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LFV in Minimal Flavor Violation extensions of the seesaw

Enrico Nardi

INFN – Laboratori Nazionali di Frascati, Italy

& Dept. de Física Teórica – Universidad Autónoma de Madrid, Spain

& Instituto de Física Teórica IFT/CSIC, Spain

Why searching for Lepton Flavor Violation (LFV) ?

- ν -oscillations indisputably signal LFV in the neutral sector.
- In extensions of the SM that can account for ν -oscillations it is natural to expect LFV also in the charged sector.
- However, in the simplest extensions (Dirac ν , SM+seesaw) LFV remains unobservable (below the $\mathcal{O}(10^{-50})$ level).
- Dirac ν : no new scale. Seesaw: New scale $\Lambda_{\cancel{L}} \sim \Lambda_{\text{GUT}}$.

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However, a (well motivated) theoretical prejudice states that:

there is New Physics (NP) around the TeV scale

since it is needed to cure the SM naturalness problem.

The flavor problem

If NP has a generic flavor structure, then FCNC constraints require $\Lambda_{\text{NP}} \gtrsim \mathcal{O}(10^5) \text{ TeV} (\gg \Lambda_{EW})$

Possible ways out:

NP is Flavor Blind

However, complete *blindness* is difficult to realize, it is theoretically unmotivated, (is boring), etc.

NP (TeV) should (*approximately*) conserve $B, B-L, CP$ (SM).
No reason for conserving *flavor*, that is not a SM symmetry.

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NP Violates Flavor Minimally

The only sources of flavor violation are the SM Yukawa couplings

Ansatz: TeV-scale NP violates flavor as much as the SM does

MFV in the Quark Sector

[G D'Ambrosio et al., NPB 645 (2002) 155, hep-ph/0207036]

Gauge invariant kinetic terms

vs. Yukawa interactions

$$\underbrace{\bar{Q}_i \not{D}_Q Q_i + \bar{u}_i \not{D}_u u_i + \bar{d}_i \not{D}_d d_i}_{U(3)_Q \times U(3)_u \times U(3)_d = \mathcal{G}_F \times U(1)_B \times U(1)_Y} + \underbrace{\bar{Q}_i Y_u^{ij} u_j H + \bar{Q}_i Y_d^{ij} d_j \tilde{H}}_{\cancel{\mathcal{G}}_F}$$

$$\mathcal{G}_F = SU(3)_Q \times SU(3)_u \times SU(3)_d$$

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To construct the MFV NP Operators \Rightarrow Spurion Technique:

- Introduce Yukawa *formal* transformations $Y_{u,d} \rightarrow V_Q Y_{u,d} V_{u,d}^\dagger$
- Require formal invariance under the flavor group \mathcal{G}_F .

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Dipole

Contact

Suppressed by Y_d

$$\frac{1}{\Lambda_{NP}^2} \times \bar{Q} Y_u Y_u^\dagger Q \cdot (D_\mu F^{\mu\nu}); \quad \bar{Q} Y_u Y_u^\dagger Q \cdot (\bar{Q} Q); \quad \bar{d} Y_d^\dagger Y_u Y_u^\dagger Q \cdot (\bar{Q} Q)$$

MFV in the Lepton Sector

[V. Cirigliano et al. NPB 728 (2005) 121; V. Cirigliano and B. Grinstein, NPB752, 18 (2006)]

[R. Alonso et al., JHEP 1106, 037 (2011), [arXiv:1103.5461].]

$$\boxed{\text{SM:}} \quad \underbrace{\bar{l}_i \not{D} l_i + \bar{e}_i \not{D} e_i}_{U(3)_\ell \times U(3)_e = \mathcal{G}_F^{SM} \times U(1)_L} \quad + \quad \underbrace{\bar{l}_i Y_e^{ij} e_j H}_{U(1)_e \times U(1)_\mu \times U(1)_\tau} \quad \Rightarrow$$

The SM Lepton sector is incomplete $\left[\begin{array}{l} \text{no } \nu\text{-masses} \\ \text{no } \nu\text{-oscillat.} \end{array} \right]$. A choice for a specific SM extension must be made:

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$$\underbrace{\bar{\ell} \not{D} \ell + \bar{e} \not{D} e}_{U(3)_\ell \times U(3)_e} + \underbrace{\bar{N} \not{D} N}_{\text{Kinetic}} + \underbrace{\bar{\ell}_i Y_e^{ij} e_j H + \bar{\ell}_i Y_\nu^{ij} N_j \tilde{H}}_{\mathcal{G}_F} + \frac{1}{2} \underbrace{\mu_L \bar{N}_i^c Y_M^{ij} N_j}_{\text{Majorana}}$$

