τ→μγ decay in extensions with a vectorlike generation

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$\tau \to \mu\gamma$ Decay in Extensions with a Vector Like Generation

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Abstract

An analysis is given of the decay $\tau \to \mu + \gamma$ in MSSM extensions with a vector like generation. Here mixing with the mirrors allows the possibility of this decay. The analysis is done at one loop with the exchange of charginos and neutralinos and of sleptons and mirror sleptons in the loops. It is shown that a branching ratio $\mathcal{B}(\tau \to \mu\gamma)$ in the range $4.4 \times 10^{-8} - 10^{-9}$ can be gotten which would be accessible to improved experiment such as at SuperB factories for this decay. The effects of CP violation on this decay are also analyzed.

Keywords: Lepton flavor change, $\tau \to \mu\gamma$, vector multiplets
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1 Introduction

Violation of lepton flavor is an important indicator of new physics beyond the standard model. In the absence of a CKM type matrix in the leptonic sector, flavor violations can only arise due to new physics and thus decays such as $l_i \to l_j\gamma$ $(i \neq j)$ are important probes of new physics. We focus here on the decay $\tau \to \mu + \gamma$ on which Babar Collaboration [1] and Belle Collaboration [2] have put new limits on the branching ratio. Thus The current experimental limit on the branching ratio of this process from the BaBar Collaboration [1] based on 470fb^{-1} of data and from the Belle Collaboration [2] using 535 fb^{-1} of data is

$$\begin{aligned} \mathcal{B}(\tau \to \mu + \gamma) &< 4.4 \times 10^{-8} \quad \text{at } 90\% \text{ CL} \quad \text{(BaBar)} \\ \mathcal{B}(\tau \to \mu + \gamma) &< 4.5 \times 10^{-8} \quad \text{at } 90\% \text{ CL} \quad \text{(Belle)} \end{aligned} \tag{1}$$

At the SuperB factories[3, 4, 5] (for a review see [6]) the limit is expected to reach $\mathcal{B}(\tau \to \mu+\gamma) \sim 1\times 10^{-9}$ as shown in Fig.(1). Thus it is of interest to see if theoretical estimates for this branching ratio lie close to the current experimental limits to be detectable in improved experiment.

Here we explore this process in the presence of a new vector like generation in an extension of MSSM. Vector like multiplets arise quite naturally in a variety of grand unified models[7] and some of them can escape supermassive mass growth and can remain light down to the electroweak scale. Recently an analysis was given of the EDM of the tau in the framework of an extension of the minimal supersymmetric standard model with a vector like multiplets [8]. Specifically mixing of the standard model leptons with the mirror leptons, and mixing of the sleptons with mirror sleptons, were considered and it was found that such contributions could put the tau EDM in the detectable range. Here we extend this analysis to investigate the contributions from a vector like lepton multiplet to the flavor changing process $\tau \to \mu + \gamma$. This decay is forbidden at the tree level due to vector current conservation and can only arise at the loop level. The current work is a logical extension of the previous works where mixings with a vector like multiplet and with mirrors were considered [9, 10, 8, 11, 12]. Implications of additional vector multiplets in other contexts have been explored by many previous authors (see, e.g.,[13, 14, 15, 16]). Several studies already exist on the analysis of $\tau \to \mu\gamma$ decay [17, 18, 19, 20, 21, 22, 23, 24]. However, none of them explore the class of models discussed here.

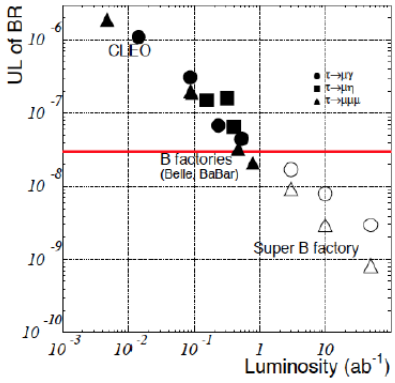

Figure 1: A display of the upper limits on the branching ratio $\mathcal{B}(\tau^- \to \mu^-\gamma)$ (and for $\tau^- \to \mu^-\gamma, \mu^-\mu^+\mu^-$) from the previous experiments and for the anticipated experiments as a function of the integrated luminosity. Figure is taken from Ref. [4].

2 Extension of MSSM with a Vector Multiplet

We begin with a brief discussion on extension of MSSM where we include vector like lepton multiplets since such a combination is anomaly free. First under $SU(3)_C \times SU(2)_L \times U(1)_Y$ the leptons of the three generations transform as follows

$$\psi_{iL} \equiv \begin{pmatrix} \nu_{iL} \\ l_{iL} \end{pmatrix} \sim (1, 2, -\frac{1}{2}), l^c_{iL} \sim (1, 1, 1), \ \nu^c_{iL} \sim (1, 1, 0), \ i = 1, 2, 3 \tag{2}$$

where the last entry on the right hand side of each $\sim$ is the value of the hypercharge Y defined so that $Q = T_3 + Y$. These leptons have $V - A$ interactions. We can now add a vector like multiplet where we have a fourth family of leptons with $V - A$ interactions whose transformations can be gotten from Eq.(2) by letting i run from 1-4. A vector like lepton multiplet also has mirrors and so we consider these mirror leptons which have $V + A$ interactions. Their quantum numbers are as follows

$$\chi^c \equiv \begin{pmatrix} E^c_L \\ N^c_L \end{pmatrix} \sim (1, 2, \frac{1}{2}), E_L \sim (1, 1, -1), N_L \sim (1, 1, 0). \tag{3}$$

The vector like extension also has a quark sector which in addition to the usual sequential generation of quarks

$$q_{iL} \equiv \begin{pmatrix} t_{iL} \\ b_{iL} \end{pmatrix} \sim (3, 2, \frac{1}{6}), b^c_{iL} \sim (3^*, 1, \frac{1}{3}), \ t^c_{iL} \sim (3^*, 1, -\frac{2}{3}), \ i = 1, 2, 3 \tag{4}$$

also has a corresponding mirror generation

$$Q^c \equiv \begin{pmatrix} B_L^c \\ T_L^c \end{pmatrix} \sim (3^*, 2, -\frac{1}{6}), B_L \sim (3^*, 1, -\frac{1}{3}), T_L \sim (3, 1, \frac{2}{3}). \tag{5}$$

The MSSM Higgs doublets as usual have the quantum numbers

$$H_1 \equiv \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} \sim (1, 2, -\frac{1}{2}), \; H_2 \equiv \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} \sim (1, 2, \frac{1}{2}). \tag{6}$$

As mentioned already we assume that the vector multiplet escapes acquiring mass at the GUT scale and remains light down to the electroweak scale. As in the analysis of Ref.[8] interesting new physics arises when we consider the mixing of the first three generations of leptons with the mirrors of the vector like multiplet. Actually we will limit ourselves to the second and third generations since only these are relevant for the computation of the decay $\tau \to \mu\gamma$. Thus the superpotential of the model may be written in the form

$$\begin{aligned} W = -\mu\epsilon_{ij}\hat{H}_1^i\hat{H}_2^j + \epsilon_{ij}[f_1\hat{H}_1^i\hat{\psi}_L^j\hat{\tau}_L^c + f_1'\hat{H}_2^j\hat{\psi}_L^i\hat{\nu}_{\tau L}^c + f_2\hat{H}_1^i\hat{\chi}^{cj}\hat{N}_L + f_2'H_2^j\hat{\chi}^{ci}\hat{E}_L \\ +h_1H_1^i\hat{\psi}_{\mu L}^j\hat{\mu}_L^c + h_1'H_2^j\hat{\psi}_{\mu L}^i\hat{\nu}_{\mu L}^c] + f_3\epsilon_{ij}\hat{\chi}^{ci}\hat{\psi}_L^j + f_3'\epsilon_{ij}\hat{\chi}^{ci}\hat{\psi}_{\mu L}^j + f_4'\hat{\mu}_L^c\hat{E}_L + f_5'\hat{\nu}_{\mu L}^c\hat{N}_L \end{aligned} \tag{7}$$

where $\hat{\psi}_L$ stands for $\hat{\psi}_{3L}$ and $\hat{\psi}_{\mu L}$ stands for $\hat{\psi}_{2L}$. Here we assume a mixing between the mirror generation and the third lepton generation through the couplings f_3, f_4 and f_5. We also assume mixing between the mirror generation and the second lepton generation through the couplings f_3', f_4' and f_5'. *The above six mass terms are responsible for generating lepton flavor changing process, $\tau \to \mu\gamma$.*

