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

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Theoretische Physik 1
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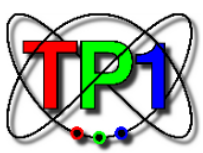
Outline:

- Introduction
- Formalism
- Low-energy phenomenology for leptons



Low-Energy Phenomenology for Leptons: Introduction

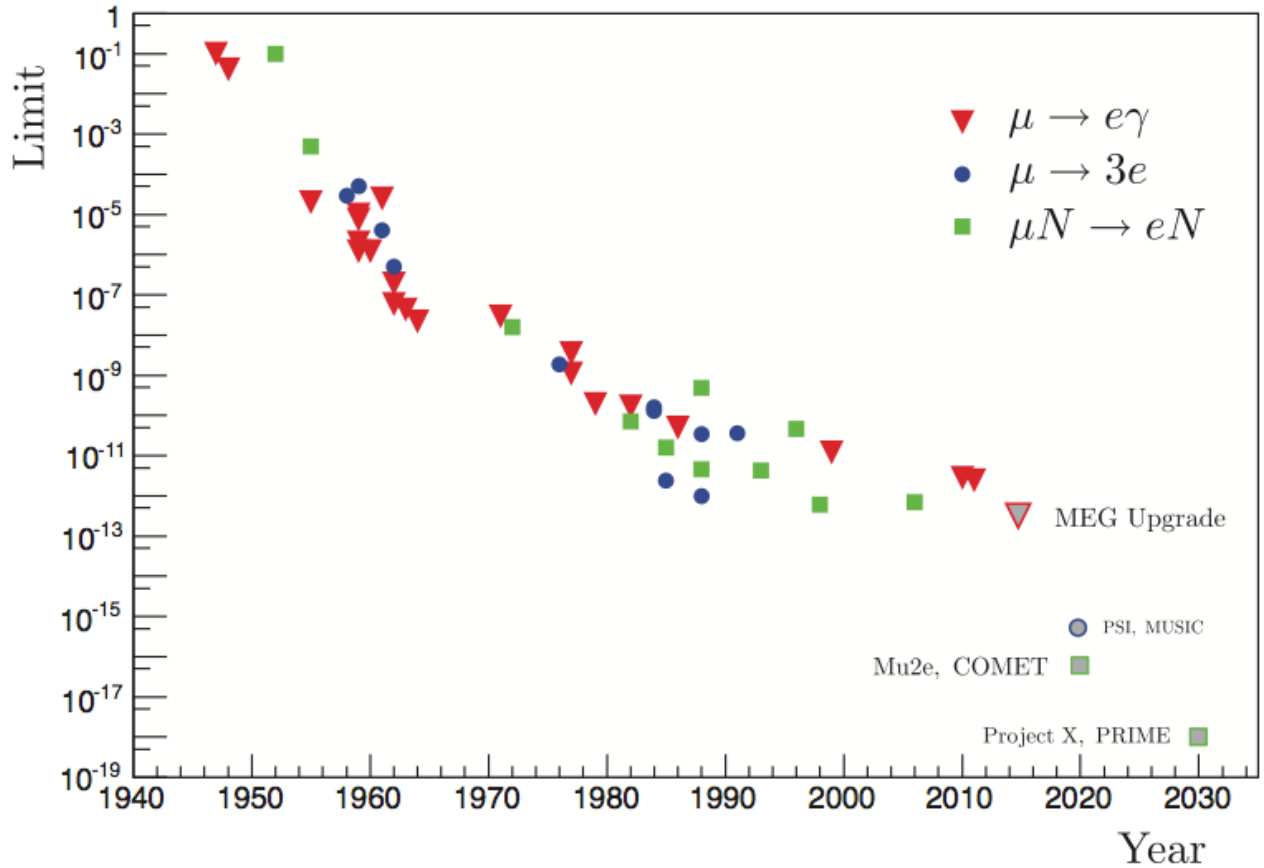
- Charged radiative lepton decays
  $\mu \to e\gamma$ & $\tau \to \mu\gamma$ ...
- Decay into three leptons
  $\mu \to 3e$ & $\tau \to 3\mu$ ...
- $N\,\mu \to N\,e$

Tiny Branchingratios after neutrino mass inclusion into the SM

$$\mathrm{BR}(\mu \to \mathrm{e}\gamma)_{\mathrm{theo}} \sim 10^{-54} \qquad \mathrm{BR}(\mu \to \mathrm{e}\gamma)_{\mathrm{exp}} < 5.7 \cdot 10^{-13}$$