$U(3)_\ell \times U(3)_e \times U(3)_N = \mathcal{G}_F \times U(1)_L$
 ~~\mathcal{G}_F~~
 ~~$U(1)_L$~~

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3 spurions $Y_e, Y_\nu, Y_M \implies$ The leading MLFV effective terms:

$$\Delta_8^{(1)} = Y_\nu Y_\nu^\dagger, \quad \Delta_6 = Y_\nu Y_M^\dagger Y_\nu^T, \quad \Delta_8^{(2)} = Y_\nu Y_M^\dagger Y_M Y_\nu^\dagger, \quad Y_e \Delta, \quad \dots$$

Predictivity: Y_ν, Y_M (18) $\Leftrightarrow m_\nu, U_{\text{PMNS}}$ (9)

Two ansatzs can match No. LFV paramts to No. observables:

$$1) Y_M \propto I_{3 \times 3}$$

Reduced symmetry: $SU(3)_N \rightarrow SO(3)_N \times CP$

[V. Cirigliano, B. Grinstein, G. Isidori, M.B. Wise, NPB 728 (2005) 121]

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$$U = U_{\text{PMNS}}$$

2) $Y_\nu \propto \mathcal{U}_Y$ (Unitary)

Symmetry: $SU(3)_N \times SU(3)_\ell \rightarrow SU(3)_{N+\ell}$

[R. Alonso, G. Isidori, L. Merlo, L. A. Munoz, EN, JHEP 1106, 037 (2011)]

$$\Delta_6 = \frac{v^2}{\mu_L} U \frac{1}{\mathbf{m}_\nu} U^T; \quad \Delta_8^{(2)} = \Delta_6 \cdot \Delta_6^\dagger = \frac{v^4}{\mu_L^2} U \frac{1}{\mathbf{m}_\nu^2} U^\dagger \quad \Delta_8^{(1)} = I_{3 \times 3}$$

- The second scenario (2) allows for CP .
- Non-Abelian symmetries for TBM imply $Y_\nu^0 \propto \mathcal{U}_Y$ at LO.

[E. Bertuzzo, P. Di Bari, F. Feruglio, EN, JHEP 0911:036, (2009)]

MLFV Operators: $l \rightarrow l' \gamma$; $\mu + A \rightarrow e + A$; $l \rightarrow 3l'$

$l \rightarrow l' \gamma$ ($\mu \rightarrow e$; $l \rightarrow 3l'$) (On-shell photonic operators only)

$$O_{RL}^{(1)} = g' H^\dagger \bar{e}_R \sigma^{\mu\nu} \lambda_e \Delta \ell_L \cdot B_{\mu\nu}$$

$$O_{RL}^{(2)} = g H^\dagger \bar{e}_R \sigma^{\mu\nu} \tau^a \lambda_e \Delta \ell_L \cdot W_{\mu\nu}^a$$

$$B(\mu \rightarrow eee) \simeq \frac{1}{160} B(\mu \rightarrow e\gamma)$$

$$\frac{\Gamma(\mu Ti \rightarrow eTi)}{\Gamma(\mu Ti \rightarrow \text{capt})} \simeq \frac{1}{240} B(\mu \rightarrow e\gamma)$$

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$\mu + A \rightarrow e + A$ (off-shell photonic; 4-fermions contact, LO)

$$O_{LL}^{(1)} = \bar{\ell}_L \gamma^\mu \Delta \ell_L \cdot (H^\dagger i D_\mu H)$$

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$l \rightarrow l' l'' l'''$ (4-leptons contact, LO)

$$O_{4L}^{(1)} = \bar{l}_L \gamma^\mu \Delta l_L \cdot (\bar{l}_L \gamma_\mu l_L)$$