If we assume a mixing between the mirror generation and the first lepton generation through additional set of parameters f_3'', f_4'' and f_5'', one can have the corresponding process of $\mu \to e\gamma$. However, since the mixings with the first generation are independent of the mixings with the second and the third generation, the $\mu \to e\gamma$ decay is not correlated with the $\tau \to \mu\gamma$ decay. For this reason we limit our analysis to the $\tau \to \mu\gamma$ decay. We will focus here on the supersymmetric sector. Then through the terms $f_3, f_4, f_5, f_3', f_4', f_5'$ one can have a mixing between the third generation and the second generation leptons which allows the decay of $\tau \to \mu\gamma$ through loop corrections that include charginos, neutralinos and scalar lepton exchanges with the photon being emitted by the chargino (see the left diagram of Fig.(2)) or by a charged slepton (see the right diagram of Fig.(2)). The mass terms for the leptons and mirrors arise from the term

$$\mathcal{L} = -\frac{1}{2}\frac{\partial^2 W}{\partial A_i \partial A_j}\psi_i\psi_j + H.c. \tag{8}$$

where ψ and A stand for generic two-component fermion and scalar fields. After spontaneous breaking of the electroweak symmetry, ($< H_1^1 >= v_1/\sqrt{2}$ and $< H_2^2 >= v_2/\sqrt{2}$), we have the following set of mass terms written in the 4-component spinor notation

$$-\mathcal{L}_m = \begin{pmatrix} \bar{\tau}_R & \bar{E}_R & \bar{\mu}_R \end{pmatrix} \begin{pmatrix} f_1 v_1/\sqrt{2} & f_4 & 0 \\ f_3 & f_2' v_2/\sqrt{2} & f_3' \\ 0 & f_4' & h_1 v_1/\sqrt{2} \end{pmatrix} \begin{pmatrix} \tau_L \\ E_L \\ \mu_L \end{pmatrix} +$$
$$+ \begin{pmatrix} \bar{\nu}_{\tau R} & \bar{N}_R & \bar{\nu}_{\mu R} \end{pmatrix} \begin{pmatrix} f_1' v_2/\sqrt{2} & f_5 & 0 \\ -f_3 & f_2 v_1/\sqrt{2} & -f_3' \\ 0 & f_5' & h_1' v_2/\sqrt{2} \end{pmatrix} \begin{pmatrix} \nu_{\tau L} \\ N_L \\ \nu_{\mu L} \end{pmatrix} + H.c. \tag{9}$$

Here the mass matrices are not Hermitian and one needs to use bi-unitary transformations to diagonalize them. Thus we write the linear transformations

$$\begin{pmatrix} \tau_R \\ E_R \\ \mu_R \end{pmatrix} = D_R^\tau \begin{pmatrix} \tau_{1_R} \\ \tau_{2_R} \\ \tau_{3_R} \end{pmatrix},$$
$$\begin{pmatrix} \tau_L \\ E_L \\ \mu_L \end{pmatrix} = D_L^\tau \begin{pmatrix} \tau_{1_L} \\ \tau_{2_L} \\ \tau_{3_L} \end{pmatrix}, \tag{10}$$

uch that

$$D_R^{\tau\dagger} \begin{pmatrix} f_1 v_1/\sqrt{2} & f_4 & 0 \\ f_3 & f_2' v_2/\sqrt{2} & f_3' \\ 0 & f_4' & h_1 v_1/\sqrt{2} \end{pmatrix} D_L^\tau = diag(m_{\tau_1}, m_{\tau_2}, m_{\tau_3}). \tag{11}$$

The same holds for the neutrino mass matrix

$$D_R^{\nu\dagger} \begin{pmatrix} f_1' v_2/\sqrt{2} & f_5 & 0 \\ -f_3 & f_2 v_1/\sqrt{2} & -f_3' \\ 0 & f_5' & h_1' v_2/\sqrt{2} \end{pmatrix} D_L^\nu = diag(m_{\nu_1}, m_{\nu_2}, m_{\nu_2}). \tag{12}$$

In Eq.(11) τ_1, τ_2, τ_3 are the mass eigenstates and we identify the tau lepton with the eigenstate 1, i.e., $\tau = \tau_1$, and we identify τ_2 with a heavy mirror eigenstate with a mass in the hundreds of GeV and τ_3 is identified as the muon. Similarly ν_1, ν_2, ν_3 are the mass eigenstates for the neutrinos, where we identify ν_1 as the light tau neutrino, ν_2 as the heavier mass eigen state and ν_3 as the muon neutrino. The scalar mass^2 matrices of the model are calculated in Appendix A, where we show that they are 6×6 hermitian matrices. If we

assume a mixing between the mirror generation and the three lepton generations, the lepton mass matrices would be 4×4 and the scalar lepton mass^2 matrices would be 8×8 hermitian matrices.

3 Interactions of Charginos and Neutralinos

The chargino exchange contribution to the decay of the tau into a muon and a photon arises through the left loop diagram of Fig.(2). The relevant part of Lagrangian that generates this contribution is given by

$$-\mathcal{L}_{\tau-\tilde{\nu}-\chi^+} = \sum_{\alpha=1}^{3}\sum_{i=1}^{2}\sum_{j=1}^{6}\bar{\tau}_\alpha[C^L_{\alpha ij}P_L + C^R_{\alpha ij}P_R]\tilde{\chi^c}_i\tilde{\nu}_j + H.c. \tag{13}$$

where

$$\begin{aligned} C^L_{\alpha ij} &= g[-\kappa_\tau U^*_{i2}D^{\tau *}_{R_{1\alpha}}\tilde{D}^\nu_{1j} - \kappa_\mu U^*_{i2}D^{\tau *}_{R_{3\alpha}}\tilde{D}^\nu_{5j} \\ &\quad + U^*_{i1}D^{\tau *}_{R_{2\alpha}}\tilde{D}^\nu_{4j} - \kappa_N U^*_{i2}D^{\tau *}_{R_{2\alpha}}\tilde{D}^\nu_{2j}], \\ C^R_{\alpha ij} &= g[-\kappa_{\nu_\tau} V_{i2}D^{\tau *}_{L_{1\alpha}}\tilde{D}^\nu_{3j} - \kappa_{\nu_\mu} V_{i2}D^{\tau *}_{L_{3\alpha}}\tilde{D}^\nu_{6j} \\ &+ V_{i1}D^{\tau *}_{L_{1\alpha}}\tilde{D}^\nu_{1j} + V_{i1}D^{\tau *}_{L_{3\alpha}}\tilde{D}^\nu_{5j} - \kappa_E V_{i2}D^{\tau *}_{L_{2\alpha}}\tilde{D}^\nu_{4j}], \end{aligned} \tag{14}$$

where $\tilde{D}^\nu$ is the diagonalizing matrix of the scalar 6×6 mass^2 matrix for the scalar neutrino as defined in Appendix A. κ_N, κ_τ etc that enter in the equation above are defined by

$$(\kappa_N, \kappa_\tau, \kappa_\mu) = \frac{(m_N, m_\tau, m_\mu)}{\sqrt{2}M_W\cos\beta},\ (\kappa_E, \kappa_\nu) = \frac{(m_E, m_\nu)}{\sqrt{2}M_W\sin\beta}. \tag{15}$$

