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Waiting for $\mu \to e\gamma$ from the MEG experiment

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Abstract: The Standard Model (SM) predictions for the lepton flavor-violating (LFV) processes like $\mu \to e\gamma$ are well far from any realistic experimental resolution, thus, the appearance of $\mu \to e\gamma$ at the running MEG experiment would unambiguously point towards a New Physics (NP) signal. In this article, we discuss the phenomenological implications in case of observation/improved upper bound on $\mu \to e\gamma$ at the running MEG experiment for supersymmetric (SUSY) scenarios with a see-saw mechanism accounting for the neutrino masses. We outline the role of related observables to $\mu \to e\gamma$ in shedding light on the nature of the SUSY LFV sources providing useful tools *i)* to reconstruct some fundamental parameters of the neutrino physics and *ii)* to test whether an underlying SUSY Grand Unified Theory (GUT) is at work. The perspectives for the detection of LFV signals in τ decays are also discussed.

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Contents

1 Introduction

It is a well established fact that the Standard Model (SM) of the elementary particles represents a very satisfactory model accounting for all the observed phenomena, both in (flavor-conserving) electroweak (EW) physics at the LEP/SLC and also in low-energy flavor physics.

There are only few exceptions, as the anomalous magnetic moment $(g-2)$ of the muon and some low-energy CP-violating observables measured at the B factories that could indicate that the SM might not be sufficient to describe them. Unfortunately, the hadronic uncertainties as well as the limited experimental resolutions on flavor-changing neutral current (FCNC) data prevent any conclusive evidence of New Physics (NP) effects in the quark sector.

In this respect, the FCNC phenomenology in the leptonic sector may be more promising. In fact, neutrino physics has provided unambiguous indications about the non-conservation of the lepton flavor, we therefore expect this phenomenon to occur also in the charged-lepton sector.

Interestingly, the charged LFV processes, such as $\mu \to e\gamma$, are severely suppressed in the SM (with finite, but tiny neutrino masses) due to the GIM mechanism [1], hence, their observation would unambiguously point towards a NP signal arising from an underlying NP theory operating at an energy scale not much above the TeV scale. Similarly, also the leptonic EDMs represent very powerful and clean probes of NP effects because of their high NP sensitivity and since their SM predictions are well far from any realistic experimental resolution. (See ref. [2] for a recent review about the charged LFV processes and the EDMs.)

Despite of the great success of the SM, there is a general consensus that the SM has to be regarded as an effective field theory, valid up to some still undetermined cut-off scale Λ above the EW scale. Theoretical arguments based on a natural solution of the hierarchy problem suggest that Λ should not exceed a few TeV, an energy scale that would be explored at the upcoming LHC.

Supersymmetric (SUSY) extensions of the SM are broadly considered as the most natural and well motivated scenario beyond the SM. Interestingly enough, the marriage of supersymmetry and a see-saw mechanism [3–7], accounting for the observed neutrino masses and mixing angles, naturally leads to predictions for LFV processes as $\mu \to e\gamma$ well within the experimental resolutions of the running MEG experiment at the PSI [8].[1]

In this article, we discuss the implications of a potential evidence (or improved upper bound) of $\mathrm{BR}(\mu \to e\gamma)$ at the expected sensitivities of MEG, namely at the level of $\mathrm{BR}(\mu \to e\gamma) \gtrsim 10^{-13}$ [8].

Assuming a supersymmetric framework, we exploit the correlations among $\mathrm{BR}(\mu \to e\gamma)$, the leptonic electric dipole moments (EDMs) and the SUSY effects to the $(g-2)$ of the muon. In case $\mu \to e\gamma$ will be observed, we outline the complementary role played by the leptonic EDMs and the P-odd asymmetry in $\mu^+ \to e^+\gamma$ to shed light on the nature of the LFV source. Moreover, the perspectives for the observation of LFV signals in τ decays are also discussed.

Finally, since the ultimate proof for the existence of SUSY theories will pass through the direct production of SUSY particles at the LHC experiments, we exploit the synergy and interplay of the LHC data with the potential LFV signals from low-energy experiments. In particular, assuming the relevant SUSY spectrum is known, we outline the crucial role of low energy observables in understanding the symmetry properties of the SUSY model at work in its flavour sector.

2 SUSY LFV and $\mathrm{BR}(\ell_i \to \ell_j\gamma)$

Low-energy SUSY models generally contain new sources of flavor-violation in the soft-breaking parameters. In particular, LFV effects relevant to charged leptons originate from any misalignment between fermion and sfermion mass eigenstates [3–7, 11–15]. Once non-vanishing LFV entries in the slepton mass matrices are generated, irrespective to the underlying mechanism accounting for them, LFV rare decays like $\ell_i \to \ell_j\gamma$ are naturally induced by one-loop diagrams with the exchange of gauginos and sleptons.

In particular, the decay $\ell_i \to \ell_j\gamma$ is described by the dipole operator,

$$\mathcal{L}_{\rm eff} = e\frac{m_i}{2}\bar{l}_i\sigma_{\mu\nu}F^{\mu\nu}\left(A_L^{l_il_j}P_L + A_R^{l_il_j}P_R\right)l_j + h.c., \tag{2.1}$$

and the decay rate is given by

$$\frac{\mathrm{BR}(\ell_i \to \ell_j\gamma)}{\mathrm{BR}(\ell_i \to \ell_j\nu_i\bar{\nu}_j)} = \frac{48\pi^3\alpha_{\rm em}}{G_F^2}\left(|A_L^{\ell_i\ell_j}|^2 + |A_R^{\ell_i\ell_j}|^2\right) . \tag{2.2}$$

[1]For early works on SUSY LFV processes not in the context of see-saw models, please see [9, 10].

In the case where all the SUSY particles are degenerate, with a common mass $\tilde{m}$, we find that

$$A_L^{\mu e} = \frac{\alpha_2}{4\pi}\frac{t_\beta}{\tilde{m}^2}\left[\frac{\delta_{\mu e}^L}{15} - \frac{\delta_{\mu\tau}^L\delta_{\tau e}^L}{40} - \frac{\alpha_Y}{\alpha_2}\frac{m_\tau}{m_\mu}\frac{\delta_{\mu\tau}^R\delta_{\tau e}^L}{30}\right], \tag{2.3}$$

$$A_L^{\tau\ell} = \frac{\alpha_2}{4\pi}\frac{t_\beta}{\tilde{m}^2}\frac{\delta_{\tau\ell}^L}{15}, \tag{2.4}$$

$$A_R^{\mu e} = -\frac{\alpha_Y}{4\pi}\frac{t_\beta}{\tilde{m}^2}\left[\frac{\delta_{\mu e}^R}{60} - \frac{\delta_{\mu\tau}^R\delta_{\tau e}^R}{60} + \frac{m_\tau}{m_\mu}\frac{\delta_{\mu\tau}^L\delta_{\tau e}^R}{30}\right], \tag{2.5}$$

$$A_R^{\tau\ell} = -\frac{\alpha_Y}{4\pi}\frac{t_\beta}{\tilde{m}^2}\frac{\delta_{\tau\ell}^R}{60}, \tag{2.6}$$

where $\tilde{m}$ is a typical SUSY mass running in the loop and $t_\beta = \tan\beta$ denotes the ratio of the two MSSM-Higgs vacuum expectation values (VEVs). Moreover, the mass insertion (MI) parameters $\delta_{\ell_i\ell_j}^{L/R}$ for the left/right-handed sleptons are defined as

$$\delta_{\ell_i\ell_j}^{L/R} = \frac{(m^2_{\tilde{L}/\tilde{R}})_{\ell_i\ell_j}}{\tilde{m}^2}. \tag{2.7}$$

Here, $(m^2_{\tilde{L}/\tilde{R}})$ is the left/right-handed slepton mass matrix.

Besides $\ell_i \to \ell_j\gamma$, there are also other promising LFV channels, such as $\ell_i \to \ell_j\ell_k\ell_k$ and μ-e conversion in nuclei, that could be measured with the upcoming experimental sensitivities. However, within SUSY models, these processes are dominated by the dipole transition $\ell_i \to \ell_j\gamma^*$ leading to the unambiguous prediction,

$$\begin{aligned} \mathrm{BR}(\ell_i \to \ell_j\ell_k\ell_k) &\sim \alpha_{\rm em} \times \mathrm{BR}(\ell_i \to \ell_j\gamma), \\ \mathrm{CR}(\mu \to e \text{ in N}) &\sim \alpha_{\rm em} \times \mathrm{BR}(\mu \to e\gamma). \end{aligned} \tag{2.8}$$

Thus, an experimental confirmation of the above relations would be crucial to prove the dipole nature of the LFV transitions.

Additional (sizable) contributions to LFV decays may arise from the Higgs sector through the effective LFV Yukawa interactions induced by non-holomorphic terms [16] hence, in general, the expectations of eq. (2.8) can be violated [17].

However, these effects become relevant only if $\tan\beta \sim \mathcal{O}(40-50)$ and if the Higgs masses are roughly one order of magnitude lighter then the slepton masses [17]. The last condition never occurs in our scenario hence Higgs mediated LFV effects are safely neglected in our analysis.

3 The MSSM with right-handed neutrinos

As is well known, generic low-energy SUSY models with arbitrary soft-breaking terms would induce unacceptably large flavor-violating effects. The unobserved departures from the SM in quark FCNC transitions point toward the assumption of Minimal Flavor Violation [18] or even flavor-universality in the SUSY-breaking mechanism. However, even under this

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assumption, sizable flavor-mixing effects may be generated at the weak scale by the running of the soft-breaking parameters from the (presumably high) scale of SUSY-breaking mediation [10]. In the leptonic sector, the relevance of such effects strongly depends on the assumptions about the neutrino sector. If the light neutrino masses are obtained via a see-saw mechanism, the induced flavor-mixing couplings relevant to LFV rates are naturally large [3–7].

Assuming a see-saw mechanism with three heavy right-handed neutrinos, the effective light-neutrino mass matrix obtained integrating out the heavy fields is

$$m_\nu = -Y_\nu \hat{M}^{-1} Y_\nu^T \langle H_u \rangle^2 \,, \tag{3.1}$$

where $\hat{M}$ is the 3×3 right-handed neutrino mass matrix (which breaks the lepton number conservation), Y_ν are the 3×3 Yukawa couplings between left- and right-handed neutrinos (the potentially large sources of LFV), and $\langle H_u \rangle$ is the up-type Higgs VEV. Here, we take a basis where $\hat{M}$ is diagonal. Hereafter, symbols with hat mean they are diagonal. Taking into account the renormalization-group evolution (RGE), the slepton mass matrix $(m^2_{\tilde{L}})$ acquires LFV entries given by

$$(m^2_{\tilde{L}})_{ij} \simeq -\frac{3m_0^2 + A_0^2}{8\pi^2} (Y_\nu)_{ik} (Y_\nu^\star)_{jk} \ln\left(\frac{M_X}{M_k}\right) \,, \tag{3.2}$$

with $i \neq j$ and M_X denotes the scale of SUSY-breaking mediation while m_0 and A_0 stand for the universal SUSY breaking scalar mass and trilinear coupling at M_X, respectively. Here, we assume M_X is higher than the right-handed neutrino mass scale. Starting from eq. (3.1), Y_ν can be written in the general form [14] $Y_\nu = U\sqrt{\hat{m}_\nu} R \sqrt{\hat{M}}/\langle H_u \rangle$ where R is an arbitrary complex orthogonal matrix while U is the MNS matrix.

