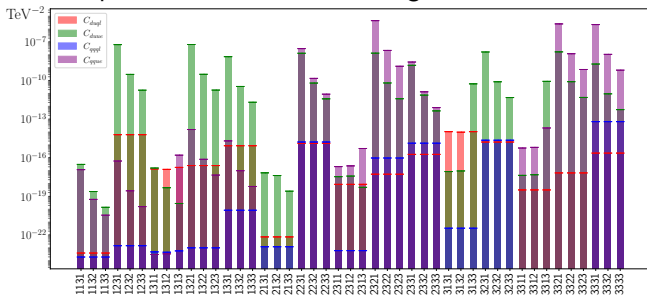


- For example

$$C_{131\ell}^{qqql}(\Lambda_{EW}) \propto C_{131\ell}^{duql}(\Lambda_{UV}) \epsilon_\pi \ln \frac{\Lambda_{UV}^2}{\Lambda_{EW}^2} + \dots$$

Baryon Number Violation in top operators?

- A more quantitative assessment using state-of-art SMEFT-LEFT



- Very stringent bounds. Hierarchy of bars well understood
- Level of fine-tuning hard to conceive/impossible to compute

$$\underbrace{d\Gamma_{p \rightarrow \dots}}_{\text{stick figure}} \sim |a C_{\text{light}}(\Lambda_{\text{UV}}) + b \ln \frac{\Lambda_{\text{UV}}}{\Lambda_{\text{eff}}} \underbrace{C_{\text{top}}(\Lambda_{\text{UV}})}_{\text{galaxy}}|^2$$

- Not a theorem. New ideas (e.g. kinematic suppression?) welcome

Baryon Number Violation in top operators?

Check parametric suppression of dominant effect keeping instead only up to leading log, $L = \epsilon_\pi \ln \frac{\Lambda_{UV}^2}{\Lambda_{EW}^2}$

$c_{duq\ell}$			c_{qqe}		
113 ℓ	V_{32}	$p \rightarrow K^+ \bar{\nu}$	1311	V_{31}	$p \rightarrow \pi^0 e^+$
213 ℓ	V_{31}	$p \rightarrow K^+ \bar{\nu}$	1312	V_{31}	$p \rightarrow \pi^0 \mu^+$
$i a 3 \ell$	$(Y_d)_{1i} (Y_u)_{aa} V_{a1} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$	$i 313$	$(Y_e)_{33} (Y_d)_{32} V_{i1} L$	$p \rightarrow K^+ \bar{\nu}$
$i 32 \ell$	$(Y_d)_{1i} (Y_u)_{33} V_{31} V_{22} L$	$p \rightarrow K^+ \bar{\nu}$	$a 311$	$(Y_d)_{13} (Y_d)_{33} V_{a1} L$	$p \rightarrow \pi^0 e^+$
131 ℓ	$(Y_d)_{11} (Y_u)_{33} V_{11} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$	$a 312$	$(Y_d)_{13} (Y_d)_{33} V_{a1} L$	$p \rightarrow \pi^0 \mu^+$
$a 31 \ell$	$(Y_d)_{2a} (Y_u)_{33} V_{22} V_{31} L$	$p \rightarrow K^+ \bar{\nu}$	132 ℓ	$(Y_e)_{\ell\ell} (Y_u)_{22} V_{22} V_{31} L$	$p \rightarrow K^+ \bar{\nu}$
313 ℓ *	$(Y_d)_{23} (Y_d)_{32} V_{21} L$	$p \rightarrow K^+ \bar{\nu}$	1i3 ℓ	$(Y_e)_{\ell\ell} (Y_u)_{33} V_{i1} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$

$c_{qqq\ell}$			c_{duue}		
113 ℓ	$V_{i1} V_{32}$	$p \rightarrow K^+ \bar{\nu}$	1131	$(Y_d)_{11} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 e^+$
131 ℓ	$V_{11} V_{32}$	$p \rightarrow K^+ \bar{\nu}$	113a	$(Y_e)_{aa} (Y_u)_{33} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$
231 ℓ	$V_{22} V_{31}$	$p \rightarrow K^+ \bar{\nu}$	1311	$(Y_d)_{11} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 e^+$
123 ℓ	$V_{21} V_{32}$	$p \rightarrow K^+ \bar{\nu}$	131a	$(Y_e)_{aa} (Y_u)_{33} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$
132 ℓ	$V_{31} V_{22}$	$p \rightarrow K^+ \bar{\nu}$	2131	$(Y_d)_{12} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 e^+$
133 ℓ	$g^2 V_{31} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$	213a	$(Y_e)_{aa} (Y_u)_{33} V_{31} L$	$p \rightarrow K^+ \bar{\nu}$
$a 33 \ell$	$(Y_d)_{13} (Y_d)_{33} V_{a2} V_{31} L$	$p \rightarrow K^+ \bar{\nu}$	231c	$(Y_d)_{12} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 \ell^+$
223 ℓ	$(Y_d)_{23} (Y_d)_{13} V_{21} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$	2313	$(Y_e)_{33} (Y_u)_{33} V_{31} L$	$p \rightarrow K^+ \bar{\nu}$
323 ℓ	$(Y_d)_{33} (Y_d)_{13} V_{21} V_{32} L$	$p \rightarrow K^+ \bar{\nu}$	313c	$(Y_d)_{13} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 \ell^+$
232 ℓ	$(Y_d)_{33} (Y_d)_{13} V_{21} V_{22} L$	$p \rightarrow K^+ \bar{\nu}$	331c	$(Y_d)_{13} (Y_u)_{33} V_{31} L$	$p \rightarrow \pi^0 \ell^+$