In Eq.(14) U and V are the matrices that diagonalize the chargino mass matrix M_C so that

$$U^* M_C V^{-1} = diag(m^+_{\tilde{\chi}_1}, m^+_{\tilde{\chi}_2}). \tag{16}$$

The neutralino exchange contribution to the tau decay arises through the right loop diagram of Fig. (2). The relevant part of Lagrangian that generates this contribution is given by

$$-\mathcal{L}_{\tau-\tilde{\tau}-\chi^0} = \sum_{\alpha=1}^{3}\sum_{i=1}^{4}\sum_{j=1}^{6}\bar{\tau}_\alpha[C'^L_{\alpha ij}P_L + C'^R_{\alpha ij}P_R]\tilde{\chi^0}_i\tilde{\tau}_j + H.c., \tag{17}$$

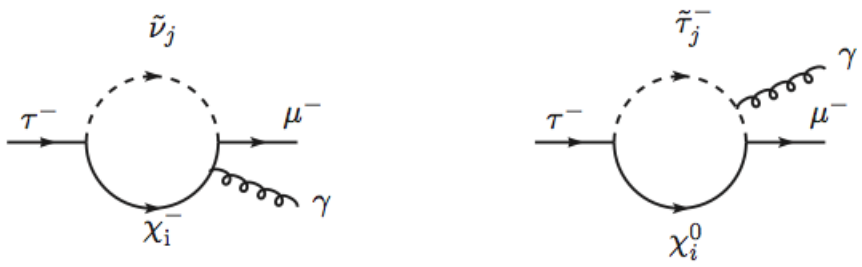

Figure 2: The diagrams that allow decay of the τ into $\mu + \gamma$ via supersymmetric loops involving the chargino and the sneutrino (left) and the neutralino and the stau (right) with emission of the photon from the charged particle inside the loop.

where as stated earlier $\tau = \tau_1$ and $\mu = \tau_3$. In Eq.(17) C'_L and C'_R are defined by

$$\begin{aligned} C'^L_{\alpha ij} &= \sqrt{2}[\alpha_{\tau i} D^{\tau *}_{R1\alpha} \tilde{D}^{\tau}_{1j} - \delta_{Ei} D^{\tau *}_{R2\alpha} \tilde{D}^{\tau}_{2j} - \gamma_{\tau i} D^{\tau *}_{R1\alpha} \tilde{D}^{\tau}_{3j} \\ &+ \beta_{Ei} D^{\tau *}_{R2\alpha} \tilde{D}^{\tau}_{4j} + \alpha_{\mu i} D^{\tau *}_{R3\alpha} \tilde{D}^{\tau}_{5j} - \gamma_{\mu i} D^{\tau *}_{R3\alpha} \tilde{D}^{\tau}_{6j}], \\ C'^R_{\alpha ij} &= \sqrt{2}[\beta_{\tau i} D^{\tau *}_{L1\alpha} \tilde{D}^{\tau}_{1j} - \gamma_{Ei} D^{\tau *}_{L2\alpha} \tilde{D}^{\tau}_{2j} - \delta_{\tau i} D^{\tau *}_{L1\alpha} \tilde{D}^{\tau}_{3j} \\ &+ \alpha_{Ei} D^{\tau *}_{L2\alpha} \tilde{D}^{\tau}_{4j} + \beta_{\mu i} D^{\tau *}_{L3\alpha} \tilde{D}^{\tau}_{5j} - \delta_{\mu i} D^{\tau *}_{L3\alpha} \tilde{D}^{\tau}_{6j}], \end{aligned} \tag{18}$$

where $\tilde{D}^{\tau}$ is the diagonalizing matrix of the 6×6 slepton mass^2 matrix.

$$\begin{aligned} \alpha_{E_j} = \frac{g m_E X^*_{4j}}{2 m_W \sin\beta}, \quad \beta_{E_j} = e X^{'}_{1j} + \frac{g}{\cos\theta_W} X^{'}_{2j} (\frac{1}{2} - \sin^2\theta_W), \\ \gamma_{E_j} = e X'^*_{1j} - \frac{g \sin^2\theta_W}{\cos\theta_W} X^{*'}_{2j}, \quad \delta_{E_j} = -\frac{g m_E X_{4j}}{2 m_W \sin\beta}, \end{aligned} \tag{19}$$

and

$$\begin{aligned} \alpha_{\tau j} = \frac{g m_\tau X_{3j}}{2 m_W \cos\beta}, \quad \alpha_{\mu j} = \frac{g m_\mu X_{3j}}{2 m_W \cos\beta}, \quad \beta_{\tau j} = \beta_{\mu j} = -e X'^*_{1j} + \frac{g}{\cos\theta_W} X'^*_{2j} (-\frac{1}{2} + \sin^2\theta_W), \\ \gamma_{\tau j} = \gamma_{\mu j} = -e X'_{1j} + \frac{g \sin^2\theta_W}{\cos\theta_W} X'_{2j}, \quad \delta_{\tau j} = -\frac{g m_\tau X^*_{3j}}{2 m_W \cos\beta}, \quad \delta_{\mu j} = -\frac{g m_\mu X^*_{3j}}{2 m_W \cos\beta}, \end{aligned} \tag{20}$$

where

$$X'_{1j} = (X_{1j} \cos\theta_W + X_{2j} \sin\theta_W), \; X'_{2j} = (-X_{1j} \sin\theta_W + X_{2j} \cos\theta_W), \tag{21}$$

and where the matrix X diagonalizes the neutralino mass matrix so that

$$X^T M_{\tilde{\chi}^0} X = diag(m_{\chi^0{}_1}, m_{\chi^0{}_2}, m_{\chi^0{}_3}, m_{\chi^0{}_4}). \tag{22}$$

4 The analysis of $\tau \to \mu + \gamma$ Branching Ratio

The decay $\tau \to \mu + \gamma$ is induced by one-loop electric and magnetic transition dipole moments, which arise from the diagrams of Fig.(2). In the dipole moment loop, the incoming muon is replaced by a tau lepton. For an incoming tau of momentum p and a resulting muon of momentum p', we define the amplitude

$$< \mu(p')|J_\alpha|\tau(p) >= \bar{u}_\mu(p')\Gamma_\alpha u_\tau(p) \tag{23}$$

where

$$\Gamma_\alpha(q) = \frac{F_2^{\tau\mu}(q) i\sigma_{\alpha\beta}q^\beta}{m_\tau + m_\mu} + \frac{F_3^{\tau\mu}(q)\sigma_{\alpha\beta}\gamma_5 q^\beta}{m_\tau + m_\mu} + ... \tag{24}$$

with $q = p' - p$ and where m_f denotes the mass of the fermion f. The branching ratio of $\tau \to \mu + \gamma$ is given by

$$\mathcal{B}(\tau \to \mu + \gamma) = \frac{24\pi^2}{5G_F^2 m_\tau^2 (m_\tau + m_\mu)^2}\{|F_2^{\tau\mu}(0)|^2 + |F_3^{\tau\mu}(0)|^2\} \tag{25}$$

where the form factors $F_2^{\tau\mu}$ and $F_3^{\tau\mu}$ arise from the chargino and the neutralino contributions as follows

$$\begin{aligned} F_2^{\tau\mu}(0) &= F_{2\chi^+}^{\tau\mu} + F_{2\chi^0}^{\tau\mu} \\ F_3^{\tau\mu}(0) &= F_{3\chi^+}^{\tau\mu} + F_{3\chi^0}^{\tau\mu} \end{aligned} \tag{26}$$