The MNS matrix contains three low-energy CP violating phases, the Dirac phase δ and two Majorana phases α and β. We use the standard parameterization [19]:

$$U \approx \begin{pmatrix} c_{13}c_{12} & s_{12}c_{13} & s_{13}\, e^{-i\delta} \\ -s_{12}c_{23} & c_{23}c_{12} & s_{23}c_{13} \\ s_{23}s_{12} & -s_{23}c_{12} & c_{23}c_{13} \end{pmatrix} \times \mathrm{diag}(e^{i\alpha}, e^{i\beta}, 1) \,, \tag{3.3}$$

where $c_{12} = \cos\theta_{12}$, $s_{12} = \sin\theta_{12}$, $c_{23} = \cos\theta_{23}$, $s_{23} = \sin\theta_{23}$, $c_{13} = \cos\theta_{13}$ and $s_{13} = \sin\theta_{13}$ with $s_{13} \lesssim 0.1$ (see table 1). In eq. (3.3), we have systematically neglected all the subleading terms proportional to s_{13} but in the U_{e3} matrix element where s_{13} provides the leading contribution. The Majorana phases α and β are neglected in the following, except for the cases in which they are relevant. A complete determination of $(m^2_{\tilde{L}})_{i\neq j}$ would require a complete knowledge of the neutrino Yukawa matrix Y_ν, which is not possible using only low-energy observables from the neutrino sector.[2] This is in contrast with the quark sector,

[2]However, the marriage of the LHC data with potential LFV signals from low-energy experiments, could provide additional tools to determine Y_ν. In particular, the off-diagonal terms in $(m^2_{\tilde{L}})_{ij} \sim (Y_\nu Y_\nu^\dagger)_{ij}$ could be extracted from the branching ratios of LFV processes, as long as the relevant SUSY spectrum is known. Then, the knowledge of both $(m^2_{\tilde{L}})_{ij}$ and the light neutrino mass matrix might allow the determination of some parameters of the see-saw mechanism [20].

Best fit values for light neutrinos
$\Delta m^2_{\rm sol} = (8.0 \pm 0.3) \times 10^{-5}$ eV^2
$\vert\Delta m^2_{\rm atm}\vert = (1.9\text{–}3.0) \times 10^{-3}$ eV^2
$\sin^2 2\theta_{12} = 0.86^{+0.03}_{-0.04}$
$\sin^2 2\theta_{23} > 0.92$
$\sin^2 2\theta_{13} < 0.19$

Table 1. Best fit values for the light neutrino parameters [21].

where similar RGE contributions to the squark soft masses are completely determined in terms of quark masses and CKM-matrix elements. As a result, the predictions for FCNC effects in the lepton sector are usually affected by sizable uncertainties.

For future convenience, it is useful to write $(m^2_{\tilde{L}})_{ij}$ in the following form

$$(m^2_{\tilde{L}})_{ij} \simeq -\frac{(3m_0^2 + A_0^2)}{8\pi^2} U_{il} U^*_{jm} H_{lm}\,, \tag{3.4}$$

with $i \neq j$ and the Hermitian matrix $H_{\rm lm}$ is defined as

$$H_{\rm lm} = \frac{(m_{\nu_l} m_{\nu_m})^{1/2} \overline{M}_k}{\langle H_u \rangle^2} R_{lk} R^*_{mk} \tag{3.5}$$

with $\overline{M}_k = M_k \ln(M_X/M_k)$.

We now discuss in detail the dependences of $(m^2_{\tilde{L}})_{ij}$ on the parameters of the neutrino sector. In spite of the many unknown parameters entering $(m^2_{\tilde{L}})_{ij}$, we note that the predictions for the correlations among LFV processes are affected by a much smaller number of unknown parameters in some typical cases. To see this point more explicitly, we consider the following ratio,

$$\frac{(m^2_{\tilde{L}})_{e\mu}}{(m^2_{\tilde{L}})_{\mu\tau}} = \frac{\sum_{ij} U_{ei} U^*_{\mu j} H_{ij}}{\sum_{ij} U_{\mu i} U^*_{\tau j} H_{ij}}, \tag{3.6}$$

and we remind that the data from various neutrino experiments suggest that the MNS matrix contains two large mixing angles, and only the U_{e3} component can be small [21]. Hence,

$$U_{e3} U^*_{\mu i} \simeq U_{e3} U^*_{\tau i} \simeq U_{e3}\ (i = 1, 2, 3), \tag{3.7}$$

while all the remaining MNS matrix elements are $\mathcal{O}(1)$. If H_{ij} does not have any structure and all the components are comparable, eq. (3.6) implies that

$$\left(m^2_{\tilde{L}}\right)_{e\mu} \simeq \left(m^2_{\tilde{L}}\right)_{\mu\tau}\,. \tag{3.8}$$

On the other hand, when only H_{3i} $(i = 1, 2, 3)$ provide the largest contributions, it turns out that

$$\frac{\left(m^2_{\tilde{L}}\right)_{e\mu}}{\left(m^2_{\tilde{L}}\right)_{\mu\tau}} \simeq \max\{U_{e3},\ H_{1j}/H_{3i},\ H_{2j}/H_{3i}\}\,. \tag{3.9}$$

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Finally, in both cases discussed above, we also find that

$$\left(m^2_{\tilde{L}}\right)_{e\mu} \simeq \left(m^2_{\tilde{L}}\right)_{e\tau} . \tag{3.10}$$

An experimental confirmation of these correlations would represent a powerful test for the above scenarios, as well as a precious tool to shed light on some unknown neutrino parameters of H_{ij} and U_{e3}.

To make the above statements clear, we consider now the specific scenarios arising when $R = 1$. In this case, H_{ij} contains only diagonal components and it takes the form

$$H_{ij} = \frac{m_{\nu_i}\overline{M}_i}{\langle H_u\rangle^2}\delta_{ij} . \tag{3.11}$$

The flavor mixing is controlled now only by three parameters, H_{11}, H_{22} and H_{33}. Even in this special case, the values of H_{ii} are not uniquely defined as they still depend on the unknown mass hierarchies for both light and heavy neutrinos.

Concerning the light neutrinos, we remind that in the hierarchical case one has

$$m_{\nu_2} - m_{\nu_1} \simeq m_{\rm sol} , \qquad m_{\nu_3} - m_{\nu_1} \simeq m_{\rm atm} , \tag{3.12}$$

where we have assumed that $m_{\nu_1} \to 0$, while in the inverted hierarchy case one has

$$m_{\nu_2} - m_{\nu_1} \simeq \frac{m^2_{\rm sol}}{2m_{\rm atm}} , \qquad m_{\nu_3} - m_{\nu_1} \simeq -m_{\rm atm} , \tag{3.13}$$

where we have assumed the limit where $m_{\nu_3} \to 0$ (the notation is such that $m_{\rm atm} = \sqrt{|\Delta m^2_{\rm atm}|}$ and $m_{\rm sol} = \sqrt{\Delta m^2_{\rm sol}}$).

Hence, in the following, we are lead with the following scenarios:

- *normal hierarchy* for the light neutrinos and *hierarchical* right-handed neutrinos; H_{ij} satisfies

$$H_{11} \ll H_{22} \ll H_{33} . \tag{3.14}$$

  Assuming that the off-diagonal elements of $(m^2_{\tilde{R}})_{ij}$ are negligible, eq. (3.14) implies that

$$\frac{{\rm BR}(\mu \to e\gamma)}{{\rm BR}(\tau \to \mu\gamma)} \simeq \frac{\left| s_{12}c_{12}(m_{\rm sol}/m_{\rm atm})(\overline{M}_2/\overline{M}_3) + U_{e3} \right|^2}{{\rm BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)/2} , \tag{3.15}$$

  in agreement with the general expectation of eq. (3.9). Large values for ${\rm BR}(\tau \to \mu\gamma) \lesssim 10^{-8}$, well within the reach of a Super B factory [22], are still possible provided $U_{e3} \lesssim 10^{-2}$ and $\overline{M}_2/\overline{M}_3 \lesssim 0.1$ (see also figure 7).

- *normal hierarchy* for the light neutrinos and *degenerate* right-handed neutrinos; H_{ij} is such that

$$H_{11} \lesssim H_{22} \lesssim H_{33} , \tag{3.16}$$

leading to the following result

$$\frac{\mathrm{BR}(\mu \to e\gamma)}{\mathrm{BR}(\tau \to \mu\gamma)} \simeq \frac{|\, s_{12}c_{12}\,(m_{\rm sol}/m_{\rm atm}) + U_{e3}\,|^2}{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)/2}\,. \tag{3.17}$$

In contrast to the previous case, it is not possible now to reduce arbitrarily $\mathrm{BR}(\mu \to e\gamma)$ reducing the value of U_{e3} because the contribution from H_{22} is not negligible. In fact, even setting $U_{e3} = 0$, it turns out that $\mathrm{BR}(\tau \to \mu\gamma) \lesssim 10^{-10} \times (\mathrm{BR}(\mu \to e\gamma)/10^{-11})$, values well far from the expected experimental resolutions of a Super B factory.

- *inverted hierarchy* for the light neutrinos and *hierarchical* right-handed neutrinos; H_{ij} is characterized by the following relation,

$$H_{11} \lesssim H_{22}\,. \tag{3.18}$$

In this scenario, the maximum allowed values for $\mathrm{BR}(\tau \to \mu\gamma)$ are obtained assuming that $m_{\nu_3}\overline{M}_3 \gg m_{\nu_2}\overline{M}_2$. In such a case, it turns out that

$$\frac{\mathrm{BR}(\mu \to e\gamma)}{\mathrm{BR}(\tau \to \mu\gamma)} \simeq \frac{|\, s_{12}c_{12}(m_{\rm atm}/m_{\nu_3})(\overline{M}_2/\overline{M}_3) + U_{e3}\,|^2}{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)/2}\,, \tag{3.19}$$

and large values for $\mathrm{BR}(\tau \to \mu\gamma)$ may be still allowed if $U_{e3} \lesssim 10^{-2}$ and depending on the unknown neutrino mass scale m_{ν_3} as well as the value of $\overline{M}_2/\overline{M}_3$.

- *inverted hierarchy* for the light neutrinos and *degenerate* right-handed neutrinos; the relation among the H_{ij} elements is given by

$$H_{11} \simeq H_{22} \gtrsim H_{33}\,. \tag{3.20}$$

In this case, we find that

$$\frac{\mathrm{BR}(\mu \to e\gamma)}{\mathrm{BR}(\tau \to \mu\gamma)} \simeq \frac{|\, s_{12}c_{12}\,(m^2_{\rm sol}/m^2_{\rm atm})/2 - U_{e3}\,|^2}{\mathrm{BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)/2}\,, \tag{3.21}$$

hence, large values for $\mathrm{BR}(\tau \to \mu\gamma)$ can be realized if $U_{e3} \lesssim 10^{-2}$. Notice that, in eq. (3.21), the contributions from H_{11} and H_{22} to $\mathrm{BR}(\mu \to e\gamma)$ cancel each other to a very large extent. This implies that the predictions for $\mathrm{BR}(\mu \to e\gamma)$ are highly sensitive to the degree of degeneracy for the right-handed neutrino masses: even a modest mass splitting would imply a strong enhancement for $\mathrm{BR}(\mu \to e\gamma)$.