Conclusions

- Phenomenological study of top-philic scenarios
- Strong interplay between different sectors
- Typical (present) situation
 - **Direct** searches of top interactions: a BSM signal **most likely** points out to BSM in **top** operators. **Weaker** bounds
 - **Indirect** searches of top operators: a BSM signal **may be** BSM in **top** operators. **Stronger** bounds.
- Certain direct BSM searches may be better motivated depending on
 - **How much stronger** bounds from indirect searches are?
 - Can there be **symmetries preventing bounds** in low-energy observables (without inducing others)?
- Low-energy physics important to understand how heavy new physics might be. Similar conclusion 5 years ago in the same workshop

Connection between low- and high-energy measurements

Antonio Rodríguez Sánchez (Lund University)

13 September 2019 10:30

Meeting room (ECT* - Villa Tambosi)

LFC19: Strong dynamics for physics within and beyond the Standard Model at LHC and Future Colliders

BACK-UP SLIDES

B and K physics

	Tree level matching	RG and 1-loop matching
$R_{K^{(*)}}^\nu$ $K \rightarrow \pi \nu \bar{\nu}$	$C_{Hq}^{(1,3)}$, $C_{lq}^{(1,3),\alpha\beta}$	C_{Hu} , $C_{qq}^{(1,3)}$, $C_{lu}^{\alpha\beta}$, $C_{qe}^{\alpha\beta}$ $C_{qu}^{(1,8)}$, C_{uu} , C_{uW}
$B \rightarrow K^{(*)} l_\alpha l_\beta$ $B_{s,d} \rightarrow l_\alpha l_\beta$ $K \rightarrow \pi l_\alpha l_\beta$ $K \rightarrow l_\alpha l_\beta$	$C_{Hq}^{(1,3)}$, $C_{lq}^{(1,3),\alpha\beta}$, $C_{qe}^{\alpha\beta}$	$C_{qq}^{(1,3)}$, $C_{lu}^{\alpha\beta}$, $C_{eu}^{\alpha\beta}$
$R_{K^{(*)}}$	$C_{lq}^{(1,3),\ell\ell}$, $C_{qe}^{\ell\ell}$	$C_{lu}^{\ell\ell}$
$B \rightarrow X_s \gamma$		$C_{Hq}^{(1,3)}$, C_{uB} , C_{uW} , C_{uG}

B and K physics

Observable	Experimental value
$B \rightarrow X_S \gamma$	$(3.49 \pm 0.19) \times 10^{-4}$ PDG

R_{K}^{ν}	2.93 ± 0.90 Belle-II
$R_{K^*}^{\nu}$	< 3.21 Belle-II

$R_K[1.1, 6]$	0.949 ± 0.047 LHCb
$R_{K^*}[1.1, 6]$	1.027 ± 0.077 LHCb
$\mathcal{B}(B \rightarrow Ke\mu)$	$< 4.5 \times 10^{-8}$ Belle
$\mathcal{B}(B \rightarrow Ke\tau)$	$< 3.6 \times 10^{-5}$ BaBar
$\mathcal{B}(B \rightarrow K\mu\tau)$	$< 4.5 \times 10^{-5}$ LHCb

Observable	Experimental value
$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu})$	$(1.14^{+0.4}_{-0.33}) \times 10^{-10}$ NA62
$\mathcal{B}(K_L \rightarrow \pi^0 \nu \bar{\nu})$	$< 3.6 \times 10^{-9}$ KOTO

$\mathcal{B}(K_S \rightarrow \mu^+ \mu^-)$	$< 2.5 \times 10^{-10}$ LHCb
$\mathcal{B}(K_L \rightarrow \mu^+ \mu^-)_{SD}$	$< 2.5 \times 10^{-9}$ Isidori:2003
$\mathcal{B}(K_L \rightarrow \mu^{\pm} e^{\mp})$	$< 5.6 \times 10^{-12}$ BNL