The chargino contribution $F_{2\chi^+}^{\tau\mu}$ is given by

$$\begin{aligned} F_{2\chi^+}^{\tau\mu} = \sum_{i=1}^{2}\sum_{j=1}^{6}[&\frac{m_\tau(m_\tau + m_\mu)}{64\pi^2 m_{\tilde{\chi}_i{}^+}^2}\{C_{3ij}^L C_{1ij}^{L*} + C_{3ij}^R C_{1ij}^{R*}\}F_1(\frac{M_{\tilde{\nu}_j}^2}{m_{\tilde{\chi}_i{}^+}^2}) \\ &+\frac{(m_\tau + m_\mu)}{64\pi^2 m_{\tilde{\chi}_i{}^+}}\{C_{3ij}^L C_{1ij}^{R*} + C_{3ij}^R C_{1ij}^{L*}\}F_2(\frac{M_{\tilde{\nu}_j}^2}{m_{\tilde{\chi}_i{}^+}^2})] \end{aligned} \tag{27}$$

where

$$F_1(x) = \frac{1}{3(x-1)^4}\{-2x^3 - 3x^2 + 6x - 1 + 6x^2 \ln x\} \tag{28}$$

and

$$F_2(x) = \frac{1}{(x-1)^3}\{3x^2 - 4x + 1 - 2x^2 \ln x\} \tag{29}$$

The neutralino contribution $F^{\tau\mu}_{2\chi^0}$ is given by

$$F^{\tau\mu}_{2\chi^0} = \sum_{i=1}^{4}\sum_{j=1}^{6}[\frac{-m_\tau(m_\tau + m_\mu)}{192\pi^2 m^2_{\tilde{\chi_i}^0}}\{C'^L_{3ij}C'^{L*}_{1ij} + C'^R_{3ij}C'^{R*}_{1ij}\}F_3(\frac{M^2_{\tilde{\tau}_j}}{m^2_{\tilde{\chi_i}^0}}) \\ -\frac{(m_\tau + m_\mu)}{64\pi^2 m_{\tilde{\chi_i}^0}}\{C'^L_{3ij}C'^{R*}_{1ij} + C'^R_{3ij}C'^{L*}_{1ij}\}F_4(\frac{M^2_{\tilde{\tau}_j}}{m^2_{\tilde{\chi_i}^0}})] \tag{30}$$

where

$$F_3(x) = \frac{1}{(x-1)^4}\{-x^3 + 6x^2 - 3x - 2 - 6x\ln x\} \tag{31}$$

and

$$F_4(x) = \frac{1}{(x-1)^3}\{-x^2 + 1 + 2x\ln x\} \tag{32}$$

The chargino contribution $F^{\tau\mu}_{3\chi^+}$ is given by

$$F^{\tau\mu}_{3\chi^+} = \sum_{i=1}^{2}\sum_{j=1}^{6}\frac{(m_\tau + m_\mu)m_{\tilde{\chi_i}^+}}{32\pi^2 M^2_{\tilde{\nu}_j}}\{C^L_{3ij}C^{R*}_{1ij} - C^R_{3ij}C^{L*}_{1ij}\}F_5(\frac{m^2_{\tilde{\chi_i}^+}}{M^2_{\tilde{\nu}_j}}) \tag{33}$$

where

$$F_5(x) = \frac{1}{2(x-1)^2}\{-x + 3 + \frac{2\ln x}{1-x}\} \tag{34}$$

The neutralino contribution $F^{\tau\mu}_{3\chi^0}$ is given by

$$F^{\tau\mu}_{3\chi^0} = \sum_{i=1}^{4}\sum_{j=1}^{6}\frac{(m_\tau + m_\mu)m_{\tilde{\chi_i}^0}}{32\pi^2 M^2_{\tilde{\tau}_j}}\{C'^L_{3ij}C'^{R*}_{1ij} - C'^R_{3ij}C'^{L*}_{1ij}\}F_6(\frac{m^2_{\tilde{\chi_i}^0}}{M^2_{\tilde{\tau}_j}}) \tag{35}$$

where

$$F_6(x) = \frac{1}{2(x-1)^2}\{x + 1 + \frac{2x\ln x}{1-x}\} \tag{36}$$

If we consider a mixing of the mirror generation with the three lepton generations, the phenomenologically parallel quantity $\mathcal{B}(\mu \to e + \gamma)$ would be possible. The corresponding expression can be obtained from Eq.(25) by replacing every μ by e and every τ by μ. However, the denominator does not have the number 5 in it in this case. The reason for this is that in the case of τ decay we have three extra possible channels into $\mu + \nu_\tau + \bar{\nu_\mu}$, $s + \nu_\tau + \bar{u}$ and $d + \nu_\tau + \bar{u}$ besides the process $e + \nu_\tau + \bar{\nu_e}$ that is similar to the ones that occurs in the case of

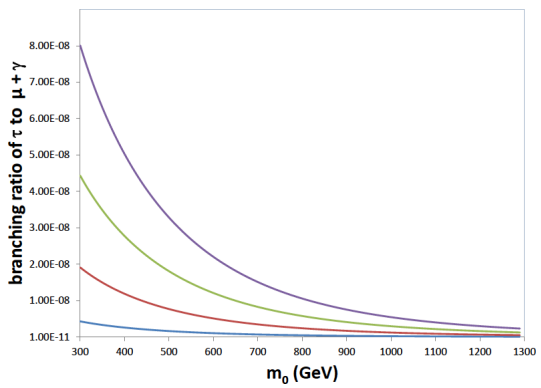

Figure 3: An exhibition of the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on m_0 when $m_N = 120$, $m_E = 150$, $|f_3| = |f_3'|$ =90, $|f_4| = |f_4'|$ =100, $|f_5| = |f_5'|$ =80, $|A_0|$ =150, $\tilde{m}_1 = 50$, $\tilde{m}_2 = 100$, $\mu = 150$, $\chi_3 = \chi_3'$ =0.6, $\chi_4 = \chi_4'$ =0.4, $\chi_5 = \chi_5'$ =0.6, α_E =0.5, α_N =0.8, and $\tan\beta$ =5, 10, 15, 20 (in ascending order at $m_0 = 300$). Here and in Figs.(4-7) masses are in GeV and angles are in rad.

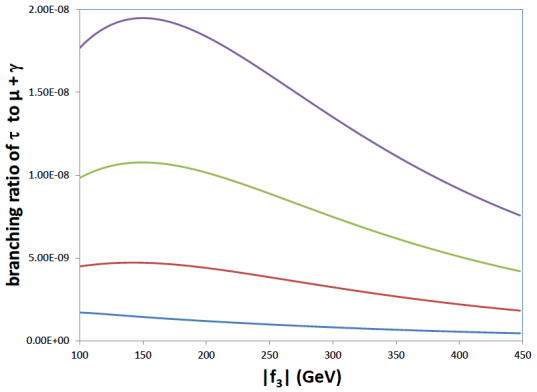

Figure 4: An exhibition of the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on $|f_3|$ when m_0 =900, $m_N = 150$, $m_E = 180$, $|f_3'|$ =100, $|f_4| = |f_4'|$ =100, $|f_5| = |f_5'|$ =70, $|A_0|$ =100, $\tilde{m}_1 = 50$, $\tilde{m}_2 = 100$, $\mu = 150$, $\chi_3 = \chi_3'$ =0.6, $\chi_4 = \chi_4'$ =0.4, $\chi_5 = \chi_5'$ =0.6, α_E =0.5, α_N =0.8, and $\tan\beta$ =5, 10, 15, 20 (in ascending order at $|f_3| = 100$.)

