Data Driven Flavour Model

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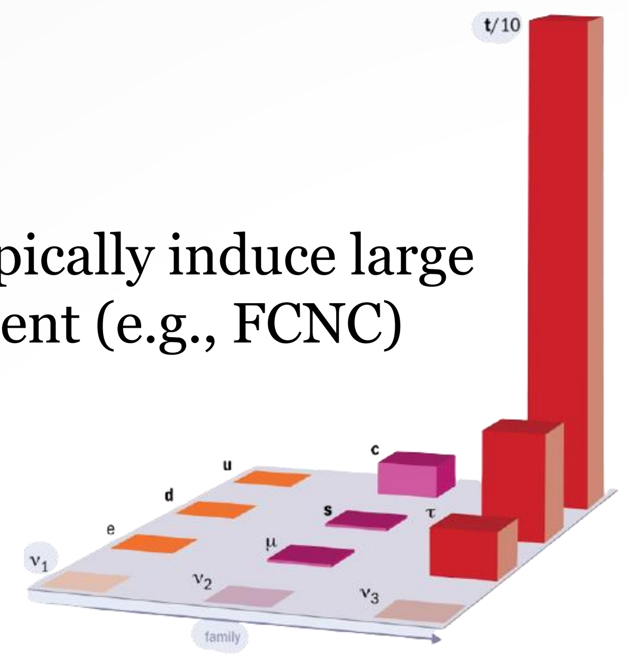
The flavour puzzle

- Naturalness issue, **in a nutshell**:
  Why SM fermions couple the way they do to the Higgs?
- Theoretically challenging to address, simple BSM extensions typically induce large rates of flavour violating processes already ruled out by experiment (e.g., FCNC)
- Many proposals in the literature with symmetry as the unifying thread: discrete or continuous, abelian or non-abelian, global or local...



- But always a top-down approach! The Data Driven Flavour Model (DDFM) is an attempt at a **bottom-up**, strictly **data driven** solution.

The idea

- Follow experimental observations! Only the **top quark Yukawa** and, if existing, the **RH neutrino Majorana mass** terms should appear in the Lagrangian at the **renormalisable level**.
- This is guaranteed by the **flavour symmetry**, present at all orders in the EFT expansion. **The rest** of the Yukawa's appear **suppressed** as **dim. 5 operators**, made invariant by the insertion of spurion fields transforming under the flavour group.

Quark sector

Quark flavour symmetry subgroup

$$\mathcal{G}_q = SU(2)_{q_L} \times SU(2)_{u_R} \times SU(3)_{d_R}$$

$$\Rightarrow$$

$$-\mathscr{L}_Y^q = y_t\, \bar{q}'_{3L}\, \tilde{\phi}\, t'_R + \Delta\mathscr{L}_Y^q + \text{h.c.}$$

$$\Delta\mathscr{L}_Y^q = \bar{Q}'_L\, \tilde{\phi}\, \Delta\mathcal{Y}_U\, U'_R + \bar{Q}'_L\, \phi\, \Delta\mathcal{Y}_D\, D'_R + \bar{q}'_{3L}\, \phi\, \mathbf{y}_D\, D'_R$$

$$Y_U = \begin{pmatrix} \langle\Delta\mathcal{Y}_U\rangle & 0 \\ 0 & 1 \end{pmatrix} \qquad Y_D = \begin{pmatrix} \langle\Delta Y_D\rangle \\ \langle y_D\rangle \end{pmatrix}$$

Fields

		$SU(2)_{q_L}$	$SU(2)_{u_R}$	$SU(3)_{d_R}$
quarks	Q'_L	2	1	1
	q'_{3L}	1	1	1
	U'_R	1	2	1
	t'_R	1	1	1
	D'_R	1	1	3
spurions	$\Delta\mathcal{Y}_U$	2	$\bar{2}$	1
	$\Delta\mathcal{Y}_D$	2	1	$\bar{3}$
	$\mathbf{y}_D$	1	1	$\bar{3}$

