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A more flavored Higgs boson in supersymmetric models

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Abstract: A Higgs boson with richer flavor interactions arises when the flavor structure encoded in supersymmetric extensions of the standard model is transmitted to the Higgs sector. The flavor-Higgs transmission mechanism can have a radiative or mixing origin, as it is illustrated with several examples, and can produce interesting Higgs signatures that can be probed at future high-energy colliders. Within the minimal SUSY extension of the SM (MSSM), the flavor mediation mechanism is of *radiative* type, as it is realized through gaugino-sfermion loops, and it transmits the flavor structure of the soft-breaking sector to the Higgs bosons; for this case we evaluate the contributions from general trilinear A-terms to the Lepton Flavor-Violating (LFV) and Flavor-Conserving (LFC) Higgs vertices. On the other hand, as an example of flavor mediation through *mixing*, we discuss an E_6-inspired multi-Higgs model, supplemented with an abelian flavor symmetry, where LFV as well as LFC Higgs effects, are found to arise, though in this case at tree-level. We find that Tevatron and LHC can provide information on the flavor structure of these models through the detection of the LFV Higgs mode $h \to \tau\mu$, while NLC can perform high-precision tests of the LFC mode $h \to \tau^+\tau^-$.

Keywords: Supersymmetric Standard Model, Higgs Physics, Rare Decays.

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1. Introduction

One of the most important goals of future high-energy colliders is to detect the Higgs boson, which remains as the only ingredient left to complete the Standard Model (SM), and whose mass is constrained by SM radiative corrections to lay in the range 110 – 185 GeV at 95 % c.l. [1]. A light higgs boson, with mass $m_h \lesssim 125\,\mathrm{GeV}$, is also predicted in weak-scale supersymmetry (SUSY) [2], which has become one of the leading candidates for physics beyond the standard model. To be consistent with the experimental data, supersymmetry has to be broken, i.e. the mass spectrum of the superpartners needs to be lifted. SUSY breaking is parameterized in the Minimal Supersymmetric SM (MSSM) by the soft-breaking lagrangian, which preserves the ultraviolet properties of exact SUSY. In turn, the combined effects of the large top quark Yukawa coupling and the soft-breaking masses, make possible to induce radiatively the breaking of the electroweak symmetry. The Higgs sector of the MSSM includes two higgs doublets, with the light Higgs boson being perhaps the strongest prediction of the model.

However, after a Higgs signal will be seen, likely at the ongoing or future hadron collider (Tevatron, LHC), it will become crucial to measure most of its properties, including its mass, spin and couplings, to elucidate its nature; this task is supposed to be possible at the next-linear collider (NLC). In particular, the Higgs coupling to light fermions could be measured at NLC with a precision of a few percent [3], which will allow to constrain the new physics laying beyond the SM. For instance, higher dimensional operators of the type $\Phi^\dagger \Phi \bar{Q}_L \Phi b_R$ involving the third family, will generate corrections to the coupling $h\bar{b}b$, which in turn will modify the dominant Higgs decay in the light mass range [4]; NLC will have a chance to bind the strength of such operators. However, once we include the 3 families, those operators will induce flavor-changing interactions in general, which can lead to a new set of Higgs signals. Whether the diagonal or the off-diagonal terms will play a more important role, will depend on the underlying model that generates those operators, whereas its detection will also depend on the capabilities of the different high-energy options considered by the high-energy physics community.

The most widely studied scenarios for Higgs searches, assume that the Flavor-Conserving (FC) Higgs-fermion couplings only depend on the diagonalized fermion mass matrices, while flavor-violating (FV) Higgs transitions are absent [5]. However, when one goes beyond the minimal realization for these models, additional fields that do mediate FV transitions often appear. These new fields could also couple to the Higgs boson, either at tree-level or radiatively, which in turn would induce Higgs-FV transitions. In this paper we are interested in studying how the Higgs sector learns about the rich flavor structure encoded in SUSY models, thereby providing a more flavored Higgs boson; focusing primarily in the leptonic decays of the lightest Higgs boson. As we shall argue below, the flavor-Higgs transmission can be classified according to their origin, as *Radiative or Mixing* mechanisms. Flavor mediation through mixing could occur in general when extra bosons (fermions) mix with the SM bosons (fermions).

Within the MSSM, it can be shown that flavor-Higgs mediation occurs through gaugino-sfermion loops [6], i.e. it is of radiative type, and it communicates the non-trivial flavor structure of the soft-breaking sector to the Higgs bosons. As an illustration of this case, we shall evaluate the SUSY contributions to the Higgs-lepton vertices, including the slepton mixing coming from the trilinear A_l-terms. The slepton mixing is constrained by the low-energy data, but it mainly suppress the FV's associated with the first two family sleptons, and still allows the flavor-mixings between the second- and third-family sleptons, the smuon ($\tilde{\mu}$) and stau ($\tilde{\tau}$), to be as large as $O(1)$ [7]. Thus, in this scheme one can neglect the mixing involving the selectrons, and the general 6×6 slepton-mass-matrix reduces down to a 4×4 matrix involving only the $\tilde{\mu} - \tilde{\tau}$ sector, similarly to the squark case first discussed in ref. [8]. Since we shall follow a bottom-up approach, we simply take an ansazt for the A-terms as being valid at the TeV-scale, which can be motivated by the large neutrino mixing detected with atmospheric neutrinos [9], especially in the framework of GUT models with flavor symmetries. Similarly, the A-terms are taken to be real, since we focus on CP-conserving Higgs observables.

On the other hand, as an example of flavor-Higgs mediation through mixing, we shall discuss an E_6-inspired multi-Higgs model, supplemented with an abelian flavor symmetry, where large Higgs-FV effects are also found to arise, though in this case at the tree-level. In this model there is a Higgs pair associated with each family. Then, to generate a realistic flavor structure for both leptons and sleptons, we include a horizontal $\mathrm{U}(1)_H$ symmetry [10], which at the same time helps to keep under control the FCNC problem. Working in a basis where only one Higgs pair gets v.e.v.'s, we prove that mixing effects between the light MSSM-like Higgs boson and the heavier non-minimal states, induce large tree-level corrections to the leptonic Higgs couplings.

