NEUTRINO STATES IN FLAVOUR-DECONSTRUCTED UV THEORIES

Erice School of Subnuclear Physics

14 June – 23 June 2024

Speaker: Andrea Sainaghi

Padua University and SGSS

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

THEORETICAL MOTIVATION

WHY FLAVOUR DECONSTRUCTION?

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

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

 $\implies \Lambda_{\rm UV}$ can be at the TeV scale

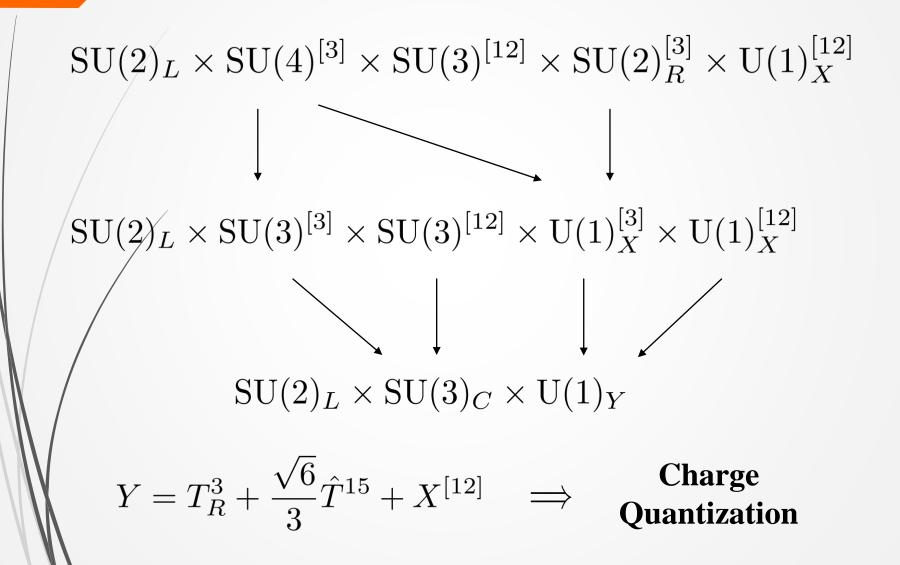
Yukawa Matrices: Generated via EFT operators

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



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

 \Rightarrow See-Saw

Type-I See-Saw

• Very heavy RH neutrinos

 $m_{
u} \sim y^2 rac{v^2}{M_B}$

Issue:

Inverse See-Saw:

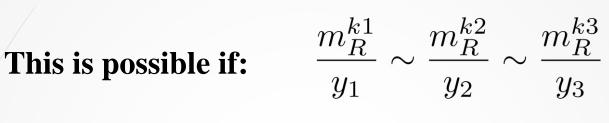
- Sterile fermions with Majorana mass matrix μ
- Heavy mass-mixing between RH neutrinos and sterile fermions

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

To compensate the hierarchical structure in the Yukawa we need an extreme hierarchy inside the Majorana mass matrix μ

THE ANARCHY CONDITION

We want an anarchical Majorana mass matrix μ



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

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**

$$M_h \approx \begin{pmatrix} \mathbb{O} & m_R^T \\ m_R & \mathbb{O} \end{pmatrix} \quad \text{It corresponds to three heavy leptonic states} \\ n^i \text{ with } \mathbf{Dirac-type } \text{ masses } M_i$$

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

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

Possible detection in the near future:

- Mu3e: $\operatorname{Br}(\mu \to eee) = \mathcal{O}(10^{-16})$
- MEG II: $Br(\mu \to e\gamma) \approx 6 \cdot 10^{-14}$
- 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