μ decay $e + \nu_\mu + \bar{\nu}_e$. We note that since the mixings of the mirror with the first generation are independent of the mixings of the mirror with the second and the third generations, the branching ratio of $\mu \to e\gamma$ is not directly correlated to the branching ratio $\tau \to \mu\gamma$. For this reason we focus on the decay $\tau \to \mu\gamma$ without trying to correlate it with the decay $\mu \to e\gamma$.

5 Estimate of size of $\mathcal{B}(\tau \to \mu\gamma)$

In this section we give a numerical analysis of $\mathcal{B}(\tau \to \mu\gamma)$ for the model where we include a leptonic vector multiplet. As discussed in the previous sections the flavor changing processes arise from the mixings between the standard model leptons and the mirrors in the vector multiplet. The mixing matrices between leptons and mirrors are diagonalized using bi-unitary transformations with matrices D_R^τ and D_L^τ. The input parameters for this sector of the parameter space are m_τ, m_E, m_μ, f_3, f_4, f_3', f_4' where f_3, f_4, f_3' and f_4' are complex masses with CP violating phases χ_3, χ_4, χ_3' χ_4'. For the slepton mass^2 matrices we need the extra input parameters of the susy breaking sector, $\tilde{M}\tau_L, \tilde{M}_E, \tilde{M}_\tau, \tilde{M}_\chi, \tilde{M}_{\mu_L}, \tilde{M}_\mu, A_\tau, A_E, A_\mu, A_N, \mu, \tan\beta$. For the sneutrino mass^2 matrices we have more input parameters, $\tilde{M}_N, \tilde{M}_{\nu_\tau}, \tilde{M}_{\nu_\mu}, A_{\nu_\mu}, A_N, A_{\nu_e}$, m_N, f_5, f_5'. The chargino and neutralino sectors need the extra two parameters $\tilde{m}_1, \tilde{m}_2$. In the analysis we will include phases since dipole moments are sensitive to phases (for a review

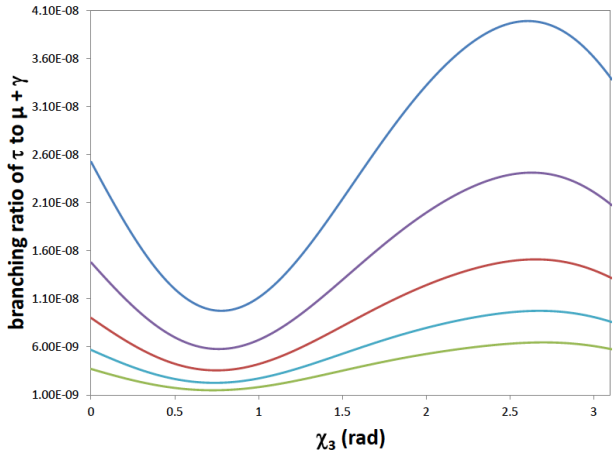

Figure 5: An exhibition of the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on χ_3 when $\tan\beta$ =10, m_N = 170, m_E = 200, $|f_3| = |f_3'|$ =250, $|f_4| = |f_4'|$ =400, $|f_5| = |f_5'|$ =90, $|A_0|$ =130, $\tilde{m}_1$ = 90, $\tilde{m}_2$ = 80, μ = 120, χ_3' =0.8, $\chi_4 = \chi_4'$ =0.9, $\chi_5 = \chi_5'$ =1.6, α_E =1.0, α_N =0.9, and m_0 =900, 800, 700, 600, 500 (in ascending order at $\chi_3 = 0.0$.)

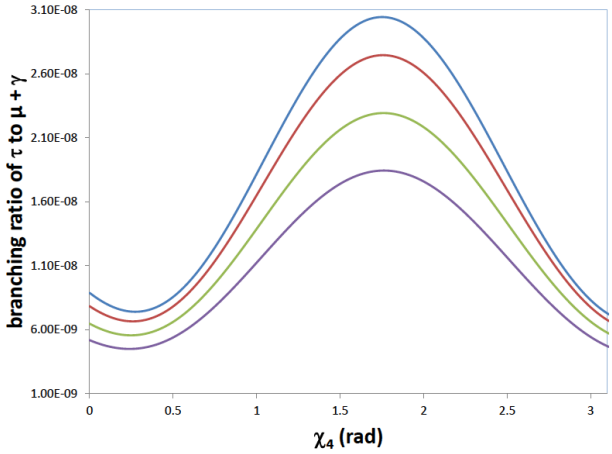

Figure 6: An exhibition of the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on χ_4 when m_0 =800, $\tan\beta$ =15, m_N = 160, m_E = 220, $|f_3'|$ =150, $|f_4| = |f_4'|$ =200, $|f_5| = |f_5'|$ =100, $|A_0|$ =160, $\tilde{m}_1$ = 100, $\tilde{m}_2$ = 90, μ = 150, $\chi_3 = \chi_3'$ =0.6, χ_4' =0.8, $\chi_5 = \chi_5'$ =1.0, α_E =.4, α_N =0.8, and $|f_3|$ =300, 250, 200, 150 (in ascending order at $\chi_4 = 0.0$.)

see [25]). Here for simplicity we assume that the only parameters that are complex in the above matrix elements are A_E, A_N, A_τ, A_μ, A_ν, f_5 and f_5' which have the phases α_E, α_N, α_τ, α_μ, α_ν, χ_5 and χ_5'. To simplify the analysis we set $\alpha_\nu = \alpha_\mu = \alpha_\tau = 0$. Thus the CP violating phases that would play a role in this analysis are

$$\chi_3, \chi_4, \chi_5, \chi_3', \chi_4', \chi_5', \alpha_E, \alpha_N. \tag{37}$$

With the above in mind, the electric dipole moments of the electron, the neutron and of the Hg atom vanish and we do not need to worry about them satisfying their upper limit constraints. To reduce the number of input parameters we assume equality of the scalar masses and of the trilinear couplings so that $\tilde{M}_a = m_0, a = \tau_L, E, \tau, \chi, \nu, \mu, \mu_L, N$ and $|A_i| = |A_0|$, $i = E, N, \tau, \nu, \mu$.

Fig.(3) gives an analysis of $\mathcal{B}(\tau \to \mu\gamma)$ as a function of m_0 for values of $\tan\beta = 5, 10, 15, 20$ with other inputs as given in the caption of Fig.(3). The branching ratio depends on the chargino and neutralino exchange contributions to $F_2^{\tau\mu}(0)$ and $F_3^{\tau\mu}(0)$ defined in Eq.(26) which depend on m_0 through the slepton masses that enter the loops. Fig.(3) exhibits a

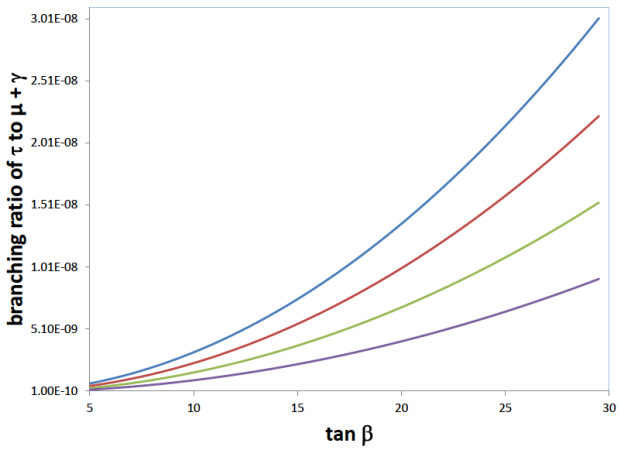

Figure 7: An exhibition of the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on $\tan\beta$ when m_0 =700, $m_N = 200$, $m_E = 300$, $|f_3| = |f_3'|$ =180, $|f_4| = |f_4'|$ =100, $|f_5| = |f_5'|$ =150, $|A_0|$ =360, $\tilde{m}_1 = 120$, $\tilde{m}_2 = 80$, $\mu = 140$, $\chi_3 = \chi_3'$ =0.7, $\chi_4 = \chi_4'$ =0.9, $\chi_5 = \chi_5'$ =.6, α_E =.9, α_N =0.4, and χ_3 =1.2, 0.8, 0.5, 0.1 (in ascending order at $\tan\beta = 30$.)

