LFV in semileptonic $\tau$ decays and $\mu - e$ conversion in nuclei in SUSY-seesaw

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Abstract. Here we review the main results of LFV in the semileptonic tau decays $\tau \to \mu PP$ ($PP = \pi^+\pi^-, \pi^0\pi^0, K^+K^-, K^0\bar{K}^0$), $\tau \to \mu V$ ($V = \rho, \phi$) as well as in $\mu - e$ conversion in nuclei within SUSY-seesaw scenarios, and compare our predictions with the present experimental bound.[4]

Keywords: Flavor symmetries, SUSY models, Right-handed neutrinos

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FRAMEWORK FOR LFV

We work within the framework of the Minimal Supersymmetric Standard Model (MSSM) enlarged by three right handed neutrinos and their SUSY partners, where potentially observable LFV effects in the charged lepton sector are expected to occur. We further assume a seesaw mechanism for neutrino mass generation and use the parameterisation $m_0 = Y_e v_2 = \sqrt{m_N^{\text{diag}} R \sqrt{m_N^{\text{diag}} U_{\text{MNS}}^\dagger}}$, with $R$ defined by $\theta_i (i = 1, 2, 3); v_i (2) = v \cos(\sin(\beta), v = 174 \text{ GeV})$. $m_N^{\text{diag}} = \text{diag}(m_{\nu_1}, m_{\nu_2}, m_{\nu_3})$ denotes the three light neutrino masses, and $m_N^{\text{diag}} = \text{diag}(m_{N_{\mu}}, m_{N_{\tau}}, m_{N_{e}})$ the three heavy ones. $U_{\text{MNS}}$ is given by the three (light) neutrino mixing angles $\theta_{12}, \theta_{13}$ and $\theta_{23}$, and three phases, $\delta, \phi_1$ and $\phi_2$. With this parameterisation it is easy to accommodate the neutrino data, while leaving room for extra neutrino mixings (from the right handed sector). It further allows for large Yukawa couplings $Y_e \sim O(1)$ by choosing large entries in $m_N^{\text{diag}}$ and/or $\theta_i$.

Here we focus in the particular LFV processes: 1) semileptonic $\tau \to \mu PP$ ($PP = \pi^+\pi^-, \pi^0\pi^0, K^+K^-, K^0\bar{K}^0$), $\tau \to \mu V$ ($V = \rho, \phi$) decays and 2) $\mu - e$ conversion in heavy nuclei. The predictions in the following are for two different constrained MSSM-seesaw scenarios, with universal and non-universal Higgs soft masses. The respective parameters (in addition to the previous neutrino sector parameters) are: 1) CMSSM-seesaw: $M_0, M_{1/2}, A_0 \tan \beta$, and sign($\mu$), and 2) NUHM-seesaw: $M_0, M_{1/2}, A_0 \tan \beta$, sign($\mu$), $M_{H_1} = M_0 (1 + \delta_1)^{1/2}$ and $M_{H_0} = M_0 (1 + \delta_2)$. The predictions presented here for the $\mu - e$ conversion rates include the full set of SUSY one-loop contributing diagrams, mediated by $\gamma$, $Z$, and Higgs bosons, as well as boxes, and do not use the Leading Logarithmic (LLLog) nor the mass insertion approximations. In the case of semileptonic tau decays we have not included the boxes which are clearly subdominant. The hadronisation of quark bilinears is performed within the chiral framework, using Chiral Perturbation Theory and Resonance Chiral Theory. This is a very short summary of the works in [1] and [2] to which we refer the reader for more details.

RESULTS AND DISCUSSION

Here we present the predictions for BR($\tau \to \mu PP$) ($PP = \pi^+\pi^-, \pi^0\pi^0, K^+K^-, K^0\bar{K}^0$), BR($\tau \to \mu V$) ($V = \rho, \phi$) and CR($\mu - e$, Nuclei) within the previously described framework and compare them with the following experimental bounds: BR($\tau \to \mu \pi^\mu$) $< 4.8 \times 10^{-7}$, BR($\tau \to \mu K^+K^-$) $< 8 \times 10^{-7}$, BR($\tau \to \mu \pi$) $< 5.8 \times 10^{-8}$, BR($\tau \to \mu \eta$) $< 5.1 \times 10^{-8}$, BR($\tau \to \mu \eta'$) $< 5.3 \times 10^{-8}$, BR($\tau \to \mu \rho$) $< 2 \times 10^{-7}$, BR($\tau \to \mu \phi$) $< 1.3 \times 10^{-7}$, CR($\mu - e$, Au) $< 7 \times 10^{-13}$ and CR($\mu - e$, Ti) $< 4.3 \times 10^{-12}$.