$\mathcal{B}(K_L \rightarrow \pi^0 \mu^+ \mu^-)$	$< 4.5 \times 10^{-10}$ KTeV
$\mathcal{B}(K_L \rightarrow \pi^0 e^+ e^-)$	$< 3.3 \times 10^{-10}$ KTeV
$\mathcal{B}(K_L \rightarrow \pi^0 e^+ \mu^-)$	$< 9.1 \times 10^{-11}$ KTeV
$\mathcal{B}(K^+ \rightarrow \pi^+ e^+ \mu^-)$	$< 7.9 \times 10^{-11}$ NA62

Observable	Experimental value
$\mathcal{B}(B_S \rightarrow ee)$	$< 11.2 \times 10^{-9}$ LHCb
$\mathcal{B}(B_S \rightarrow \mu\mu)$	$(3.01 \pm 0.35) \times 10^{-9}$ LHCb
$\mathcal{B}(B_S \rightarrow \tau\tau)$	$< 6.8 \times 10^{-3}$ LHCb
$\mathcal{B}(B_S \rightarrow e\mu)$	$< 6.3 \times 10^{-9}$ LHCb
$\mathcal{B}(B_S \rightarrow \mu\tau)$	$< 4.2 \times 10^{-5}$ LHCb
$\mathcal{B}(B_d \rightarrow ee)$	$< 3.0 \times 10^{-9}$ LHCb
$\mathcal{B}(B_d \rightarrow \mu\mu)$	$< 2.6 \times 10^{-10}$ LHCb
$\mathcal{B}(B_d \rightarrow \tau\tau)$	$< 2.1 \times 10^{-3}$ LHCb
$\mathcal{B}(B_d \rightarrow e\mu)$	$< 1.3 \times 10^{-9}$ LHCb
$\mathcal{B}(B_d \rightarrow \mu\tau)$	$< 1.4 \times 10^{-5}$ LHCb

EW/Higgs

$$\begin{aligned}\delta g_L^{Z\ell} &\leftarrow C_{uB}, C_{uW}, C_{Hu}, C_{Hq}^{(1,3)}, C_{lq}^{(1,3),\ell\ell}, C_{lu}^{\ell\ell}, \dots \\ \delta g_L^{W\ell} &\leftarrow C_{uB}, C_{uW}, C_{Hu}, C_{Hq}^{(1,3)}, C_{lq}^{(3),\ell\ell}, \dots \\ \delta g_R^{Z\ell} &\leftarrow C_{uB}, C_{uW}, C_{Hu}, C_{Hq}^{(1,3)}, C_{eu}^{\ell\ell}, C_{qe}^{\ell\ell}, \dots \\ \delta g_L^{Zb} &\leftarrow C_{Hq}^{(1,3)}, C_{Hu}, C_{qq}^{(1,3)}, \dots \\ \delta g_R^{Zb} &\leftarrow C_{Hq}^{(1)}, C_{Hu}, C_{qq}^{(1,3)}, C_{uB}, C_{uW}, \dots \\ c_{\gamma\gamma} &\leftarrow C_{uB}, C_{uW}, C_{uG} \\ c_{gg} &\leftarrow C_{uG} \\ [C_{eH}]_{\alpha\alpha} &\leftarrow C_{lequ}^{(1),\alpha\alpha} \\ [C_{uH}]_{33} &\leftarrow C_{uH}, C_{uG}, C_{Hq}^{(1,3)}, C_{qu}^{(1,8)}, \dots\end{aligned}$$

$$\delta g_L^{W\ell} = C_{HI}^{(3)} + f(1/2, 0) - f(-1/2, -1),$$

$$\delta g_L^{Z\ell} = -\frac{1}{2}C_{HI}^{(3)} - \frac{1}{2}C_{HI}^{(1)} + f(-1/2, -1),$$

$$\delta g_R^{Z\ell} = -\frac{1}{2}C_{He}^{(1)} + f(0, -1),$$

$$\delta g_L^{Zu} = \frac{1}{2}C_{Hq}^{(3)} - \frac{1}{2}C_{Hq}^{(1)} + f(1/2, 2/3),$$

$$\delta g_L^{Zd} = -\frac{1}{2}C_{Hq}^{(3)} - \frac{1}{2}C_{Hq}^{(1)} + f(-1/2, -1/3),$$