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

65 Years Of Searches



• Future upgrades with measurement starting dates around 2020 will allow multi TeV scans for additional signs of new 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

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

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

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

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

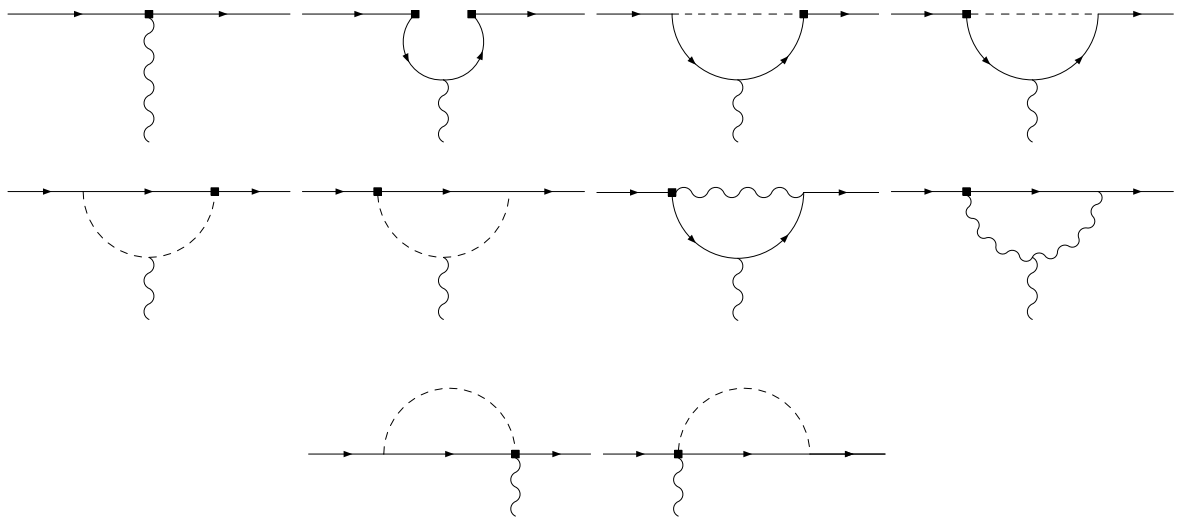
$$+ \ldots$$

[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

Pati-Salam Models: Lepton Flavour Violation

- Additional Flavon scalar fields in the **15** adjoint representation of $SU(4)$.

  $\rightarrow$ Flavour structure of quarks and leptons decouple.

- PMNS matrix is always reproduced.

- Seesaw formula for leptons valid for τ leptons $\rightarrow$ no problem with the third generation in the lepton sector.

- Generated anomalous couplings in the lepton sector:

