Lepton-flavour violation in a Pati-Salam model with gauged flavour symmetry

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Outline:

- Introduction
- The model
- LVF in Pati-Salam models

Charged Lepton-Flavour Violation

- Charged radiative lepton decays
  $\mu \to e\gamma$ & $\tau \to \mu\gamma$ ...

- Decay into three leptons
  $\mu \to 3e$ & $\tau \to 3\mu$ ...

- Lepton conversion in nuclei
  $N\,\mu \to N\,e$

Tiny Branchingratios after neutrino mass inclusion into the SM

$$\mathrm{BR}(\mu \to \mathrm{e}\gamma)_{\mathrm{theo}} \sim 10^{-54} \qquad \mathrm{BR}(\mu \to \mathrm{e}\gamma)_{\mathrm{exp}} < 4.2 \cdot 10^{-13}$$

Experimental signal $\to$ high indication of beyond SM physics

Strategy: Effective Field Theory

- New physic model with distinct hierarchy $\Lambda_{\rm NP} \gg \underbrace{v \gg m_\ell}_{IR}$
- Integrate out the NP degrees of freedom by matching onto an $SU(3) \times SU(2) \times U(1)_Y$ invariant Lagrangian at a scale $\Lambda_{\rm NP} \gg \mu \gg v$:
- Relevant dim. six operators for $\mu \to e\gamma$ include

$$\mathcal{L}_{\rm NP} \to \mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{1}{\Lambda_{\rm NP}^2} \sum_i C_i \mathcal{O}_i$$

$$\sum_i C_i \mathcal{O}_i \supset a_{B,ij}\, \bar{L}_i \Phi \sigma_{\mu\nu} E_j B^{\mu\nu} + a_{W,ij}\, \bar{L}_i \tau^a \Phi \sigma_{\mu\nu} E_j\, W^{a,\mu\nu} \qquad \text{Dipole Operators}$$

$$+ b_{LE,\,ij}\, (\bar{L}_i \gamma^\mu L_i)(\bar{E}_j \gamma_\mu E_j) + c_{1,i}\, (\bar{E}_i \gamma_\mu E_i)(\Phi^\dagger i D^\mu \Phi)$$

$$+ c_{2,i}\, (\bar{L}_i \gamma_\mu L_i)(\Phi^\dagger i D^\mu \Phi) + c_{3,i}\, (\bar{L}_i \gamma^\mu \tau^a L_i)(\Phi^\dagger i \overleftrightarrow{\tau^a D_\mu} \Phi) \qquad \text{Tree Operators}$$

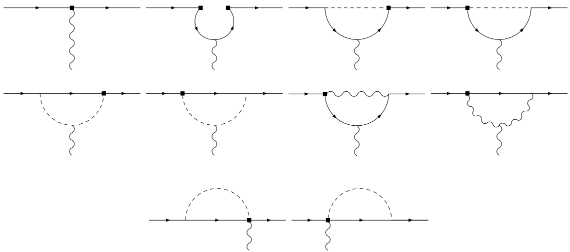
$$+ \ldots$$

[W. Buchmüller, D. Wyler]

EFT After EWSB(Lepton Sector)

$$\Phi \to \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(v + H + iG) \end{pmatrix} \qquad E \to V\psi_R, \qquad L \to U \begin{pmatrix} \nu_L \\ \psi_L \end{pmatrix}$$

- Diagram set for radiative $\mu \to e\gamma$



- Find lower bounds on Wilson coefficients [A. Crivellin, M. Hoferichter, M. Procura (2014)]
- Determine the Wilson coefficients with specfic NP models

Motivation for Pati-Salam GUT

$$SU(4) \times SU(2) \times SU(2)'$$

- Possible formulation in a manifestly left-right symmetric way.
- Leptons as 4th colour.– Right-handed neutrinos.
- PS scenarios with extended field content may realise gauge-coupling unification in a non-trivial way, without invoking SUSY.