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The organization of this paper goes as follows: in section 2 we discuss in general the possibilities for having flavor-Higgs transmission, which includes the radiative and mixing cases. We call the resulting Higgs particle "a more flavored Higgs boson", because it has FV couplings, which know more about the flavor structure of the model, unlike the minimal SM or MSSM at tree-level, where the Higgs bosons only have FC couplings. Among the models where flavor-higgs mediation occurs through mixing, we shall discuss briefly the following cases: i) the general two-Higgs doublet model (THDM), ii) A model where the SM fermions mix with mirror fermions, iii) Higgs-flavon mixing, and iv) R-parity breaking scenarios. The radiative mechanism is discussed in detail in section 3, within the context of the MSSM with general trilinear soft-breaking terms. This section includes the evaluation of the loop corrections both to the the lepton-flavor conserving (LFC) ($h \to l_i l_i$) and the flavor violating (LFV) Higgs modes ($h \to l_i l_j$). On the other hand, section 4 includes the discussion of the flavor-Higgs mediation within the context of the E_6-inspired multi-Higgs model. The phenomenological analysis for the capabilities of future colliders to bound the Higgs-FC and -FV transitions that result from this model is included in section 4 too. It is found that the induced Higgs-FV couplings can be significant enough to provide new discovery signals at the on-going Fermilab Tevatron Collider and the CERN Large Hadron Collider (LHC), which can detect the LFV mode $h \to \tau\mu$, and give information on the flavor structure of the model, while the expected NLC high-precision measurements could be used bound deviations from the SM for the LFC mode $h \to \tau^+\tau^-$. Finally our conclusions are presented in section 5.

2. Flavor-Higgs mediation mechanisms

Given the overwhelming experimental support for the SM at present energies, and the indications of radiative corrections favoring a light Higgs boson, it seems likely that this Higgs will be found sometime soon [11]. Therefore, we can assume that the description of such light Higgs boson will be given by an effective lagrangian, which starts with the SM terms, but it includes additional terms associated with new physics, namely:

$$\mathcal{L}_{\text{Higgs}} = \mathcal{L}_{H_{\text{SM}}} + \Delta\mathcal{L}_H \, , \tag{2.1}$$

$\mathcal{L}_{H_{\text{SM}}}$ includes the SM Higgs interactions (Gauge, Yukawa and Higgs potential), whereas $\Delta\mathcal{L}_H$ denotes the correction to the Higgs properties due to new physics. The strength and structure of $\Delta\mathcal{L}_H$, will depend on the nature of the new physics chosen by nature at higher energies. For instance, it may include the perturbative effects of heavy particles, after being integrated out, or even be the remaining manifestation of the underlying mechanism of electroweak symmetry breaking (EWSB). Very likely, $\Delta\mathcal{L}_H$ will include corrections to the interactions already present in the SM lagrangian, but it could also include new interactions.

Within the SM, the Higgs boson-fermion couplings are only sensitive to the fermion mass eigenvalues. However, if one considers extensions of the SM, which either present a significant source of flavor-changing transition or are aimed precisely to explain the pattern of masses and mixing angles of the quarks and leptons, then it is quite possible that such physics will include new flavor-mediating particles and interactions. Furthermore, in the presence of additional fields that have non-aligned couplings to the SM fermions, i.e. which are not diagonalized by the same rotations that diagonalize the fermion mass matrices, and that also couple to the Higgs boson, then such fields could be responsible for transmitting the rich structure of the flavor sector to the Higgs bosons interactions.

Depending on the nature of such new physics, we can identify two possibilities for flavor-Higgs mediation, namely:

1. *Radiative mediation.* In this case the Higgs sector has initially (i.e. at tree-level) diagonal couplings to the fermions. However, in the presence of new particles associated with extended flavor physics, which couple both to the Higgs and to the SM fermions, these flavor-mediating fields will induce corrections to the Yukawa couplings and/or new FCNC process at loop level. This case will be discussed in great detail in the forthcoming section, within the context of the MSSM with general trilinear terms.

2. *Mixing mediation.* Modifications to the Higgs-flavor structure can also arise when additional particles mix with the SM ones. Such new particles could be either bosons or fermions. The possibility of having scalar flavor-mediation arise when one considers new scalars with large FV couplings, these new interactions are then transmitted to the Higgs sector, through scalar-Higgs mixing. Alternatively, mixing of SM fermions with exotic ones could also induce Higgs-FV couplings. Both possibilities are illustrated next with several examples.

One model of Fermion-induced flavor-mediation was discussed in our previous paper [12], where it was shown that the presence of new mirror fermions can mix with the SM fermions, and induce large corrections to the SM flavor structure; in particular it allows for the presence of large Higgs-FV couplings. Besides having to satisfy the low-energy constrains, it turns out that these new interactions could be tested with the decay $h \to \tau\mu$. The importance of this LFV Higgs mode was presented in refs. [13, 14], while subsequent work [15]–[17] further explored the possibilities to detect it at future colliders.

The widely studied two-Higgs doublet model-III (THDM-III) [18], could also be considered as one case of scalar-induced flavor-Higgs mediation. In a basis where one Higgs doublet acquires a v.e.v., which resembles the SM Higgs, the fermionic couplings of the second doublet will induce large FV transitions, then through the mixing of both Higgs doublets, the light SM-like Higgs boson will acquire such FV interactions [19, 20].

Another example of scalar Flavor-Higgs mediation occurs when the flavon fields (S), which appear in the Froggart-Nielsen scheme [21] that is aimed to generate the hierarchy of fermion masses and mixing angles, mixes with the light SM higgs. In some cases, the flavor scale (Λ) can be close to the electroweak-scale, and the flavon S could mix with the Higgs doublet (Φ), for instance through a quartic term of the type $S^\dagger S \Phi^\dagger \Phi$, which in turn will induce Higgs-FV couplings of the form: $(m_{l_i} + m_{l_j})/\Lambda$. SUSY models with R-parity breaking provide another example of scalar-induced flavor mediation; in this case the sneutrino fields can acquire a v.e.v., which violates lepton number, and this could be transmitted to the Higgs sector by sneutrino-Higgs mixing. Models where such mixing could appear were discussed some time ago in ref. [22].

