“What is ν ?”

GGI Workshop – Arcetri, Firenze – July 13, 2012

LFV in Minimal Flavor Violation extensions of the seesaw

(Type-I seesaw with 3 RH neutrinos)

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Based mainly on:

– R. Alonso, G. Isidori, L. Merlo, L. A. Muñoz, EN JHEP06(2011)037 [arXiv:1103.5461]
– V. Cirigliano, B. Grinstein, G. Isidori, M. B. Wise, NPB728(2005) [hep-ph/0507001]
– EN, NPB (Pr. S.) 2257(2012)236 [arXiv:1112.4418]

Why Charged Lepton Flavor Violation (cLFV)?

- 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 also cLFV.
- However, in the simplest extensions (Dirac ν, SM+seesaw) cLFV remains unobservable (below the $\mathcal{O}(10^{-50})$ level).
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However, according to an old theoretical prejudice:

there ~~is~~ was New Physics around the TeV scale

since NP is needed to cure the SM naturalness problem.

The flavor problem

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

Possible ways out (apart from $\mathbf{\Lambda_{NP}} \gtrsim \mathcal{O}(\mathbf{10^5})$ TeV)

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

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

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

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To construct the MFV NP Operators $\Rightarrow$ Spurion Technique:

- Introduce Yukawa *formal* transformations $Y_{u,d} \to V_Q Y_{u,d} V_{u,d}^\dagger$
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	Dipole	*Contact*	*Suppressed by Y_d*
$\frac{1}{\Lambda_{NP}^2} \times$	$\bar{Q} \, Y_u Y_u^\dagger Q \cdot (D_\mu F^{\mu\nu})$;	$\bar{Q} \, Y_u Y_u^\dagger Q \cdot (\bar{Q} Q)$;	$\bar{d} \, Y_d^\dagger Y_u Y_u^\dagger Q \cdot (\bar{Q} Q)$

MFV in the Lepton Sector

[V. Cirigliano et al. NPB 728 (2005) 121; V. Cirigliano and B. Grinstein, NPB752, 18 (2006)]
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SM: $$\underbrace{\bar{\ell}_i \not{D}_\ell \ell_i + \quad \bar{e}_i \not{D}_e e_i}_{U(3)_\ell \times U(3)_e = \mathcal{G}_F^{SM} \times U(1)_L} \quad + \quad \underbrace{\bar{\ell}_i \, Y_e^{ij} e_j \, H}_{U(1)_e \times U(1)_\mu \times U(1)_\tau}$$

$$\Longrightarrow$$

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

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SM + seesaw:

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

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3 spurions Y_e, Y_ν, Y_M $\Rightarrow$ The leading MLFV effective terms:

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

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

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

1) $Y_M \propto I_{3\times 3}$ Reduced symmetry: $SU(3)_N \to SO(3)_N \times CP$

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2) $Y_\nu \propto \mathcal{U}_Y$ (Unitary) Symmetry: $SU(3)_N \times SU(3)_\ell \to SU(3)_{N+\ell}$

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

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

– This second scenario (2) allows for $\not{CP}$.
– Non-Abelian symmetries ($\Rightarrow$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: $\ell \to \ell' \gamma$; $\mu + A \to e + A$; $\ell \to 3\ell'$

$\ell \to \ell' \gamma$ $(\mu\text{–}e;\ \ell \to 3\ell')$ (On-shell photonic operators only)

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

$$O^{(2)}_{RL} = g H^\dagger \bar{e}_R \sigma^{\mu\nu} \tau^a \lambda_e \Delta\, \ell_L \cdot W^a_{\mu\nu}$$

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

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

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

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

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$$O_{LL}^{(4u)} = \bar{\ell}_L \gamma^\mu \Delta\, \ell_L \cdot \left(\bar{u}_R \gamma_\mu u_R\right)$$

$$O_{LL}^{(5)} = \bar{\ell}_L \gamma^\mu \tau^a \Delta\, \ell_L \cdot \left(\bar{Q}_L \gamma_\mu \tau^a Q_L\right)$$

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$\ell \to \ell'\ell''\ell'''$ (4-leptons contact, LO)

