Sensitivity to the Higgs sector of SUSY-seesaw models via LFV tau decays

M. Herrero*, J. Portolés† and A. Rodríguez-Sánchez*

*Departamento de Física Teórica and Instituto de Física Teórica, IFT-UAM/CSIC
Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain
†IFIC, Universitat de València - CSIC, Apt. Correus 22085, E-46071 València, Spain

Abstract. Here we study and compare the sensitivity to the Higgs sector of SUSY-seesaw models via the LFV tau decays: $\tau \to 3\mu$, $\tau \to \mu K^+K^-$, $\tau \to \mu\eta$ and $\tau \to \mu f_0$. We emphasize that, at present, the two latter channels are the most efficient ones to test indirectly the Higgs particles.[1].

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INTRODUCTION

Lepton Flavor Violating (LFV) tau decays provide one of the most efficient indirect tests of supersymmetric (SUSY) models with extended neutrino sector, if the seesaw mechanism for neutrino mass generation is implemented. Here we assume SUSY-seesaw models with the MSSM particle content plus three right handed neutrinos, ν_{R_i} $(i = 1,2,3)$, and their corresponding SUSY partners, $\tilde{\nu}_{R_i}$, and use the parameterisation for the Yukawa couplings given by $m_D = Y_\nu v_2 = \sqrt{m_N^{\rm diag}} R \sqrt{m_\nu^{\rm diag}} U^\dagger_{\rm MNS}$, with R defined by three complex angles θ_i; $v_{1(2)} = v\cos(\sin)\beta$, $v = 174$ GeV; $m_\nu^{\rm diag} = {\rm diag}\,(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})$ denotes the three light neutrino masses, and $m_N^{\rm diag} = {\rm diag}\,(m_{N_1}, m_{N_2}, m_{N_3})$ the three heavy ones. With this parameterisation it is easy to accommodate the ν data and also get large $Y_\nu \sim \mathcal{O}(1)$, by choosing large $m_N^{\rm diag}$ and/or θ_i.

The sensitivity to the Higgs sector of these SUSY-seesaw models can appear only via the LFV processes that are mediated by Higgs particles. This is the case of the tau decay channels considered here, whose present experimental bounds are respectively at ${\rm BR}(\tau \to 3\mu) < 3.2 \times 10^{-8}$, ${\rm BR}(\tau \to \mu K^+K^-) < 3.4 \times 10^{-8}$, ${\rm BR}(\tau \to \mu\eta) < 5.1 \times 10^{-8}$ and ${\rm BR}(\tau \to \mu f_0) < 3.4 \times 10^{-8}$ (assuming ${\rm BR}(f_0 \to \pi^+\pi^-) \simeq 1$). The interest of these channels is that for scenarios with heavy SUSY soft masses of the order of 1 TeV, where the predicted rates for the $\tau \to \mu\gamma$ channel lay below the present experimental bound, ${\rm BR}(\tau \to \mu\gamma) < 1.6 \times 10^{-8}$, still some of the Higgs-mediated processes can indeed be at the present experimental reach if the relevant Higgs mass is light enough, say of the order of 100-250 GeV. We will focus here in the type of constrained SUSY-seesaw scenarios called NUHM-seesaw (standing for Non Universal Higgs Mass) where this kind of

[1] Talk given at the SUSY09 conference, Boston, by M. Herrero.

spectrum with light Higgs and heavy SUSY particles is possible. The input parameters are M_0, $M_{1/2}$, A_0 $\tan\beta$, sign(μ), $M_{H_1} = M_0(1+\delta_1)^{1/2}$ and $M_{H_2} = M_0(1+\delta_2)^{1/2}$. In refs. [1] and [2] the proper choices of δ_1 and δ_2 leading to the wanted light Higgs sector can be found. Notice that $\delta_1 = \delta_2 = 0$ corresponds to the usual constrained model (CMSSM-seesaw) with all scalar masses being universal, but this model does not lead to the scenario with heavy SUSY and light Higgs particles that we are interested here, so we will not considered it next. Most of the results reported here are extracted from the works [1] and [2] to which we refer the reader for more details.