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In section 5 of this paper, we shall discuss another model where scalar flavor-Higgs mediation is realized. It is an E_6-inspired multi-Higgs model, where large LFV-Higgs effects are also found to arise, though in this case at the tree-level. The model includes a Higgs pair associated with each family, and is supplemented with an abelian flavor symmetry $\mathrm{U}(1)_H$ that generates a realistic flavor structure for both quarks and leptons, via proper powers of a single suppression factor [10, 23]. This symmetry also helps to keep under control the usual FCNC problem that appears in multi-Higgs models, whenever each scalar field couples to both u- and d-type fermions. Working in a basis where only one Higgs pair gets v.e.v.'s, we prove that mixing effects between the light MSSM-like Higgs boson and the heavier non-minimal states, induce large tree-level corrections to the leptonic Higgs couplings.

In summary: our previous discussion illustrates that the appearance of Higgs-FV couplings is quite a generic phenomena associated with flavor physics beyond the SM, and in fact it can be used to probe several aspects of the flavor problem. Although we shall explore the consequences of the flavor-Higgs mediation mechanisms for the leptonic Higgs couplings, it can also be applied to the quark sector. In fact, implications for B-physics were discussed first in ref. [6], mainly in the minimal SUSY-GUT context. Top quark physics was discussed in our previous work [8] for the MSSM, where charged Higgs production through cb fusion was studied too. A more systematic evaluation of other rare top quark decays [24]–[26], will appear elsewhere [27].

3. Flavor-Higgs transmission within the minimal supersymmetric model

For good reasons, weak-scale supersymmetry has become one of the leading candidates for physics beyond the standard model (SM), notably by sensibly explaining electroweak symmetry breaking (EWSB). Being a new fundamental space-time symmetry, SUSY necessarily extends the SM flavor structure by including superpartners for all fermions, and thus it adds further puzzles to the flavor sector. Within the Minimal Supersymmetric SM (MSSM) SUSY is broken softly, in a manner that maintains its ultraviolet properties, while respecting the phenomenological constraints. However, the soft breaking sector of the MSSM is often problematic with low-energy flavor changing neutral current (FCNC) data without making specific assumptions about its free parameters. One of the most popular assumptions is the universality of squark masses and proportionality of the trilinear A-terms to the fermion Yukawa couplings. This is however not a generic feature, and certain forms of non-diagonal A-terms were studied recently [28, 29]. Evolution from a high-energy scale, such as the GUT scale, is one possible source that generates non-minimal soft-breaking terms. Moreover, in models that also attempt to address the flavor problem, the sfermion soft-terms may reflect the underlying flavor symmetry of the fermion sector. The soft-terms flavor structure could then be transmitted radiatively to the Higgs sector, through gaugino-sfermion loops, which is the focus of our paper. We shall evaluate here the corrections to the h^0 leptonic coupling, including both the lepton flavor violating (LFV) $(h \to l_i l_j)$ and the lepton-conserving (LFC) $(h \to l_i l_i)$ decay modes.

3.1 The MSSM with non-diagonal A-terms

To evaluate the strength of the radiative Flavor-Higgs transmission in the MSSM, we shall discuss first the slepton mass matrices, and the form that the Higgs-slepton and gaugino-lepton-slepton interactions take when expressed in the sfermion mass eigenstate basis.

The MSSM soft-breaking slepton sector contains the following quadratic mass-terms and trilinear A-terms:

$$-\widetilde{L}_i^\dagger (M_{\widetilde{L}}^2)_{ij}\widetilde{E}_j - \widetilde{E}_i^\dagger (M_{\widetilde{E}}^2)_{ij}\widetilde{E}_j + (A_l^{ij}\widetilde{L}_i H_d \widetilde{E}_j + \text{c.c.})\,, \tag{3.1}$$

$\widetilde{L}_i$ and E_j denote the doublet and singlet slepton fields, respectively, with $i,j(=1,2,3)$ being the family indices. For the charged slepton sector, this gives a generic 6×6 mass matrix,

$$\widetilde{\mathcal{M}}_u^2 = \begin{pmatrix} M_{LL}^2 & M_{LR}^2 \\ M_{LR}^{2\,\dagger} & M_{RR}^2 \end{pmatrix}, \tag{3.2}$$

where

$$\begin{aligned} M_{LL}^2 &= M_{\widetilde{L}}^2 + M_l^2 + \frac{1}{6}\cos 2\beta\,(4m_w^2 - m_z^2)\,, \\ M_{RR}^2 &= M_{\widetilde{E}}^2 + M_l^2 + \frac{2}{3}\cos 2\beta \sin^2\theta_w\, m_z^2\,, \\ M_{LR}^2 &= A_l v\sin\beta/\sqrt{2} - M_l\,\mu\cot\beta\,, \end{aligned} \tag{3.3}$$

with $m_{w,z}$ denoting the masses of $(W^\pm,\, Z^0)$ and M_l being the lepton mass matrix. For convenience, we will choose a basis where $M_l(=M_l^{\rm diag})$ is diagonal.

In our *minimal* scheme, we consider all large LFV to *solely* come from non-diagonal A_l in the slepton-sector, in a manner that respects the low-energy constrains and CCB-VS bounds [30], which in fact allow the flavor-mixings between the smuon ($\tilde{\mu}$) and stau ($\tilde{\tau}$), to be as large as $O(1)$. Although such large mixing could be associated with the large $\nu_\mu - \nu_\tau$ mixing observed in atmospheric neutrinos [9], we shall follow a bottom-up approach, where we simply take as an ansazt the following form of the A-terms, taken also to be real and valid at the TeV-scale. Thus, we neglect the mixing between selectrons and the other sleptons. In such minimal FCNC schemes the general 6×6 slepton-mass-matrix reduces down to a 4×4 matrix involving only the $\tilde{\mu}-\tilde{\tau}$ sector, similarly to the quark sector discussed in ref. [8]. Thus, we define at the weak scale,

$$A_l = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & x \\ 0 & y & 1 \end{pmatrix} A_0\,, \tag{3.4}$$

where, x and y can be of $O(1)$, representing a naturally large flavor-mixing in the $\tilde{\mu}-\tilde{\tau}$ sector. Moreover, identifying the non-diagonal A_l as the only source of the observable LFV phenomena implies the slepton-mass-matrices $M_{\widetilde{L},\widetilde{E}}^2$ in eqs. (3.2) and (3.3) to be nearly diagonal. For simplicity, we define

$$M_{LL}^2 \simeq M_{RR}^2 \simeq \widetilde{m}_0^2\,\mathbb{I}_{3\times 3}\,, \tag{3.5}$$

with $\widetilde{m}_0$ being a common scale for the scalar-masses.