In conclusion, large values for $\mathrm{BR}(\mu \to e\gamma)$ are possible in all the scenarios we have discussed; in contrast, the attained values for $\mathrm{BR}(\tau \to \mu\gamma)$ are typically very constrained by the current experimental bounds on $\mathrm{BR}(\mu \to e\gamma)$. The most promising scenarios for $\tau \to \mu\gamma$ are those with *normal* or *inverted hierarchy* for the light neutrinos and *hierarchical* right-handed neutrinos. In any case, large values for $\mathrm{BR}(\tau \to \mu\gamma)$ would require $U_{e3} \lesssim 10^{-2}$.

Moreover, since $(m^2_{\tilde{L}})_{e\mu} \simeq (m^2_{\tilde{L}})_{e\tau}$, $\mathrm{BR}(\tau \to e\gamma)$ is always very suppressed in all the above scenarios once the current bound on $\mathrm{BR}(\mu \to e\gamma)$ is imposed.

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One could wonder whether the picture we have outlined so far changes when we relax the condition $R = 1$. In this case, barring accidental cancellations, it seems difficult to suppress simultaneously all the parameters of H_{1i} and H_{2i} $(i = 1, 2, 3)$ while keeping a large value for H_{33}. Thus, when $R \neq 1$, we end up with the generic prediction of eq. (3.8), irrespective to the details for the light and heavy neutrino masses.

4 The SUSY SU(5) model with right-handed neutrinos

More stable predictions for LFV effects in SUSY theories may be obtained embedding the SUSY model within Grand Unified Theories (GUTs) where the see-saw mechanism can naturally arise (such as SO(10)). In this case, the GUT symmetry allows us to obtain some hints about the unknown neutrino Yukawa matrix Y_ν. Moreover, in GUT scenarios there are additional flavor-violating contributions to slepton mass terms stemming from the quark sector [11, 12]. For instance, within SU(5), as both Q and e^c are hosted in the 10 representation, the CKM matrix mixing of the left-handed quarks will give rise to off-diagonal entries in the running of the right-handed slepton soft masses $(m^2_{\tilde{R}})_{ij}$ due to the interaction of the colored Higgs [11, 12]. These effects are completely independent from the structure of Y_ν and can be regarded as new irreducible LFV contributions within SUSY GUTs. In particular, the expression for $(m^2_{\tilde{R}})_{ij}$ within a SUSY SU(5) model reads

$$\left(m^2_{\tilde{R}}\right)_{ij} = -3\frac{(3m_0^2 + A_0^2)}{8\pi^2}(e^{i\hat{\phi}_d} V^T \hat{y}_u^2 V^* e^{-i\hat{\phi}_d})_{ij} \ln\frac{M_X}{M_{\rm G}}\,, \tag{4.1}$$

with $i \neq j$. Here, we have assumed the colored Higgs mass to be the GUT scale $M_{\rm G}$ and $M_{\rm G} < M_X$. Moreover, $\hat{y}_u$ is the up-quark Yukawa coupling, V is the CKM matrix and $\hat{\phi}_d$ stands for additional physical CP-violating phases.

Within a pure SUSY SU(5) model, where right-handed neutrinos are absent, only the flavor structures $(m^2_{\tilde{R}})_{ij}$ are at work and it turns out that

$$\frac{{\rm BR}(\mu \to e\gamma)}{{\rm BR}(\tau \to \mu\gamma)} \simeq \frac{|V_{\rm td}|^2}{{\rm BR}(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}\,, \tag{4.2}$$

thus, ${\rm BR}(\tau \to \mu\gamma) \lesssim 2 \times 10^{-8} \times ({\rm BR}(\mu \to e\gamma)/10^{-11})$. However, as we will show in the numerical analysis, all the processes ${\rm BR}(\ell_i \to \ell_j\gamma)$ turn out to be very suppressed in this scenario, except for few cases. The main reasons for such a strong suppression are that *i)* the relevant sources of LFV, i.e. $(m^2_{\tilde{R}})_{ij}$, are CKM suppressed, *ii)* only $U(1)_Y$ interactions contribute to the LFV processes, *iii)* the total amplitude generating ${\rm BR}(\ell_i \to \ell_j\gamma)$ suffers from strong cancellations in large regions of the parameter space [13]. As a result, large values for ${\rm BR}(\ell_i \to \ell_j\gamma)$ could be achieved only for light SUSY particles and for moderate to large values of $\tan\beta$ and A_0; in this regime, the indirect constraints, specially from the lower bound on the lightest Higgs boson mass and from ${\rm BR}(B \to X_s\gamma)$, become very strong and ${\rm BR}(\ell_i \to \ell_j\gamma)$ can hardly reach the expected experimental resolutions.

The situation can drastically change if the SUSY SU(5) model is enlarged to include right-handed neutrinos ($SU(5)_{\rm RN}$). In this case, besides the flavor structures $(m^2_{\tilde{R}})_{ij}$ of eq. (4.1), we also have the $(m^2_{\tilde{L}})_{ij}$ MIs.

In the following, we assume a $SU(5)_{RN}$ model setting $R = 1$ and assuming the scenario with *normal hierarchy* for the light neutrinos and *hierarchical* right-handed neutrinos. This leads to the following expression for $(m^2_{\tilde{L}})_{ij}$

$$\left(m^2_{\tilde{L}}\right)_{ij} \simeq -\frac{(3m_0^2 + A_0^2)}{8\pi^2} U_{i3} U^*_{j3} \frac{m_{\nu_3} \overline{M}_3}{\langle H_u \rangle^2} \,. \tag{4.3}$$

In the $SU(5)_{RN}$ model, the dominant contributions to $\mu \to e\gamma$ arise either from $\delta^L_{\mu e}$ (and $\delta^L_{\mu\tau}\delta^L_{\tau e}$) through the loop exchange of charginos/sneutrinos or from $\delta^L_{\mu\tau}\delta^R_{\tau e}$ through the loop exchange of a pure Bino; hence, $BR(\mu \to e\gamma)$ can be written as $BR(\mu \to e\gamma) \sim a|\delta^L_{\mu e}|^2 + b|\delta^L_{\mu\tau}\delta^R_{\tau e}|^2$ [23] with a, b being functions of the SUSY parameters. We note that, while $\delta^L_{\mu\tau}\delta^R_{\tau e}$ is $\sim U_{\mu 3} V_{\rm td}$ and thus predictable in terms of known parameters, $\delta^L_{\mu e}$ depends on the unknown mixing angle U_{e3} as $\delta^L_{\mu e} \sim U_{e3}$. Concerning the correlation between $BR(\mu \to e\gamma)$ and $BR(\tau \to \mu\gamma)$, we can write

$$\frac{BR(\mu \to e\gamma)}{BR(\tau \to \mu\gamma)} \simeq \frac{\left(\,|U_{e3}|^2,\, |\delta^R_{\tau e}|^2\,\right)}{BR(\tau \to \mu\nu_\tau\bar{\nu}_\mu)}\,, \tag{4.4}$$

in case $BR(\mu \to e\gamma)$ is dominated by $\delta^L_{\mu e}$ (if $U_{e3} \gtrsim 10^{-2}$) or $\delta^L_{\mu\tau}\delta^R_{\tau e}$ (if $U_{e3} < 10^{-2}$), respectively. In the latter case, we can expect large values for $BR(\tau \to \mu\gamma)$ while taking $BR(\mu \to e\gamma)$ easily under control as $|\delta^R_{\tau e}| \lesssim 10^{-3}$ (see figure 7).

In the numerical section, we will discuss about the predictions for LFV processes as arising both in the pure SUSY SU(5) model without right-handed neutrinos as well as in the $SU(5)_{RN}$ model.

In this article, we assume the minimal structure for the Yukawa couplings in $SU(5)_{RN}$, for simplicity. However, more realistic models may introduce extra contribution to flavor violation in the sfermion mass matrices.

It is known that the minimal SUSY SU(5) GUT has two phenomenological problems: *i)* the quark-lepton mass relations [24] and *ii)* the proton decay induced by the colored Higgs exchange [25–27]. The introduction of symmetries, like the Peccei-Quinn [28] and the $U(1)_R$ symmetries [29], provides an economical solution to the problem *ii)*, as they suppress the baryon-number violating dimension-five operators induced by the colored-Higgs exchange. For the problem *i)*, the introduction of non-minimal Higgs/matter or higher-dimensional operators with SU(5)-breaking Higgs has been proposed. This proposal might be also a (partial) solution to the problem *ii)*, if the colored Higgs coupling is accidentally suppressed [30]. The new Higgs/matter or higher-dimensional interactions induce, in general, new sources of flavor violation in the sfermion mass matrices. For example, sizable flavor mixings in the left-handed slepton mass matrix might be generated even in the minimal SUSY SU(5) GUT (without right-handed neutrinos) when higher-dimensional operators are introduced to explain the quark-lepton mass relations [31]. Since these new flavor violating interactions are assumed to be negligible in this article, our results have to be regarded as conservative predictions of the $SU(5)_{RN}$ model, barring accidental cancellations among different contributions.

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Observable	Present exp. bound
$\mathrm{BR}(\mu \to e\gamma)$	1.2×10^{-11}
$\mathrm{BR}(\mu \to eee)$	1.1×10^{-12}
$\mathrm{CR}(\mu \to e \text{ in Ti})$	4.3×10^{-12}
$\mathrm{BR}(\tau \to \mu\gamma)$	4.5×10^{-8}
$\mathrm{BR}(\tau \to e\gamma)$	1.1×10^{-7}
$\mathrm{BR}(\tau \to \mu\mu\mu)$	1.9×10^{-7}
$\mathrm{BR}(\tau \to \mu\eta)$	1.5×10^{-7}

Table 2. Present experimental bounds on representative LFV decays of τ and μ leptons [21].

5 Muon $(g-2)$ vs. $\mathrm{BR}(\ell_i \to \ell_j\gamma)$

Even if $\mu \to e\gamma$ will be observed, we could never access directly to the flavor-violating parameters $\delta^{L,R}_{\ell_i\ell_j}$, since the branching ratio $\mathrm{BR}(\mu \to e\gamma)$ depends also on the SUSY particle masses and other parameters such as $\tan\beta$. These latter parameters should be ultimately determined at the LHC/linear collider experiments in the future. On the other hand, it is known that the SUSY effects to the muon $(g-2)$ are well correlated with $\mathrm{Br}(\mu \to e\gamma)$ since they both are dipole transitions [32]; this is especially true in SUSY see-saw models [32] where the dominant effects to both processes arise from the one-loop diagrams induced by chargino exchange. Thus, normalizing $\mathrm{Br}(\mu \to e\gamma)$ to the SUSY effects to the muon $(g-2)$, we may get access to the mass insertion parameters.

Most recent analyses of the muon $(g-2)$ converge towards a 3σ discrepancy in the 10^{-9} range [33]: $\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} \approx (3\pm1)\times10^{-9}$ where $a_\mu = (g-2)/2$. Despite substantial progress both on the experimental [34] and on the theoretical sides, the situation is not completely clear yet. However, the possibility that the present discrepancy may arise from errors in the determination of the hadronic leading-order contribution to Δa_μ seems to be unlikely, as recently stressed in ref. [35].