Phenomenology

Operators	Bound on $\Lambda/\sqrt{a_i}$	Observables
$\mathcal{O}_1$, $\mathcal{O}_2$	5.9 TeV	ϵ_K, Δm_{B_d}, Δm_{B_s}
$\mathcal{O}_{17}$, $\mathcal{O}_{18}$	4.1 TeV	$B_s \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-$
$\mathcal{O}_{21}$, $\mathcal{O}_{22}$	3.4 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\mathcal{O}_{25}$, $\mathcal{O}_{26}$	6.1 TeV	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$\mathcal{O}_{27}$, $\mathcal{O}_{28}$	1.7 TeV	$B \to K^*\mu^+\mu^-$
$\mathcal{O}_{29}$, $\mathcal{O}_{30}$, $\mathcal{O}_{31}$, $\mathcal{O}_{32}$	5.7 TeV	$B_s \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-$
$\mathcal{O}_{33}$, $\mathcal{O}_{34}$	5.7 TeV	$B_s \to \mu^+\mu^-$, $B \to K^*\mu^+\mu^-$

Similar to MFV [D'Ambrosio et al.], but the DDFM can accommodate **non universal** $e/\mu - \tau$ effects!

Lepton sector

Lepton flavour symmetry subgroup

$$\mathcal{G}_\ell^{\text{EFC}} = SU(3)_{\ell_L} \times SU(2)_{e_R} \times SO(3)_{N_R}$$

$$\Rightarrow$$

$$-\mathscr{L}_Y^{\ell,\text{EFC}} = \frac{1}{2}\Lambda_{LN}\, \bar{N}'^c_R\, Y_N\, N'_R + \Delta\mathscr{L}_Y^{\ell,\text{EFC}} + \text{h.c.}$$

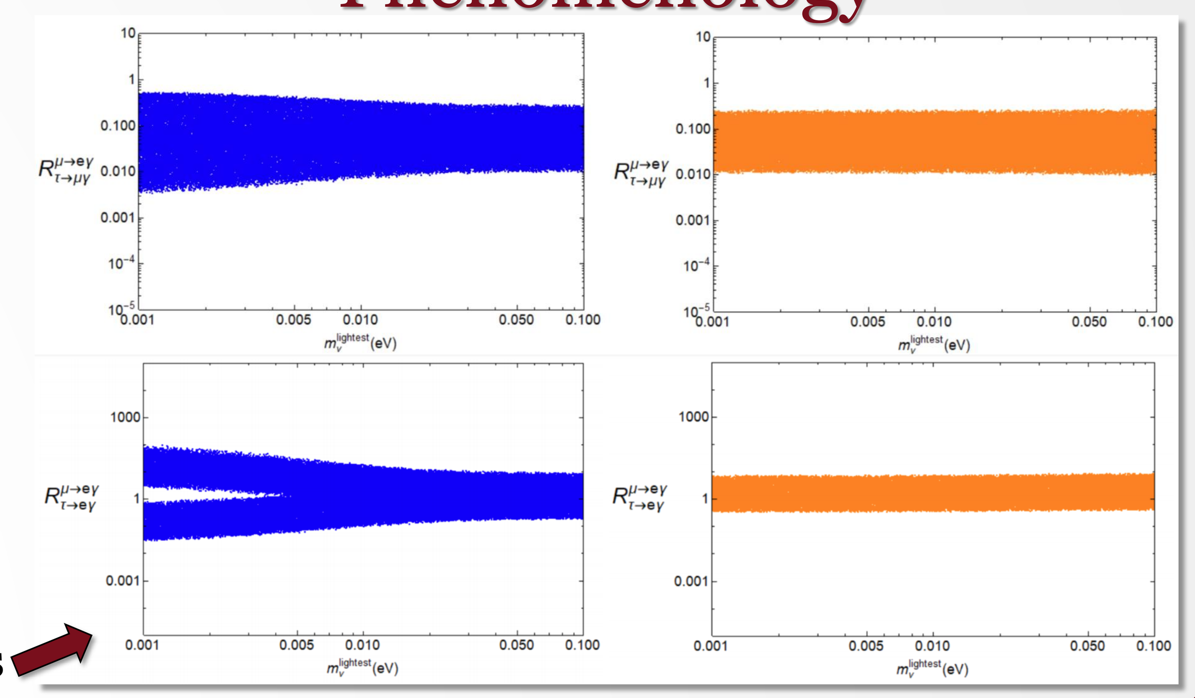
$$\Delta\mathscr{L}_Y^{\ell,\text{EFC}} = \bar{L}'_L\, \phi\, \Delta\mathcal{Y}_E\, E'_R + \bar{L}'_L\, \phi\, \mathbf{y}_E\, \tau'_R + \bar{L}'_L\, \tilde{\phi}\, \mathcal{Y}_\nu\, N'_R$$