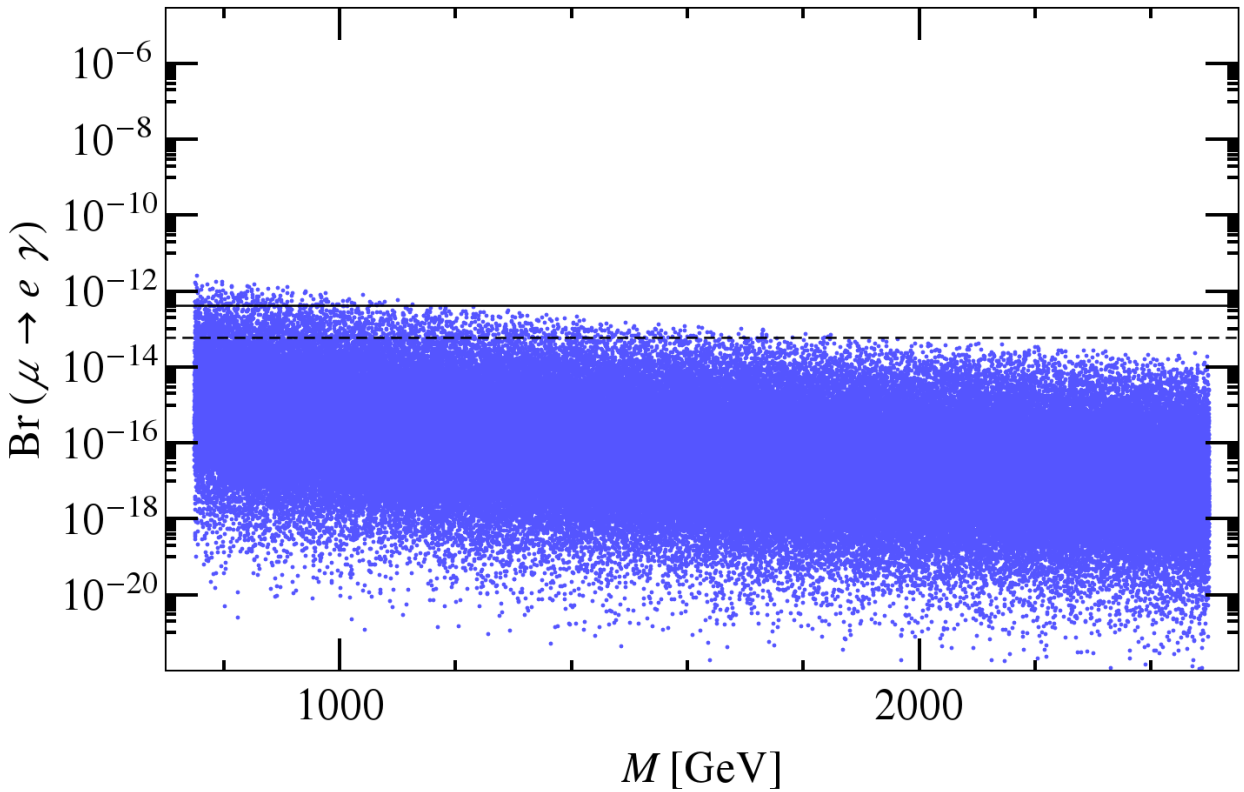
$$\begin{aligned}\mathcal{L}_{\text{LFV}} = & \frac{g}{2\,c_W}\left(\Delta g^{ij}_{Z\bar{\ell}_L\ell_L} Z^\mu (\bar{\ell}_i \gamma_\mu P_L \ell_j) - \Delta g^{ij}_{Z\bar{\ell}_R\ell_R} Z^\mu (\bar{\ell}_i \gamma_\mu P_R \ell_j)\right) \\ & - \frac{g}{\sqrt{2}} \Delta g^{ij}_{W\bar{\nu}_L\ell_L} W^{+\mu}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

- Contributions to dimension six dipole and four-fermion operators are strongly suppressed.

Low-energy Phenomenology in Quark sector: Parameter scan

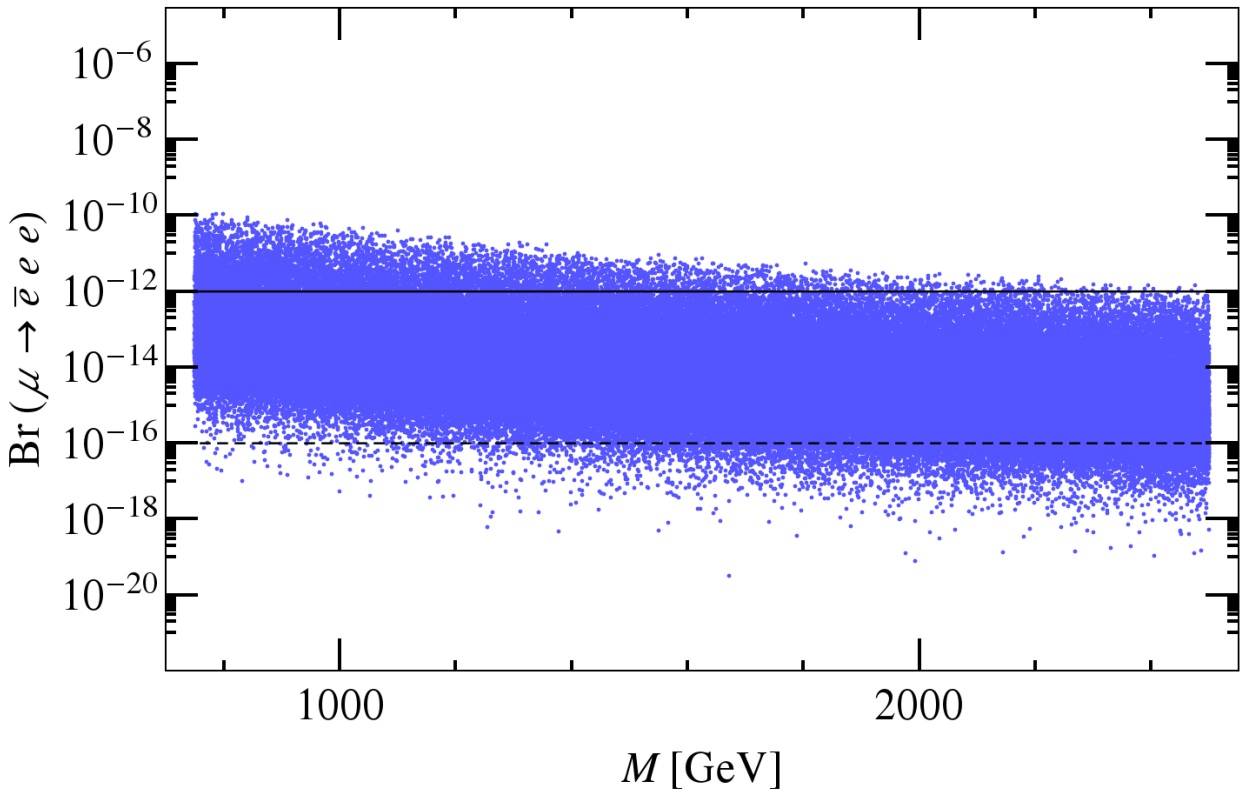
- Scan 1:
  - Choose again $\beta \in [1,\ 15]$, $\lambda \in [1.5,\ 3]$, $M \in [750,\ 2000]$ GeV.
  - Restrict singular values of flavon matrix s_ℓ to avoid fine-tuned solutions.
  - Arbitrary mixing angles and phases for rotation matrices.
- Scan 2:
  - Fix $M = 1$ TeV and define two parameter sets:
    1. Arbitrary mixing angles.
    2. Small mixing angles in rotation matrices (smaller than $\pi/6$ for standard CKM convention).
- $\mathcal{O}(200.000)$ parameter points for each scan strategy.

