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Abstract. In this work we explore a lepton flavor violation effect induced at one loop for a flavor structure in an extended minimal standard supersymmetric model, considering an ansatz for the trilinear term. In particular we find a finite expression which will show the impact of this phenomena in the $h \to \mu\tau$ decay, produced by a mixing in the trilinear coupling of the soft supersymmetric Lagrangian.

1. Introduction

In the Standard Model (SM) lepton flavor violation processes were forbidden by the lepton number conservation, which is not associated with a gauge symmetry. In the SM, the spontaneous breaking of the electroweak symmetry produces eigenstates of the remaining gauge group that are not in general eigenstates of the mass matrix [1, 2, 3, 4]. But after diagonalization of the mass matrix, the electroweak coupling matrix is also diagonal in the mass basis, therefore there is no possibility for lepton flavor violation. Nevertheless, this symmetry is lost in neutrino oscillation found in experiments [5, 6, 7, 8], which forces the model structure to go beyond the SM.

This lost symmetry on leptons observed in the neutrino mixing evidence opens also the possibility of lepton flavor violation in the charged sector. Experimental data taken from CMS at $8\,TeV$ with $19.7 fb^{-1}$ had shown an excess for $BR(h^0 \to \tau\mu)$ of 2.4σ with best fit branching fraction of $0.84^{+0.39}_{-0.37}\%$ [9]. Nevertheless data from ATLAS has shown only a 1σ significance for the same process [10]. Moreover, also recent measurements at $13\,TeV$, although with only $2.3 fb^{-1}$ of data, has shown no evidence of excess. It was even reported [11] a best fit branching fraction of -0.56%. The sign change may imply a statistical error of the data. Even for those latest reports, if they are confirmed, they will indicate a very low range for this lepton flavor violation processes to occur at these energies. These will set stringent bounds to any model beyond the SM. One of the works toward this direction is done in [12], where it has been explored it in a Two Higgs Doublet Model with flavor violation in the Yukawa couplings, a model known as THDM-III [13]. In order to fit these restrictions bounds, the model we proposed in this work of

a scalar flavor extended MSSM, should show exclusions regions in the parameter space.

The most recent data by the LHC at 13 TeV have not shown evidence for supersymmetry for different channels and observables as events with one lepton as final state [11], jets and leptons or three leptons [14], missing energy [15]. The experimental search is mainly for the Lightest Supersymmetric Particle (LSP) as missing energy, these reports analyses the data for simplified supersymmetric models at this specific energy. The results of these analysis have reduced the parameter space for Minimal Supersymmetric Standard Model (MSSM). Nevertheless we claim that is important to fully explore the possible parameter space for different non-simple supersymmetric low energy models knowing that Supersymmetry still solves many phenomenological issues [16, 17] and also is needed for many GUT models. A review on flavor violation processes in the MSSM considering neutrino mixing can be found in [18].

2. Flavor mixed sleptons

As the evidence on flavor violation in charged lepton is not yet conclusive but gives low values for these branching ratios, one possibility is to have a mixed flavor structure in an unseen sector as the sfermions, and then this mixing will induce flavor violation through radiative corrections. The mixing of slepton states will be given by a flavor structure in the mass matrix, specifically we explore the possibility of having mixing flavor terms in the trilinear couplings of the soft supersymmetric Lagrangian.

$$\mathcal{L}_{soft}^f = -\sum_{\tilde{f}_i} \tilde{M}_{\tilde{f}}^2 \tilde{\bar{f}}_i \tilde{f}_i - (A_{\tilde{f},i} \tilde{\bar{f}}_L^i H_1 \tilde{f}_R^{\ i} + h.c), \tag{1}$$

where $\tilde{f}$ are the scalar fields in the supermultiplet. In the case of sfermions, as they are scalar particles, the L, R are just labels which point out to the fermionic SM partners, but they no longer have left and right $SU(2)$ properties. In general they may mix in two physical states. Once the EW symmetry breaking is considered, the trilinear term of the soft SUSY Lagrangian for the sleptonic sector takes the following form

$$\mathcal{L}_{H\tilde{f}_i\tilde{f}_j} = \frac{A_l^{ij}}{\sqrt{2}} \left[(\phi_1^0 - i\chi_1^0)\tilde{l}_{iR}^*\tilde{l}_{jL} - \sqrt{2}\phi_1^-\tilde{l}_{iR}^*\tilde{\nu}_{jL} + v_1\tilde{l}_R^*\tilde{l}_L \right] + h.c.$$