Within this minimal scheme, we observe that the first family sleptons $\tilde{e}_{L,R}$ decouple from the rest in (3.2) so that, in the slepton basis $(\tilde{\mu}_L,\, \tilde{\mu}_R,\, \tilde{\tau}_L,\, \tilde{\tau}_R)$, the 6×6 mass-matrix is reduced to the following 4×4 matrix,

$$\widetilde{\mathcal{M}}_{\tilde{l}}^2 = \begin{pmatrix} \widetilde{m}_0^2 & 0 & 0 & A_x \\ 0 & \widetilde{m}_0^2 & A_y & 0 \\ 0 & A_y & \widetilde{m}_0^2 & X_\tau \\ A_x & 0 & X_\tau & \widetilde{m}_0^2 \end{pmatrix}, \tag{3.6}$$

where

$$A_x = x\widehat{A}\,, \qquad A_y = y\widehat{A}\,, \qquad \widehat{A} = Av\sin\beta/\sqrt{2}\,, \qquad X_\tau = \widehat{A} - \mu\, m_\tau \tan\beta\,. \tag{3.7}$$

The reduced slepton mass matrix (3.6) has 6 zero-entries in total and is simple enough to allow an exact diagonalization. Therefore, when evaluating loop amplitudes one can use the exact slepton mass-diagonalization, without invoking the popular but crude mass-insertion approximation.

We have worked out the general diagonalization of (3.6) for any $(x,\, y)$. The mass-eigenvalues of the eigenstates $(\tilde{\mu}_1,\, \tilde{\mu}_2,\, \tilde{\tau}_1,\, \tilde{\tau}_2)$ are,

$$\begin{aligned} M_{\tilde{\mu}1,2}^2 &= \widetilde{m}_0^2 \mp \frac{1}{2}|\sqrt{\omega_+} - \sqrt{\omega_-}|\,, \\ M_{\tilde{\tau}1,2}^2 &= \widetilde{m}_0^2 \mp \frac{1}{2}|\sqrt{\omega_+} + \sqrt{\omega_-}|\,, \end{aligned} \tag{3.8}$$

where $\omega_\pm = X_\tau^2 + (A_x \pm A_y)^2$. From (3.8), we can deduce the mass-spectrum of the smuon-stau sector as

$$M_{\tilde{\tau}1} < M_{\tilde{\mu}1} < M_{\tilde{\mu}2} < M_{\tilde{\tau}2}\,. \tag{3.9}$$

The 4×4 rotation matrix of the diagonalization is given by,

$$\begin{pmatrix} \tilde{\mu}_L \\ \tilde{\mu}_R \\ \tilde{\tau}_L \\ \tilde{\tau}_R \end{pmatrix} = \begin{pmatrix} c_1c_3 & c_1s_3 & s_1s_4 & s_1c_4 \\ -c_2s_3 & c_2c_3 & s_2c_4 & -s_2s_4 \\ -s_1c_3 & -s_1s_3 & c_1s_4 & c_1c_4 \\ s_2s_3 & -s_2c_3 & c_2c_4 & -c_2s_4 \end{pmatrix} \begin{pmatrix} \tilde{\mu}_1 \\ \tilde{\mu}_2 \\ \tilde{\tau}_1 \\ \tilde{\tau}_2 \end{pmatrix}, \tag{3.10}$$

with

$$s_{1,2} = \frac{1}{\sqrt{2}}\left[1 - \frac{X_t^2 \mp A_x^2 \pm A_y^2}{\sqrt{\,\omega_+\omega_-}}\right]^{1/2}, \qquad s_4 = \frac{1}{\sqrt{2}}\,, \tag{3.11}$$

and $s_3 = 0$ (if $xy = 0$), or, $s_3 = 1/\sqrt{2}$ (if $xy \neq 0$), where $s_j^2 + c_j^2 = 1$.

Figure 1 shows the resulting slepton spectra for typical soft-breaking parameters in the range 0.3 – 0.9 TeV, $m_A = 200\,\mathrm{GeV}$, and $\tan\beta = 5, 20, 40$. We can observe that both $\tilde{\tau}_1$ and $\tilde{\tau}_2$ differ significantly from the common scalar mass $\widetilde{m}_0$. Furthermore, the stau $\tilde{\tau}_1$ can be as light as about $100 - 300\,\mathrm{GeV}$, which will have an important effect in the loop calculations. Furthermore, even for $x \simeq 0.5$ the smuon masses can differ from $\widetilde{m}_0$ by as much as $30 - 50\,\mathrm{GeV}$; with these mass values the slepton phenomenology would have to be reconsidered, since one is not allowed to sum over all the selectrons and smuons when evaluating slepton cross-sections, as it is usually assumed in the constrained MSSM.