$$\frac{1}{2}\bar{\nu}'^c_L\, m_\nu\, \nu'_L + \text{h.c.} \qquad m_\nu = \frac{v^2}{2\Lambda_{LN}}\, Y_\nu^* Y_\nu^\dagger$$

Fields

		$SU(3)_{\ell_L}$	$SU(2)_{e_R}$	$SO(3)_{N_R}$
leptons	L'_L	3	1	1
	E'_R	1	2	1
	τ'_R	1	1	1
	N'_R	1	1	3
spurions	$\Delta\mathcal{Y}_E$	3	$\bar{2}$	1
	$\mathbf{y}_E$	3	1	1
	$\mathcal{Y}_\nu$	3	1	3

Phenomenology



Similar to the type-I Seesaw MLFV [Cirigliano et al.], but **different** for the τ! In MLFV these ratios have less freedom [Dihn et al.].

Flavon scalar potential

- Promoting the spurions to **flavons**, the minimisation of the scalar potential can provide a dynamical (albeit fine-tuned) solution to the flavour puzzle, compatible with the full structure of fermion masses and mixings (and certain **Majorana phases** are predicted!).

$$A_U = \text{Tr}\left(\Delta\mathcal{Y}_U\Delta\mathcal{Y}_U^\dagger\right) \qquad A_D = \text{Tr}\left(\Delta\mathcal{Y}_D\Delta\mathcal{Y}_D^\dagger\right)$$

$$A_{UU} = \text{Tr}\left(\Delta\mathcal{Y}_U\Delta\mathcal{Y}_U^\dagger\Delta\mathcal{Y}_U\Delta\mathcal{Y}_U^\dagger\right) \qquad A_{DD} = \text{Tr}\left(\Delta\mathcal{Y}_D\Delta\mathcal{Y}_D^\dagger\Delta\mathcal{Y}_D\Delta\mathcal{Y}_D^\dagger\right)$$

$$A_{UD} = \text{Tr}\left(\Delta\mathcal{Y}_U\Delta\mathcal{Y}_U^\dagger\Delta\mathcal{Y}_D\Delta\mathcal{Y}_D^\dagger\right)$$

$$B_D = \mathbf{y}_D\mathbf{y}_D^\dagger \qquad B_{DD} = \mathbf{y}_D\Delta\mathcal{Y}_D^\dagger\Delta\mathcal{Y}_D\mathbf{y}_D^\dagger \qquad D_U = \det\left(\Delta\mathcal{Y}_U\right)$$