The SUSY contribution to the muon $g-2$, $\Delta a_\mu^{\rm SUSY}$, in the limit of a degenerate SUSY spectrum reads

$$\Delta a_\mu^{\rm SUSY} \simeq \frac{\alpha_2}{8\pi}\,\frac{5}{6}\,\frac{m_\mu^2}{\tilde m^2}\,t_\beta\,. \tag{5.1}$$

For a natural choice of the SUSY parameters $t_\beta = 10$ and $\tilde m = 300\,\mathrm{GeV}$, it turns out that $\Delta a_\mu^{\rm SUSY} \simeq 1.5\times10^{-9}$ and the current observed anomaly can be easily explained.

Now, let us discuss the correlation between $\Delta a_\mu^{\rm SUSY}$ and the branching ratios of $\ell_i \to \ell_j\gamma$. Given our ignorance about the MI parameters $\delta^{L,R}_{\ell_i\ell_j}$, we will first perform a model-independent analysis, treating the MIs $\delta^{L,R}_{\ell_i\ell_j}$ as free parameters and analysing their phenomenological impact separately. In particular, we will consider two cases for $\mu \to e\gamma$, *i)* $\delta^L_{\mu e}/\ \delta^L_{\mu\tau}\delta^L_{\tau e}$ dominance, and *ii)* $\delta^L_{\mu\tau}\delta^R_{\tau e}/\ \delta^R_{\mu\tau}\delta^L_{\tau e}$ dominance.

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Assuming a degenerate SUSY spectrum, it is straightforward to find

$$\begin{aligned}
\mathrm{BR}(\mu \to e\gamma) &\approx 2 \times 10^{-12} \left[\frac{\Delta a_\mu^{\mathrm{SUSY}}}{3 \times 10^{-9}}\right]^2 \left|\frac{\delta^L_{\mu e}}{10^{-4}}\right|^2, \\
\mathrm{BR}(\mu \to e\gamma) &\approx 3 \times 10^{-13} \left[\frac{\Delta a_\mu^{\mathrm{SUSY}}}{3 \times 10^{-9}}\right]^2 \left|\frac{\delta^L_{\mu\tau}\delta^L_{\tau e}}{10^{-4}}\right|^2, \\
\mathrm{BR}(\mu \to e\gamma) &\approx 2 \times 10^{-11} \left[\frac{\Delta a_\mu^{\mathrm{SUSY}}}{3 \times 10^{-9}}\right]^2 \left|\frac{\delta^L_{\mu\tau}\delta^R_{\tau e}}{10^{-4}}\right|^2 \\
&\quad + (L \leftrightarrow R), \\
\mathrm{BR}(\tau \to \ell\gamma) &\approx 8 \times 10^{-8} \left[\frac{\Delta a_\mu^{\mathrm{SUSY}}}{3 \times 10^{-9}}\right]^2 \left|\frac{\delta^L_{\tau\ell}}{10^{-2}}\right|^2.
\end{aligned} \tag{5.2}$$

The main message from the above relations is that, as long as we intend to explain the muon $(g-2)$ anomaly within SUSY theories, the branching ratios for $\ell_i \to \ell_j\gamma$ are determined, to some extent, once we specify the LFV sources. In the numerical section, we will address this point in more details.

In table 3, we report the bounds on the MIs $\delta^L_{l_i l_j}$ arising from the current experimental bounds on $\mathrm{BR}(\ell_i \to \ell_j\gamma)$ imposing $\Delta a_\mu^{\mathrm{SUSY}} = 3 \times 10^{-9}$, corresponding to the central value of the muon $(g-2)$ anomaly. Moreover, in the last column of table 3 we also show the expectations for the MIs $\delta^L_{l_i l_j}$ within the $\mathrm{SU(5)_{RN}}$ scenario with hierarchical right-handed neutrinos for the reference values $M_3^{(\mathrm{r})} = 10^{13}\,\mathrm{GeV}$ and $U_{e3}^{(\mathrm{r})} = 0.1$. The predictions for $\delta^L_{\mu e}$ and $\delta^L_{\tau e}$ scale with U_{e3} as $(U_{e3}/U_{e3}^{(\mathrm{r})})$ while all the $\delta^L_{l_i l_j}$'s scale with M_3 as $(M_3/M_3^{(\mathrm{r})})$. Table 3 shows that, once we explain the muon $(g-2)$ anomaly through SUSY effects, the current experimental resolutions on $\mathrm{BR}(\ell_i \to \ell_j\gamma)$ already set tight constraints on the neutrino parameters U_{e3} and M_3: if U_{e3} is close to its experimental upper bound, i.e. if $U_{e3} = 0.1$, we are lead with $M_3 \lesssim 10^{13}\,\mathrm{GeV}$.

6 Leptonic EDMs

Within a SUSY framework, CP-violating sources are naturally induced by the soft SUSY breaking terms through *i)* flavor conserving F-terms (such as the $B\mu$ parameter in the Higgs potential or the A terms for trilinear scalar couplings) [36] and *ii)* flavor-violating D-terms (such as the squark and slepton mass terms) [37]. It seems quite likely that the two categories *i)* and *ii)* of CP violation are controlled by different physical mechanisms, thus, they may be distinguished and discussed independently.

In the case *i)*, it is always possible to choose a basis where only the μ and A parameters remain complex [36]. The CP-violating phases generally lead to large electron and neutron EDMs as they arise already at the one-loop level. For example, when $t_\beta = 10$, $\tilde{m} = 300\,\mathrm{GeV}$, $d_e \sim 6 \times 10^{-25}(\sin\theta_\mu + 10^{-2}\sin\theta_A)\, e\,\mathrm{cm}$.

Observable	Exp. bound on $\lvert\delta\rvert$	$\lvert\delta\rvert$ in $\mathrm{SU}(5)_{\mathrm{RN}}$
$\mathrm{BR}(\mu \to e\gamma)$	$\lvert\delta^L_{\mu e}\rvert < 3 \times 10^{-4}$	$\sim 3 \times 10^{-4}$
$\mathrm{BR}(\mu \to e\gamma)$	$\lvert\delta^L_{\mu\tau}\delta^L_{\tau e}\rvert < 10^{-3}$	$\sim 10^{-6}$
$\mathrm{BR}(\mu \to e\gamma)$	$\lvert\delta^L_{\mu\tau}\delta^R_{\tau e}\rvert < 10^{-3}$	$\sim 10^{-5}$
$\mathrm{BR}(\tau \to e\gamma)$	$\lvert\delta^L_{\tau e}\rvert < 6 \times 10^{-2}$	$\sim 3 \times 10^{-4}$
$\mathrm{BR}(\tau \to \mu\gamma)$	$\lvert\delta^L_{\tau\mu}\rvert < 4 \times 10^{-2}$	$\sim 4 \times 10^{-3}$

Table 3. Bounds on the effective LFV couplings $\delta^L_{l_i l_j}$ from the current experimental bounds on the radiative LFV decays of τ and μ leptons (see table 2) by setting $\Delta a^{\mathrm{SUSY}}_\mu = 3 \times 10^{-9}$. The expectations for the $\delta^L_{l_i l_j}$'s within the $\mathrm{SU}(5)_{\mathrm{RN}}$ scenario with hierarchical right-handed neutrinos are reported in the last column and they correspond to the reference values $M_3^{(\mathrm{r})} = 10^{13}\,\mathrm{GeV}$ and $U_{e3}^{(\mathrm{r})} = 0.1$. The predictions for $\delta^L_{\mu e}$ and $\delta^L_{\tau e}$ scale with U_{e3} as $(U_{e3}/U_{e3}^{(\mathrm{r})})$ while all the $\delta^L_{l_i l_j}$'s scale with M_3 as $(M_3/M_3^{(\mathrm{r})})$. Improving the experimental resolutions on $\mathrm{BR}(\mu \to e\gamma)$, the bounds on $\delta^L_{\mu e}$ and $\delta^L_{\mu\tau}\delta^{R(L)}_{\tau e}$ reported in this table will scale as $[\mathrm{BR}(\mu \to e\gamma)_{\mathrm{exp}}/1.2 \times 10^{-11}]^{1/2}$. The scaling properties for the other flavor transitions are obtained in the same way.

In the case *ii)*, the leptonic EDMs induced by *flavor dependent* phases (flavored EDMs) read [37]

$$\frac{d_\ell}{e} \simeq -\frac{\alpha_Y}{4\pi}\left(\frac{m_\tau}{\tilde{m}^2}\right) t_\beta\, \frac{\mathrm{Im}\left(\delta^R_{\ell\tau}\delta^L_{\tau\ell}\right)}{30}\,, \tag{6.1}$$

where a common SUSY mass $\tilde{m}$ has been assumed. If $t_\beta = 10$ and $\tilde{m} = 300\,\mathrm{GeV}$, it turns out that $d_e \sim 10^{-22} \times \mathrm{Im}(\delta^R_{e\tau}\delta^L_{\tau e})\, e\,\mathrm{cm}$.

One of the most peculiar features disentangling the EDMs as induced by *flavor blind* or *flavor dependent* phases regards their scaling properties with different leptons. In particular,

$$\begin{aligned} \frac{d_e}{d_\mu} &= \frac{m_e}{m_\mu} && \textit{flavor blind}\,\text{phases}, \\ \frac{d_e}{d_\mu} &= \frac{\mathrm{Im}(\delta^R_{e\tau}\delta^L_{\tau e})}{\mathrm{Im}(\delta^R_{\mu\tau}\delta^L_{\tau\mu})} && \textit{flavor dependent}\,\text{phases}\,. \end{aligned} \tag{6.2}$$

In the case of *flavor blind* phases, the current bound $d_e < 1.7 \times 10^{-27}\, e\,\mathrm{cm}$ [21] implies that $d_\mu \lesssim 3.5 \times 10^{-25}\, e\,\mathrm{cm}$. On the contrary, in presence of *flavor dependent* phases, the leptonic EDMs typically violate the naive scaling and values for $d_\mu > 2 \times 10^{-25}\, e\,\mathrm{cm}$ are still allowed.

Moreover, when the EDMs are generated by *flavor blind* phases, they are completely unrelated to LFV transitions (although correlations with CP and flavor violating transitions in the B-meson systems are still possible [38]). By contrast, the flavored EDMs are closely related to LFV processes as $\ell_i \to \ell_j\gamma$ since they are both generated by LFV effects and they arise from similar dipole operators. If the EDMs and LFV processes will be observed, their correlation will provide a precious tool to disentangle the LFV source responsible for LFV transitions.

Actually, if $\mathrm{BR}(\mu \to e\gamma)$ is dominated by the term $\delta^R_{\mu\tau}\delta^L_{\tau e}$ and/or $\delta^L_{\mu\tau}\delta^R_{\tau e}$, we get

$$d_e \simeq \frac{d_\mu}{x_R x_L} \simeq 2 \times 10^{-26}\, e\,\mathrm{cm} \sqrt{\frac{\mathrm{BR}(\mu \to e\gamma)/10^{-11}}{x_R^2 + x_L^2}}\,, \tag{6.3}$$

where $x_{R/L} = |\delta^{R/L}_{\mu\tau}/\delta^{R/L}_{e\tau}|$ and maximum phases have been assumed. Eq. (6.3) implies the following constraint for the flavored leptonic EDMs,

$$d_e d_\mu \lesssim \left(1.6 \times 10^{-26}\, e\,\mathrm{cm}\right)^2 \times \frac{\mathrm{BR}(\mu \to e\gamma)}{10^{-11}}\,. \tag{6.4}$$

The bound of eq. (6.4) arises when $\mathrm{BR}(\mu \to e\gamma)$ is generated by the combination of left- and right-handed slepton mixing, it doesn't depend on the details of the SUSY spectrum and it is saturated when $x_R = x_L$.

