BSM Flavoured Correlations

based on **2109.07490**

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Motivation

- In the SM both quarks and leptons come with 3 distinct ***flavours*** whose **masses** show a very **hierarchical** structure. The lack of an explanation for such fact is known as the **SM flavour puzzle**. Is there a deeper **underlying theory**? What would its **consequences** imply?
- Different **experiments** and **searches** probe different aspects of flavour physics: how far can we push the synergy between **Higgs physics**, **EDMs** and **flavour observables**?

The Effective Lagrangian

- Assuming NP can be described within the **SMEFT**, there is just one type of **dimension-6 operator** contributing to the modification of the Yukawa interactions:

$$\mathcal{L} \subset -\bar{F}'_L Y'_f \overset{(\sim)}{H} f'_R - \bar{F}'_L C'_f \overset{(\sim)}{H} f'_R \frac{H^\dagger H}{\Lambda_f^2} + \text{h.c.} \xrightarrow[\text{+ Mass Basis}]{\text{EWSB}} \mathcal{L} \subset -\bar{f}_L Y_f f_R \frac{v}{\sqrt{2}} - \bar{f}_L \left(Y_f + \frac{v^2}{\Lambda_f^2} C_f \right) f_R \frac{h}{\sqrt{2}} + \text{h.c.}$$

Notice that in principle the **NP scale**, Λ, can be **different** in the quark and lepton sector!

- Parametrize **deviations**:

Effective Yukawa: $\hat{Y}_f \equiv Y_f + \dfrac{v^2}{\Lambda^2} C_f$

Phenomenological Lagrangian: $\mathcal{L}_{\text{eff.}} = \dfrac{y^{\text{SM}}_{ffh}}{\sqrt{2}} \left(\kappa_f \bar{f} f + \tilde{\kappa} \bar{f} i \gamma_5 f \right) h$ SM: $\kappa_f = 1\,,\ \tilde{\kappa}_f = 0$

Deviation Parameter: $r_f^2 \equiv \dfrac{|\hat{y}_{ffh}|^2}{|y^{\text{SM}}_{ffh}|^2} = \dfrac{v^2 |\hat{y}_{ffh}|^2}{2 m_f^2} = \kappa_f^2 + \tilde{\kappa}_f^2$

Minimal Flavour Violation

The Model

- MFV: the only source of flavour and CP-violation in the SM comes from the Yukawas. For each fermion species a $U(3)$ **symmetry** is associated
- The Yukawas are promoted to **spurion fields** transforming as bi-triplets of the above flavour symmetry

$$C'_f = c'_f Y'_f \longrightarrow$$

- *No flavour-violating terms!*
- *Only one c'_f for each fermion sector!*

Froggatt-Nielsen

The Model

- New $U(1)$ **symmetry** and **SM-*singlet* scalar field** ϕ
- **Fermions** and ϕ **transform** under the new symmetry and the Yukawa terms are made invariant adding powers of ϕ/Λ_F

- Once the ϕ takes **VEV**, each term is **suppressed** by powers of $\epsilon \equiv \langle \phi \rangle / \Lambda_F$

$$Y_f = \text{diag}\left(y_{f_1} \epsilon^{n_{F_1} + n_{f_1}}, y_{f_2} \epsilon^{n_{F_2} + n_{f_2}}, y_{f_3} \epsilon^{n_{F_3} + n_{f_3}} \right) \qquad C_{f,ij} \approx \mathcal{O}(1) \epsilon^{n_{F_i} + n_{f_j}} e^{i\theta_{f,ij}}$$

- The FN **charges** n_f and ϵ are **free parameters** $\to$ fit to masses!