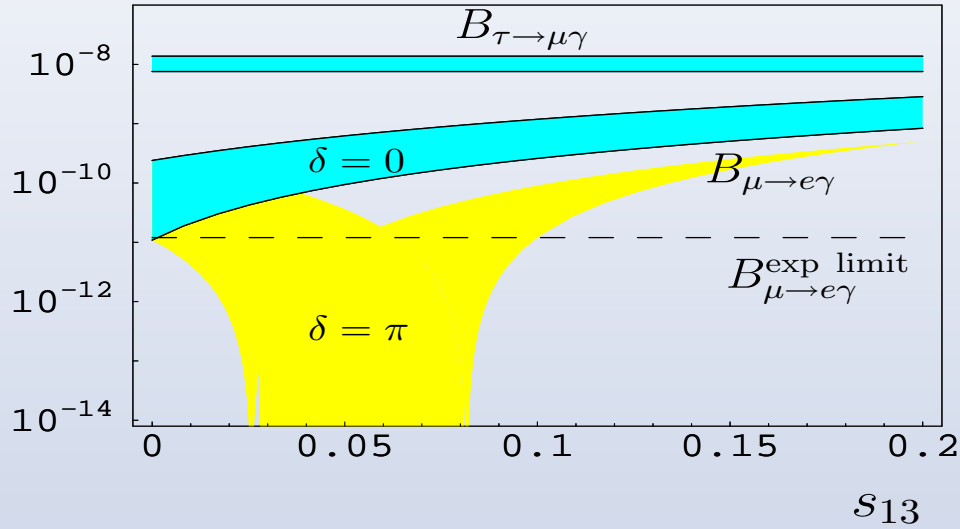
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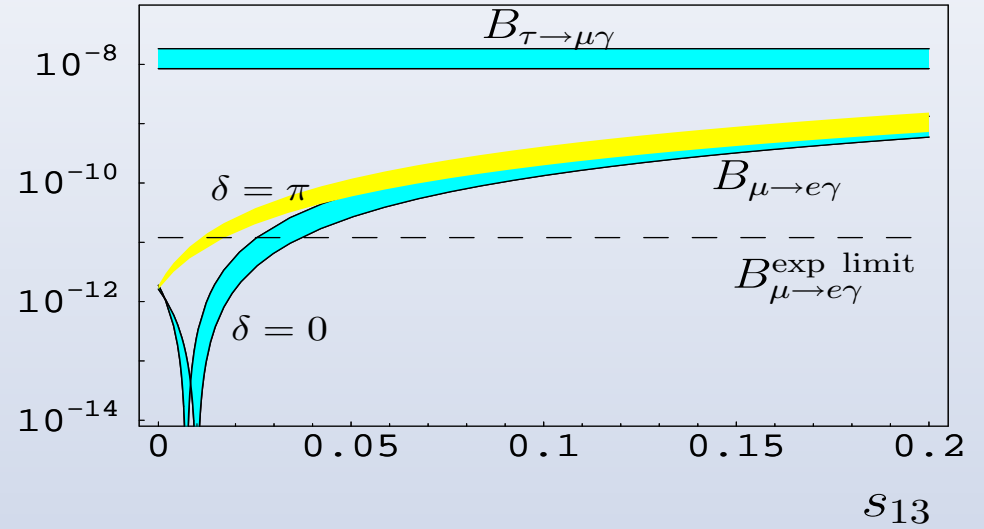
MLFV Predictions: $l \rightarrow l' \gamma$; $\mu + A \rightarrow e + A$; $l \rightarrow 3l'$

Case 1. $B_{\tau \rightarrow \mu \gamma}$ and $B_{\mu \rightarrow e \gamma}$ for $v \mu_L / \Lambda_{NP}^2 = 5 \times 10^7$ as a function of s_{13} .