The contribution to the elements of the sfermion mass matrix come from the interaction of the Higgs scalars with the sfermions, which appear in different terms of the superpotential and soft-SUSY breaking terms as is fully explained in [19, 20]. In the case of the slepton mass matrix, as we said before, the contributions coming from *mass soft terms* are $\tilde{M}_{l,LL}^2$, $\tilde{M}_{l,RR}^2$, from trilinear couplings after EW symmetry breaking A_{ij}^l and from the $F, D-$terms. We arrange them in a block mass matrix as follows

$$\tilde{M}_l^2 = \begin{pmatrix} m_{LL,l}^2 & m_{LR,l}^2 \\ m_{RL,l}^2 & m_{RR,l}^2 \end{pmatrix} . \tag{2}$$

The elements of the sleptons mass matrix eq. (2), for the different flavors given by $i, j = e, \mu, \tau$ are

$$m_{LL,l}^2 = \tilde{M}_{\tilde{L},l}^2 + m_{l_L}^2 + \frac{1}{2}\cos 2\beta(2M_W^2 - M_Z^2), \tag{3}$$

$$m_{RR,l}^2 = \tilde{M}_{\tilde{E},l}^2 + m_{l_R}^2 - \cos 2\beta \sin^2\theta_W M_Z^2, \tag{4}$$

$$m_{LR,l}^2 = \frac{A_l v \cos\beta}{\sqrt{2}} - m_l \mu_{susy} \tan\beta. \tag{5}$$

The soft terms are not the only contributions to the sfermion mass elements, the supersymmetric auxiliary fields F and D coming from the superpotential also contribute to this mass matrix.

In the present work, we assume the mass terms coming from SUSY breaking terms dominate over the EW terms coming from auxiliary F and D fields so we can safely approximate the diagonal elements to a soft susy scale m_S as $m_{RR}^2 \approx m_{LL}^2 = m_S^2 \mathbf{1_{2\times 2}}$.

In order to analyze the consequences of a flavor structure we construct an ansatz for the trilinear terms A_t. Our procedure is similar to the work done in Ref. [21] for FCNC's in the quark sector through an ansatz of soft-susy terms. In our case we consider the whole two families contributions and of the same order of magnitude, having the following form for the trilinear term

$$A_l = \begin{pmatrix} 0 & 0 & 0 \\ 0 & w & y \\ 0 & y & 1 \end{pmatrix} A_0. \tag{6}$$

In this case, one could have at tree level the selectrons in a singlet irreducible representation decoupled from the other two families of sleptons. This would give rise to a 4×4 matrix, diagonalizable through a unitary matrix $Z_{\tilde{l}}$, such that $Z_{\tilde{l}}^{\dagger} \tilde{M}_l^2 Z_{\tilde{l}} = \tilde{M}_{diag}^2$.

We will have then physical non-degenerate slepton masses[1]

$$m_{\tilde{\tau}_{1,2}}^2 = \frac{1}{2}(2\tilde{m}_S^2 - X_m - X_t \pm R) \;,$$

$$m_{\tilde{\mu}_{1,2}}^2 = \frac{1}{2}(2\tilde{m}_S^2 + X_m + X_t \pm R) \;, \tag{7}$$

where $R = \sqrt{4A_y^2 + (X_t - X_m)^2}$ with $A_y = \frac{1}{\sqrt{2}}yA_0 v \cos\beta$, $X_m = \frac{1}{\sqrt{2}}wA_0 v \cos\beta - \mu_{susy} m_\mu \tan\beta$ and $X_t = \frac{1}{\sqrt{2}}A_0 v \cos\beta - \mu m_\tau \tan\beta$.