Flavour Symmetry at Work

- **Deviations** in each sector are **related**!

$$\overset{(\sim)}{\kappa}_{f_1} = \overset{(\sim)}{\kappa}_{f_2} = \overset{(\sim)}{\kappa}_{f_3} \quad \Rightarrow \quad r^2_{f_1} = r^2_{f_2} = r^2_{f_3} \qquad \text{and} \qquad r_f^2 = 1 + \frac{v^4}{\Lambda_f^4} |c'_f|^2 + 2 \frac{v^2}{\Lambda_f^2} \text{Re}\, c'_f$$

Attention!
These relations are exact for **MFV** and include $\mathcal{O}(1)$ **coefficients** for **FN**

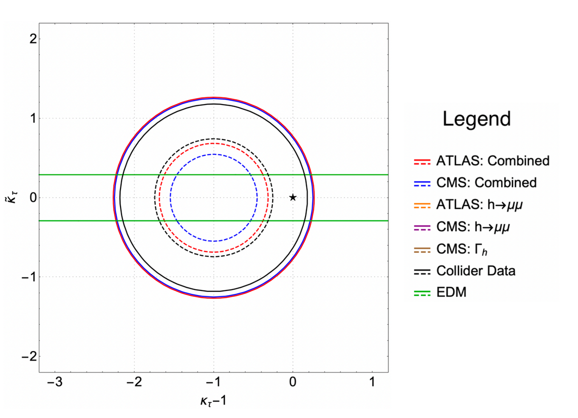
Higgs Physics

- Data from Higgs **production/decay**

- Global χ^2 fit:

Bounds:

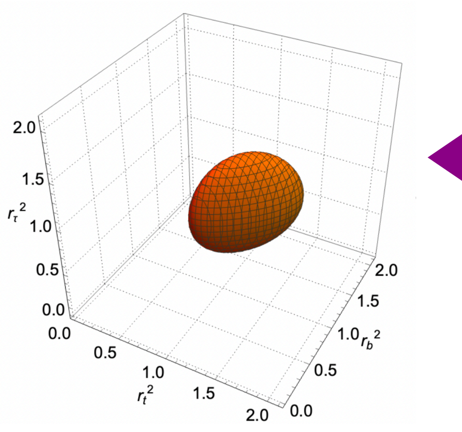
$0.98 \lesssim r_t^2 \lesssim 1.31$
$r_c^2 \lesssim 2.36$
$0.73 \lesssim r_b^2 \lesssim 1.08$
$0.56 \lesssim r_\tau^2 \lesssim 1.40$
$0.36 \lesssim r_\mu^2 \lesssim 1.85$



- NP scale and deviations:

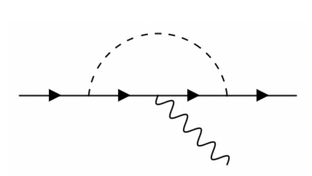
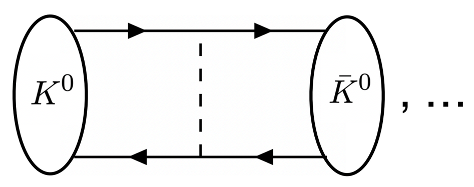
$\sin\theta_{u,33} = 0$	$\Lambda_q \gtrsim 0.8$ TeV
$\sin\theta_{e,11} = 0 = \sin\theta_{e,33}$	$\Lambda_\ell \gtrsim 0.5$ TeV

$0.82 \lesssim r^2_{t,c,u} \lesssim 1.61$
$0.67 \lesssim r^2_{b,s,d} \lesssim 1.52$
$0.49 \lesssim r^2_{\tau,\mu,e} \lesssim 1.51$



Flavour Observables

- Data from **flavour-violating processes**

$\mu^- \to e^- \gamma$  , K-mixing  , ...