NORMAL



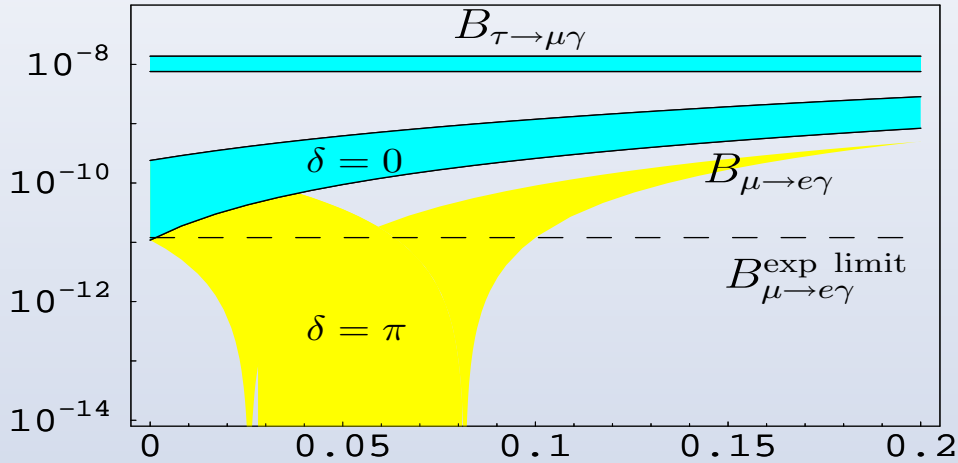
INVERTED



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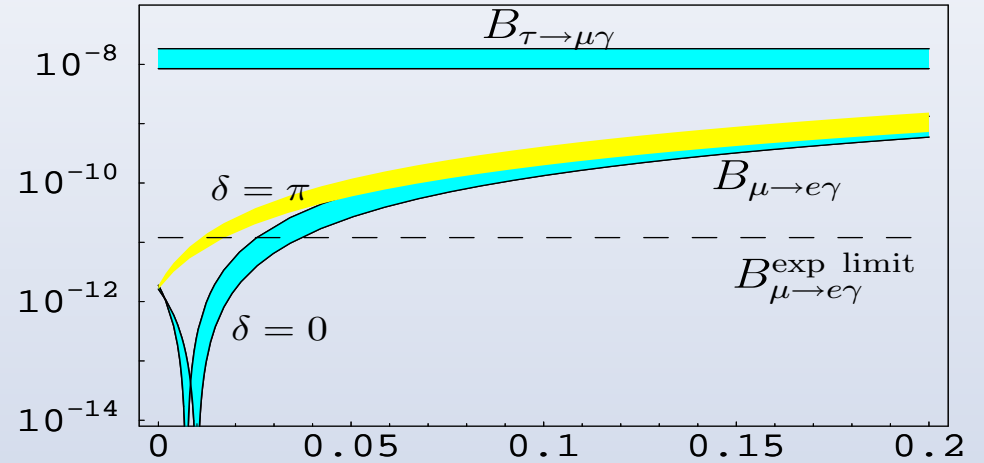
NORMAL



$m_{\nu}^{\text{lightest}} = 0$

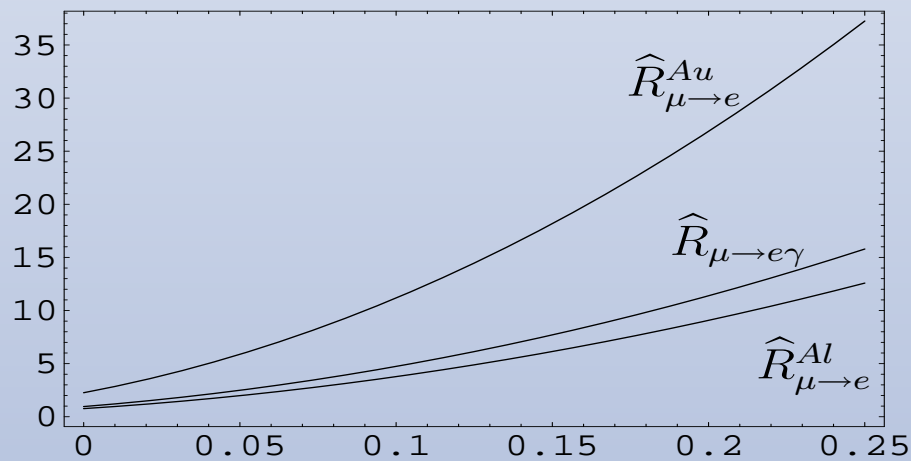
s_{13}

INVERTED



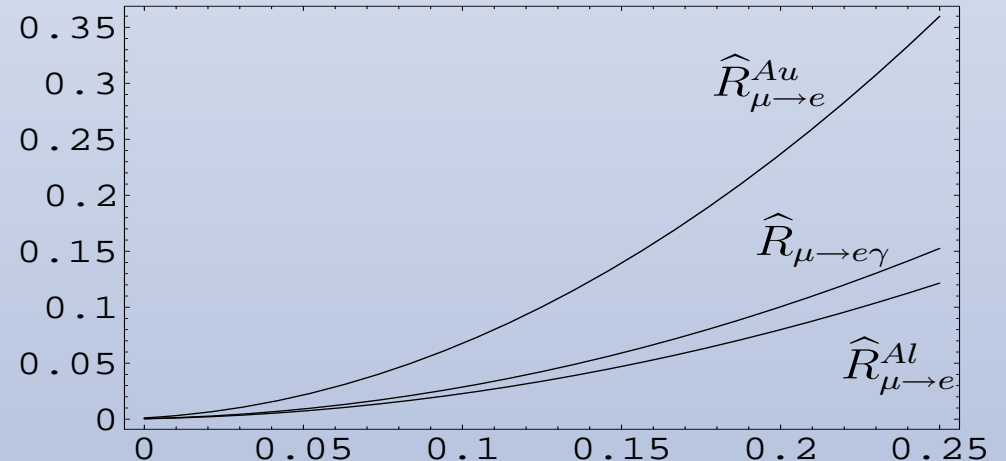
$m_{\nu}^{\text{lightest}} = 0.2 \text{ eV}$

s_{13}



Vertical units $\times \sim 2 \cdot 10^{-12}$ ($\delta = 0$)