We observe that, within the $\mathrm{SU(5)_{RN}}$ scenario, d_e grows linearly with U_{e3} since $d_e \sim \delta^R_{e\tau}\delta^L_{\tau e}$ with $\delta^L_{\tau e} \sim U_{e3}$ while d_μ does not depend on U_{e3}. As a result, it turns out that

$$\left(\frac{d_e}{d_\mu}\right)_{\mathrm{SU(5)_{RN}}} \simeq \frac{U_{e3}V_{\mathrm{td}}}{U_{\mu 3}V_{\mathrm{ts}}}\,. \tag{6.5}$$

In the pure SUSY see-saw model, the leptonic EDMs are highly suppressed if the right-handed neutrino masses are degenerate, similarly to the quark sector. In contrast, if the right-handed neutrinos are not degenerate, the predictions for the EDMs might be significantly enhanced by means of threshold corrections to the SUSY breaking terms [39]. The EDMs are sensitive to the Dirac and Majorana phases in the MNS matrix as well as to the phases in R. However, they still remain well below any future (realistic) experimental resolution. Indeed, we have explicitly checked that, after imposing the current experimental bound on $\mathrm{BR}(\mu \to e\gamma)$, we end up with contributions to the electron EDM of order $d_e \lesssim 10^{-34}$ $e$cm, irrespective to the details of the heavy/light neutrino sectors. On the contrary, when the see-saw mechanism is embedded in a SUSY GUT scheme, as $\mathrm{SU(5)_{RN}}$, d_e may naturally saturate its current experimental upper bound. Hence, any experimental evidence for the leptonic EDMs at the upcoming experiments could naturally points towards a SUSY GUT framework with an underlying see-saw mechanism specially if $\mu \to e\gamma$ would also be observed at the MEG experiment.

Interestingly enough, the synergy of apparently unrelated low-energy experiments, as the leptonic EDMs and LFV processes (like $\mu \to e\gamma$), represents a powerful tool to shed light on the underlying NP theory that is at work.

7 The P-odd asymmetry in $\mu^+ \to e^+\gamma$

In case LFV processes as $\ell_i \to \ell_j\gamma$ will be observed at the upcoming experiments, a crucial question would be to understand which is the kind of LFV source responsible for such a NP signal. In this respect, a very useful tool will be provided by the asymmetries defined by means of initial muon polarization. Experimentally, polarized positive muons are available by the surface muon method because muons emitted from π^+'s stopped at target surface are

100% polarized in the direction opposite to the muon momentum. Interestingly enough, in ref. [40] it has been shown that the muon polarization is useful to suppress the background processes in the $\mu^+ \to e^+\gamma$ search. As for the signal distribution of $\mu^+ \to e^+\gamma$, the angular distribution with respect to the muon polarization can distinguish between $\mu^+ \to e^+_L\gamma$ and $\mu^+ \to e^+_R\gamma$. In particular, one can define the P-odd asymmetry $A(\mu^+ \to e^+\gamma)$ as [41]

$$A(\mu^+ \to e^+\gamma) = \frac{|A_L|^2 - |A_R|^2}{|A_L|^2 + |A_R|^2}\,. \tag{7.1}$$

As we will show, the knowledge of $A(\mu^+ \to e^+\gamma)$ will represent a powerful tool to shed light on the nature of the LFV sources, in particular to disentangle whether an underlying SUSY GUT theory is at work or not.

In fact, a pure (non-GUT) SUSY see-saw predicts $A(\mu^+ \to e^+\gamma) = +1$ to a very good accuracy, as the largely dominant amplitude is $A^{\mu e}_L \sim \delta^L_{\mu e}$ (in fact it turns out that $A^{\mu e}_R \sim (m_e/m_\mu) \times A^{\mu e}_L$). Thus, any experimental evidence departing from this expectation would likely support the idea of a SUSY see-saw model embedded in GUT scenarios where, in addition to $A^{\mu e}_L$, a sizable amplitude $A^{\mu e}_R \sim \delta^L_{\mu\tau}\delta^R_{\tau e}$ is also generated. Should this happen, we would also expect large values for $\mathrm{BR}(\tau \to \mu\gamma)$ arising from $\delta^L_{\mu\tau}$.

8 Numerical analysis

In this section, we present the numerical results relative to the observables discussed in the previous sections both in the low-energy (model independent) approach and in the $\mathrm{SU(5)_{RN}}$ model described in previous section.

Starting with the model independent analysis, in figure 1, we show the predictions for $\mathrm{BR}(\mu \to e\gamma)$ and $\Delta a^{\mathrm{SUSY}}_\mu$ as obtained by means of a scan over the SUSY parameters $3 < \tan\beta < 50$, $(m_{\tilde{\ell}}, \mu, M_{\tilde{W}} = 2M_{\tilde{B}}) \leq 1\,\mathrm{TeV}$, assuming a common slepton mass $m_{\tilde{\ell}}$.

Blue points refer to the case where $\mathrm{BR}(\mu \to e\gamma)$ is generated only by $\delta^L_{\mu e}$; the quite strong correlation between $\mathrm{BR}(\mu \to e\gamma)$ and $\Delta a^{\mathrm{SUSY}}_\mu$ does not change significantly if $\delta^L_{\mu\tau}\delta^L_{\tau e}$ also contributes to $\mathrm{BR}(\mu \to e\gamma)$. Green points refer to the case where $\mathrm{BR}(\mu \to e\gamma)$ is generated only by $\delta^L_{\mu\tau}\delta^R_{\tau e}$; now, the correlation between $\mathrm{BR}(\mu \to e\gamma)$ and $\Delta a^{\mathrm{SUSY}}_\mu$ is rather loose with respect to the previous case. This behavior can be understood remembering that $\mathrm{BR}(\mu \to e\gamma)$ is induced now only by the $\mathrm{U(1)}_Y$ interactions by means of the pure Bino exchange. Still, some useful information may be extracted from figure 1: the explanation of the muon $(g-2)$ anomaly through SUSY effects implies a lower bound for $\mathrm{BR}(\mu \to e\gamma)$ which clearly depends on the size of the LFV source.

In figure 2, we show the allowed regions for d_e and d_μ compatible with the current upper bounds on $\mathrm{BR}(\tau \to e\gamma)$ and $\mathrm{BR}(\tau \to \mu\gamma)$; the green (blue) region corresponds to $\mathrm{BR}(\mu \to e\gamma) \leq 10^{-11}(10^{-13})$. The plot has been obtained through a scan over the same input parameters of figure 1 with the addition of $10^{-5} < (\delta^{L,R}_{e\mu}, \delta^{L,R}_{e\tau}, \delta^{L,R}_{\mu\tau}) < 1$, and the LFV sources are treated in a model-independent way allowing, in particular, for maximum CP-violating phases. The black line in figure 2 corresponds to the naive scaling of the leptonic EDMs, i.e. $d_e/d_\mu = m_e/m_\mu$, as it would happen if the EDMs were generated by flavor blind phases.

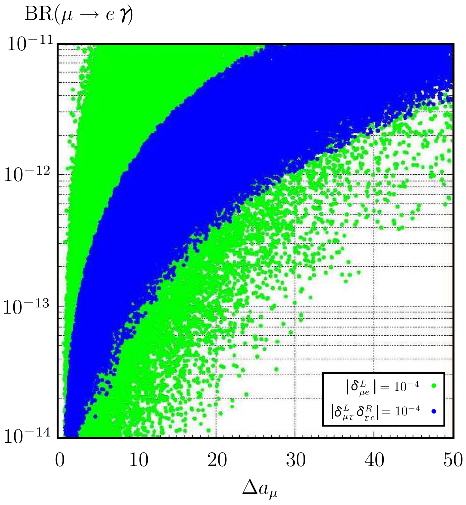

Figure 1. BR($\mu \to e\gamma$) vs. the SUSY contribution to the muon anomalous magnetic moment $\Delta a_\mu^{\rm SUSY}$. The plot has been obtained by means of a scan over the following SUSY parameter space: $3 < \tan\beta < 50$, $(m_{\tilde{\ell}}, \mu, M_{\tilde{W}} = 2M_{\tilde{B}}) \leq 1\,$TeV. Blue points correspond to the case where BR($\mu \to e\gamma$) is generated by the only $\delta^L_{\mu e}$ MI (we set $|\delta^L_{\mu e}| = 10^{-4}$), while green points refer to the case where BR($\mu \to e\gamma$) is generated by the only $\delta^L_{\mu\tau}\delta^R_{\tau e}$ MI (we set $(|\delta^L_{\mu\tau}\delta^R_{\tau e}| = 10^{-4})$). For different values of $|\delta^L_{\mu e}|$ and $|\delta^L_{\mu\tau}\delta^R_{\tau e}|$, BR($\mu \to e\gamma$) scales as $(|\delta^L_{\mu e}|/10^{-4})^2$ and $(|\delta^L_{\mu\tau}\delta^R_{\tau e}|/10^{-4})^2$, respectively.

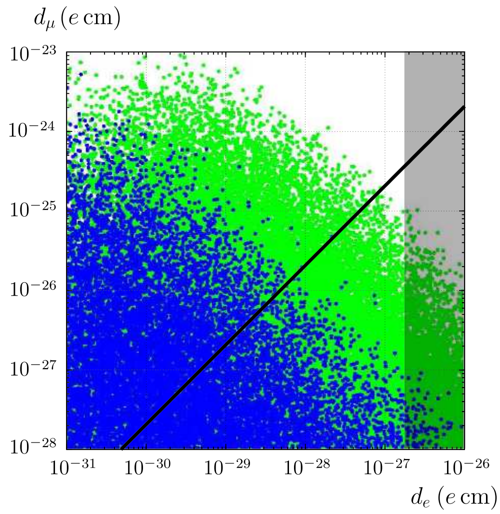

Figure 2. Model independent correlation between d_e vs. d_μ with the same input parameters of figure 1 and varying $10^{-5} < (\delta^{L,R}_{e\mu}, \delta^{L,R}_{e\tau}, \delta^{L,R}_{\mu\tau}) < 1$. The current experimental constraints on BR($\tau \to \mu\gamma$) and BR($\tau \to e\gamma$) have been imposed. Moreover, the green and blue points correspond to BR($\mu \to e\gamma$) $< (10^{-11}, 10^{-13})$, respectively. The black line corresponds to the naive scaling $d_e/d_\mu = m_e/m_\mu$. The grey region is excluded by the current experimental upper bound on d_e.