sharp dependence on $\tan\beta$ which enters $F_2^{\tau\mu}(0)$ and $F_3^{\tau\mu}(0)$ also via the slepton masses as well as through the chargino and neutralino mass matrices. Further, the couplings $C^{L,R}$ and $C'^{L,R}$ are also affected by variations in m_0 and $\tan\beta$. The analysis of Fig.(3) shows that there is a significant part of the parameter space where $\mathcal{B}(\tau \to \mu\gamma)$ lies in the range $O(10^{-8})$ consistent with the upper limit of Eq.(1). Fig.(4) gives an analysis of $\mathcal{B}(\tau \to \mu\gamma)$ as a function of $|f_3|$, where f_3 is an off diagonal term in the mass matrix of Eq.(9), for $\tan\beta$ values as in Fig.(3) and the other inputs are as given in the caption of Fig.(4). As in Fig.(3) one finds a sharp dependence on $\tan\beta$. This dependence of $|f_3|$ arises since it enters in the matrix elements diagonalizing matrices $D^{\tau}_{L,R}$ and this way it affects both chargino and neutralino exchange contributions. The entire parameter space exhibited in this figure is consistent with the upper limits of Eq.(1).

We discuss now the effect of CP phases on $\mathcal{B}(\tau \to \mu\gamma)$. As mentioned above the phases of Eq.(37) have no effect on the EDMs of the electron, on the EDM of the neutron or on EDM of the Hg atom and these phases only affect phenomena related to the second and the third generation leptons. Fig.(5) gives a display of $\mathcal{B}(\tau \to \mu\gamma)$ as a function of χ_3 for values of $m_0 = 900, 800, 700, 600, 500$ GeV (in ascending order) when $\tan\beta = 10$ and the other inputs are as shown in the caption of Fig.(5). Here one finds that $\mathcal{B}(\tau \to \mu\gamma)$ has a significant dependence on χ_3. Thus, for instance, for the case $m_0 = 500$ GeV (top curve) one finds that $\mathcal{B}(\tau \to \mu\gamma)$ can vary in the range $(1 \times 10^{-8} - 4 \times 10^{-8})$ as χ_3 varies in the range $(0, \pi)$. Again $\mathcal{B}(\tau \to \mu\gamma)$ displayed in this analysis is consistent with the upper limit of Eq.(1) over the entire range of parameters exhibited.

Another analysis on the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on CP phases is exhibited in Fig.(6) where a plot of $\mathcal{B}(\tau \to \mu\gamma)$ as a function of χ_4 is given for the case when $|f_3| = (300, 250,$ 200, 150) GeV (in ascending order), $\tan\beta = 15$ and other inputs are as given in the caption of Fig.(6). Again a very significant variation in $\mathcal{B}(\tau \to \mu\gamma)$ is seen as χ_4 varies in the range $(0, \pi)$. Specifically one finds that for the case $|f_3| = 150$, $\mathcal{B}(\tau \to \mu\gamma)$ varies in the range $(8 \times 10^{-9} - 3 \times 10^{-8})$. Further, over the entire parameter space analysed in Fig.(6) $\mathcal{B}(\tau \to \mu\gamma)$ is consistent with the upper limit of Eq.(1). Finally, in Fig.(7) we exhibit the dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on $\tan\beta$ when $\chi_3 = 1.2, 0.8, 0.5, 0.1$ (in ascending order) with other parameters as defined in the caption of Fig.(7). A sharp dependence of $\mathcal{B}(\tau \to \mu\gamma)$ on $\tan\beta$ can be seen. Specifically one finds that for the case $\chi_3 = 0.1$ (the top curve) $\mathcal{B}(\tau \to \mu\gamma)$ varies in the range $(1 \times 10^{-10} - 3 \times 10^{-8})$ which is more than an order of magnitude variation as $\tan\beta$ varies in the range (5-30).

In summary in the analyses presented in Fig.(3-7), one finds that $\mathcal{B}(\tau \to \mu\gamma)$ can be quite large often lying just below the current experimental limits which implies that this part of the parameter space will be accessible to future experiments, specifically SuperB factories which can probe $\mathcal{B}(\tau \to \mu\gamma)$ as low as 10^{-9}. We note that the flavor changing interactions of Eq.(7) also contribute to the muon anomalous magnetic moment $g_\mu - 2$ which is very precisely determined experimentally. This can come about by the exchange of a tau and a photon in the loop but since each vertex is one loop order, the contribution is three loop order which would be tiny compared to other standard model electroweak contributions. One should also consider the constraints arising from the S and T parameters. However, the S and T constraints are not very stringent for a vector like multiplet, see e.g., [26]. The choice of parameters in our analysis is consistent with this work.

6 Conclusion

Lepton flavor changing processes provide an important window to new physics beyond the standard model. In this work we have analyzed the decay $\tau \to \mu + \gamma$ in extensions of the MSSM with vector like leptonic multiplets which are anomaly free. Specifically we consider mixings between the standard model generations of leptons with the mirror leptons in the vector multiplet. *It is because of these mixings which are parametrized by f_3, f_4, f_5 and f'_3, f'_4, f'_5 as defined in Eq.(7) that lepton flavor violations appear.* We focus on the supersymmetric sector and compute contributions to this process arising from diagrams with exchange

of charginos and sneutrinos in the loop and with the exchange of neutralinos and staus in the loop. These loops do not preserve lepton flavor. A full analytic analysis of these loops was given which constitute the main result of this work. A numerical analysis was also carried out and it is found that there exists a significant part of the parameter space where one can have the branching ratio for this process in the range $4.4 \times 10^{-8} - 10^{-9}$, where 4.4×10^{-8} at 90% CL is the upper limit from BaBar (see Eq.(1)) and the lower limit is the sensitivity that the SuperB factories will achieve. Thus it is very likely that improved experiment with a better sensitivity may be able to probe this class of models.

Finally we wish to remark on the implications of the recent LHC data specifically as it relates to the Higgs boson discovery for the present analysis. Here we note that the precise determination of the Higgs mass achieved in recent LHC data has no direct implication on the analysis. However, the new vector like multiplet could have an effect on the loop corrections to the Higgs decay branching ratios such as $h \to \tau\bar{\tau}, W^+W^-$ etc. Computation of such corrections are outside the scope of this work. The current work also has implications for collider phenomenology. Some of the collider phenomenology for this class of models specifically as relates to the mirrors was discussed in [11] (see also [27]). The signatures for a vector like lepton multiplet would arise from a Drell-Yan process such as in $pp \to Z^* + X$ with $Z^* \to E^c + \bar{E}^c$ with $E^c + \bar{E}^c$ decaying into $\tau\bar{\tau}$. Thus one should see an excess of $\tau\bar{\tau}$ events. However, the detection efficiency of taus is poorer than the detection efficiency for the muons and for this reason the detection of the vector like leptons and vector like sleptons will be more difficult than the detection of, for example, smuons produced by the Drell-Yan process. A more detailed discussion of this issue requires a separate analysis and is outside the scope of this work.