$$\delta g_R^{Zu} = -\frac{1}{2}C_{Hu} + f(0, 2/3),$$

$$\delta g_R^{Zd} = -\frac{1}{2}C_{Hd} + f(0, -1/3),$$

$$\delta c_z = C_{H\Box} - \frac{1}{4}C_{HD} - \frac{3}{2}\Delta_{GF}, \quad c_{z\Box} = \frac{1}{2g_L^2} (C_{HD} + 2\Delta_{GF}),$$

$$c_{gg} = \frac{4}{g_5^2} C_{HG},$$

$$c_{\gamma\gamma} = 4 \left(\frac{1}{g_L^2} C_{HW} + \frac{1}{g_Y^2} C_{HB} - \frac{1}{g_L g_Y} C_{HWB} \right), \quad c_{zz} = 4 \left(\frac{g_L^2 C_{HW} + g_Y^2 C_{HB} + g_L g_Y C_{HWB}}{(g_L^2 + g_Y^2)^2} \right),$$

$$c_{z\gamma} = 4 \left(\frac{C_{HW} - C_{HB} - \frac{g_L^2 - g_Y^2}{2g_L g_Y} C_{HWB}}{g_L^2 + g_Y^2} \right),$$

where

$$f(T^3, Q) \equiv \left\{ -Q \frac{g_L g_Y}{g_L^2 - g_Y^2} C_{HWB} - \mathbf{1} \left(\frac{1}{4} C_{HD} + \frac{1}{2} \Delta_{GF} \right) \left(T^3 + Q \frac{g_Y^2}{g_L^2 - g_Y^2} \right) \right\} \mathbf{1}, \quad (1)$$

$$\text{and } \Delta_{GF} = [C_{HI}^{(3)}]_{11} + [C_{HI}^{(3)}]_{22} - \frac{1}{2}[C_{II}]_{1221}.$$

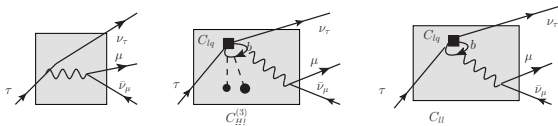
Charged Lepton Flavor-Violating decay modes

- Use [JHEP 05 \(2017\) 117](#) and [JHEP 03 \(2021\) 256](#) and use DsixTools to run to 1 TeV

Observable	Experimental limit
$\mathcal{B}(\mu \rightarrow e\gamma)$	5.0×10^{-13} MEG
$\mathcal{B}(\mu \rightarrow 3e)$	1.2×10^{-12} SINDRUM
$\mathcal{B}(\mu \text{ Au} \rightarrow e \text{ Au})$	8.3×10^{-13} SINDRUM
$\mathcal{B}(\tau \rightarrow e\gamma)$	3.9×10^{-8} BaBar
$\mathcal{B}(\tau \rightarrow 3e)$	3.2×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow e \bar{\mu} \mu)$	3.2×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow e\pi^0)$	9.5×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow e\eta)$	1.1×10^{-7} Belle
$\mathcal{B}(\tau \rightarrow e\eta')$	1.9×10^{-7} Belle

Observable	Experimental limit
$\mathcal{B}(\tau \rightarrow e\pi^+\pi^-)$	2.7×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow eK^+K^-)$	4.1×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow \mu\gamma)$	5.0×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow 3\mu)$	2.5×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow \mu \bar{e} e)$	2.1×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow \mu\pi^0)$	1.3×10^{-7} Belle
$\mathcal{B}(\tau \rightarrow \mu\eta)$	7.7×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow \mu\eta')$	1.5×10^{-7} Belle
$\mathcal{B}(\tau \rightarrow \mu\pi^+\pi^-)$	2.5×10^{-8} Belle
$\mathcal{B}(\tau \rightarrow \mu K^+K^-)$	5.2×10^{-8} Belle

Leptons



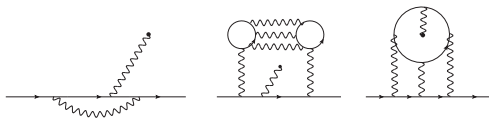
Tests of LFU comparing with $\mu \rightarrow e$

$$\frac{g_\tau}{g_e} - 1 = 0.0038 (C_{lq}^{(3),33} - C_{lq}^{(3),11})$$

$$\frac{g_\tau}{g_\mu} - 1 = 0.0038 (C_{lq}^{(3),33} - C_{lq}^{(3),22})$$

Observable	Experimental value HFLAV	
	$l = e$	$l = \mu$
$g_\tau/g_l - 1$	$(2.7 \pm 1.4) \times 10^{-3}$	$(0.9 \pm 1.4) \times 10^{-3}$