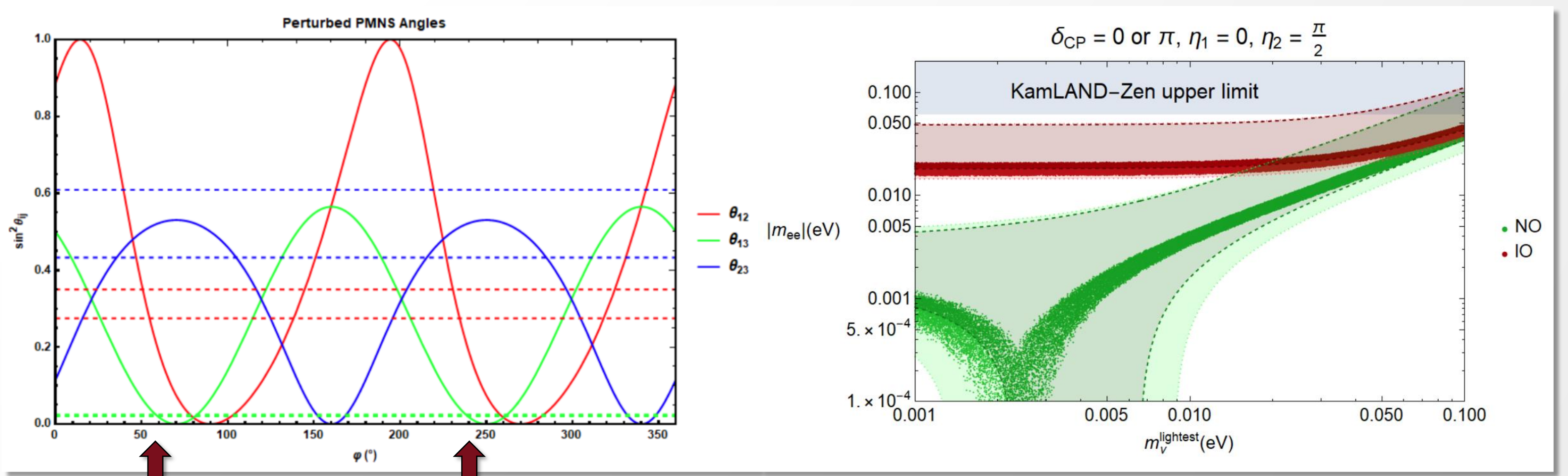
$$A_E = \text{Tr}\left(\Delta\mathcal{Y}_E\Delta\mathcal{Y}_E^\dagger\right) \qquad A_\nu = \text{Tr}\left(\mathcal{Y}_\nu\mathcal{Y}_\nu^\dagger\right)$$

$$A_{EE} = \text{Tr}\left(\Delta\mathcal{Y}_E\Delta\mathcal{Y}_E^\dagger\Delta\mathcal{Y}_E\Delta\mathcal{Y}_E^\dagger\right) \qquad A_{\nu\nu1} = \text{Tr}\left(\mathcal{Y}_\nu\mathcal{Y}_\nu^\dagger\mathcal{Y}_\nu\mathcal{Y}_\nu^\dagger\right)$$

$$A_{E\nu} = \text{Tr}\left(\Delta\mathcal{Y}_E\Delta\mathcal{Y}_E^\dagger\mathcal{Y}_\nu\mathcal{Y}_\nu^\dagger\right) \qquad A_{\nu\nu2} = \text{Tr}\left(\mathcal{Y}_\nu\mathcal{Y}_\nu^T\mathcal{Y}_\nu^*\mathcal{Y}_\nu^\dagger\right)$$

$$B_E = \mathbf{y}_E\mathbf{y}_E^\dagger \qquad B_{EE} = \mathbf{y}_E^\dagger\Delta\mathcal{Y}_E\Delta\mathcal{Y}_E^\dagger\mathbf{y}_E \qquad B_{E\nu} = \mathbf{y}_E^\dagger\mathcal{Y}_\nu\mathcal{Y}_\nu^\dagger\mathbf{y}_E$$

$$D_\nu = \det\left(\mathcal{Y}_\nu\right)$$



In **contrast** to MFV, where fully realistic solutions are not possible! [Alonso et al. 1, 2]

Thanks for your attention!

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