7 Appendix A

In this appendix, we consider the mixings of the charged sleptons and the charged mirror sleptons. The mass^2 matrix of the slepton - mirror slepton comes from three sources, the F term, the D term of the potential and soft susy breaking terms. Using the superpotential of Eq.(7) the mass terms arising from it after the breaking of the electroweak symmetry are given by $\mathcal{L}_F$ and $\mathcal{L}_D$

$$
\begin{aligned}
-\mathcal{L}_F = &(m_E^2 + |f_3|^2 + |f_3'|^2)\tilde{E}_R\tilde{E}_R^* + (m_N^2 + |f_3|^2 + |f_3'|^2)\tilde{N}_R\tilde{N}_R^* \\
&+(m_E^2 + |f_4|^2 + |f_4'|^2)\tilde{E}_L\tilde{E}_L^* + (m_N^2 + |f_5|^2 + |f_5'|^2)\tilde{N}_L\tilde{N}_L^* \\
&+(m_\tau^2 + |f_4|^2)\tilde{\tau}_R\tilde{\tau}_R^* + (m_{\nu_\tau}^2 + |f_5|^2)\tilde{\nu}_{\tau R}\tilde{\nu}_{\tau R}^* + (m_\tau^2 + |f_3|^2)\tilde{\tau}_L\tilde{\tau}_L^* \\
&+(m_\mu^2 + |f_4'|^2)\tilde{\mu}_R\tilde{\mu}_R^* + (m_\mu^2 + |f_3'|^2)\tilde{\mu}_L\tilde{\mu}_L^* + (m_{\nu_\tau}^2 + |f_3|^2)\tilde{\nu}_{\tau L}\tilde{\nu}_{\tau L}^* \\
&+(m_{\nu_\mu}^2 + |f_3'|^2)\tilde{\nu}_{\mu L}\tilde{\nu}_{\mu L}^* + (m_{\nu_\mu}^2 + |f_5'|^2)\tilde{\nu}_{\mu R}\tilde{\nu}_{\mu R}^* \\
&+\{-m_\tau\mu^*\tan\beta\tilde{\tau}_L\tilde{\tau}_R^* - m_N\mu^*\tan\beta\tilde{N}_L\tilde{N}_R^* - m_{\nu_\tau}\mu^*\cot\beta\tilde{\nu}_{\tau L}\tilde{\nu}_{\tau R}^* \\
&-m_\mu\mu^*\tan\beta\tilde{\mu}_L\tilde{\mu}_R^* - m_{\nu_\mu}\mu^*\cot\beta\tilde{\nu}_{\mu L}\tilde{\nu}_{\mu R}^* \\
&-m_E\mu^*\cot\beta\tilde{E}_L\tilde{E}_R^* + (m_E f_3^* + m_\tau f_4)\tilde{E}_L\tilde{\tau}_L^* \\
&+(m_E f_4 + m_\tau f_3^*)\tilde{E}_R\tilde{\tau}_R^* + (m_E f_3'^* + m_\mu f_4')\tilde{E}_L\tilde{\mu}_L^* \\
&+(m_E f_4' + m_\mu f_3'^*)\tilde{E}_R\tilde{\mu}_R^* + (m_{\nu_\tau} f_5 - m_N f_3^*)\tilde{N}_L\tilde{\nu}_{\tau L}^* \\
&+(m_N f_5 - m_{\nu_\tau} f_3^*)\tilde{N}_R\tilde{\nu}_{\tau R}^* + (m_{\nu_\mu} f_5' - m_N f_3^*)\tilde{N}_L\tilde{\nu}_{\mu L}^* \\
&+(m_N f_5' - m_{\nu_\mu} f_3'^*)\tilde{N}_R\tilde{\nu}_{\mu R}^* + f_3' f_3^*\tilde{\mu}_L\tilde{\tau}_L^* + f_4 f_4'^*\tilde{\mu}_R\tilde{\tau}_R^* \\
&+f_3' f_3^*\tilde{\nu}_{\mu L}\tilde{\nu}_{\tau_L^*} + f_5 f_5'^*\tilde{\nu}_{\mu R}\tilde{\nu}_{\tau R}^* + H.c.\}.
\end{aligned} \tag{38}
$$

Similarly the mass terms arising from the D term are given by

$$
\begin{aligned}
-\mathcal{L}_D = &\frac{1}{2}m_Z^2\cos^2\theta_W\cos 2\beta\{\tilde{\nu}_{\tau L}\tilde{\nu}_{\tau L}^* - \tilde{\tau}_L\tilde{\tau}_L^* + \tilde{\nu}_{\mu L}\tilde{\nu}_{\mu L}^* - \tilde{\mu}_L\tilde{\mu}_L^* + \tilde{E}_R\tilde{E}_R^* - \tilde{N}_R\tilde{N}_R^*\} \\
&+\frac{1}{2}m_Z^2\sin^2\theta_W\cos 2\beta\{\tilde{\nu}_{\tau L}\tilde{\nu}_{\tau L}^* + \tilde{\tau}_L\tilde{\tau}_L^* + \tilde{\nu}_{\mu L}\tilde{\nu}_{\mu L}^* + \tilde{\mu}_L\tilde{\mu}_L^* \\
&-\tilde{E}_R\tilde{E}_R^* - \tilde{N}_R\tilde{N}_R^* + 2\tilde{E}_L\tilde{E}_L^* - 2\tilde{\tau}_R\tilde{\tau}_R^* - 2\tilde{\mu}_R\tilde{\mu}_R^*\}.
\end{aligned} \tag{39}
$$

In addition we have the following set of soft breaking terms

$$
\begin{aligned}
V_{soft} = &\tilde{M}_{\tau L}^2\tilde{\psi}_{\tau L}^{i*}\tilde{\psi}_{\tau L}^i + \tilde{M}_\chi^2\tilde{\chi}^{ci*}\tilde{\chi}^{ci} + \tilde{M}_{\mu L}^2\tilde{\psi}_{\mu L}^{i*}\tilde{\psi}_{\mu L}^i + \tilde{M}_{\nu_\tau}^2\tilde{\nu}_{\tau L}^{c*}\tilde{\nu}_{\tau L}^c \\
&+\tilde{M}_{\nu_\mu}^2\tilde{\nu}_{\mu L}^{c*}\tilde{\nu}_{\mu L}^c + \tilde{M}_\tau^2\tilde{\tau}_L^{c*}\tilde{\tau}_L^c + \tilde{M}_\mu^2\tilde{\mu}_L^{c*}\tilde{\mu}_L^c + \tilde{M}_E^2\tilde{E}_L^*\tilde{E}_L + \tilde{M}_N^2\tilde{N}_L^*\tilde{N}_L \\
&+\epsilon_{ij}\{f_1 A_\tau H_1^i\tilde{\psi}_{\tau L}^j\tilde{\tau}_L^c - f_1' A_{\nu_\tau} H_2^i\tilde{\psi}_{\tau L}^j\tilde{\nu}_{\tau L}^c + h_1 A_\mu H_1^i\tilde{\psi}_{\mu L}^j\tilde{\mu}_L^c - h_1' A_{\nu_\mu} H_2^i\tilde{\psi}_{\mu L}^j\tilde{\nu}_{\mu L}^c \\
&+f_2 A_N H_1^i\tilde{\chi}^{cj}\tilde{N}_L - f_2' A_E H_2^i\tilde{\chi}^{cj}\tilde{E}_L + H.c.\}
\end{aligned} \tag{40}
$$