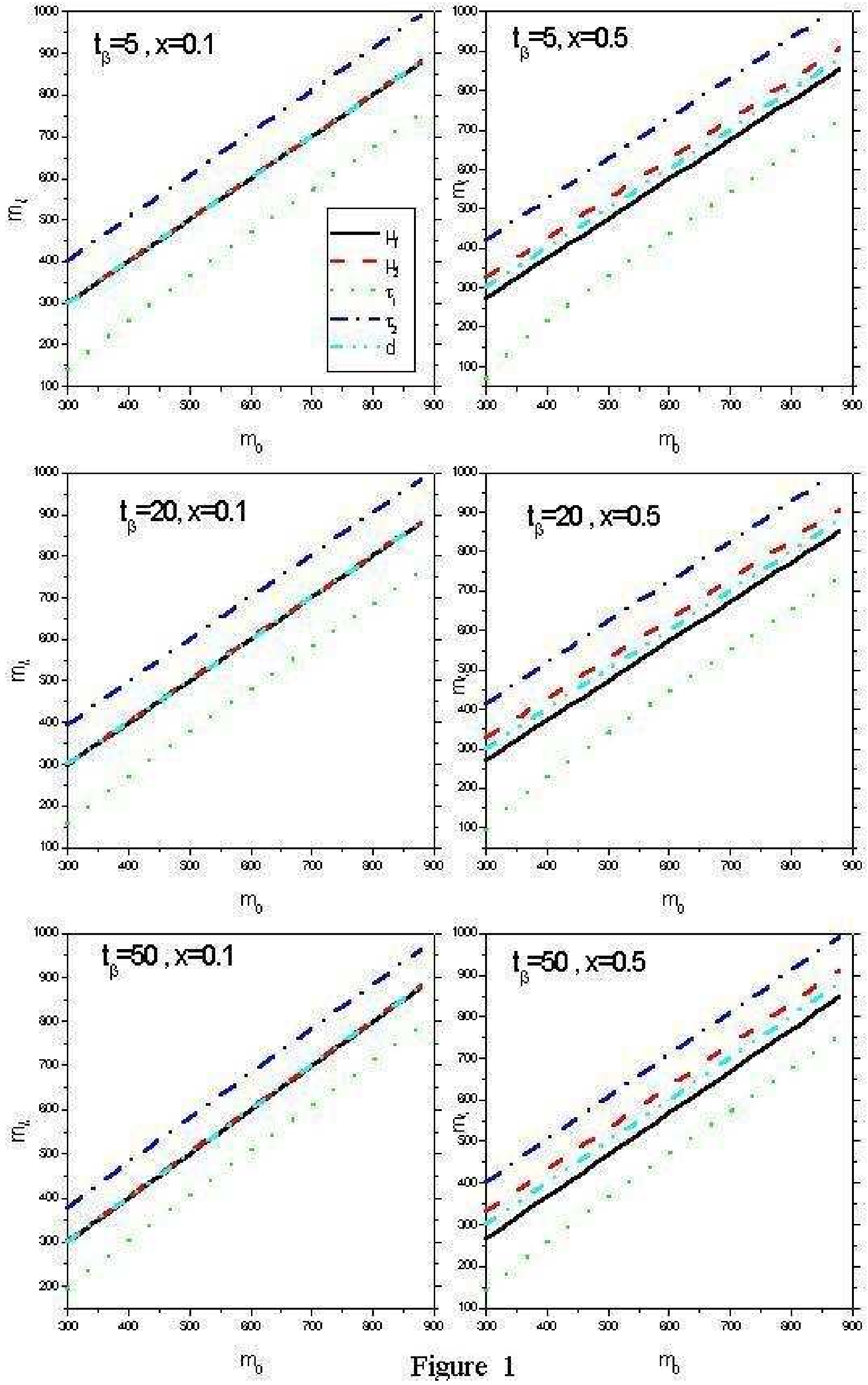

Figure 1: Mass spectrum for the smuon and stau sleptons as a function of the SUSY scale ($\tilde{m}_0$), for $x = 0.1, 0.5$ and $\tan\beta = 5, 20, 50$. The line labeled with d corresponds to the degenerated case.

3.2 Higgs-sfermion and gaugino-sfermion interactions

To describe the radiative flavor-Higgs mixing, we need to discuss the slepton-Higgs and gaugino vertices in the mass-eigenstate basis. We shall present formulae for the light Higgs boson (h), though the generalization to the full Higgs spectrum is straightforward. In terms of interaction states, the lagrangian that describes the Higgs-slepton-slepton vertices can be written as:

$$\mathcal{L}_{h\tilde{l}\tilde{l}} = h^0 \left[\rho_L \tilde{l}^*_{Li} \tilde{l}_{Li} + \rho_R \tilde{l}^*_{Ri} \tilde{l}_{Ri} + \left(\rho_{LR} \tilde{l}^*_{Li} \frac{A_{ij}}{A_0} \tilde{l}_{Rj} + \text{h.c.} \right) \right], \tag{3.12}$$

where:

$$\begin{aligned}
\rho_L &= g_Z m_Z \sin(\alpha+\beta) \left(\frac{1}{2} + s_W^2 \right) \\
\rho_R &= g_Z m_Z \sin(\alpha+\beta)(-s_W^2) \\
\rho_{LR} &= \frac{A_0 \sin\alpha}{\sqrt{2}},
\end{aligned} \tag{3.13}$$

and A_{ij} given by eq. (3.4). Then, we can transform this lagrangian from the weak basis $(\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\tau}_L, \tilde{\tau}_R)$ to the mass-eigenstate basis $(\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\tau}_1, \tilde{\tau}_2)$. The result can be written in terms of a 3×3 rotated coupling matrix: $\mathcal{H}_{\alpha\beta} = \mathcal{H}_{\beta\alpha} = O \tilde{\rho}_{\alpha\beta} O^T$, where $\tilde{O}$ denotes the rotation matrix appearing in eq. (3.10), and

$$\tilde{\rho} = \begin{pmatrix} \rho_L & 0 & 0 & x\rho_{LR} \\ 0 & \rho_R & y\rho_{LR} & 0 \\ 0 & y\rho_{LR} & \rho_L & \rho_{LR} \\ x\rho_{LR} & 0 & \rho_{LR} & \rho_R \end{pmatrix} \tag{3.14}$$

The resulting Higgs-slepton couplings can be expressed then as:

$$\mathcal{L} = h^0 (\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\tau}_1, \tilde{\tau}_2) \mathcal{H}_{\alpha\beta} (\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\tau}_1, \tilde{\tau}_2)^T. \tag{3.15}$$

Similarly, the interaction between gauginos and lepton-slepton pairs can be rotated to the mass-eigenstate basis too. The result can be expressed as follows:

$$\mathcal{L}_{\text{int}} = \bar{\chi}^0_m [\eta^{mL}_{\alpha k} P_L + \eta^{mR}_{\alpha k} P_R] \tilde{l}_\alpha l_k + \text{h.c.}, \tag{3.16}$$

where χ^0_m denotes the neutralinos ($m = 1, \ldots, 4$), while $\tilde{l}_\alpha$ correspond to the mass-eigenstate sleptons. The factors $\eta^{mN}_{\alpha k}$ are obtained after one substitute the rotation matrices for both the neutralinos and sleptons in the interaction lagrangian.