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



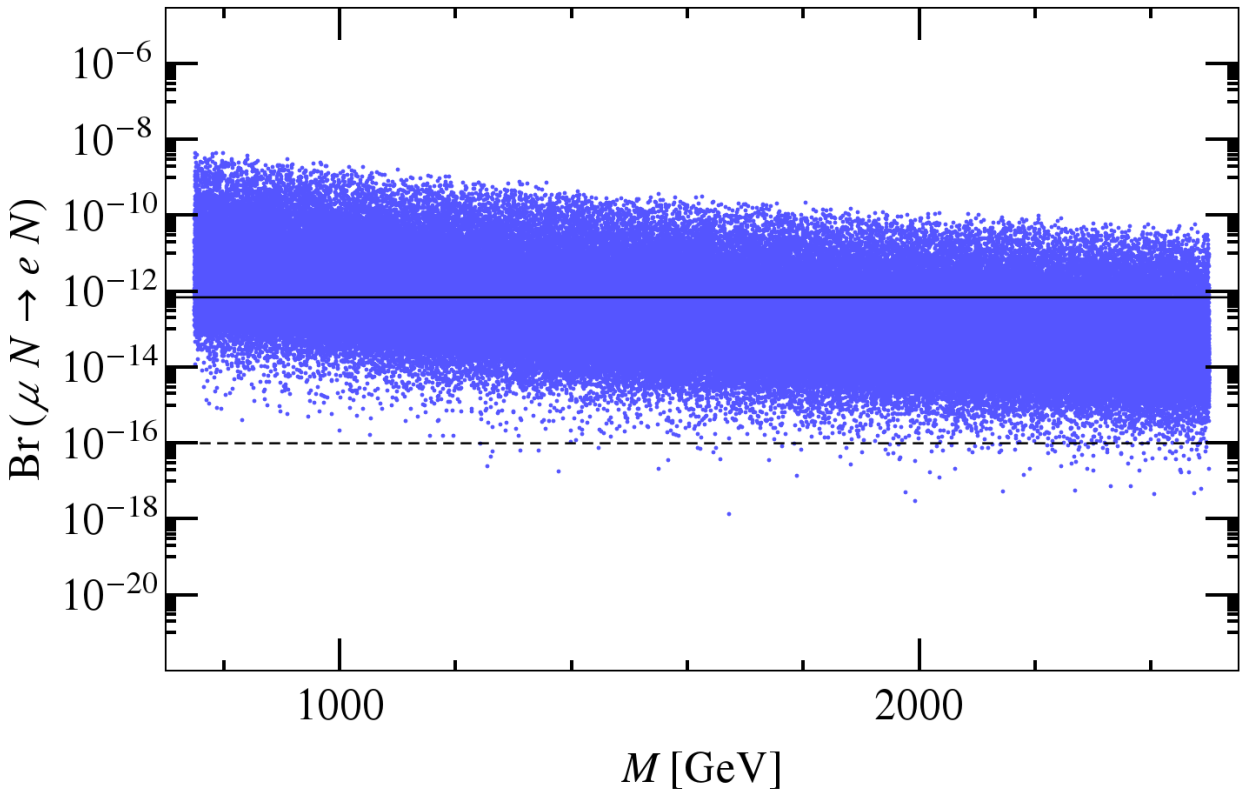
- BR scale with small parameter $\epsilon_d^4 \propto 1/M^4$.
- Most parameter points compatible with present and future bounds.