RESULTS AND DISCUSSION

The numerical results for the branching ratios of the studied LFV tau decays are summarized in fig. 1. They are full one loop results and do not make use of any approximation like the mass insertion, large $\tan\beta$, nor the leading logarithmic approximations. The mass spectra for all the involved particles in the loops that contribute to these processes are computed within the NUHM-seesaw model, by solving the RGEs also to one loop level. In the case of the semileptonic decays we have used the standard techniques in chiral theory to describe the final hadrons in terms of quark bilinears. In particular, the channels with pseudo Goldstone bosons (PGB), P, like π, K and η, are treated within Chiral Perturbation Theory (χPT) to leading order, $\mathcal{O}(p^2)$, where the results are given in terms of $F_\pi = 92.4$ MeV and m_P. The additional contributions from resonances, R, in channels of the type $\tau \to \mu PP$ are taken into account within Resonance Chiral Theory (RχT), where the results are given in terms of F_π, m_P, m_R and well established form factors. In particular for the $\tau \to \mu K^+K^-$ channel the contributions from the $\rho(770)$, $\omega(782)$ and $\phi(1020)$ are considered via the electromagnetic vector form factor, $F_V^{K^+K^-}$. On the other hand, the $\eta(548)$ is defined via mixing between the octet, η_8, and singlet, η_0, components of the $P(0^-)$ nonet of PGB in χPT. Concretely we assume here a mixing angle of $\theta = -18^o$. The $f_0(980)$ is defined via mixing between the octet, R_8, and singlet, R_0, components of the $R(0^+)$ nonet of resonances in RχT. Concretely we assume here two choices for this mixing angle, $\theta_S = 7^o$ and 30^o. Notice that we have selected the semileptonic channels where the final hadrons have a relevant strange quark content, and consequently the sensitivity to the Higgs particles is greater than in those with just up and/or down quarks.

Besides the total rates, we also show separately in fig. 1 the various contributions to these processes: 1) $\tau \to 3\mu$ can be mediated by a γ, a Z boson, boxes and h^0, H^0 and A^0 [3], 2) $\tau \to \mu K^+K^-$ by a γ (also Z, but it is negligible) and h^0, H^0, 3) $\tau \to \mu\eta$ by a Z boson and A^0, and 4) $\tau \to \mu f_0$ by h^0 and H^0. We conclude that although the Higgs contributions in all these processes grow very fast with $\tan\beta$, still at large $\tan\beta$ values these are fairly dominated by the γ contribution in the cases of $\tau \to 3\mu$ and $\tau \to \mu K^+K^-$. Therefore, these are not sensitive to the Higgs sector. We have checked that this is true even for a very heavy SUSY spectra where the γ contribution gets reduced considerably. In $\tau \to \mu K^+K^-$ the Higgs contribution is relevant for $M_{\rm SUSY} > 750$ GeV, but there the rates are too small compared to the present bound. In contrast, the $\tau \to \mu\eta$ and $\tau \to \mu f_0$ channels are clearly sensitive to the Higgs sector. In fig. 1 we see that the A^0 contribution dominates BR($\tau \to \mu\eta$) for $\tan\beta > 20$ and the H^0 contribution dominates

BR($\tau \to \mu f_0$) at all $\tan\beta$ values. We also conclude from this figure that the approximate formulas found in refs. [1] and [2] for large $\tan\beta$, whose simplest forms are given by,

$$\mathrm{BR}(\tau \to \mu\eta(548))_{\mathrm{approx}} = 1.2\times 10^{-7}\,|\delta_{32}|^2 \left(\frac{100}{m_{A^0}(\mathrm{GeV})}\right)^4 \left(\frac{\tan\beta}{60}\right)^6$$

$$\mathrm{BR}(\tau \to \mu f_0(980))_{\mathrm{approx}} = \begin{pmatrix} 7.3\times 10^{-8}\ (\theta_S = 7^\circ) \\ 4.2\times 10^{-9}\ (\theta_S = 30^\circ) \end{pmatrix} |\delta_{32}|^2 \left(\frac{100}{m_{H^0}(\mathrm{GeV})}\right)^4 \left(\frac{\tan\beta}{60}\right)^6,$$

provide a very good approximation to the full result. This is also shown in fig.2 where BR($\tau \to \mu\eta$) and BR($\tau \to \mu f_0(980)$) are displayed as a function of the relevant Higgs mass. We see clearly in this figure that these two channels are sensitive to masses within the range 100-250 GeV, for large $\tan\beta$, θ_2 and m_{N_3}. Finally, fig.3 illustrates several