To carry out the forthcoming analysis of LFV Higgs transitions, we choose to work with the simplified case $x = y$, which gives: $c_1 = c_2 = c_{\tilde{l}}$, $s_1 = s_2 = s_{\tilde{l}}$ and $c_3 = s_3 = c_4 = s_4 = 1/\sqrt{2}$. The corresponding expression for the matrix $\mathcal{H}_{\alpha\beta}$, is given by,

$$\begin{aligned}
\mathcal{H}_{11} &= \rho_L + \rho_R + 2\rho_{LR}(s_{\tilde{l}}^2 + 2 s_{\tilde{l}} c_{\tilde{l}} x) \\
\mathcal{H}_{12} &= (\rho_L - \rho_R)(s_{\tilde{l}}^2 - c_{\tilde{l}}^2) \\
\mathcal{H}_{13} &= 2\rho_{LR}[s_{\tilde{l}} c_{\tilde{l}} - (s_{\tilde{l}}^2 - c_{\tilde{l}}^2)]
\end{aligned}$$

$(\tilde{l}_\alpha, l_k)$	$\eta^L_{\alpha k}$	$\eta^R_{\alpha k}$
$(\tilde{\mu}_1, \mu)$	$-c_{\tilde{l}}\frac{g_1}{2}$	$-c_{\tilde{l}}g_1$
$(\tilde{\mu}_1, \tau)$	$s_{\tilde{l}}\frac{g_1}{2}$	$s_{\tilde{l}}g_1$
$(\tilde{\mu}_2, \mu)$	$-c_{\tilde{l}}\frac{g_1}{2}$	$-c_{\tilde{l}}g_1$
$(\tilde{\mu}_2, \tau)$	$s_{\tilde{l}}\frac{g_1}{2}$	$-s_{\tilde{l}}g_1$
$(\tilde{\tau}_1, \mu)$	$-s_{\tilde{l}}\frac{g_1}{2}$	$s_{\tilde{l}}g_1$
$(\tilde{\tau}_1, \tau)$	$-c_{\tilde{l}}\frac{g_1}{2}$	$c_{\tilde{l}}g_1$
$(\tilde{\tau}_2, \mu)$	$-s_{\tilde{l}}\frac{g_1}{2}$	$-s_{\tilde{l}}g_1$
$(\tilde{\tau}_2, \tau)$	$-c_{\tilde{l}}\frac{g_1}{2}$	$-c_{\tilde{l}}g_1$

Table 1: Slepton-lepton-neutralino couplings ($\eta^{mN}_{\alpha k}$) for the case when $x = y$ and $\chi^0_1 = \tilde{B}$.

$$\begin{aligned}
\mathcal{H}_{14} &= (\rho_L - \rho_R) 2 s_{\tilde{l}} c_{\tilde{l}} \\
\mathcal{H}_{22} &= \rho_L + \rho_R + 2\rho_{LR}(-s^2_{\tilde{l}} + 2 s_{\tilde{l}} c_{\tilde{l}} x) \\
\mathcal{H}_{23} &= (\rho_L - \rho_R) 2 s_{\tilde{l}} c_{\tilde{l}} \\
\mathcal{H}_{24} &= 2\rho_{LR}[-s_{\tilde{l}} c_{\tilde{l}} - (s^2_{\tilde{l}} - c^2_{\tilde{l}})] \\
\mathcal{H}_{33} &= \rho_L + \rho_R + 2\rho_{LR}(c^2_{\tilde{l}} - 2 s_{\tilde{l}} c_{\tilde{l}} x) \\
\mathcal{H}_{34} &= (\rho_L - \rho_R)(s^2_{\tilde{l}} - c^2_{\tilde{l}}) \\
\mathcal{H}_{44} &= \rho_L + \rho_R + 2\rho_{LR}(-c^2_{\tilde{l}} - 2 s_{\tilde{l}} c_{\tilde{l}} x)\,.
\end{aligned} \tag{3.17}$$

On the other hand, the expressions for $\eta^{mL,R}_{\alpha k}$, simplify further for the case when the neutralino is taken as the bino, which we will assume in the calculation of Higgs LFV decays; the resulting coefficients ($\eta^{L,R}_{\alpha k}$) are shown in table 1.

3.3 Bounds on the LFV parameters from $l_i \to l_j + \gamma$

Although the slepton mixing is constrained by low-energy data [7], flavor-mixing between the second- and third-family sleptons, the smuon ($\tilde{\mu}$) and stau ($\tilde{\tau}$), are allowed to be as large as $O(1)$. Here, we are interested in obtaining bounds on the parameters x and m_0, applying the exact slepton mass-diagonalization to evaluate the LFV transition $\tau \to \mu + \gamma$. In our scheme, since the selectron decouples form the other sleptons, it is not possible to induce LFV transitions for the first family.

Using the interaction lagrangian (3.14), one can rewrite the general expressions for the SUSY contributions to the decays $l_i \to l_j + \gamma$ given in ref. [31]. The expression for the decay width $\Gamma(\tau \to \mu + \gamma)$, including the bino-smuon and stau contributions, has the form:

$$\Gamma(\tau \to \mu + \gamma) = \frac{\alpha m^5_\tau}{4\pi}\left[\sum_\alpha |A_{L\alpha}|^2 + |A_{R\alpha}|^2\right], \tag{3.18}$$

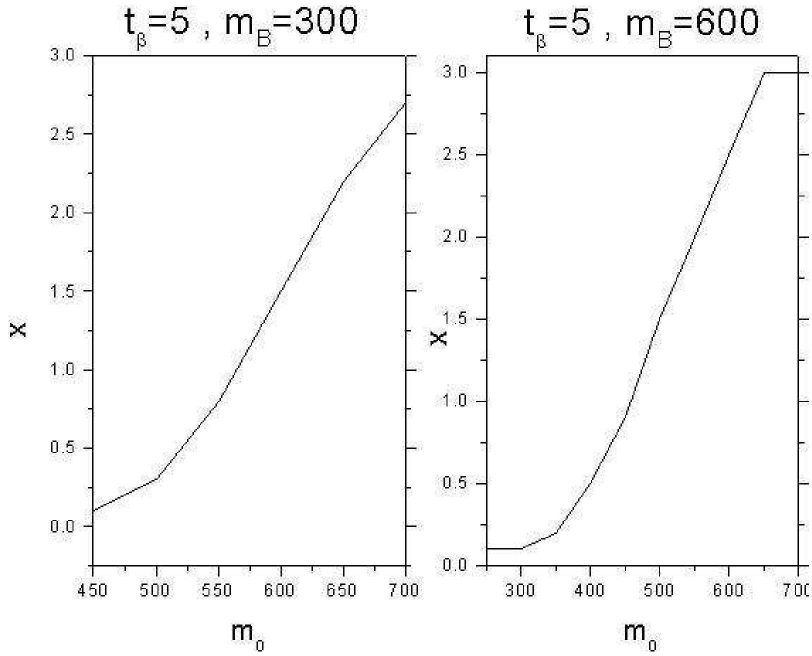

Figure 2: Allowed values of the parameter x obtained from $\tau \to \mu + \gamma$, for $\tan\beta = 5$ and bino mass $m_B = 300(a), 600\,\text{GeV}$ (b). The excluded region lies above the curves shown in the figure.