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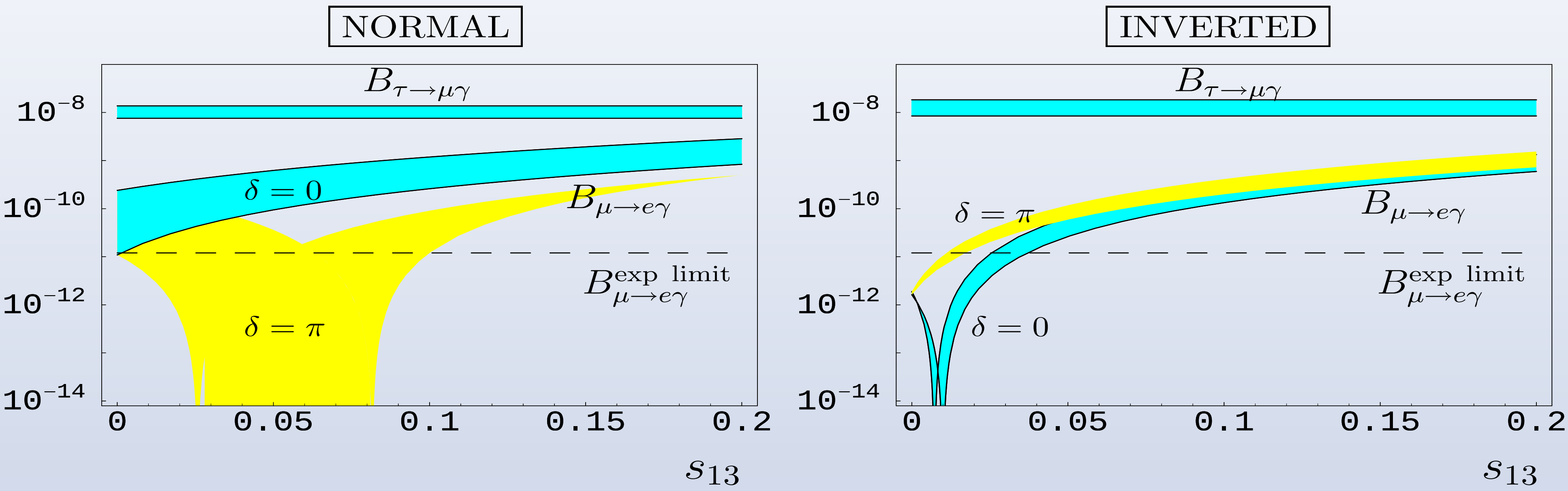
Case 1. $B_{\tau\to\mu\gamma}$ and $B_{\mu\to e\gamma}$ for $v\mu_L/\Lambda^2_{NP} = 5\times 10^7$ as a function of s_{13}.