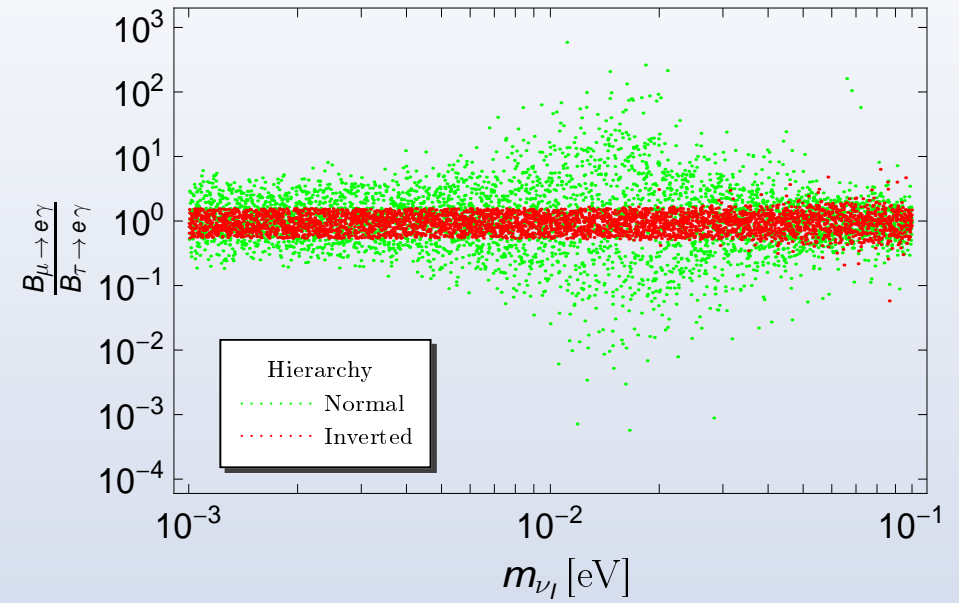
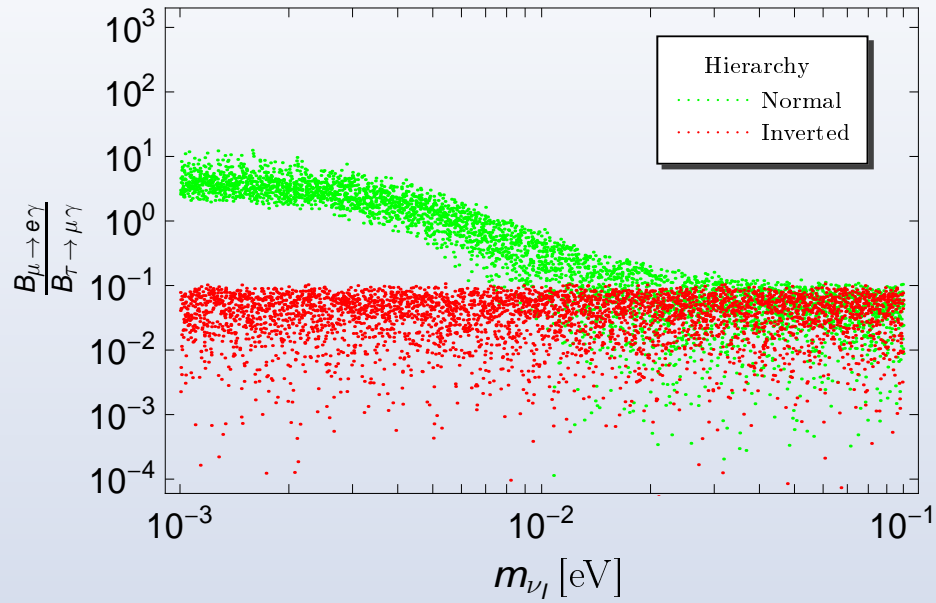
s_{13}