where

$$A_{R\alpha} = \frac{1}{32\pi^2 m^2_{\tilde{l}_\alpha}} \left[\eta^R_{\tilde{l}_\alpha \tau} \eta^R_{\tilde{l}_\alpha \mu} f_1(x_\alpha) + \eta^R_{slp_\alpha \tau} \eta^L_{\tilde{l}_\alpha \mu} \frac{m_{\tilde{B}}}{m_\tau} f_2(x_\alpha) \right] \tag{3.19}$$

with $x_\alpha = m^2_{\tilde{B}}/m^2_{\tilde{l}_\alpha}$, and the functions $f_{1,2}(x_\alpha)$ are given in ref. [31]. $A_{L\alpha}$ is obtained by making the substitutions $L \to R, R \to L$ in Eq. (20).

The decay width depends on the SUSY parameters, and determining the allowed region in the plane $x - \widetilde{m}_0$ seems the most convenient choice. Using the current bound $B.R.(\tau \to \mu + \gamma) < 10^{-6}$ gives the exclusion limits shown in figure 2. The excluded region lies above the curves shown in the figure. We can see that for values of the scalar mass parameter $\widetilde{m}_0 \simeq 200\,\text{GeV}$, the proportionality solution to the SUSY flavor problem is preferred, while for heavier masses, i.e. $\widetilde{m}_0 \simeq 650\,\text{GeV}$, the decoupling of sfermions solves the problem, since FCNC transitions are suppressed for heavy squarks. For $\widetilde{m}_0 \simeq 600\,\text{GeV}$, and $\tan\beta = 5$, x is allowed to be as large as 2.5, which will induce a large slepton mixing and Higgs-FV transitions, that could possibly be detectable.

On the other hand, SUSY contributions to the muon anomalous magnetic moment Δa_μ, can also be discussed in this framework, but given the present uncertainties regarding the hadronic corrections, it is enough to consider only the LFV tau decay bound.

3.4 The corrections to $h^0 l_i l_j$ and $h^0 l_i l_i$ vertex

Large SUSY correction to the Yukawa couplings, in particular those related to the top and bottom couplings that arise in the large $\tan\beta$, have been studied in the literature [32], while the flavor changing Higgs couplings that arise in the d- and u-type quark sector were studied in [6] and [8], respectively. Before describing the full SUSY corrections to the Yukawa matrices within our framework, it is convenient to discuss them using the notation of ref. [33]. There, the tree-level lepton Yukawa matrix h^l_{ij} is modified by radiative corrections, in such a way that the leptons couple to both Higgs doublets H_d and H_u. Namely,

$$\mathcal{L}_Y = \bar{E}_i[h^l_{ij} + \delta h^l_{ij}]H_d L_j + \bar{E}_i(\Delta h^l)_{ij} H_u L_j + \text{h.c.}\,, \tag{3.20}$$

where L_i, E_j denote the three-family lepton doublets and singlets, respectively.

The soft-breaking terms A^l_{ij} contribute to δh^l_{ij} through the slepton-gaugino loops, thereby realizing the *radiative* flavor-Higgs mediation mechanism. One can show that for most regions of parameter space the corrections to the lepton masses are proportional to $\cos\beta$ and are thus suppressed for large $\tan\beta$. Moreover, it can be shown that the corresponding corrections to the diagonal Higgs-lepton couplings are negligible too. Although one could expect that the FV Higgs-lepton couplings are also suppressed, it turns out that this is not the case, and the corresponding LFV Higgs decays, such as $h \to \tau\mu$, are induced at appreciable rates. Furthermore, one does not need to have very large LFV couplings, since the striking characteristics of the LFV Higgs signals will facilitate its observation at future colliders.

On the other hand, the SUSY-conserving (F- and D-terms) do contribute to Δh^l_{ij}, and may be enhanced for large $\tan\beta$. However, one can see that such correction are dominantly flavor-conserving, because the $H_u - \tilde{l}_i - \tilde{l}_i$ couplings are diagonal in flavor space. Thus, eq. (3.17) provides a consistent treatment of the radiative flavor-Higgs mediation. Namely, one can use the dominant correction contained in eq. (3.20) to describe the LFC Higgs interactions $h\tau^+\tau^-$, as it was done in ref. [33]. In fact, their numerical results show that these corrections are observable only for a limited region of parameter space.

An estimate of the LFV Higgs couplings hl_il_j, could be obtained along these lines, using only the approximate expression for δh_{ij}. However, to take advantage of having a more precise sfermion mass diagonalization, we prefer to perform a complete loop calculation, which allows us to study the effect of the slepton mass-eigenstates in the loop amplitude. Thus, we shall write the vertex hl_il_j as follows:

$$g_{hl_il_j} = [(F_L)_{ij} P_L + (F_R)_{ij} P_R] \tag{3.21}$$

i.e. in terms of the form factors $F_{L,R}$. Due to the small lepton masses, one can safely neglect the contribution from the self-energy corrections (from smuon-bino and stau-bino loops), and thus $F_{L,R}$ contains only the vertex corrections (from smuon-stau-bino triangle loops).[1]

In our minimal FC scheme, with large smuon-stau mixing, the SUSY slepton-bino loops can induce the LFV higgs decay $h \to \tau\mu$. It is known that the branching ratio for this mode, within the context of the SM with light neutrinos, is extremely small, ($\lesssim 10^{-7} - 10^{-8}$), so that this channel becomes an excellent window for probing new physics [13].

[1] Additional graphs involving charginos and sneutrinos are neglected here, mainly to reduce the number of parameters.

$m_{\tilde{B}}$	$\widetilde{m}_0 = 450\,\mathrm{GeV}$	$\widetilde{m}_0 = 600\,\mathrm{GeV}$
150 GeV	1.1×10^{-7} (3.0×10^{-8})	5.0×10^{-5} (1.2×10^{-5})
300 GeV	3.1×10^{-7} (8.0×10^{-8})	8.0×10^{-5} (2.1×10^{-5})
600 GeV	5.3×10^{-5} (1.4×10^{-5})	4.4×10^{-4} (1.2×10^{-4})

Table 2: Br$[h \to \tau\mu]$ is shown for a sample set of SUSY inputs with $(\mu, m_A) = (0.2, 0.3)$ TeV, $A = \widetilde{m}_0/2$ and $\tan\beta = 5(10)$. The numbers in each entry are obtained using the maximum value $x_{max}(\simeq 1.2 - 3.0)$ allowed for the given set of SUSY parameters.