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



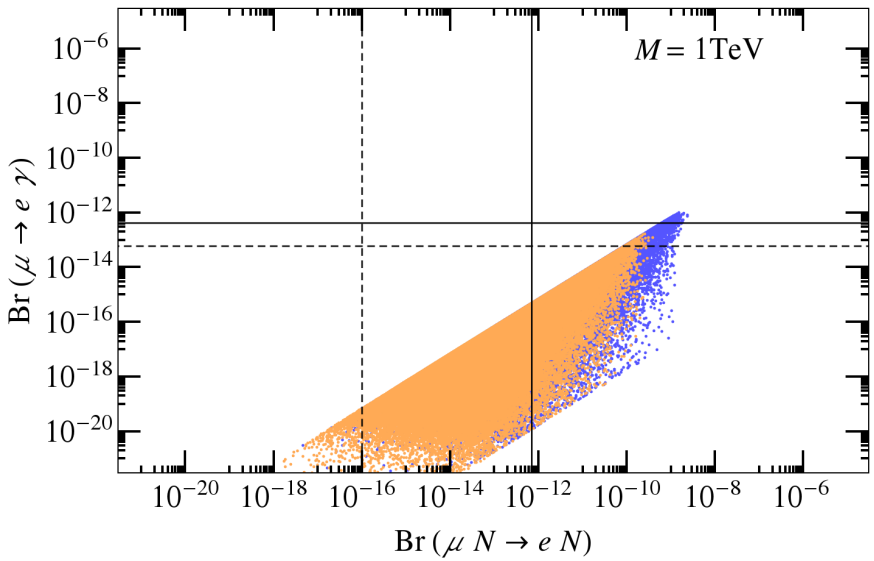
- BR scale with small parameter $\epsilon_d^4 \propto 1/M^4$.
- possible LVF signals at future experiments.

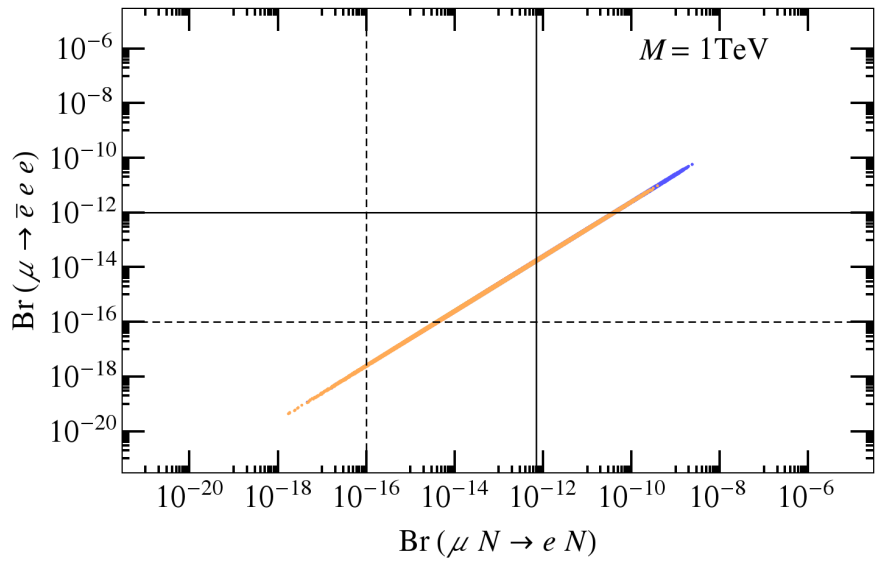
Lepton Flavour Violation: $\mu N \rightarrow e N$



- BR scale with small parameter $\epsilon_d^4 \propto 1/M^4$.
- Possible LVF signals at future experiments

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





- $\mu \to 3e$ and $N\,\mu \to N\,\mu$ strongly correlated, due to similar tree-level contributions.
- Orange points represent models with mixing angles smaller than $\pi/6$.

Conclusions

- 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

Possible future outlook:

- Reproduction flavon VEVS from realistic models
- Simplified flavour models with a distinguished third generation