Symmetries

- Pati-Salam Gauge Group(contains SM)

$$\begin{array}{ccc} SU(4) \times & \underbrace{SU(2) \times SU(2)'} \\ \downarrow & \downarrow \\ SU(3)_c \times & SU(2)_L \times U(1)_Y \end{array}$$

- Flavour Symmetry (gauged):

$$SU(3)_{\mathrm{I}} \times SU(3)_{\mathrm{II}}$$

- Explicit Left-Right Symmetry:

$$Z_2 \ : \begin{cases} SU(2) \leftrightarrow SU(2)' \\ SU(3)_{\mathrm{I}} \leftrightarrow SU(3)_{\mathrm{II}} \end{cases}$$

Scalars and VEVs

- Higgs Bi-Doublet(flavour-neutral)

$$H \quad \text{VeVs}: \; v_u, v_d \; \sim \mathcal{O}(100\,\text{GeV})$$

- PS Singlets and Triplets(flavour bi- triplets)

$$S,\; T \quad \text{VeVs}: \; S, T \; \gg \; \mathcal{O}(500\,\text{GeV})$$

- $SU(4)$ Adjoints(flavour bi- triplets)

$$S_{15},\; T_{15} \quad \text{VeVs}: \; S, T \; \gg \; \mathcal{O}(500\,\text{GeV})$$

- Scalars for the Majorana Sector $\sim \mathcal{O}(M_{\text{GUT}})$

- Dirac Mass term $M \; \sim \; \mathcal{O}(500\,\text{GeV})$

Features/Comments

- Generic breaking of the Flavour and Pati-Salam symmetries near the GUT scale
New heavy bosons negligible for low- energy phenomology!

- Scalar potential not specified explicitly written. (Ongoing project with simplier Flavour gauge groups)

- low- energy phenomology dominated by contributions of the new heavy fermions ($m >$ LHC reach)

$$
\begin{aligned}
\mathcal{L}_{\mathrm{LFV}} \;=\; & \frac{g}{2\,c_W}\left(\Delta g^{ij}_{Z\bar{\ell}_L\ell_L} Z^{\mu}(\bar{\ell}_i\gamma_\mu P_L\ell_j) - \Delta g^{ij}_{Z\bar{\ell}_R\ell_R} Z^{\mu}(\bar{\ell}_i\gamma_\mu P_R\ell_j)\right) \\
& - \frac{g}{\sqrt{2}}\Delta g^{ij}_{W\bar{\nu}_L\ell_L} W^{+\mu}(\bar{\nu}_i\gamma_\mu P_L\ell_j) + \text{h.c.} \\
& + \frac{3}{2}\Delta g^{ij}_{h\bar{\ell}\ell}\frac{h}{\sqrt{2}}(\bar{\ell}_i P_R\ell_j) + \frac{1}{2}\Delta g^{ij}_{h\bar{\ell}\ell}\frac{v}{\sqrt{2}}(\bar{\ell}_i P_R\ell_j) + \text{h.c.}
\end{aligned}
$$

- NP effects suppressed by $\epsilon_{u,d} \;=\; \frac{v_{u,d}}{M}$

Effective Yukawa Matrices for charged Fermions

First approximation: Neglect mixing between heavy fermions.

- Quarks

$$Y_U \sim -\lambda \left[\frac{1}{(s+t)_u} + \frac{1}{s_u} \right] \quad Y_D \sim -\lambda \left[\frac{1}{(s+t)_d} + \frac{1}{s_d} \right]$$

- Charged Leptons

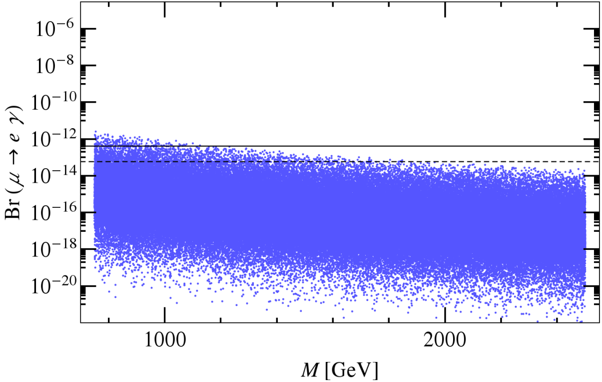
$$Y_l \sim -\lambda \left[\frac{1}{(s+t)_l} + \frac{1}{s_l} \right]$$

- Relation between the Y_x and the $s_i,\ t_i$ not invertible

Numerical solution non-trivial due to large hierachies in eigenvalues and mixing angles.