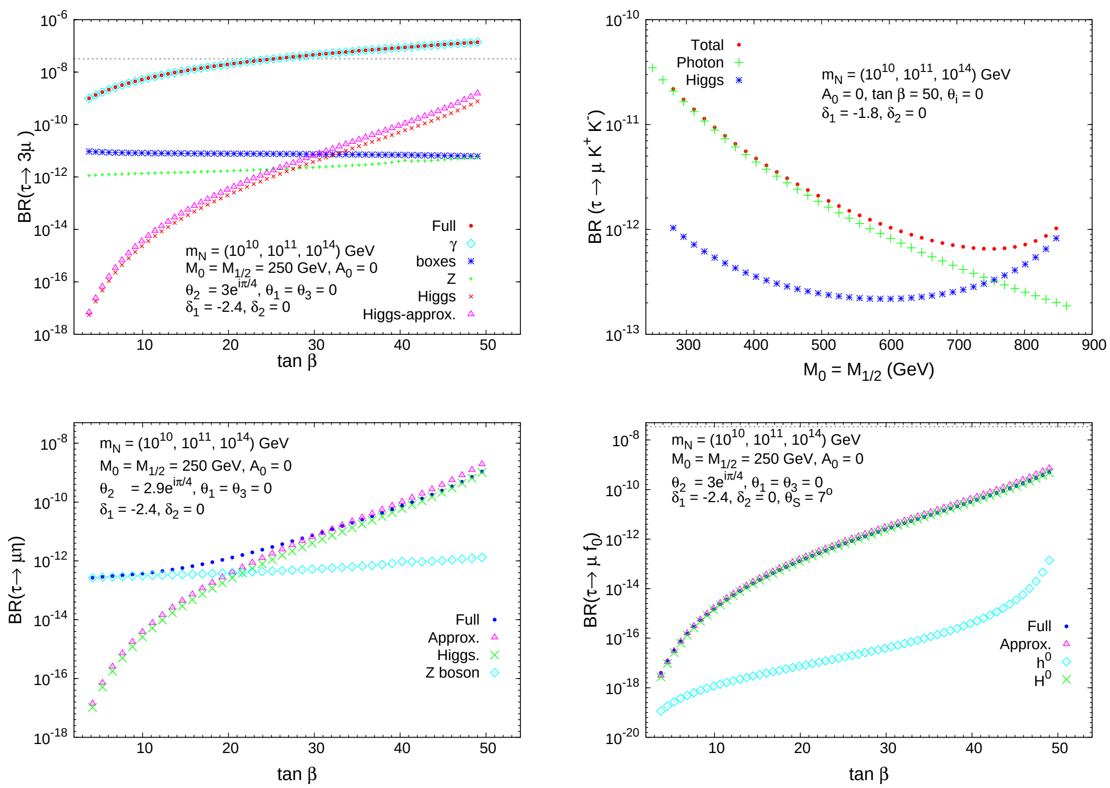

FIGURE 1. The various contributions to BR($\tau \to 3\mu$) (upper left), BR($\tau \to \mu K^+K^-$) (upper right), BR($\tau \to \mu\eta$) (lower left) and BR($\tau \to \mu f_0$) (lower right). The horizontal lines are the experimental bounds

examples for the relevant parameter δ_{32} that meassures approximately the size of the LFV in the tau-mu sector in seesaw scenarios with a) hierarchical and b) degenerate heavy neutrinos N. We see that in both scenarios values as large as $|\delta_{32}| \sim 1-10$ can be obtained. Therefore, with such large values and the present experimental upper limits one can extract lower bounds for the relevant Higgs mass and upper bounds for $\tan\beta$. This is the main conclusion of this work. The case of $\tau \to \mu f_0$ is illustrated in the last plot of fig.3, where one can see the excluded regions in the $(m_{H^0}, \tan\beta)$ plane.