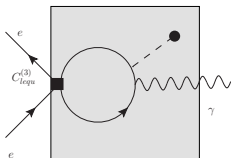
Leptons: magnetic moments



$$\alpha^{-1}(a_e) = 137.035999166(15) \quad \text{PhysRevLett.130.071801}$$

$$\alpha^{-1}(Cs) = 137.035999046(27) \quad \text{Science 360, 191}$$

$$\alpha^{-1}(Rb) = 137.035999206(11) \quad \text{Nature 588}$$



Rydberg frequency [codata](#)

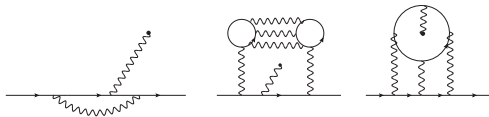
$$\frac{\alpha^2 m_e c^2}{2h} = 3.2898419602508(64) \text{ Hz}$$

$$h/m_e?$$

$$(m_e/m_C) (m_C/m_{Cs}) \frac{m_{Cs}}{h}$$

Use JHEP 07 (2021) 107

Leptons: magnetic moments



Similar for the muon

$$\Delta a_e = -4.8 \times 10^{-8} C_{lequ}^{(3),11} + 7.1 \times 10^{-11} C_{lequ}^{(1),11},$$

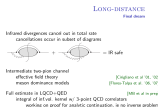
$$\Delta a_\mu = -1.0 \times 10^{-5} C_{lequ}^{(3),22} + 1.5 \times 10^{-8} C_{lequ}^{(1),22}.$$

Considering SM tensions...

Observable	Experimental value	
	$\ell = e$	$\ell = \mu$
Δa_ℓ	$(2.8 \pm 7.4) \times 10^{-13}$	$(20.0 \pm 8.4) \times 10^{-10}$

Cabibbo angle

- $\pi \rightarrow \ell\nu$ $K \rightarrow \ell\nu$ $\tau \rightarrow K\nu, \pi\nu$
 - No phase space. Goldstone parity: $(\epsilon_{L-R}, \epsilon_P)$
 - $f_{\pi, K}$ from the lattice. Ratios better known (dependence on lattice scale)
 - Other uncertainties: radiative corrections, experimental
- $K \rightarrow \pi\ell\nu$
 - Probing $\epsilon_{L+R}^S, \epsilon_T^S, \epsilon_S^S$
 - Energy-dependent form factors, but smooth
 - Uncertainties: $f_+(0)$, experiment, Radiative corrections
- $\tau \rightarrow \pi\pi\nu$. Resonance jungle. But same form factor as $e^+e^- \rightarrow$ hadrons [Phys.Rev.Lett. 122 \(2019\) 22, 221801](#) Main uncertainty: radiative corrections. Some progress...[Bruno et al.](#)



Cabibbo angle

- $\tau \rightarrow$ inclusive. Total decay width. OPE prediction for V_{us} independently confirmed by lattice, **ETMC**. Experiments could improve BR precision (potential V_{us} closer to K , enough to test realistic BSM?)
- $n \rightarrow pe\nu$, $\mathcal{N} \rightarrow \mathcal{N}'e\nu$. $p \ll M_n \sim M_p$. Non-relativistic EFT

$$\mathcal{L}^{(0)} = -(\psi_p^\dagger \psi_n) \left[C_V^+ \bar{e}_L \gamma^0 \nu_L + C_S^+ \bar{e}_R \nu_L \right] + (\psi_p^\dagger \sigma^k \psi_n) \left[C_A^+ \bar{e}_L \gamma^k \nu_L + C_T^+ \bar{e}_R \gamma^0 \gamma^k \nu_L \right],$$

$$\begin{aligned} \mathcal{L}^{(1)} = \frac{1}{2m_N} \{ & iC_P^+ (\psi_p^\dagger \sigma^k \psi_n) \nabla_k (\bar{e}_R \nu_L) - C_M^+ \epsilon^{ijk} (\psi_p^\dagger \sigma^j \psi_n) \nabla_i (\bar{e}_L \gamma^k \nu_L) \\ & - iC_E^+ (\psi_p^\dagger \sigma^k \psi_n) \nabla_k (\bar{e}_L \gamma^0 \nu_L) - iC_{E'}^+ (\psi_p^\dagger \sigma^k \psi_n) \partial_t (\bar{e}_L \gamma^k \nu_L) \\ & - iC_{T1}^+ (\psi_p^\dagger \psi_n) \nabla_k (\bar{e}_R \gamma^0 \gamma^k \nu_L) + iC_{T2}^+ (\psi_p^\dagger \psi_n) (\bar{e}_R \overleftrightarrow{\partial}_t \nu_L) + 2iC_{T3}^+ (\psi_p^\dagger \sigma^k \psi_n) (\bar{e}_R \overleftrightarrow{\nabla}_k \nu_L) \\ & - iC_{FV}^+ (\psi_p^\dagger \overleftrightarrow{\nabla}_k \psi_n) (\bar{e}_L \gamma^k \nu_L) + iC_{FA}^+ (\psi_p^\dagger \sigma^k \overleftrightarrow{\nabla}_k \psi_n) (\bar{e}_L \gamma^0 \nu_L) + C_{FT}^+ \epsilon^{ijk} (\psi_p^\dagger \sigma^i \overleftrightarrow{\nabla}_j \psi_n) (\bar{e}_R \gamma^0 \gamma^k \nu_L) \}, \end{aligned}$$