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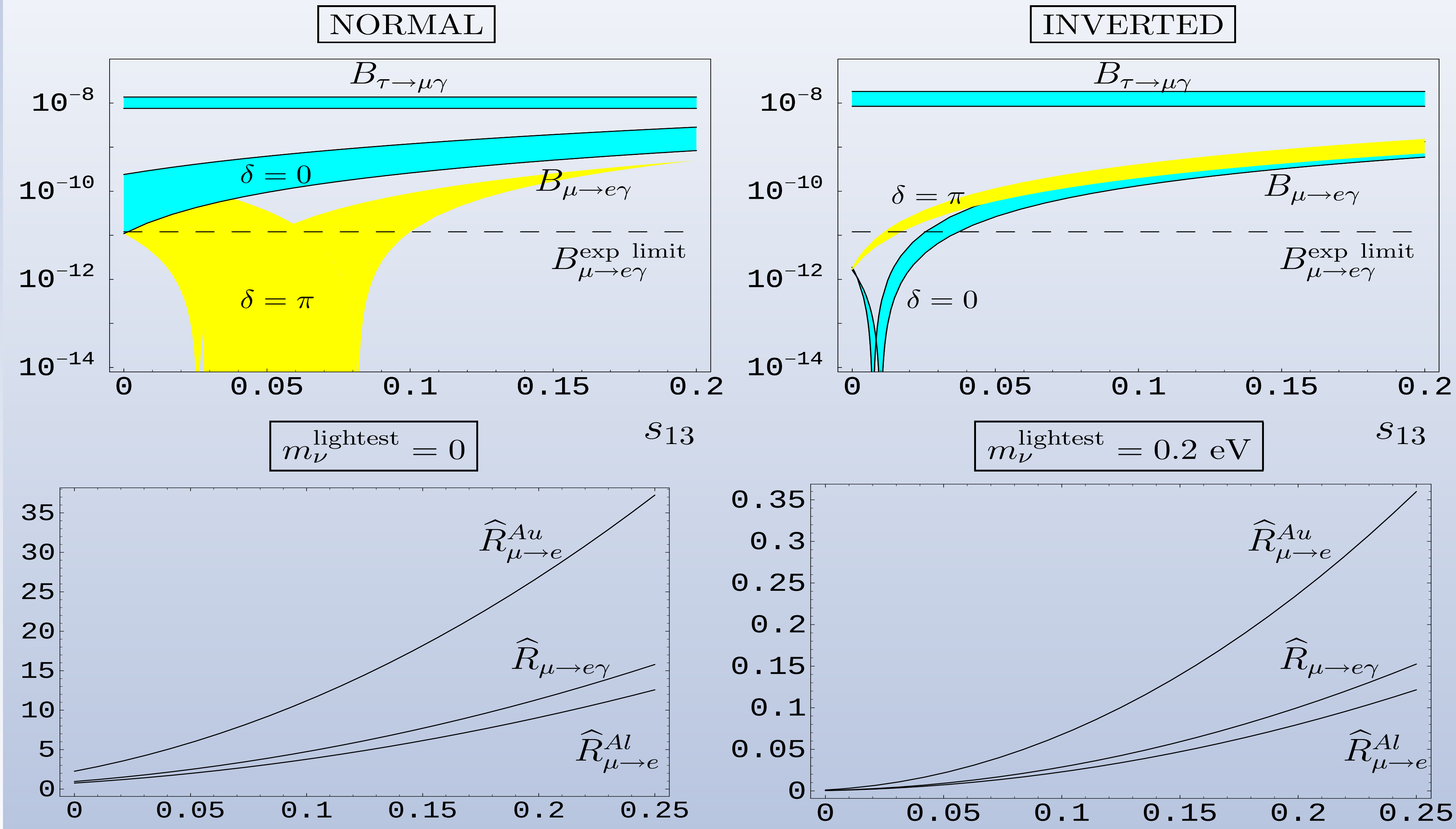