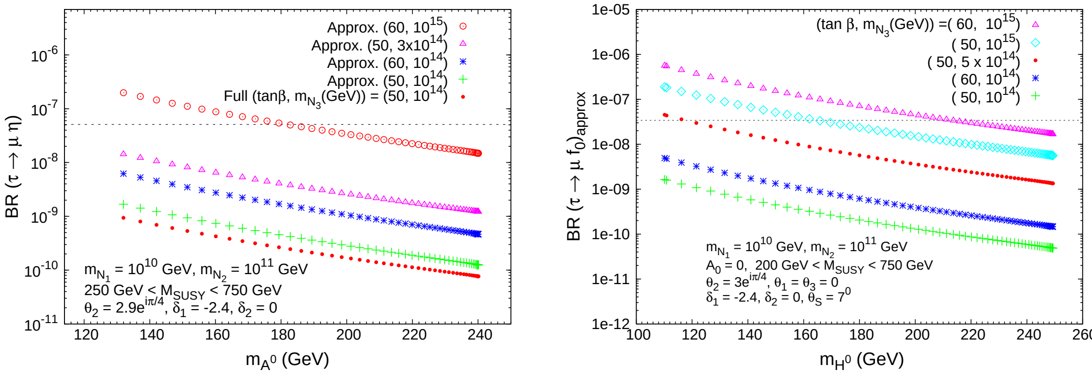

FIGURE 2. BR($\tau \to \mu \eta$) (left) and BR($\tau \to \mu f_0(980)$) (right) as a function of the relevant Higgs mass. The horizontal dashed line in each plot is the present experimental upper bound

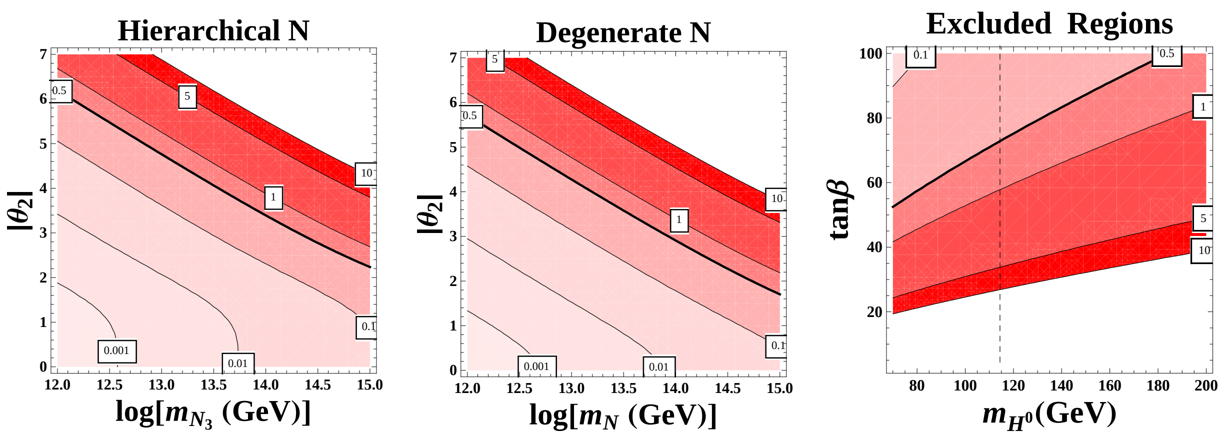

FIGURE 3. Left (central) panel: contours of $|\delta_{32}|$ in SUSY-seesaw for hierarchical (degenerate) heavy neutrinos. Right panel: Excluded regions in the $(m_{H^0}, \tan\beta)$ plane from the study of $\tau \to \mu f_0$. The exluded areas are those above the contour lines corresponding to fixed $|\delta_{32}| = 0.1, 0.5, 1, 5, 10$.

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