We may write the transformation which diagonalizes the mass matrix as a 4×4 rotation matrix for sleptons $Z_{\tilde{l}}$, which is in turn a 2×2 block matrix $Z_{\tilde{l}}^{\dagger} \tilde{M}_{\mu-\tau}^2 Z_{\tilde{l}} = \tilde{M}_{l,diag}^2$, explicitly having the form

$$Z_{\tilde{l}} = \frac{1}{\sqrt{2}} \begin{pmatrix} \Phi & -\Phi \\ \Phi\sigma^3 & \Phi\sigma^3 \end{pmatrix} \;, \tag{8}$$

where σ_3 is the Pauli matrix and

$$\Phi = \begin{pmatrix} -\sin\frac{\varphi}{2} & -\cos\frac{\varphi}{2} \\ \cos\frac{\varphi}{2} & -\sin\frac{\varphi}{2} \end{pmatrix}, \quad \tan\varphi = \frac{2A_y}{X_m - X_t}, \tag{9}$$

The non-physical states are transformed to the physical eigenstates as

$$\begin{pmatrix} \tilde{\mu}_L \\ \tilde{\tau}_L \\ \tilde{\mu}_R \\ \tilde{\tau}_R \end{pmatrix} = Z_{\tilde{l}} \begin{pmatrix} \tilde{l}_1 \\ \tilde{l}_2 \\ \tilde{l}_3 \\ \tilde{l}_4 \end{pmatrix} \tag{10}$$

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[1] We assign the label $\tilde{\tau}, \tilde{\mu}$ to the masses to show the relation to the non-FV sleptons.

Table 1. Expressions of the respective interactions of the Higgs boson h^0 with two sleptons

$g_{h^0 \tilde{f} \tilde{f}}$	$\tilde{\mu}_1$	$\tilde{\mu}_2$	$\tilde{\tau}_1$	$\tilde{\tau}_2$
$\tilde{\mu}_1$	$s_\varphi^2 T_{\tilde{\tau}}^+ + c_\varphi^2 T_{\tilde{\mu}}^+ - \frac{1}{4}G$	$\frac{1}{4}G(1 - 4s_w^2)$	0	$s_\varphi c_\varphi(T_{\tilde{\tau}}^+ - T_{\tilde{\mu}}^+)$
$\tilde{\mu}_2$	$*$	$s_\varphi^2 T_{\tilde{\tau}}^- + c_\varphi^2 T_{\tilde{\mu}}^- - \frac{1}{4}G$	$s_\varphi c_\varphi(T_{\tilde{\tau}}^- - T_{\tilde{\mu}}^-)$	0
$\tilde{\tau}_1$	0	$*$	$s_\varphi^2 T_{\tilde{\mu}}^- + c_\varphi^2 T_{\tilde{\tau}}^- - \frac{1}{4}G$	$\frac{1}{4}G(1 - 4s_w^2)$
$\tilde{\tau}_2$	$*$	0	$*$	$s_\varphi^2 T_{\tilde{\mu}}^+ + c_\varphi^2 T_{\tilde{\tau}}^+ - \frac{1}{4}G$

2.1. Higgs flavor violation coupling with sleptons

The Lagrangian which gives the interaction of scalar neutral light Higgs h^0-slepton-slepton is given as

$$\mathcal{L}_{h^0 \tilde{l} \tilde{l}} = Q_{\tilde{l}} \left[\tilde{l}_L^* \tilde{l}_L + \tilde{l}_R^* \tilde{l}_R \right] h^0 + G \left[(-\frac{1}{2} + s_w^2) \tilde{l}_L^* \tilde{l}_L - s_w^2 \tilde{l}_R^* \tilde{l}_R \right] h^0 + \chi_{\tilde{l}} \left[\tilde{l}_L^* \tilde{l}_R + \tilde{l}_R^* \tilde{l}_L \right] \tag{11}$$

where

$$Q_{\tilde{\mu},\tilde{\tau}} = \frac{g m_{\tilde{\mu},\tilde{\tau}}^2 \sin \alpha}{M_w \cos \beta} , \tag{12}$$

$$G = g_z M_z \sin(\alpha + \beta) , \tag{13}$$

$$X_{\tilde{\mu},\tilde{\tau}} = \frac{g m_{\tilde{\mu},\tilde{\tau}} \sin \alpha}{2 M_w \cos \beta} (A_{\tilde{\mu},\tilde{\tau}} - \mu \cot \alpha) . \tag{14}$$

Then, in the slepton physical states, as rotated by (10), the couplings to the light Higgs boson are given as in table 1, where $T_{\tilde{l}}^\pm = Q_{\tilde{l}} \pm X_{\tilde{l}}$. We have simplified the notation using $s_\varphi = \sin \frac{\varphi}{2}$ and $c_\varphi = \cos \frac{\varphi}{2}$.