We now pass to the numerical analysis relative to the SU(5)$_{\rm RN}$ model. In general, since SUSY GUT models present a rich flavor structure, many flavor-violating phenomena [42] as well as leptonic and hadronic (C)EDMs are generated [43]. Moreover, since within SUSY GUTs leptons and quarks sit into same multiplets, the flavor violation in the

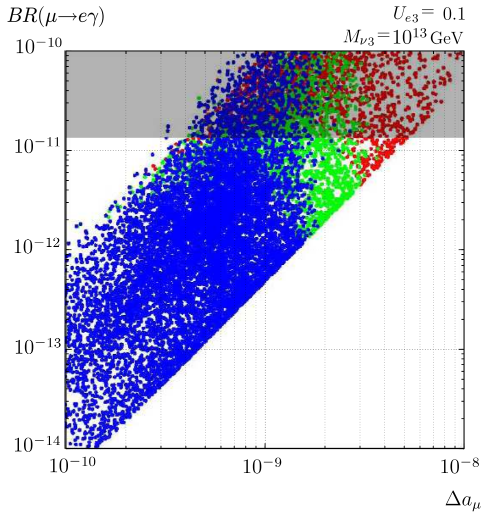

Figure 3. $\mathrm{BR}(\mu \to e\gamma)$ vs. $\Delta a_\mu^{\mathrm{SUSY}}$ in the $\mathrm{SU(5)_{RN}}$ model assuming a hierarchical spectrum for both light and heavy neutrinos, $m_{\nu_3} = 0.05$eV, $M_3 = 10^{13}$ GeV and $U_{e3} = 0.1$. The plot has been obtained varying the SUSY parameters in the following ranges: $100\,\mathrm{GeV} < m_0, M_{1/2} < 1\,\mathrm{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ and $\mu > 0$. Green (blue) points satisfy the constraints from $\mathrm{BR}(B \to X_s\gamma)$ at the 99% C.L. (90% C.L.) limit. The grey region is excluded by the current experimental upper bound on $\mathrm{BR}(\mu \to e\gamma)$.

squark and slepton sectors may be correlated [42]. However, in this paper, we focus only on the $\mathrm{SU(5)_{RN}}$ predictions for the leptonic sector, although the hadronic processes are systematically taken into account to constrain the SUSY parameter space.

In the following, we assume the gravity mediated mechanism for the SUSY breaking terms and we take $M_X = 2.4 \times 10^{18}$ GeV.

In figure 3, we show the predictions for $\mathrm{BR}(\mu \to e\gamma)$ vs. $\Delta a_\mu^{\mathrm{SUSY}}$ assuming $m_{\nu_3} = 0.05$eV, $M_3 = 10^{13}$ GeV and $U_{e3} = 0.1$ and varying the SUSY parameters in the ranges $m_0, M_{1/2} < 1\,\mathrm{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ and $\mu > 0$.

The blue (green) points satisfy the constraints from $\mathrm{BR}(B \to X_s\gamma)$ [21] at the 99% (90%) C.L. limit,[3] while the red ones do not. As shown in figure 3, sizable SUSY effects to the muon $(g-2)$, at the level of $\Delta a_\mu^{\mathrm{SUSY}} \sim 10^{-9}$, lead to values for $\mathrm{BR}(\mu \to e\gamma)$ well within the MEG reach for natural values of the neutrino parameters M_3 and U_{e3}. Moreover, we note that the constraint from $\mathrm{BR}(B \to X_s\gamma)$ at the 90% (99%) C.L. allows SUSY contributions to the muon $(g-2)$ as large as $\Delta a_\mu^{\mathrm{SUSY}} \lesssim 1(2) \times 10^{-9}$.

In figure 4, we show the electron and muon EDMs vs. $\mathrm{BR}(\mu \to e\gamma)$ assuming maximum CP-violating phases. We vary the input parameters as $m_0, M_{1/2} < 1\,\mathrm{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ and $\mu > 0$; we also take $m_{\nu_3} = 0.05$eV, $10^{10} < M_3 < 10^{15}$GeV and we consider three different values for $U_{e3} = 0.1, 0.01, 0.001$. The attained values by d_e and d_μ, compatible with the current experimental bound on $\mathrm{BR}(\ell_i \to \ell_j\gamma)$, are well within the expected future experimental sensitivities for d_e, at least. It is noteworthy that, even in

[3]We have evaluated $\mathrm{BR}(B \to X_s\gamma)$ including the SM effects at the NNLO [47] and the NP contributions at the LO in this paper.

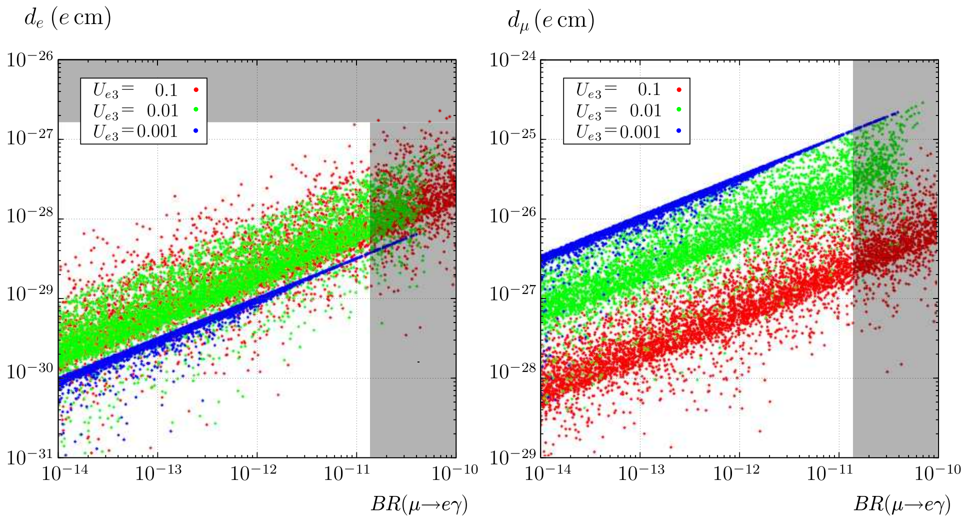

Figure 4. In the upper (lower) plot we show the electron (muon) EDM d_e (d_μ) vs. BR($\mu \to e\gamma$) in the SU(5)$_{\rm RN}$ model assuming maximum CP-violating phases. The input parameters are given as $m_0, M_{1/2} < 1\,\text{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ and $\mu > 0$. For the neutrino sectors, we assume a hierarchical spectrum for both light and heavy neutrinos and we take $m_{\nu_3} = 0.05\text{eV}$, $10^{10} < M_3 < 10^{15}\,\text{GeV}$. The grey regions are excluded by the current experimental upper bounds on BR($\mu \to e\gamma$) and d_e.

the pessimistic case in which $\mu \to e\gamma$ will not be observed at the MEG experiment (at the level of BR($\mu \to e\gamma$) $\lesssim 10^{-13}$), the predictions for d_e are still typically well above the level of $10^{-31}e$ cm.

Besides the running MEG experiment, also other experiments, i.e. Mu2e at Fermilab [44] and COMET at J-parc [45], looking for μ-e conversion in nuclei with expected sensitivities of order $10^{-(16-17)}$, are planed. These sensitivities would indirectly probe BR($\mu \to e\gamma$) at the level of BR($\mu \to e\gamma$) $\lesssim 10^{-14}$ (see eq. (2.8)). Furthermore, the PRISM/PRIME experiment, in which a very intensive pulsed beam is produced by the FFAG muon storage ring, is also planed and its ultimate sensitivity to μ-e conversion in nuclei should reach the $10^{-(18-19)}$ level [45]. Thus, μ–e conversion experiments and the electron EDM would represent the most promising and powerful tool to probe the SU(5)$_{\rm RN}$ model after the MEG experiment.

We remind that when U_{e3} is very small, d_e, d_μ and BR($\mu \to e\gamma$) turn out to be highly correlated, as they are generated by very similar Bino induced diagrams; looking at figure 4, this correlation is evident in the case of blue points, corresponding to $U_{e3} = 10^{-3}$. In the scenario with a negligibly small $U_{e3} \leq 10^{-3}$, both BR($\tau \to \mu\gamma$) and d_μ assume their maximum values as the constraints from BR($\mu \to e\gamma$) are quite relaxed in this case.

In figure 5, we show the correlation between d_e vs d_μ assuming maximum CP-violating phases and the same input parameters as in figure 4. As shown by the eq. (6.4), the flavored leptonic EDMs are bounded by the experimental limit on BR($\mu \to e\gamma$). The dots excluded at the levels of BR($\mu \to e\gamma$) $< 10^{-11}$ and BR($\mu \to e\gamma$) $< 10^{-13}$ are also indicated in figure 5.

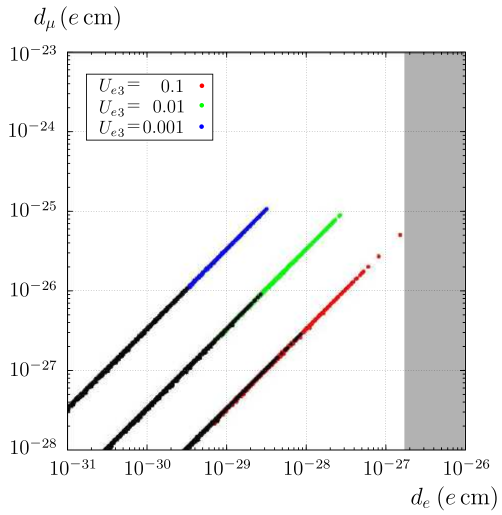

Figure 5. Electron EDM d_e vs. muon EDM d_μ in the $\mathrm{SU}(5)_{\mathrm{RN}}$ model assuming maximum CP-violating phases. The input parameters are given as in figure 4 and the current constraints from $\mathrm{BR}(\ell_i \to \ell_j\gamma)$ have been imposed. The black dots correspond to $\mathrm{BR}(\mu \to e\gamma) \leq 10^{-13}$. The grey region is excluded by the current experimental upper bound on d_e.

In the upper plot of figure 6, we show the values attained by the P-odd asymmetry $A(\mu^+ \to e^+\gamma)$ given in eq. (7.1) as a function of U_{e3} for three different values of $\mathrm{BR}(\mu \to e\gamma) = (3, 1, 0.3) \times 10^{-12}$, corresponding to the green, red and blue bands of figure 6, respectively.

The plot has been obtained in the following way: we have performed a scan over the input parameters $m_0, M_{1/2} < 1\,\mathrm{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ (we set $\mu > 0$) and $10^{10} < M_3 < 10^{15}\,\mathrm{GeV}$ (we set $m_{\nu_3} = 0.05\mathrm{eV}$). Then, after imposing all the existing constraints arising from flavor observables (both in the leptonic and hadronic sectors), direct searches as well as from theoretical constraints, we have selected all the sets of input parameters producing a same value for $\mathrm{BR}(\mu \to e\gamma)$; in particular we have considered the three cases $\mathrm{BR}(\mu \to e\gamma) = (3, 1, 0.3) \times 10^{-12}$.

We note that when the parameter U_{e3} is large ($U_{e3} \sim 0.1$), the $\mathrm{BR}(\mu \to e\gamma)$ is almost determined by the amplitude $A_L \sim \delta_L^{\mu e} \sim U_{e3}$ and we expect $A(\mu^+ \to e^+\gamma) \sim +1$, as it is confirmed numerically by the figure 6. In contrast, when U_{e3} is very small ($U_{e3} \lesssim 10^{-4}$), the $\mathrm{BR}(\mu \to e\gamma)$ is dominated by the amplitude $A_R \sim \delta_L^{\mu\tau}\delta_R^{\tau e}$ and $A(\mu^+ \to e^+\gamma)$ approaches to -1, as shown by the figure 6. When U_{e3} is neither very close to 0.1 nor to zero, we expect $A(\mu^+ \to e^+\gamma)$ in the range $A(\mu^+ \to e^+\gamma) \in (-1, +1)$. It is noteworthy to observe that already for U_{e3} values not so far from 0.1, $A(\mu^+ \to e^+\gamma)$ can depart sizably from $A(\mu^+ \to e^+\gamma) = +1$.