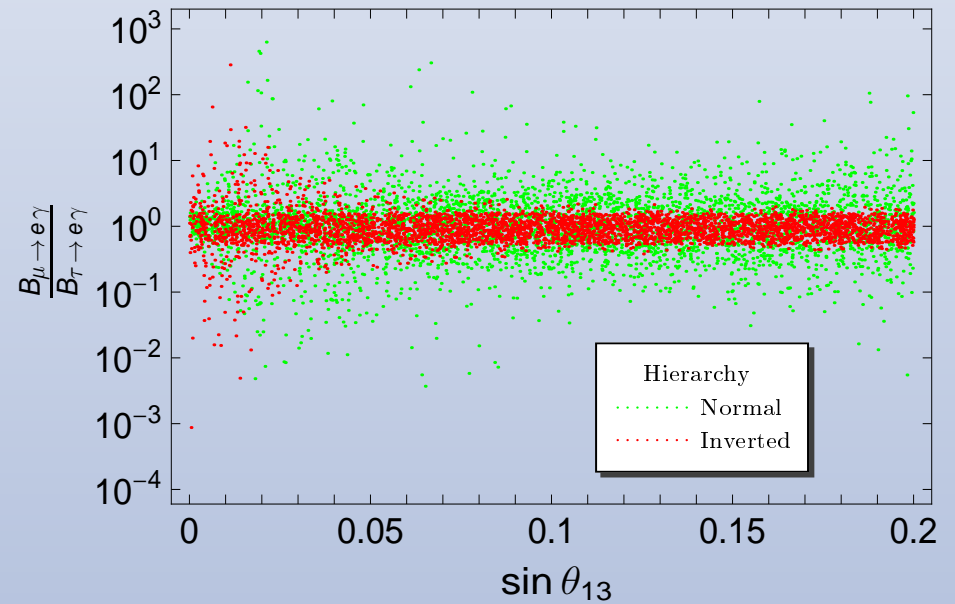
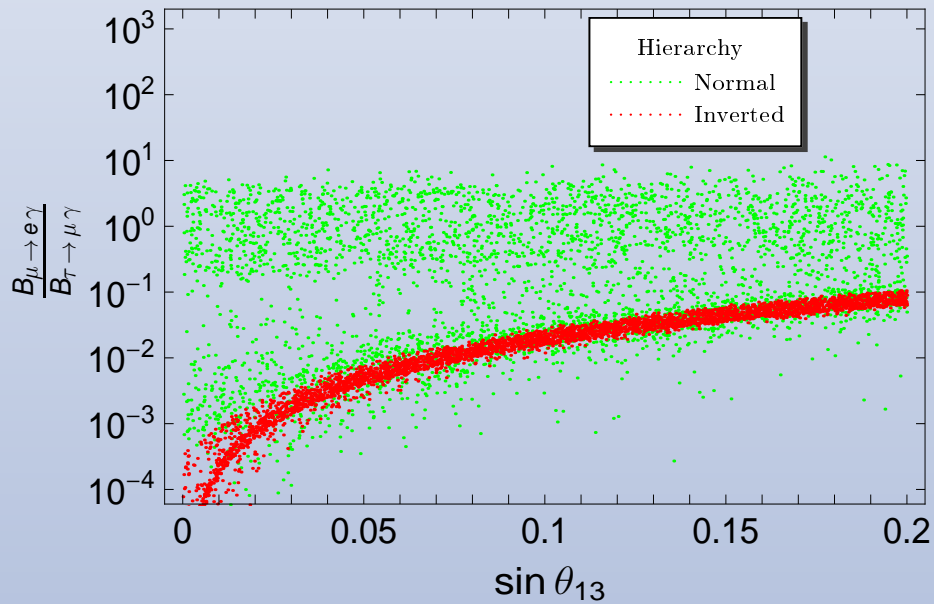
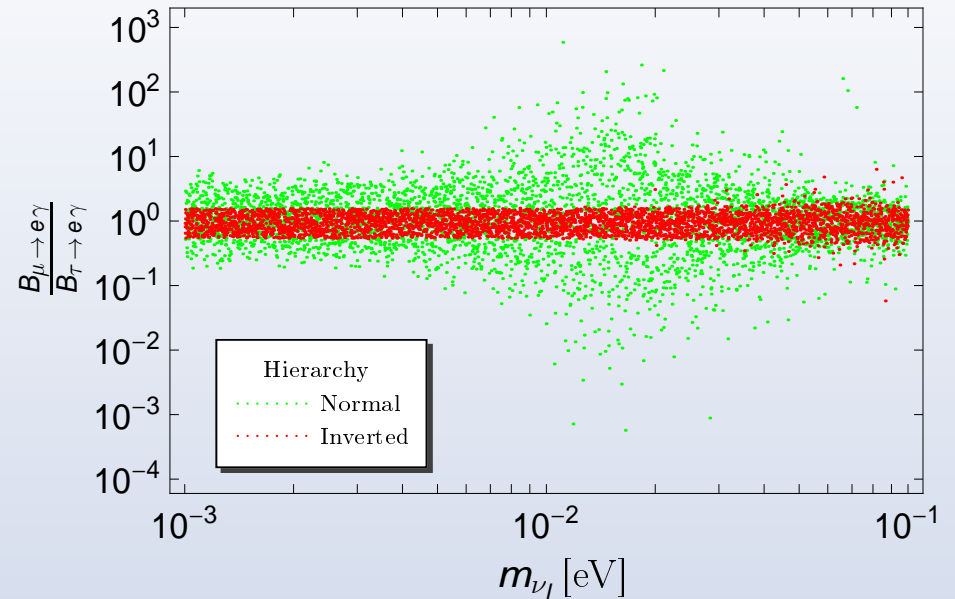