JHEP 02 (2024) 091

What about CPV? See for example [Eur.Phys.J.C 82 \(2022\) 12, 1134](#)

Cabibbo angle

$$\mathcal{L}_{\text{eff}} \approx -\frac{G_{\mu} V_{ud}}{\sqrt{2}} \left[\left(1 + \epsilon_L^{D\ell} \right) \bar{\ell} \gamma_{\mu} (1 - \gamma_5) \nu_{\ell} \cdot \bar{u} \gamma^{\mu} (1 - \gamma_5) D + \epsilon_R^{D\ell} \bar{\ell} \gamma_{\mu} (1 - \gamma_5) \nu_{\ell} \cdot \bar{u} \gamma^{\mu} (1 + \gamma_5) D \right. \\ \left. + \bar{\ell} (1 - \gamma_5) \nu_{\ell} \cdot \bar{u} \left[\epsilon_S^{D\ell} - \epsilon_P^{D\ell} \gamma_5 \right] D + \frac{1}{4} \epsilon_T^{D\ell} \bar{\ell} \sigma_{\mu\nu} (1 - \gamma_5) \nu_{\ell} \cdot \bar{u} \sigma^{\mu\nu} (1 - \gamma_5) D \right] + \text{h.c.}$$

$$\begin{pmatrix} \hat{V}_{us} \equiv V_{us} (1 + \epsilon_L^{su} + \epsilon_R^s) \\ \epsilon_L^{dso} \equiv \epsilon_L^{do} + \frac{\hat{V}_{us}^2}{1 - V_{us}^2} \epsilon_L^{so} \\ \epsilon_R^d \\ \epsilon_S^{do} \\ \epsilon_P^{do} \\ \hat{\epsilon}_L^{dso/a} \\ \epsilon_R^{su/a} \\ \epsilon_R^s \\ \epsilon_P^{so} \\ \epsilon_L^{d\mu/a} - \epsilon_P^{d\mu} \frac{m_{\mu}^2}{m_{\nu} (m_{\nu} + m_{\mu})} \\ \epsilon_S^{s\mu} \\ \epsilon_P^{s\mu} \\ \hat{\epsilon}_T^{s\mu} \\ \epsilon_L^{d\tau/a} \\ \epsilon_P^{d\tau} \\ \hat{\epsilon}_T^{d\tau} \\ \epsilon_L^{s\tau/a} - \epsilon_P^{s\tau} \frac{m_{\tau}^2}{m_{\nu} (m_{\nu} + m_{\tau})} \\ \epsilon_L^{s\tau/a} + 0.08(1) \epsilon_S^{s\tau} - 0.38 \epsilon_P^{s\tau} + 0.40(13) \epsilon_T^{s\tau} \end{pmatrix} = \begin{pmatrix} 0.22306(56) \\ 2.2(8.6) \\ -3.3(8.2) \\ 3.0(9.9) \\ 1.3(3.4) \\ -0.4(1.1) \\ 0.8(2.2) \\ 0.2(5.0) \\ -0.3(2.0) \\ -0.5(1.8) \\ -2.6(4.4) \\ -0.6(4.1) \\ 0.2(2.2) \\ 0.1(1.9) \\ 9.2(8.6) \\ 1.9(4.5) \\ 0.0(1.0) \\ -0.7(5.2) \end{pmatrix} \times 10^{\wedge} \begin{pmatrix} 0 \\ -3 \\ -3 \\ -4 \\ -6 \\ -3 \\ -3 \\ -2 \\ -5 \\ -2 \\ -4 \\ -3 \\ -2 \\ -2 \\ -3 \\ -2 \\ -1 \\ -2 \end{pmatrix}$$

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- Simplified scenario: LFU and forget about contact terms, $\epsilon_{P,T,S} = 0$

- $\theta_{12}^{KI3} < \theta_{12}^{KI2} < \theta_{12}^{\beta}$
- ϵ_R^s needed for first (opposite interference with SM). Possible explanation: VLQ doublet. E.g.