In the lower plot of figure 6, we show the correlation between $A(\mu^+ \to e^+\gamma)$ and $\mathrm{BR}(\tau \to \mu\gamma)$ assuming an experimental evidence for $\mu \to e\gamma$ at the level of $\mathrm{BR}(\mu \to e\gamma) = 3 \times 10^{-12}$. It is found that a sizable departure from the value $A(\mu^+ \to e^+\gamma) = +1$ would most likely imply a lower bound for $\tau \to \mu\gamma$. In figure 6 it turns out that $\mathrm{BR}(\tau \to \mu\gamma) \gtrsim 10^{-9}$ and this is specially true if we also require an explanation of the muon $(g-2)$

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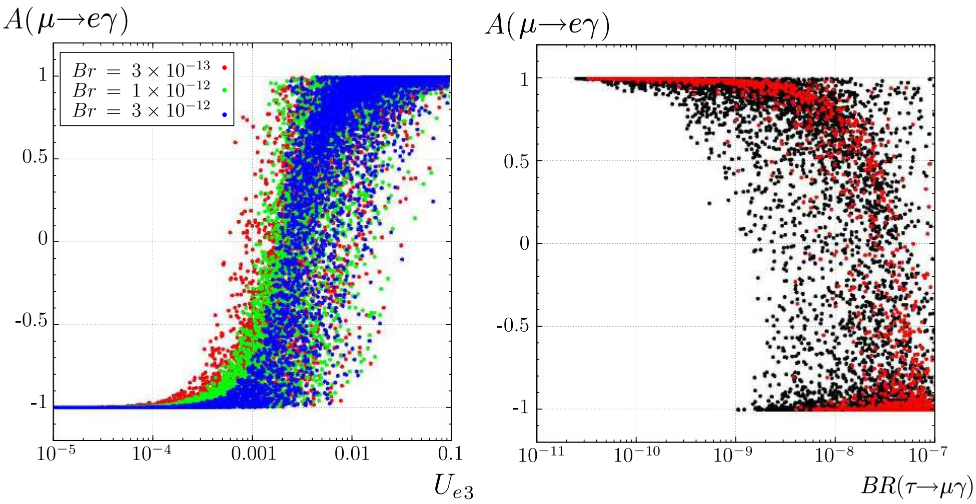

Figure 6. Upper plot: P-odd asymmetry in $\mu^+ \to e^+\gamma$, $A(\mu^+ \to e^+\gamma)$, vs. U_{e3} in the $\mathrm{SU(5)_{RN}}$ model for three different values of $\mathrm{BR}(\mu \to e\gamma) = (3, 1, 0.3) \times 10^{-12}$. Lower plot: $A(\mu^+ \to e^+\gamma)$ vs. $\mathrm{BR}(\tau \to \mu\gamma)$ assuming $\mathrm{BR}(\mu \to e\gamma) = 3 \times 10^{-12}$. Both plots have been obtained by means of a scan of the input parameters $m_0, M_{1/2} < 1\,\mathrm{TeV}$, $|A_0| < 3m_0$, $3 < \tan\beta < 50$ and $\mu > 0$. For the neutrino sectors, we have assumed a hierarchical spectrum for both light and heavy neutrinos and we take $m_{\nu_3} = 0.05\mathrm{eV}$, $10^{10} < M_3 < 10^{15}\,\mathrm{GeV}$ and $10^{-5} \leq U_{e3} \leq 0.1$. All the points of both plots satisfy the constraints from $b \to s\gamma$ at the 99% C.L. limit and $m_{h^0} > 111.4\,\mathrm{GeV}$. Red points in the lower plot also satisfy $\Delta a_\mu^{\mathrm{SUSY}} \geq 1 \times 10^{-9}$.

anomaly in terms of SUSY effect, as shown by the red points in the lower plot of figure 6, corresponding to $\Delta a_\mu^{\mathrm{SUSY}} \geq 1 \times 10^{-9}$. If we assume values for $\mathrm{BR}(\mu \to e\gamma)$ smaller than $\mathrm{BR}(\mu \to e\gamma) = 3 \times 10^{-12}$, the corresponding predictions for $\mathrm{BR}(\tau \to \mu\gamma)$ will decrease of the same factor as $\mathrm{BR}(\mu \to e\gamma)$.

In figure 7, we show the correlation between $\mathrm{BR}(\mu \to e\gamma)$ and $\mathrm{BR}(\tau \to \mu\gamma)$ for three different values of $U_{e3} = (0.001, 0.01, 0.1)$. We recall that while $\mathrm{BR}(\tau \to \mu\gamma)$ is not sensitive to U_{e3}, $\mathrm{BR}(\mu \to e\gamma)$ crucially depends on U_{e3}. As shown in figure 7, if $U_{e3} = 0.1$, namely if U_{e3} is close to its current experimental upper bound, the current bound $\mathrm{BR}(\mu \to e\gamma) \lesssim 10^{-11}$ already implies that $\mathrm{BR}(\tau \to \mu\gamma) \lesssim 10^{-9}$, a level that is most probably beyond the reach of the Super B factories. In such a case, it is clear that $\mu \to e\gamma$ would represent the golden channel where to look for SUSY LFV signals given the expected experimental resolutions at the running MEG experiment $\mathrm{BR}(\mu \to e\gamma) \lesssim 10^{-13}$. In contrast, as shown in figure 7, if U_{e3} will turn out to be smaller than $U_{e3} = 0.1$, there are regions where both MEG and the Super B factories are expected to detect LFV signals. In the extreme case where U_{e3} is very small, say $U_{e3} \lesssim 10^{-3}$, $\tau \to \mu\gamma$ could still lie well within the Super B factories reach while $\mathrm{BR}(\mu \to e\gamma)$ could result too small to be seen at the MEG experiment.

Hence, we want to stress here that $\mu \to e\gamma$ and $\tau \to \mu\gamma$ are very important and complementary probes of LFV effects arising in SUSY theories.

In the upper (lower) plot of figure 8, we show the values reached by $\mathrm{BR}(\mu \to e\gamma)$ within the $\mathrm{SU(5)_{RN}}$ model in the $(m_0, M_{1/2})$ plane setting $\mu > 0$, $A_0 = 0$ and $\tan\beta = 10$ ($\tan\beta = 30$). We assume $m_{\nu_3} = 0.05\mathrm{eV}$, $M_3 = 10^{13}\,\mathrm{GeV}$ and $U_{e3} = 0.1$. In both plots, the

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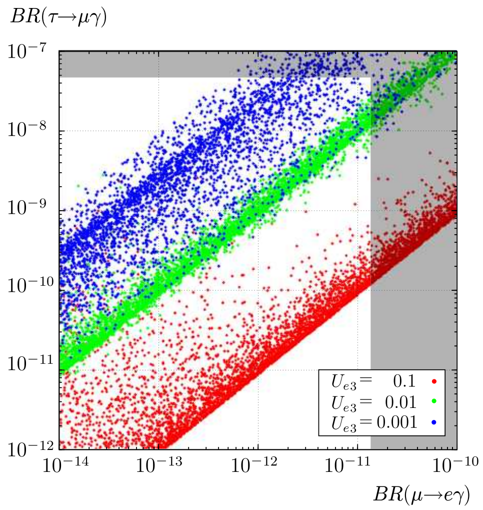

Figure 7. BR($\mu \to e\gamma$) vs. BR($\tau \to \mu\gamma$) in the SU(5)$_{\rm RN}$ model. The plot has been obtained by means of a scan over the same input parameters of figure 4. The grey regions are excluded by the current experimental upper bounds on BR($\mu \to e\gamma$) and BR($\tau \to \mu\gamma$).

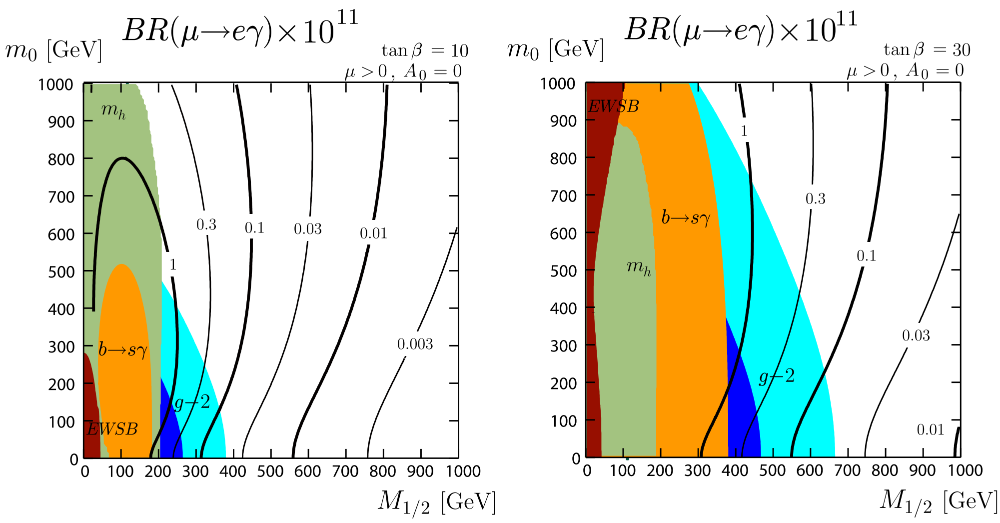

Figure 8. Upper plot: contour plot in the $(m_0, M_{1/2})$ plane showing the values attained by BR($\mu \to e\gamma$) in the SU(5)$_{\rm RN}$ model for $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$. For the neutrino sector, we assume a hierarchical spectrum for both light and heavy neutrinos and we take $m_{\nu_3} = 0.05$eV, $M_3 = 10^{13}$ GeV and $U_{e3} = 0.1$. Lower plot: same as in the upper plot but for $\tan\beta = 30$. In both plots, the grey region is excluded by the constraint from the lower bound on the lightest Higgs boson mass m_{h^0} (we impose $m_{h^0} > 111.4$ GeV), the orange region is excluded by the constraints on BR($B \to X_s\gamma$) at the 99% C.L. limit, the light- blue (blue) region satisfies $\Delta a_\mu^{\rm SUSY} > 1(2) \times 10^{-9}$ and finally the red region is excluded by the requirement of a correct EWSB.

grey region is excluded by the constraint from the lower bound on the lightest Higgs boson mass m_{h^0} (we impose $m_{h^0} > 111.4$ GeV), the orange region is excluded by the constraints on BR($B \to X_s\gamma$) at the 99% C.L. limit, the light blue (blue) region satisfies $\Delta a_\mu^{\rm SUSY} > 1(2)\times 10^{-9}$, and finally the red region is excluded by the requirement of a correct electroweak