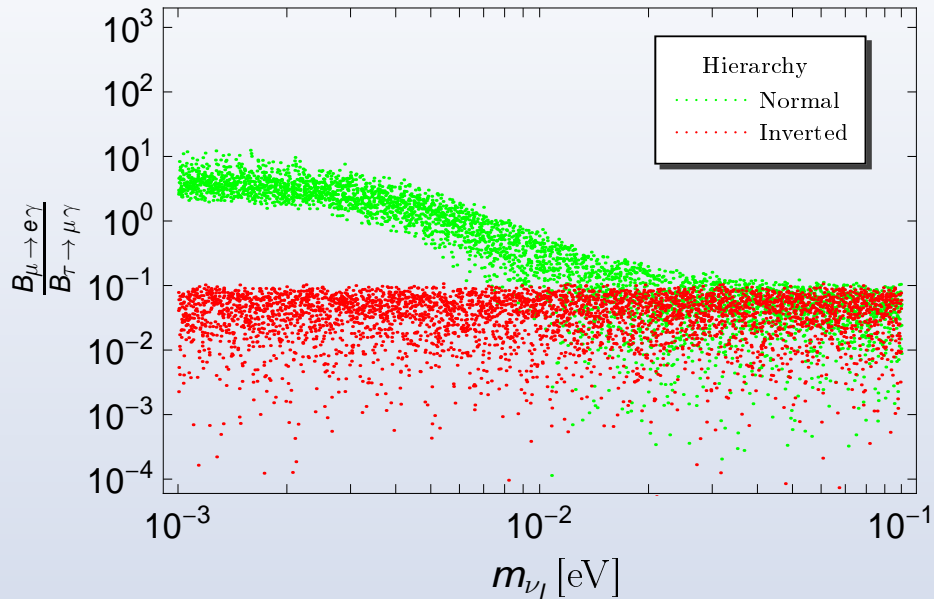
(Ti $4 \cdot 10^{-12}$; Au $7 \cdot 10^{-13}$)