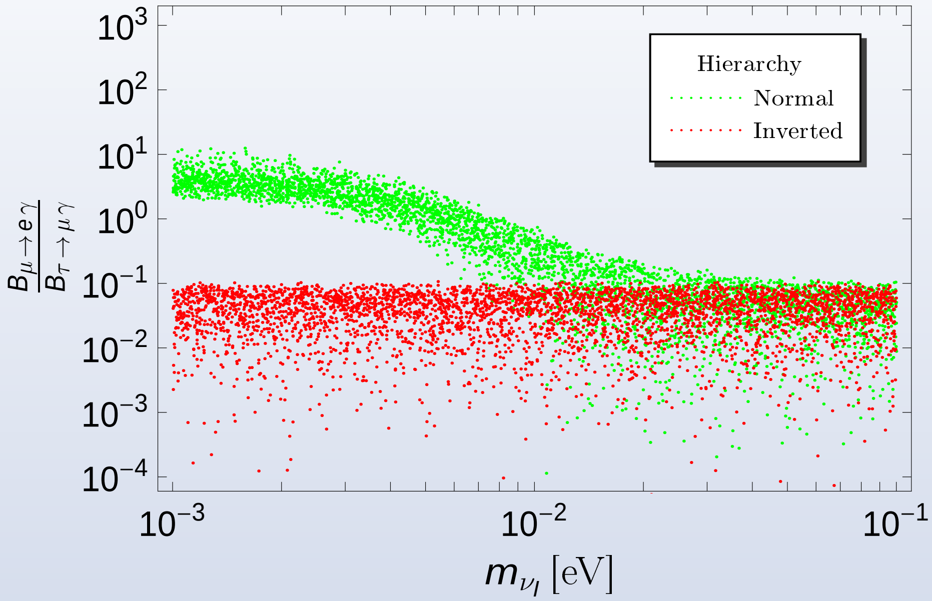
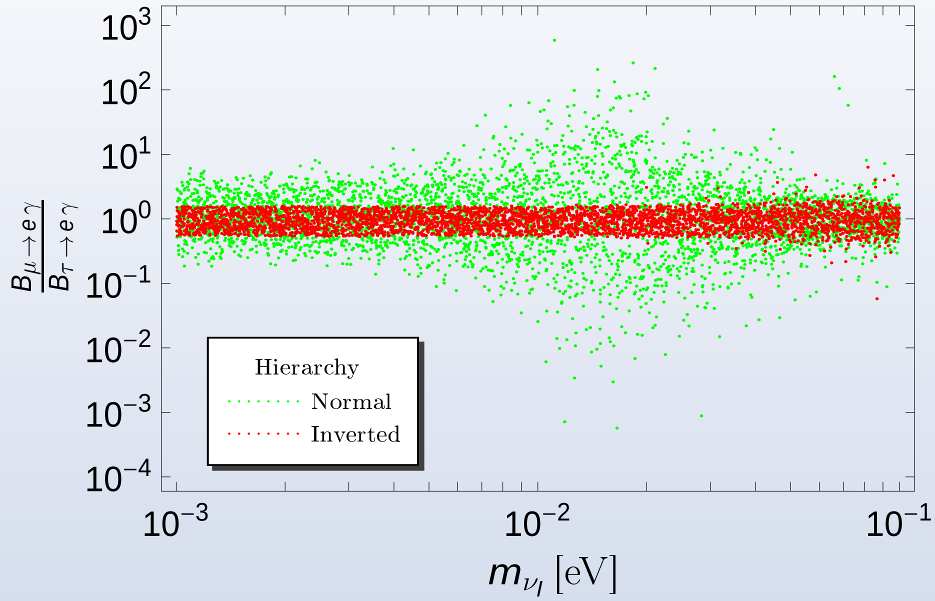


