# NEUTRINO STATES IN FLAVOUR-DECONSTRUCTED UV THEORIES

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Based on my Master Thesis with G. Isidori and P. Paradisi

# THEORETICAL MOTIVATION

# WHY FLAVOUR DECONSTRUCTION?

**SM Gauge Group:** $\mathrm{SU}(2)_L \times \mathrm{SU}(3)_C \times \mathrm{U}(1)_Y$

**Universality Hypothesis:** three generations for each type of fermions charged identically under it

But couplings with Higgs are different: from $\mathcal{O}(1)$ to $\mathcal{O}(10^{-6})$

**Flavour deconstruction:** It explains the non-trivial hierarchical structure of Yukawa matrices (*flavour problem)*

**Assumptions:**

- Flavour non-universal UV completion of the SM
- Higgs is charged under the third generation sector

# UV THEORY AT THE TEV

We break the universality of the third generation and embed this gauge sector in a **Pati-Salam** like gauge group

This allows that the Barion Number is conserved classically

$\Longrightarrow \quad \Lambda_{\mathrm{UV}}$ can be at the TeV scale

**Yukawa Matrices:**

Generated via EFT operators

$\Longrightarrow$ The light-generation Yukawa couplings are naturally suppressed

$$Y \sim \begin{pmatrix} \varepsilon_R & \varepsilon_4 \\ \varepsilon_R \varepsilon_4 & 1 \end{pmatrix}$$

We can provide a **UV origin** to the EFT operators by means of very few massive vector-like fermions (VLFs)

# A SPECIFIC EXAMPLE

$$\mathrm{SU}(2)_L \times \mathrm{SU}(4)^{[3]} \times \mathrm{SU}(3)^{[12]} \times \mathrm{SU}(2)_R^{[3]} \times \mathrm{U}(1)_X^{[12]}$$

$$\mathrm{SU}(2)_L \times \mathrm{SU}(3)^{[3]} \times \mathrm{SU}(3)^{[12]} \times \mathrm{U}(1)_X^{[3]} \times \mathrm{U}(1)_X^{[12]}$$

$$\mathrm{SU}(2)_L \times \mathrm{SU}(3)_C \times \mathrm{U}(1)_Y$$

$$Y = T_R^3 + \frac{\sqrt{6}}{3}\hat{T}^{15} + X^{[12]} \quad \Longrightarrow$$

**Charge Quantization**

# NEUTRINO MASSES

# THE ISSUE WITH NEUTRINOS

**Features of these models:**

- Right-handed (RH) neutrinos are already present
- The neutrino and up-type quark Yukawa matrices are very similar

**Goal:** Explain the observed small anarchical neutrino masses

$\Longrightarrow$ See-Saw

**Type-I See-Saw**

- Very heavy RH neutrinos

$$m_\nu \sim y^2 \frac{v^2}{M_R}$$

**Inverse See-Saw:**

- Sterile fermions with Majorana mass matrix $\mu$
- Heavy mass-mixing between RH neutrinos and sterile fermions

$$m_\nu \sim \mu\, y^2 \frac{v^2}{m_R^2}$$

**Issue:** To compensate the hierarchical structure in the Yukawa we need an extreme hierarchy inside the Majorana mass matrix $\mu$

# THE ANARCHY CONDITION

We want an anarchical Majorana mass matrix $\mu$

**This is possible if:** $$\frac{m_R^{k1}}{y_1} \sim \frac{m_R^{k2}}{y_2} \sim \frac{m_R^{k3}}{y_3}$$

$$\Longleftrightarrow \qquad Y^N \sim \begin{pmatrix} \varepsilon & \varepsilon \\ \varepsilon^2 & 1 \end{pmatrix} \qquad\qquad m_R \sim \begin{pmatrix} \varepsilon & 1 \\ \varepsilon & 1 \end{pmatrix}$$

In this scenario all the hierarchies precisely cancel, both in the mixing matrices and active neutrino mass matrix

## How to implement it:

- Add a new scalar field charged under the third-generation Gauge sector
- Assume a new very general symmetry under which are charged only the sterile fermions and this new scalar field

These condition are easy to implement in flavour-deconstructed models

# HEAVY NEUTRINO STATES

In the Inverse See-Saw we generate a **heavy mass-matrix**

$$M_h \approx \begin{pmatrix} \mathbb{O} & m_R^T \\ m_R & \mathbb{O} \end{pmatrix}$$

It corresponds to three heavy leptonic states $n^i$ with **Dirac-type** masses $M_i$

Since $m_R$ is hierarchical, the three masses have the following parametrical structure where $v_F$ is the NP energy scale

$$M_3 \sim v_F \qquad M_2 \sim \frac{m_c}{m_t} v_F \qquad M_1 \sim \frac{m_u}{m_t} v_F$$

## Interactions with SM:

- Charged weak currents with W and charged leptons
- Neutral weak currents with Z and SM neutrinos
- Higgs and SM neutrinos

Interactions with the three generations are anarchical with suppression factor

$$V \sim v/v_F$$

# LFV PRECISION OBSERVABLES

**Observable to look at:**

- Rare muon decay channels $\mu \to e\gamma$ or $\mu \to eee$
- Direct production at colliders (DELPHI, CMS, ATLAS)
- (Semi)leptonic meson decays (BEBC, CHARM)

The process that currently put the stringiest bound on the scale is given by

$$\mathrm{Br}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}|\delta_\nu|^2 \quad \text{with} \quad \delta_\nu \sim \frac{v^2}{v_F^2} \quad \Longrightarrow \quad v_F/v \gtrsim 100$$

**Possible detection in the near future:**

- Mu3e : $\mathrm{Br}(\mu \to eee) = \mathcal{O}(10^{-16})$
- MEG II: $\mathrm{Br}(\mu \to e\gamma) \approx 6 \cdot 10^{-14}$
- FCC-ee: LFV in Z decays

# CONCLUSION

**These models are able to:**

- Explain the Charge Quantization
- Solve the flavour problem (hierarchical fermion masses)
- Explain the observed neutrino mass spectrum
- Could offer a solution to the hierarchy problem

**They are very interesting:**

- Minimality (not many new DOFs)
- Naturalness (without any source of fine tuning)
- They offer a large variety of possible BSM physics at the TeV
- They predict detection of LFV effects in precision experiments in the near future