As a general result in LFV processes that can be mediated by Higgs bosons we have found that the $H^0$ and $A^0$ contributions are relevant at large $\tan \beta$ if the Higgs masses are light enough. It is in this aspect where the main difference between the two considered scenarios lies. Within the CMSSM, light Higgs $H^0$ and $A^0$ bosons are only possible for low $M_{\text{SUSY}}$ (here we take $M_{\text{SUSY}} = M_0$), and by choosing $M_0 = M_{1/2}$ to reduce the number of input parameters. In contrast, within the NUHM, light Higgs bosons can be
SUSY bosons, which is non-decoupling. The decays involving \( m_0 \) reach in the low region, due to the contribution of light Higgs bosons, which has a stronger coupling to the Higgs bosons. On the other hand, the largest predicted rates are for \( \tau \to \mu \eta \) and \( \tau \to \mu \eta' \) channels, largely dominated by the \( A^0 \) boson exchange. Fig. 3 shows that BR(\( \tau \to \mu \eta \)) reaches the experimental bound for large heaviest neutralino mass, large \( \tan \beta \), large \( \theta_i \) angles and low \( m_{A^0} \).

For the choice of input parameters in this figure, it occurs at \( m_{A^0} = 10^{15} \text{ GeV} \), \( \tan \beta = 60 \), \( \theta_2 = 2.9 \pi/4 \) and \( m_{\mu^0} = 180 \text{ GeV} \). A set of useful formulae for all these channels, within the mass insertion approximation which are valid at large \( \tan \beta \), are presented in [2]. We have shown that the predictions with these formulae agree with the full results within a factor of about 2. In the case of \( \tau \to \mu \eta \) this comparison is shown in Fig. 3. Similar conclusions are found for \( \tau \to \mu \eta' \). The next relevant channel in sensitivity to the Higgs sector is \( \tau \to \mu K^+ K^- \), but it is still below the present experimental bound. To our knowledge, there are not experimental bounds yet available for \( \tau \to \mu K^0 \bar{K}^0 \) and \( \tau \to \mu \pi^0 \pi^0 \).

Next we comment on the results for \( \mu - e \) conversion in nuclei. Fig. 4 shows our predictions of the conversion rates for Titanium as a function of \( M_{\text{SUSY}} \) in both CMSSM and NUHM scenarios. As in the case of semileptonic tau decays, the sensitivity to the Higgs contribution is only manifest in the NUHM scenario. The predictions for CR(\( \mu - e \), Ti) within the CMSSM scenario are largely dominated by the photon contribution and present a decoupling behaviour at large \( M_{\text{SUSY}} \).
In this case the present experimental bound is only reached at low $M_{SUSY}$. The perspectives for the future are much more promising. If the announced sensitivity by PRISM/PRIME of $10^{-18}$ is finally attained, the full studied range of $M_{SUSY}$ will be covered.

Fig.4 also illustrates that within the NUHM scenario the Higgs contribution dominates at large $M_{SUSY}$ for light Higgs bosons. The predicted rates are close to the present experimental bound not only in the low $M_{SUSY}$ region but also for heavy SUSY spectra. As in the previous semileptonic tau decays, we have found in addition a simple formula for the conversion rates, within the mass insertion approximation, which is valid at large tan $\beta$ \cite{1} and can be used for further analysis.

The predictions of the $\mu-e$ conversion rates for several nuclei are collected in Fig.5. We can see again the growing behaviour with $M_{SUSY}$ in the large $M_{SUSY}$ region due to the non-decoupling of the Higgs contributions. At present, the most competitive nuclei for LFV searches is Au where, for the choice of input parameters in this figure, all the predicted rates are above the experimental bound. We have also shown in \cite{1} that $\mu-e$ conversion in nuclei is extremely sensitive to $\theta_{13}$, similarly to $\mu\rightarrow e\gamma$ and $\mu\rightarrow 3e$ and, therefore, a future measurement of this mixing angle can help in the searches of LFV in the $\mu-e$ sector.

In conclusion, we have shown that semileptonic tau decays nicely complement the searches for LFV in the $\tau-\mu$ sector, in addition to $\tau\rightarrow \mu\gamma$. The future prospects for $\mu-e$ conversion in Ti are the most promising for LFV searches. Both processes, semileptonic tau decays and $\mu-e$ conversion in nuclei are indeed more sensitive to the Higgs sector than $\tau\rightarrow 3\mu$.

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