s_{13}

MLFV Predictions (Case 2): $\frac{B_{\mu \rightarrow e \gamma}}{B_{\tau \rightarrow \mu \gamma}}$; $\frac{B_{\mu \rightarrow e \gamma}}{B_{\tau \rightarrow e \gamma}}$

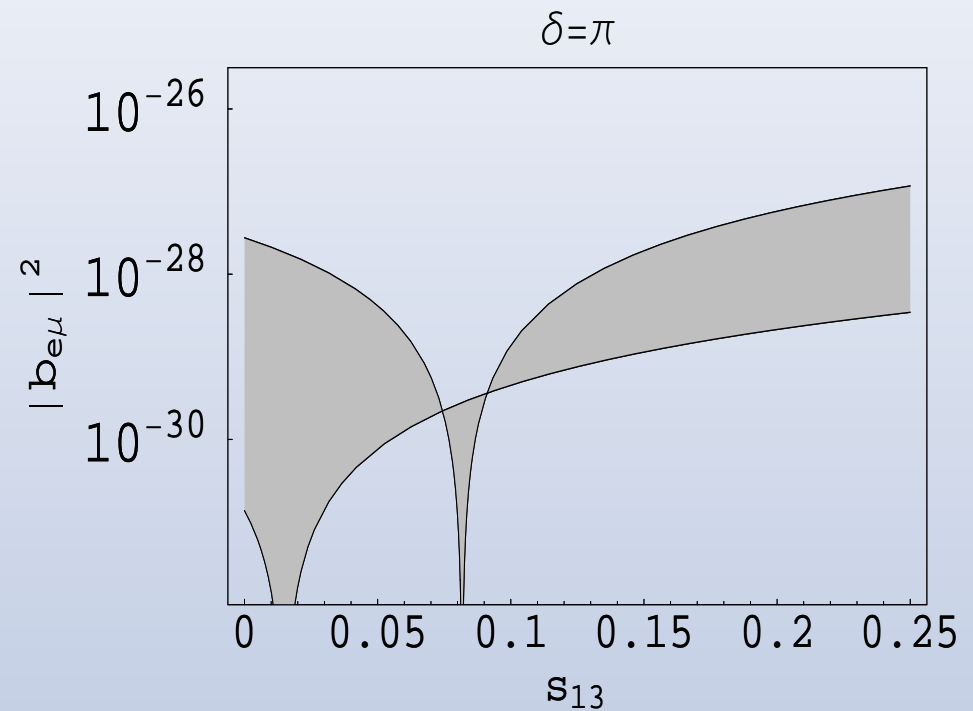
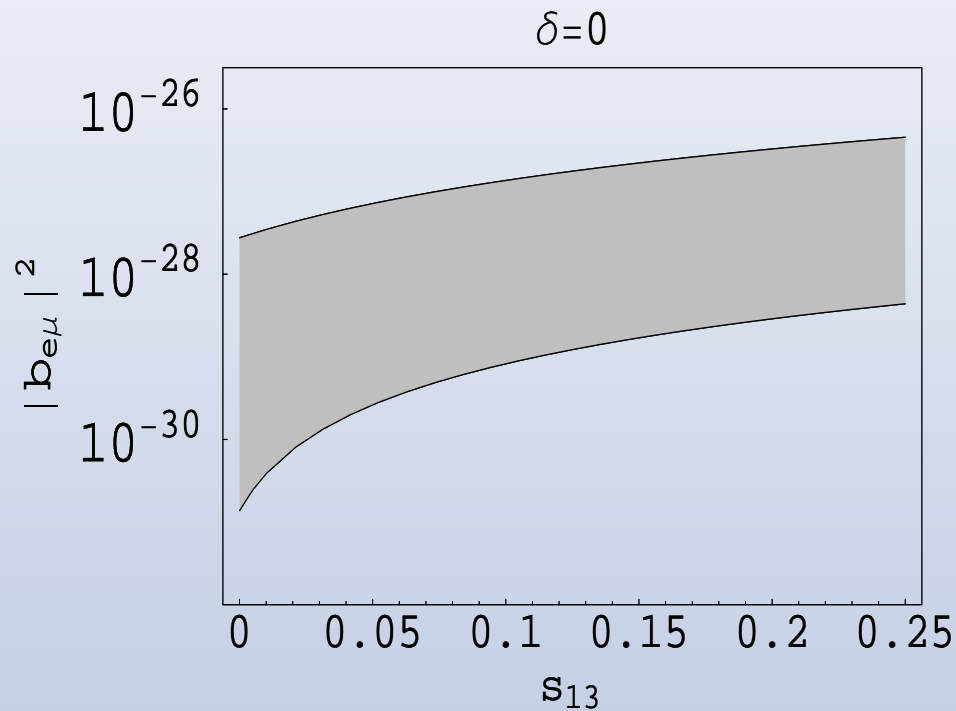


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MLFV Predictions (Case 1): $\frac{\Gamma_{\mu \rightarrow 3e}}{\Gamma_{\mu \rightarrow e\nu\bar{\nu}}}$

$$\frac{\Gamma_{\mu \rightarrow 3e}}{\Gamma_{\mu \rightarrow e\nu\bar{\nu}}} = (\text{Wilson Coeff.}) \times \left(\frac{v\mu_L}{\Lambda_{NP}^2} \right)^2 \times |b_{e\mu}|^2 \sim (10^{14} - 10^{16}) \times |b_{e\mu}|^2$$



$B_{\mu \rightarrow 3e}$ for normal neutrino mass hierarchy and $\delta = 0, \pi$.

Shaded band: $0 \leq m_\nu^{\min} \leq 0.2 \text{ eV}$ (Upper edge: $m_\nu^{\min} = 0$)

CONCLUSIONS

- MFV is a **reasonable guess** about the behaviour of TeV scale NP with respect to FV.
- In the lepton sector, a **double guess** is needed: a specific SM extension to account for ν masses has to be assumed first.
- Contrary to common belief, MLFV **does not imply** suppression of the LFV processes involving the lightest generations with respect to the heavy ones.
- The LFV processes $\ell \rightarrow \ell' \gamma$, μ - e conversion, $\ell \rightarrow 3\ell'$, are sensitive to different NP operators, and thus provide **complementary informations**.