3. Radiative Higgs flavour violation decay

In this section we show the construction of the radiative induced Higgs flavor violation decay. We assume the following convention: the slepton which interacts with the muon (tau) is labeled with the index i (j), see Fig 1. The notation used for the coupling between the bino $\tilde{B}$, the
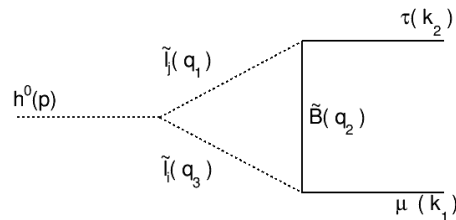
Figure 1. *1-loop SUSY slepton flavor mixing contribution to $h^0 \to \mu\tau$.*

slepton $\tilde{l}$ and the lepton l, for $l = \mu, \tau$, which is denoted as $\tilde{B}\tilde{l}l$, can be written in terms of three types of coefficients for each lepton. We use a_k, for the ones in the coupling with the muon and

Table 2. Coefficients for $a_{2,3}$ and $b_{2,3}$ of Bino-slepton-lepton couplings $g_{\tilde{B}\tilde{l}l}$ given in eq. (15)

$i,j=1$		2	3	4		1	2	3	4
a_2^i	1	3	3	1	a_3^i	3	1	1	3
b_2^j	1	3	3	1	b_3^j	3	1	1	3

b_k for coefficients in the coupling with the tau; with $k = 1,2,3$; then we have this couplings written as:

$$g_{\tilde{B}\tilde{l}_i\mu} = a_1^i[a_2^i + a_3^i\gamma^5] \ ,$$
$$g_{\tilde{B}\tilde{l}_j\tau} = b_1^j[b_2^j + b_3^j\gamma^5] \ , \tag{15}$$

where the first type of coefficients are given as

$$a_1^i = \frac{g}{4}\tan\theta_W a_{\tilde{l}_i} \ , \tag{16}$$

$$b_1^j = -\frac{g}{4}\tan\theta_W b_{\tilde{l}_j} \ , \tag{17}$$

being $a_{\tilde{l}_i} = s_\varphi(-c_\varphi)$ for $\tilde{\mu}_{1,2}(\tilde{\tau}_{1,2})$, while $b_{\tilde{l}_j} = c_\varphi,(s_\varphi)$ for $\tilde{\mu}_{1,2}(\tilde{\tau}_{1,2})$. And the rest of the coefficients, type 2 and 3 are numbers shown in table 2.

Now we write the invariant amplitude for the $h^0 \to \mu\tau$ decay with slepton $\tilde{l}_i, \tilde{l}_j$ running inside the loop as indicated in lines above, in such a way that it is possible to identify every vertex, propagator and external fermion legs, see figure 3

$$\mathcal{M}_{ij} = \int \frac{d^4q}{(2\pi)^4}\bar{v}(k_1)[\imath g_{\tilde{B}\tilde{l}_i\mu}]\left[\frac{\imath(\not{q} - \not{k}_2 + m_B)}{(q - k_2)^2 - m_B^2}\right][\imath g_{\tilde{B}\tilde{l}_j\tau}]\left[\frac{\imath}{(q - p)^2 - m_i^2}\right]\left[\frac{\imath}{q^2 - m_j^2}\right][\imath g_{h\tilde{l}_i\tilde{l}_j}]u(k_2) \tag{18}$$

After the loop momentum integration over $q = q_1$, the amplitude can be written in the following form

$$\mathcal{M}_{ij} = \bar{v}(k_1)[A^{ij} + B^{ij}\gamma^5]u(k_2) \ , \tag{19}$$

where

$$A^{ij} = a_1^i b_1^j \big[(a_2^i b_2^j + a_3^i b_3^j)m_B F^{ij} + (-a_2^i b_2^j + a_3^i b_3^j)m_\tau F^{ij}$$
$$+ (a_2^i b_2^j - a_3^i b_3^j)m_\tau F_{II}^{ij} - (a_2^i b_2^j - a_3^i b_3^j)m_\mu F_{III}^{ij}\big] \ , \tag{20}$$

$$B^{ij} = a_1^i b_1^j \big[(a_2^i b_3^j + a_3^i b_2^j)m_B F^{ij} - (a_3^i b_2^j - a_2^i b_3^j)m_\tau F^{ij}$$
$$+ (a_3^i b_2^j - a_2^i b_3^j)m_\tau F_{II}^{ij} - (a_2^i b_3^j - a_3^i b_2^j)m_\mu F_{III}^{ij}\big] \ . \tag{21}$$