From $\mathcal{L}_{F,D}$ and by giving the neutral Higgs their vacuum expectation values in V_{soft} we can produce the the mass^2 matrix $M^2_{\tilde{\tau}}$ in the basis $(\tilde{\tau}_L, \tilde{E}_L, \tilde{\tau}_R, \tilde{E}_R, \tilde{\mu}_L, \tilde{\mu}_R)$. We label the matrix elements of these as $(M^2_{\tilde{\tau}})_{ij} = M^2_{ij}$ where

$$
\begin{gathered}
M^2_{11} = \tilde{M}^2_{\tau L} + m^2_\tau + |f_3|^2 - m^2_Z cos2\beta(\frac{1}{2} - \sin^2\theta_W), \\
M^2_{22} = \tilde{M}^2_E + m^2_E + |f_4|^2 + |f'_4|^2 + m^2_Z cos2\beta \sin^2\theta_W, \\
M^2_{33} = \tilde{M}^2_\tau + m^2_\tau + |f_4|^2 - m^2_Z cos2\beta \sin^2\theta_W, \\
M^2_{44} = \tilde{M}^2_\chi + m^2_E + |f_3|^2 + |f'_3|^2 + m^2_Z cos2\beta(\frac{1}{2} - \sin^2\theta_W), \\
M^2_{55} = \tilde{M}^2_{\mu L} + m^2_\mu + |f'_3|^2 - m^2_Z cos2\beta(\frac{1}{2} - \sin^2\theta_W), \\
M^2_{66} = \tilde{M}^2_\mu + m^2_\mu + |f'_4|^2 - m^2_Z cos2\beta \sin^2\theta_W, \\
M^2_{12} = M^{2*}_{21} = m_E f^*_3 + m_\tau f_4, \\
M^2_{13} = M^{2*}_{31} = m_\tau(A^*_\tau - \mu \tan\beta), \\
M^2_{14} = M^{2*}_{41} = 0, M^2_{15} = M^{2*}_{51} = f'_3 f^*_3, \\
M^{2*}_{16} = M^{2*}_{61} = 0, M^2_{23} = M^{2*}_{32} = 0, \\
M^2_{24} = M^{2*}_{42} = m_E(A^*_E - \mu \cot\beta), M^2_{25} = M^{2*}_{52} = m_E f'_3 + m_\mu f'^*_4, \\
M^2_{26} = M^{2*}_{62} = 0, M^2_{34} = M^{2*}_{43} = m_E f_4 + m_\tau f^*_3, M^2_{35} = M^{2*}_{53} = 0, M^2_{36} = M^{2*}_{63} = f_4 f'^*_4 \\
M^2_{45} = M^{2*}_{54} = 0, M^2_{46} = M^{2*}_{64} = m_E f'^*_4 + m_\mu f'_3, \\
M^2_{56} = M^{2*}_{65} = m_\mu(A^*_\mu - \mu \tan\beta)
\end{gathered}
\tag{41}
$$

Here the terms $M^2_{11}, M^2_{13}, M^2_{31}, M^2_{33}$ arise from soft breaking in the sector $\tilde{\tau}_L, \tilde{\tau}_R$, the terms $M^2_{55}, M^2_{56}, M^2_{65}, M^2_{66}$ arise from soft breaking in the sector $\tilde{\mu}_L, \tilde{\mu}_R$, and the terms M^2_{22}, M^2_{24}, M^2_{42}, M^2_{44} arise from soft breaking in the sector $\tilde{E}_L, \tilde{E}_R$. The other terms arise from mixing between the staus, smuons and the mirrors. We assume that all the masses are of the electroweak size so all the terms enter in the mass^2 matrix. We diagonalize this hermitian mass^2 matrix by the unitary transformation $\tilde{D}^{\tau\dagger} M^2_{\tilde{\tau}} \tilde{D}^\tau = diag(M^2_{\tilde{\tau}_1}, M^2_{\tilde{\tau}_2}, M^2_{\tilde{\tau}_3}, M^2_{\tilde{\tau}_4}, M^2_{\tilde{\tau}_5}, M^2_{\tilde{\tau}_6})$. There is a similar mass^2 matrix in the sneutrino sector. In the basis $(\tilde{\nu}_{\tau L}, \tilde{N}_L, \tilde{\nu}_{\tau R}, \tilde{N}_R, \tilde{\nu}_{\mu L}, \tilde{\nu}_{\mu R})$ we can write the sneutrino mass^2 matrix in the form $(M^2_{\tilde{\nu}})_{ij} = m^2_{ij}$ where

$$m_{11}^2 = \tilde{M}_{\tau L}^2 + m_{\nu_\tau}^2 + |f_3|^2 + \frac{1}{2} m_Z^2 cos2\beta,$$
$$m_{22}^2 = \tilde{M}_N^2 + m_N^2 + |f_5|^2 + |f_5'|^2,\ m_{33}^2 = \tilde{M}_{\nu_\tau}^2 + m_{\nu_\tau}^2 + |f_5|^2,$$
$$m_{44}^2 = \tilde{M}_\chi^2 + m_N^2 + |f_3|^2 + |f_3'|^2 - \frac{1}{2} m_Z^2 cos2\beta,$$
$$m_{55}^2 = \tilde{M}_{\mu L}^2 + m_{\nu_\mu}^2 + |f_3'|^2 + \frac{1}{2} m_Z^2 cos2\beta,$$
$$m_{66}^2 = \tilde{M}_{\nu_\mu}^2 + m_{\nu_\mu}^2 + |f_5'|^2,$$
$$m_{12}^2 = m_{21}^{2*} = m_{\nu_\tau} f_5 - m_N f_3^*,$$
$$m_{13}^2 = m_{31}^{2*} = m_{\nu_\tau}(A_{\nu_\tau}^* - \mu \cot\beta),\ m_{14}^2 = m_{41}^{2*} = 0,$$
$$m_{14}^2 = m_{41}^{2*} = 0, m_{15}^2 = m_{51}^{2*} = f_3' f_3^*, m_{16}^2 = m_{61}^{2*} = 0,$$
$$m_{23}^2 = m_{32}^{2*} = 0, m_{24}^2 = m_{42}^{2*} = m_N(A_N^* - \mu \tan\beta), m_{25}^2 = m_{52}^{2*} = -m_N f_3' + m_{\nu_\mu} f_5'^*,$$
$$m_{26}^2 = m_{62}^{2*} = 0,\ m_{34}^2 = m_{43}^{2*} = m_N f_5 - m_{\nu_\tau} f_3^*,$$
$$m_{35}^2 = m_{53}^{2*} = 0, m_{36}^2 = m_{63}^{2*} = f_5 f_5'^*, m_{45}^2 = m_{54}^{2*} = 0$$
$$m_{46}^2 = m_{64}^{2*} = -m_{\nu_\mu} f_3' + m_N f_5'^*, m_{56}^2 = m_{65}^{2*} = m_{\nu_\mu}(A_{\nu_\mu}^* - \mu \cot\beta). \quad (42)$$

As in the charged slepton sector here also the terms $m_{11}^2, m_{13}^2, m_{31}^2, m_{33}^2$ arise from soft breaking in the sector $\tilde{\nu}_{\tau L}, \tilde{\nu}_{\tau R}$, the terms $m_{55}^2, m_{56}^2, m_{65}^2, m_{66}^2$ arise from soft breaking in the sector $\tilde{\nu}_{\mu L}, \tilde{\nu}_{\mu_R}$, and the terms $m_{22}^2, m_{24}^2, m_{42}^2, m_{44}^2$ arise from soft breaking in the sector $\tilde{N}_L, \tilde{N}_R$. The other terms arise from mixing between the physical sector and the mirror sector. Again as in the charged lepton sector we assume that all the masses are of the electroweak size so all the terms enter in the mass^2 matrix. This mass^2 matrix can be diagonalized by the unitary transformation $\tilde{D}^{\nu\dagger} M_{\tilde{\nu}}^2 \tilde{D}^\nu = diag(M_{\tilde{\nu}_1}^2, M_{\tilde{\nu}_2}^2, M_{\tilde{\nu}_3}^2, M_{\tilde{\nu}_4}^2, M_{\tilde{\nu}_5}^2, M_{\tilde{\nu}_6}^2)$. The states $\tilde{\tau}_i, \tilde{\nu}_i;\ i = 1-6$ are the slepton and sneutrino mass eigenstates.

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