Phys.Rev.D 108 (2023) 3, 035022

$$\epsilon_R^s \sim C_{Hud}^{12} \sim \frac{h_u^* h_s}{M_Q^2}$$

- But beware of $K \rightarrow \pi\pi!$ e.g.2311.00021

One parameter fits

SMEFiT, [JHEP 11 \(2021\) 089](#)

Class	Coefficients	Warsaw basis	95% CL Individual	95% CL Marginalised
Dipoles	c_{tG}	C_{uG}	[0.01,0.11]	[0.01,0.23]
	c_{tW}	C_{uW}	[-0.085,0.030]	[-0.28,0.13]
	c_{tZ}	$-s_\theta C_{uB} + c_\theta C_{uW}$	[-0.038,0.090]	[-0.50,0.14]
Higgs-Top	c_{HQ}^3	$C_{Hq}^{(3)}$	[-0.39,0.34]	[-0.42,0.31]
	$c_{HQ}^{(-)}$	$C_{Hq}^{(1)} - C_{Hq}^{(3)}$	[-1.1,1.5]	[-2.7,2.7]
	c_{Ht}	C_{Hu}	[-2.8,2.2]	[-15,4]
	c_{tH}	C_{uH}	[-1.3,0.4]	[-0.5,2.9]
4 quarks	c_{QQ}^1	$2C_{qq}^{(1)} - \frac{2}{3}C_{qq}^{(3)}$	[-2.3,2.0]	[-3.7,4.4]
	c_{QQ}^8	$8C_{qq}^{(3)}$	[-6.8,5.9]	[-13,10]
	c_{Qt}^1	$C_{qu}^{(1)}$	[-1.8,1.9]	[-1.5,1.4]
	c_{Qt}^8	$C_{qu}^{(8)}$	[-4.3,3.3]	[-3.4,2.5]
	c_{tt}^1	C_{uu}	[-1.1,1.0]	[-0.88,0.81]

One parameter fits

Wilson	$\mu \rightarrow e$		$\tau \rightarrow \mu$		$\tau \rightarrow e$	
	Limit	Dominant	Limit	Dominant	Limit	Dominant
$C_{lequ}^{(3)}$	3.9×10^{-9}	$\mu \rightarrow e\gamma$	5.0×10^{-5}	$\tau \rightarrow \mu\gamma$	4.4×10^{-5}	$\tau \rightarrow e\gamma$
$C_{lequ}^{(1)}$	3.6×10^{-5}	$\mu \rightarrow 3e, e\gamma$	2.7×10^{-2}	$\tau \rightarrow \mu\gamma$	2.4×10^{-2}	$\tau \rightarrow e\gamma$
$C_{lq}^{(3)}$	6.7×10^{-5}	$\mu Au \rightarrow eAu$	7.1×10^{-2}	$\tau \rightarrow \mu\pi\pi$	7.4×10^{-2}	$\tau \rightarrow e\pi\pi$
$C_{lq}^{(1)}$	4.0×10^{-5}	$\mu Au \rightarrow eAu$	1.1×10^{-1}	$\tau \rightarrow \mu\pi\pi$	1.1×10^{-1}	$\tau \rightarrow e\pi\pi$
C_{lu}	4.0×10^{-5}	$\mu Au \rightarrow eAu$	1.0×10^{-1}	$\tau \rightarrow \mu\pi\pi$	1.1×10^{-1}	$\tau \rightarrow e\pi\pi$
C_{eu}	3.6×10^{-5}	$\mu Au \rightarrow eAu$	1.0×10^{-1}	$\tau \rightarrow \mu\pi\pi$	1.1×10^{-1}	$\tau \rightarrow e\pi\pi$
C_{qe}	3.6×10^{-5}	$\mu Au \rightarrow eAu$	1.0×10^{-1}	$\tau \rightarrow \mu\pi\pi$	1.0×10^{-1}	$\tau \rightarrow e\pi\pi$

Gaussian fits

Limited attempt to overcome previous limitations

- Take $\vec{C} = (C_{qq}^{(+)}, C_{qq}^{(-)}, C_{uu}, C_{qu}^{(1)}, C_{qu}^{(8)}, C_{Hq}^{(+)}, C_{Hq}^{(-)}, C_{Hu}, C_{uH}, C_{uG}, C_{uW}, C_{uB})$.