The F functions are given as

$$F^{ij} = -g_{h\tilde{l}_i\tilde{l}_j} \frac{\iota}{16\pi^2} C0[m_H^2, m_\mu^2, m_\tau^2, m_j^2, m_i^2, m_B^2] \,, \tag{22}$$

$$F_{II}^{ij} = -g_{h\tilde{l}_i\tilde{l}_j} \frac{\iota}{(16\pi^2)[m_H^2 - (m_\mu + m_\tau)^2][m_H^2 - (m_\mu - m_\tau)^2]}$$
$$\times \big[- C0(m_H^2, m_\mu^2, m_\tau^2, m_j^2, m_i^2, m_B^2)\big[m_B^2(m_H^2 + m_\mu^2 - m_\tau^2)$$
$$+ m_H^4 + m_\mu^2(m_i^2 - 2m_j^2) - m_H^2(m_i^2 + m_\mu^2 + 2m_\tau^2) + m_\tau^2(m_i^2 - m_\mu^2) + m_\tau^4\big]$$
$$- 2m_\mu^2 B0(m_\mu^2, m_B^2, m_i^2) + B0(m_\tau^2, m_B^2, m_j^2)(m_\mu^2 + m_\tau^2 - m_H^2)$$
$$- B0(m_H^2, m_i^2, m_j^2)(m_\tau^2 - m_\mu^2 - m_H^2)\big] \,, \tag{23}$$

$$F_{III}^{ij} = -g_{h\tilde{l}_i\tilde{l}_j} \frac{\iota}{(16\pi^2)[m_H^2 - (m_\mu + m_\tau)^2][m_H^2 - (m_\mu - m_\tau)^2]}$$
$$\times \big[- C0(m_H^2, m_\mu^2, m_\tau^2, m_j^2, m_i^2, m_B^2)\big[m_\tau^2(m_B^2 + m_H^2 - 2m_i^2 + m_j^2 + m_\mu^2)$$
$$- m_\tau^4 + (m_B^2 - m_j^2)(m_H^2 - m_\mu^2)\big] + 2m_\tau^2 B0(m_\tau^2, m_B^2, m_j^2)$$
$$+ B0(m_\mu^2, m_B^2, m_i^2)(m_H^2 - m_\mu^2 - m_\tau^2) - B0(m_H^2, m_i^2, m_j^2)(m_H^2 - m_\mu^2 + m_\tau^2)\big] \,. \tag{24}$$

Then the differential width for the process $h^0 \to \tau\mu$ can be calculated using the amplitude transition matrix as

$$d\Gamma = \frac{1}{32\pi^2} \sum_{spin} |\mathcal{M}_T|^2 \frac{|p|}{m_H^2} d\Omega, \tag{25}$$

$$|p| = \sqrt{(m_H^2 - (m_\tau - m_\mu)^2)(m_H^2 - (m_\tau + m_\mu)^2)} \,. \tag{26}$$

Notice that the total amplitude includes all possible combinations of sleptons in the internal lines, then

$$\mathcal{M}_T = \sum_{i,j} \mathcal{M}_{ij}. \tag{27}$$

4. Conclusions

In this work we consider a flavor structure on trilinear soft terms, assuming a two family mixing in the sleptons we explore the consequences of this structure in a particular process involving lepton flavor violation for the Higgs boson. We obtain non-degenerate slepton masses for four of the sleptons which are decoupled from the first family and mixed in flavor. We also found that in physical basis two specific couplings of the Higgs boson with sleptons are zero, *i.e.* $g_{h^0\tilde{\mu}_1\tilde{\tau}_1} = g_{h^0\tilde{\mu}_2\tilde{\tau}_2} = 0$.
We obtain the expression for the one-loop radiative correction of the specific process $h^0 \to \tau\mu$. The expression we obtain is found to be UV-finite and can be used to restrict the parameter space of the supersymmetric model applied to this process, as it is very restricted by the experimental data. This kind of structure also gives extra contribution to $BR(\tau \to \mu\gamma)$ and to the muon anomalous magnetic moment $g - 2$. So a complete exploration of the parameter for all these processes will be a goal for a further work.

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