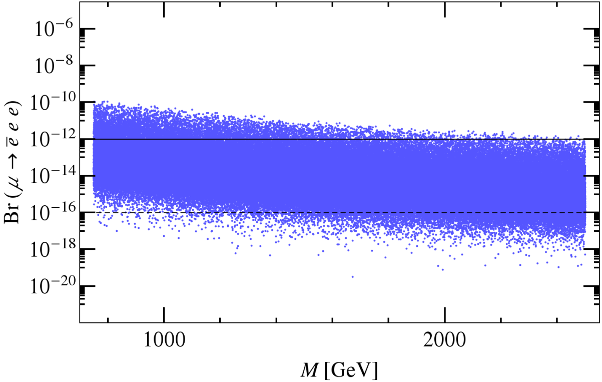
$\rightarrow$ Sophisticated Numerical Scan

Lepton Flavour Violation: $\mu \to e\gamma$



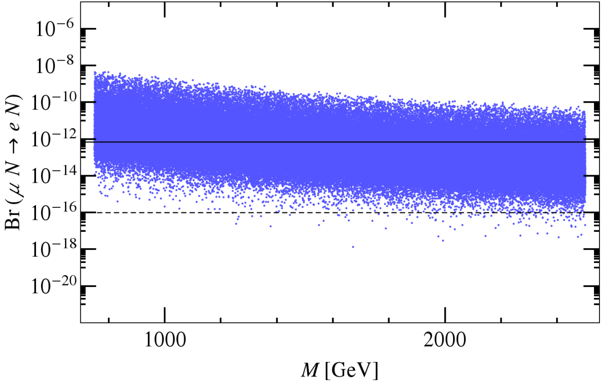
- Most parameter points compatible with present and future bounds.

Lepton Flavour Violation: $\mu \to 3e$



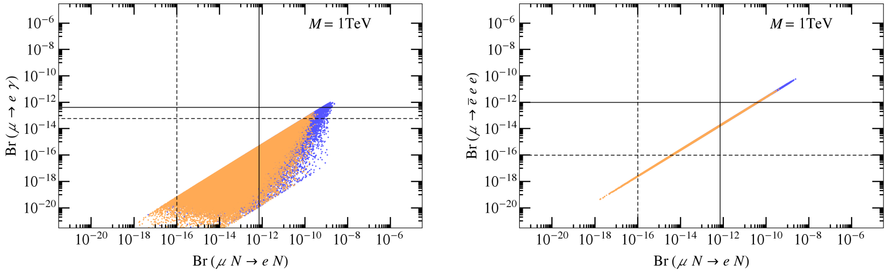
- Possible LVF signals at future experiments.

Lepton Flavour Violation: $\mu N \rightarrow e N$



- Possible LVF signals at future experiments

Lepton Flavour Violation: Correlations for $M = 1\,\mathrm{TeV}$



- $\mu \to 3e$ and $N\,\mu \to N\,\mu$ strongly correlated, due to similar tree-level contributions.

- Orange points represent models with lower flavour changing mixing angle contributions in the generation of mass matrices.

Conclusions

$$[SU(4) \times SU(2) \times SU(2)'] \times [SU(3)_{\mathrm{I}} \times SU(3)_{\mathrm{II}}]$$

- Horizontal and vertical unification with dynamical symmetry breaking
- Future charged LVF signals possible for muonic decays mediated via tree-level decays
- Charged LVF via similar τ decays at least three magnitudes below current limits
- Muon g-2 and electric dipole moments contributions of the Pati-Salam model too small

Current Project

- Simplified flavour model with a distinguished third generation using bottom up aproach.