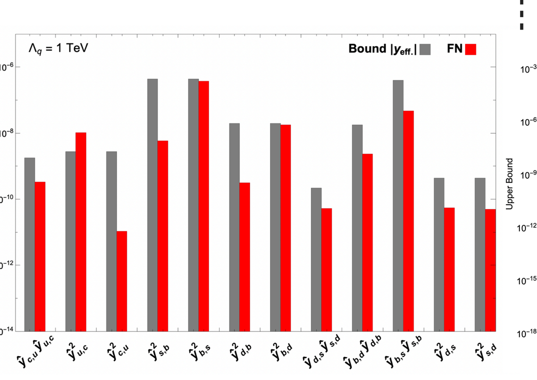
- Without flavour symmetry: $\Lambda_q \approx (60 - 300)$ TeV

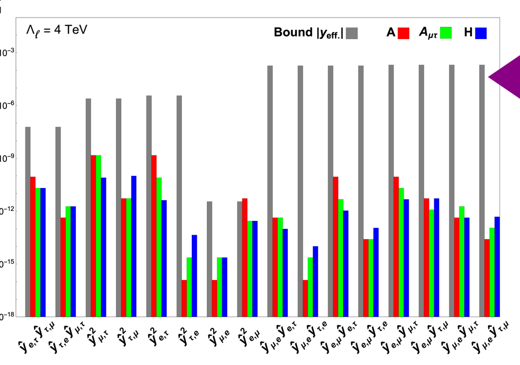
CP-Conserving

$\Lambda_q \gtrsim 1$ TeV
$\Lambda_\ell \gtrsim 4$ TeV

CP-Violating

$\Lambda_q \gtrsim 3$ TeV
$\Lambda_\ell \gtrsim 1$ TeV

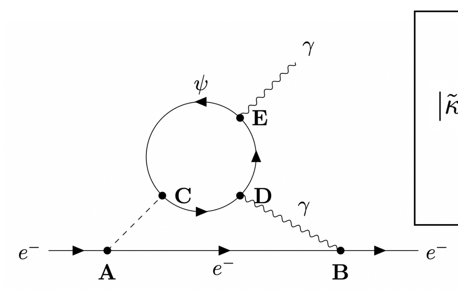




EDM

$$|d_e| < 1.1 \times 10^{-29}\ \text{e cm}\,, \qquad \text{at } 90\%\ \text{C.L.}$$

- Computed through **Bar-Zee** diagram:



Bounds

$|\tilde{\kappa}_t| \lesssim 0.0012\,,\quad |\tilde{\kappa}_b| \lesssim 0.24\,,\quad |\tilde{\kappa}_\tau| \lesssim 0.29$
$|\tilde{\kappa}_c| \lesssim 0.37\,,\quad |\tilde{\kappa}_\mu| \lesssim 31\quad |\tilde{\kappa}_e| \lesssim 0.0017$

- **Stronger** bounds!

$$|\tilde{\kappa}_{t,c,u}| \lesssim 0.0012\,, \qquad |\tilde{\kappa}_{b,s,d}| \lesssim 0.24\,, \qquad |\tilde{\kappa}_{\tau,e,\mu}| \lesssim 0.0017$$

- NP scale and deviations:

$\sin\theta_{u,33} = 1$	$\Lambda_q \gtrsim 7.4$ TeV
$\sin\theta_{e,11} = 1 = \sin\theta_{e,33}$	$\Lambda_\ell \gtrsim 6.0$ TeV

$0.998 \lesssim r_q^2 \lesssim 1.002$
$0.997 \lesssim r_\ell^2 \lesssim 1.003$

Take Home Messages

Flavour symmetries:

- are well motivated both to **explore BSM physics** and to **understand the SM Yukawa** structure!
- allow to **connect** and **correlate** very different **experimental searches** and **constraints** and can **lower** considerably the **NP scale** to **1-10 TeV**!!

- **CP violating** $\to$ unless the **phases** of the **diagonal** couplings are zero, the **EDM** put the **strongest bounds**, followed by flavour observables.
- **CP conserving** $\to$ most constrained by **flavour observables**: **Higgs physics**' bounds are of the **same order** of magnitude and could become **relevant** in future searches!