Veritical units $\times \sim 2 \cdot 10^{-12}$ ($\delta = 0$) (Ti $4 \cdot 10^{-12}$; Au $7 \cdot 10^{-13}$)

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





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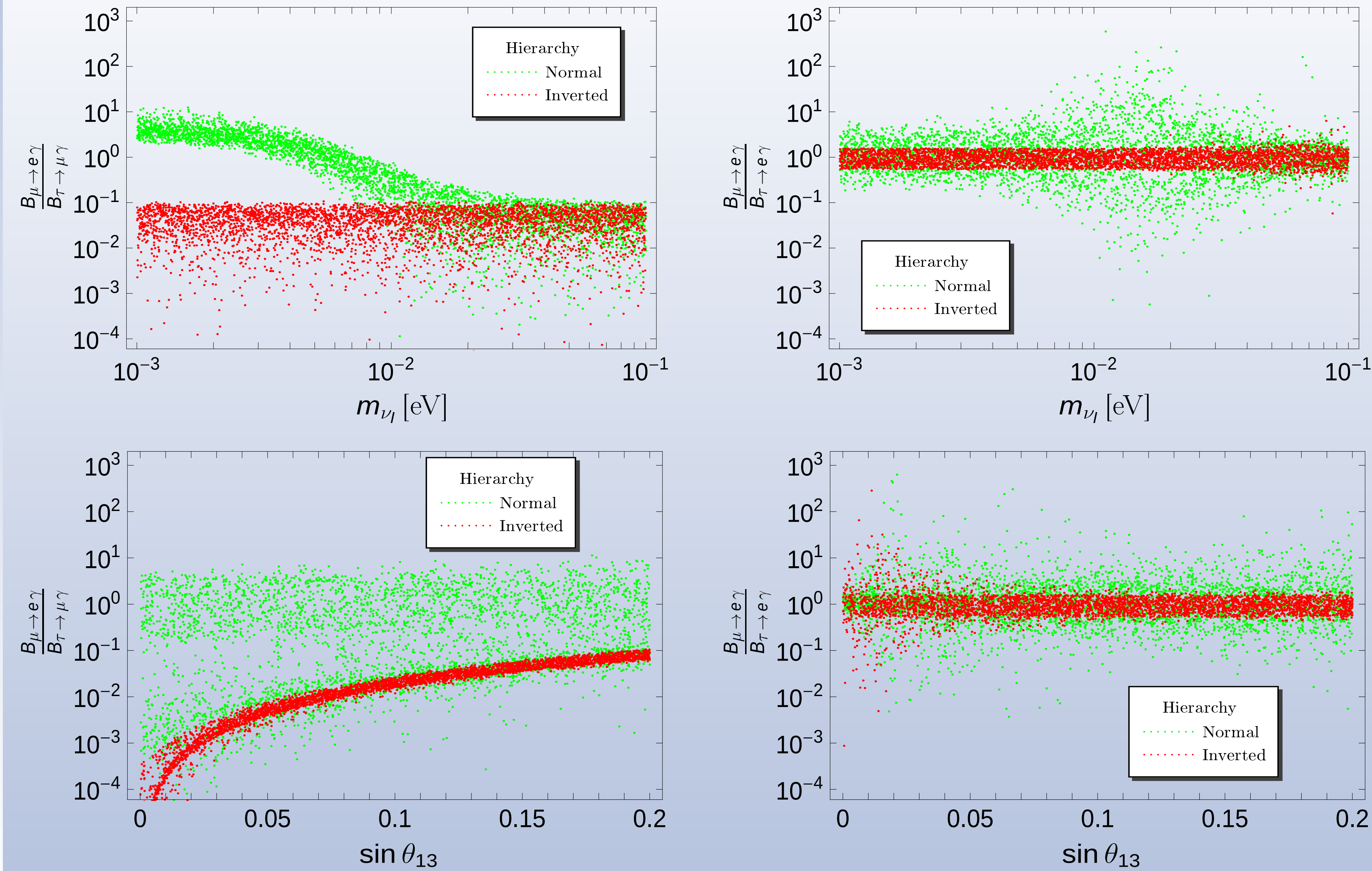
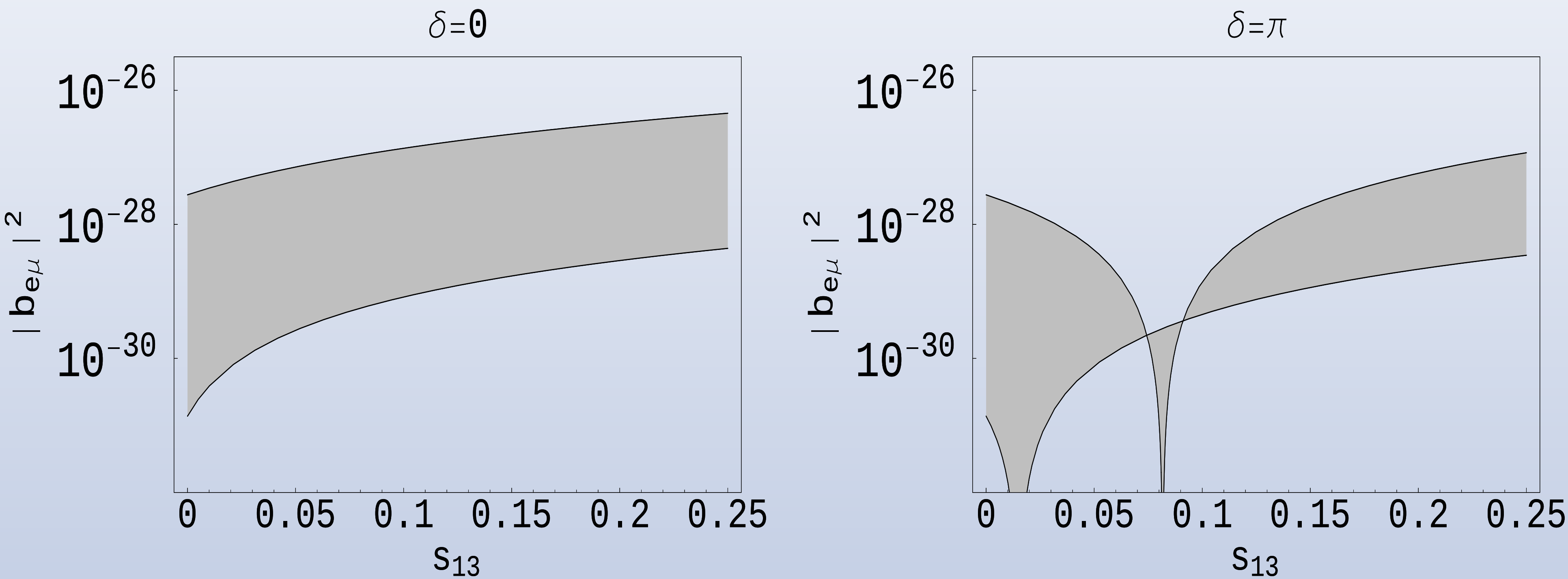


MLFV Predictions (Case 1): $\frac{\Gamma_{\mu\to 3e}}{\Gamma_{\mu\to e\nu\bar{\nu}}}$

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



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

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

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- Even with MFV, experimental constraints on FCNC & LFV imply $\Lambda_{NP} > (\gg) 10$ TeV. (Is the original motivation for MFV matched ?)
- As a general remark, the LFV processes $\ell \to \ell' \gamma$, μ-e conversion, $\ell \to 3\ell'$, are sensitive to different NP operators, and thus provide complementary informations.