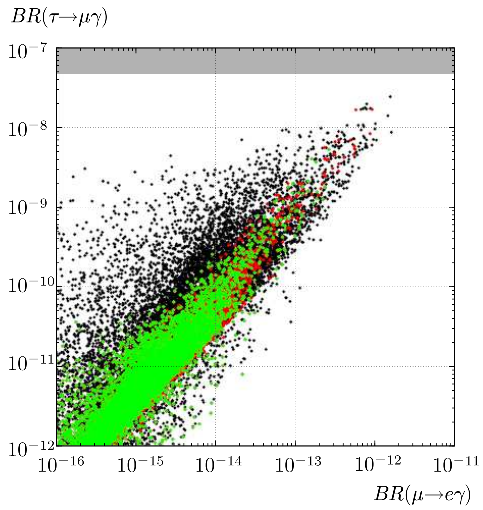

Figure 9. BR($\mu \to e\gamma$) vs. BR($\tau \to \mu\gamma$) in a pure SUSY SU(5) model without right-handed neutrinos. The plot has been obtained by means of a scan over the same input parameters of figure 4. Red and green dots satisfy the $B \to X_s\gamma$ constraints at the 99% C.L. limit while black dots do not. Green dots additionally satisfy $m_{h^0} > 111.4\,\text{GeV}$. All the points satisfy $\Delta a_\mu^{\text{SUSY}} \leq 5 \times 10^{-9}$. The grey region is excluded by the current experimental upper bound on BR($\tau \to \mu\gamma$).

symmetry breaking (EWSB). We note that, passing from the case of $\tan\beta = 10$ to the case of $\tan\beta = 30$, the indirect constraints, specially from $B \to X_s\gamma$, become stronger; however, the predictions for both $\Delta a_\mu^{\text{SUSY}}$ and BR($\mu \to e\gamma$) increase while increasing $\tan\beta$, so, as a final result, $\Delta a_\mu^{\text{SUSY}}$ and BR($\mu \to e\gamma$) reach large values even for heavy masses $(m_0, M_{1/2}) \lesssim 1\,\text{TeV}$. Moreover, we have found that the requirement of a neutral lightest SUSY particle does not exclude any region in the $(m_0, M_{1/2})$ plane, in contrast to what happens in the constrained MSSM. The motivation is that, within SUSY GUTs, the lightest stau is heavier than in the constrained MSSM because of GUT effects stemming from the gauge interaction above the GUT scale, where the gauge couplings are unified.

Now let us comment about the prediction we would expect removing the assumptions $R = 1$. In the general case where $R \neq 1$, it turns out that $\delta_L^{\mu e} \sim \delta_L^{\tau\mu}$ and this leads to the following considerations: *i)* BR($\mu \to e\gamma$) is always dominated by $\delta_{\mu e}^L$, hence we expect $A(\mu^+ \to e^+\gamma) = +1$, *ii)* BR($\tau \to \mu\gamma$) and d_μ are very suppressed because of the tight constraints from BR($\mu \to e\gamma$). Moreover, irrespective to whether $R = 1$ or $R \neq 1$ and irrespective to the details of the light and heavy neutrino masses, the relation $\delta_{\mu e}^L \sim \delta_{\tau e}^L$ always holds thus implying a strong suppression for BR($\tau \to e\gamma$) at the level of BR($\tau \to e\gamma$)/BR($\mu \to e\gamma$) $\simeq$ 1/BR($\tau \to e\nu_\tau\bar{\nu}_e$).

Finally, we show BR($\mu \to e\gamma$) vs. BR($\tau \to \mu\gamma$) in a pure SUSY SU(5) model without right-handed neutrinos in figure 9. As anticipated in previous sections, these processes are typically quite suppressed as BR($\mu \to e\gamma$) $\lesssim 10^{-(13-14)}$ and BR($\tau \to \mu\gamma$) $\lesssim 10^{-(9-10)}$. However, there is a on-negligible fraction of points lying within the experimentally interesting region where BR($\mu \to e\gamma$) $\gtrsim 10^{-13}$ and/or BR($\tau \to \mu\gamma$) $\gtrsim 10^{-9}$. This last situation happens only for large values of $\tan\beta$ as BR($\ell_i \to \ell_j\gamma$) $\sim \tan^2\beta$. Thus, a legitimate

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warning is whether in this region of the parameter space it is possible to satisfy all the indirect constraints, specially those arising from processes enhanced by powers of $\tan\beta$ as $B \to X_s\gamma$, $B_s \to \mu^+\mu^-$, $B \to \tau\nu$, and the muon anomalous magnetic moment $(g-2)$ [46]. In the figure, the red and green dots satisfy the $\mathrm{BR}(B \to X_s\gamma)$ constraints at the 99% C.L. limit. As is well known, the charged Higgs contribution interferes constructively with the SM one while the relative sign between the chargino and the SM amplitudes is given by $\mathrm{sign}(A_t\ \mu)$ as $A^{\mathrm{bsg}}_{\tilde{\chi}^-} \propto [\mu A_t/m^4_{\tilde{q}}] \times \tan\beta$. Thus, to keep $A_{\tilde{\chi}^-}$ under control with very large values of $\tan\beta$, we need large sfermion masses and small A_t. Remembering that $A_t(m_t) \simeq 0.25A_0 - 2M_{1/2}$, we expect that small values for $A_t(m_t)$ are obtainable for positive and large A_0 compared to $M_{1/2}$ and this is exactly what we find numerically in the region where $\mathrm{BR}(\mu \to e\gamma) \gtrsim 10^{-13}$ and/or $\mathrm{BR}(\tau \to \mu\gamma) \gtrsim 10^{-9}$. Moreover, the overall size for the total SUSY amplitude is also reduced by means of cancellations between charged Higgs and chargino contributions. Notice also that when A_0 is large, $\mathrm{BR}(\ell_i \to \ell_j\gamma)$ is enhanced as $\mathrm{BR}(\ell_i \to \ell_j\gamma) \sim |\delta^{ij}|^2$ with the MI parameters $\delta^{ij} \sim (3m_0^2 + A_0^2)$.

Concerning $\mathrm{BR}(B_s \to \mu^+\mu^-)$, we remind that its dominant amplitude is approximately given by $A_{\tilde{\chi}^-} \propto [\mu A_t/m^2_{\tilde{q}}] \times [\tan^3\beta/M_A^2]$ hence, $A_{\tilde{\chi}^-}$ can be taken under control for small enough A_t values and this is already guaranteed by the constraints from $\mathrm{BR}(B \to X_s\gamma)$.

In contrast to $B_s \to \mu^+\mu^-$ and $B \to X_s\gamma$, $B_u \to \tau\nu$ receives NP effects already at the tree level by the charged Higgs exchange. These effects are particularly enhanced when $\tan\beta$ is large and if the heavy Higgs is light. However, we find that $B \to \tau\nu$ receives sizable but small enough NP effects as for $\tan\beta \sim 40$ we find a quite heavy charged Higgs, i.e. $M_{H^+} \gtrsim 400$ GeV.

Likewise, it is easy to find the SUSY contributions to the muon anomalous magnetic moment of the required size to explain its discrepancy with the SM expectation $\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \approx (3 \pm 1) \times 10^{-9}$. This discrepancy can be accommodated only with a positive μ sign, in agreement with the $B \to X_s\gamma$ requirements.

9 Conclusions

Motivated by the running MEG experiment, that will achieve an impressive resolution on the branching ratio of $\mu \to e\gamma$ at the level of $\mathrm{BR}(\mu \to e\gamma) \lesssim 10^{-13}$, in this article we have addressed the phenomenological implications, within supersymmetric scenarios, of *i)* an observation of $\mu \to e\gamma$, *ii)* a significant improvement of the $\mathrm{BR}(\mu \to e\gamma)$ upper bound.

In particular, we have exploited the correlations among $\mathrm{BR}(\mu \to e\gamma)$, the leptonic electric dipole moments (EDMs) and the $(g-2)$ of the muon both in a model-independent way, i.e. without making any assumption about the origin of the soft SUSY breaking terms, and in a specific but more predictive scenario such as a supersymmetric SU(5) model with right handed neutrinos.

In the following, we summarize the main results of our model-independent analysis:

- The desire of an explanation for the muon $(g-2)$ anomaly $\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} \approx (3 \pm 1) \times 10^{-9}$ in terms of SUSY effects, leads to values for $\mathrm{BR}(\mu \to e\gamma)$ well within the MEG resolutions even for extremely tiny flavor mixing angles of order $\delta_{e\mu} \sim 10^{-5}$. This implies that the MEG sensitivities will enable us to test or to exclude a wide class of models predicting larger mixing angles.

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- Since the leptonic EDMs as induced by flavor effects are closely related to LFV processes as $l_i \to l_j\gamma$, an experimental evidence for $\mu \to e\gamma$ could likely imply large leptonic EDMs, well within their planned experimental resolutions (for the electron EDM, at least). In case both $\mu \to e\gamma$ and the electron EDM will be observed, their correlation will provide a precious tool to disentangle among the soft SUSY breaking terms violating the lepton flavor.

Concerning the analysis within a SUSY SU(5) model with right handed neutrinos we have found that

- A SUSY contribution to the $(g-2)$ of the muon at the level of $\Delta a_\mu^{\rm SUSY} \approx (3\pm1)\times10^{-9}$ leads to values for BR($\mu \to e\gamma$) well within the MEG sensitivities even when the unknown neutrino mixing angle U_{e3} (to which BR($\mu \to e\gamma$) is very sensitive) is very small at the level of $U_{e3} < 10^{-3}$.

- The predictions for the electron EDM typically lie above the value $d_e \gtrsim 10^{-30} e\,\text{cm}$ for BR($\mu \to e\gamma$) $\gtrsim 10^{-13}$.

- In case $\mu \to e\gamma$ would be observed, the knowledge of the P-odd asymmetry $A(\mu^+ \to e^+\gamma)$ defined by means of initial muon polarization would represent a crucial tool to shed light on the nature of the LFV sources, in particular to disentangle whether an underlying SUSY GUT theory is at work or not. In fact, the pure MSSM with right-handed neutrinos unambiguously predicts that $A(\mu^+ \to e^+\gamma) = +1$ while a SUSY SU(5) model with right-handed neutrinos predicts $A(\mu^+ \to e^+\gamma) \in (-1, +1)$.

- An experimental evidence for $\mu \to e\gamma$ with a corresponding $A(\mu^+ \to e^+\gamma)$ departing sizably from $A(\mu^+ \to e^+\gamma) = +1$ would most likely imply large (visible) values for BR($\tau \to \mu\gamma$).

- Both $\mu \to e\gamma$ and $\tau \to \mu\gamma$ turn out to be very sensitive probe of LFV effects arising in SUSY SU(5) models with right handed neutrinos. While BR($\tau \to \mu\gamma$) is not sensitive to U_{e3}, the predictions for BR($\mu \to e\gamma$) are strongly affected by the unknown value of U_{e3}. As a result, both BR($\mu \to e\gamma$) and BR($\tau \to \mu\gamma$) can turn out to be the best probes of LFV in SUSY theories.

In conclusion, the outstanding experimental sensitivities of the MEG experiment searching for $\mu \to e\gamma$, may provide a unique opportunity to get the first evidence of New Physics in low-energy flavor processes. Should this happen, we have outlined, within SUSY theories, those low-energy observables that are also likely to show New Physics signals. Most importantly, a correlated study of the processes we have discussed in this work would represent a crucial step towards a deeper understanding of the underlying New Physics theory that is at work.

Acknowledgments

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