- $\chi^2 = \chi_{\text{best-fit}}^2 + (C_i - \mu_{C_i})(\sigma^2)_{ij}^{-1}(C_j - \mu_{C_j}) = \chi_{\text{best-fit}}^2 + \frac{(K_i - \mu_{K_i})^2}{\sigma_{K_i}^2}$

Coefficient	Gaussian fit [TeV ⁻²]	Coefficient	Gaussian fit [TeV ⁻²]
K_1	0.0019 ± 0.0023	K_7	0.54 ± 0.79
K_2	0.0179 ± 0.0083	K_8	0.74 ± 0.88
K_3	-0.002 ± 0.015	K_9	-0.8 ± 1.3
K_4	-0.016 ± 0.021	K_{10}	-0.7 ± 1.8
K_5	0.044 ± 0.029	K_{11}	12 ± 13
K_6	-0.30 ± 0.38	K_{12}	-11 ± 16

$$U_{uc} = \begin{pmatrix} -1.00 & 0.000 & 0.000 & -0.016 & -0.004 & -0.004 & 0.021 & -0.001 & 0.000 & 0.000 & 0.000 & 0.000 \\ -0.005 & -0.089 & -0.015 & 0.058 & 0.000 & 0.984 & -0.004 & -0.117 & 0.000 & -0.009 & 0.044 & 0.063 \\ 0.004 & 0.011 & -0.039 & 0.018 & -0.001 & -0.1 & 0.145 & -0.28 & 0.015 & -0.494 & 0.447 & 0.667 \\ -0.007 & -0.013 & 0.09 & -0.053 & -0.003 & 0.081 & -0.316 & 0.64 & 0.024 & -0.673 & -0.126 & -0.059 \\ 0.005 & 0.007 & -0.074 & 0.042 & -0.002 & -0.025 & 0.259 & -0.525 & 0.025 & -0.548 & -0.213 & -0.55 \\ -0.004 & -0.041 & 0.025 & 0.067 & 0.006 & -0.004 & -0.128 & 0.084 & 0.006 & 0.022 & 0.853 & -0.492 \\ -0.006 & -0.137 & 0.078 & 0.196 & 0.96 & -0.017 & 0.09 & 0.047 & -0.065 & -0.007 & -0.017 & 0.008 \\ 0.002 & -0.349 & -0.006 & 0.646 & -0.248 & -0.029 & 0.545 & 0.318 & 0.014 & 0.001 & -0.012 & 0.006 \\ 0.005 & 0.007 & 0.028 & -0.138 & 0.077 & 0.017 & 0.145 & 0.06 & 0.973 & 0.037 & 0.017 & -0.003 \\ 0.023 & 0.221 & 0.074 & -0.569 & 0.053 & 0.092 & 0.684 & 0.292 & -0.212 & -0.002 & 0.095 & -0.057 \\ 0.006 & -0.798 & 0.451 & -0.364 & -0.071 & -0.059 & -0.038 & -0.122 & -0.039 & 0.000 & -0.012 & 0.007 \\ -0.004 & 0.404 & 0.876 & 0.235 & -0.058 & 0.025 & 0.017 & -0.093 & 0.013 & 0.000 & -0.01 & 0.006 \end{pmatrix}$$

- Assume $\Lambda_{BSM} \sim 1 \text{ TeV}$. Very loosely, using [Phys.Lett.B 726 \(2013\) 697-702](#)

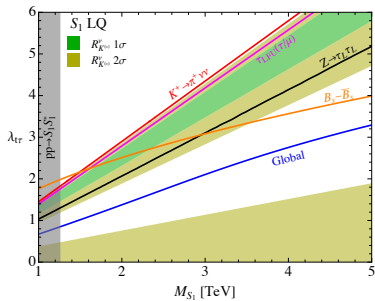
$$V_{\text{EFT}} \sim \frac{\pi^6}{720} \left(\frac{4\pi}{\text{TeV}^2} \right)^3 \left(\frac{4\pi}{\text{TeV}^2} \right)^8 \left(\frac{4\pi}{\text{TeV}^2} \right)^3$$

- Experimental constraints reduce it to a tiny fraction ($\sim 10^{-31}$)

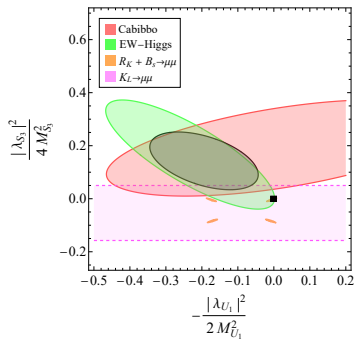
Applications to UV models

- $S_1 \sim (\bar{\mathbf{3}}, \mathbf{1})_{+1/3}$

$$\mathcal{L} \supset \lambda_{t\tau} \bar{q}_3^c i\sigma_2 l_3 S_1 + \text{h.c.},$$



- Top-philic LQ for the Cabibbo tension



- Killed by B/K physics (unless top-philic condition is imposed in down-quark basis)