Therefore, the one-loop SUSY-EW induced amplitude for $h^0 \to l_i l_j$ is given by:

$$A(h \to l_i l_j) = i\,\overline{u}_i(k_2)\,(F_L P_L + F_R P_R)\,u_j(k_1)\,, \tag{3.22}$$

The resulting expressions for $F_{L,R}$, including only the vertex corrections, are:

$$\begin{aligned} F_L^V &= \frac{g_1^2 m_{\tilde{B}}}{32\pi^2} \sum_{\alpha\beta} \lambda_{jk}^L C_0(m_h^2, m_\tau^2, 0; m_{\tilde{l}_\alpha}, m_{\tilde{B}}, m_{\tilde{l}_\beta})\,, \\ F_R^V &= \frac{g_1^2 m_{\tilde{B}}}{32\pi^2} \sum_{\alpha\beta} \lambda_{\alpha\beta}^R C_0(m_h^2, m_t^2, 0; m_{\tilde{l}_\alpha}, m_{\tilde{B}}, m_{\tilde{l}_\beta})\,, \end{aligned} \tag{3.23}$$

where $\tilde{l}_{\alpha,\beta} \in (\tilde{\mu}_1, \tilde{\mu}_2, \tilde{\tau}_1.\tilde{\tau}_2)$, C_0 denotes the 3-point C-function of Passarino-Veltman [34]. $\lambda_{\alpha k}^{L,R}$ is the product of the relevant $h\tilde{l}_\alpha\tilde{l}_\beta$ and $\tilde{l}_\alpha\tilde{B}\tau(\mu)$ couplings, i.e. $\lambda_{\alpha\beta}^L = \mathcal{H}_{\alpha\beta}\eta_{\alpha\mu}^L\eta_{\beta\tau}^{R*}$ and $\lambda_{\alpha\beta}^R = \mathcal{H}_{\alpha\beta}\eta_{\alpha\mu}^R\eta_{\beta\tau}^{L*}$.

Finally, the width for the decay process $h^0 \to l_i l_j$ (adding both final states $l_i^+ l_j^-$ and $l_i^- l_j^+$) is given by:

$$\Gamma(h \to l_i l_j) = \frac{m_h}{8\pi}(|F_L|^2 + |F_R|^2)\,, \tag{3.24}$$

On the other hand, if we were interested in using a lagrangian of type (1) to describe the light Higgs boson, we would have to work in the decoupling limit, namely when the remaining Higgs sector is very heavy ($m_A \gg m_Z$), though in fact this can be achieved even for moderate masses of order $m_A \gtrsim 600\,\mathrm{GeV}$. Results for the branching ratio of the LFV Higgs mode are shown in table 2 for several combinations of parameters, which are consistent with the bounds obtained from the LFV tau decay.

In order to study the possibility to detect the LFV higgs decays at hadron colliders, one can use the gluon-fusion mechanism for single Higgs production. Assuming that the production cross-section is of similar strength to the SM case, about 1.2 pb for $m_H = 125\,\mathrm{GeV}$ at Tevatron [35], it will allow to produce 12,000 Higgs bosons with an integrated luminosity of $10\,\mathrm{fb}^{-1}$. Thus, for $B.R.(H \to \tau\mu/\tau e) \simeq 10^{-4}$, Tevatron can produce $O(1)$ events, and its detection is hopeless. While at LHC, it will be possible to produce about 10^6 Higgs bosons through the gluon fusion mechanism [35], with an integrated luminosity of $100\,\mathrm{fb}^{-1}$. Then, to determine the detection prospects for the signal, we need to study the main backgrounds to the $h \to \tau\mu$ signal, which are dominated by Drell-Yan tau pair and WW pair production. In ref. [15] it was proposed to reconstruct the hadronic and electronic tau decays, assuming the following cuts: i) For the transverse muon and jet momentum:

	Run-2	LHC
$B.R._{\rm min}$	$5.\times 10^{-2}$ $(3.\times 10^{-2})$	$5.\times 10^{-3}$ $(8.\times 10^{-4})$

Table 3: Minimum $B.R.(h \to \mu\tau)$ that can allow detection of the LFV Higgs decays. Results are shown for Tevatron Run-2 with 20 (60) fb^{-1}, and the LHC with 10 (100) fb^{-1}, for $m_h = 125\,\mathrm{GeV}$.

$p_T^\mu > m_h/5$, $p_T^\pm > 10\,\mathrm{GeV}$, ii) Jet rapidity for Tevatron (LHC): $|\eta| < 2(2.5)$, iii) The angle between the missing transverse momentum and the muon direction: $\phi(\mu,\pm) > 160^o$. The resulting bounds on the LFV higgs couplings, expressed as a minimum b.r. required to have a 3σ signal, are shown in table 3.

For the region of parameter space where $m_{\tilde{B}} \simeq \widetilde{m}_0 \simeq 600\,\mathrm{GeV}$ and low $\tan\beta$, we can obtain $B.R. \simeq 4\times 10^{-4}$, which is several orders of magnitude larger than the SM result, and only about one-half of the value required to get a 3σ signal at LHC [15, 16]. This result can be taken as a motivation to look for further improvements in the search strategy to discriminate the signal from the SM backgrounds, or to consider several running years to enhance the luminosity. These decay branching ratios are very sensitive to the mixing parameter x. One reason is that the branching ratio (or decay width) contains, besides other mass-diagonalization effects, a power factor x^2 associated with the Higgs-FV coupling that appears in the triangle loops. Another reason is that unlike the usual analyses with mass-insertion approximation, we have performed exact slepton mass diagonalization, so that staus and/or smuons can have significant mass-splitting, as was also shown in figure 1.

4. Higgs sector in an E_6-inspired model with a horizontal U(1) symmetry

Multi-Higgs SUSY models are particularly motivated by E_6 unification models, where a Higgs pair could be associated with each family; so to say: each generation requires its own Higgs sector [36]. If one assumes that the Higgs-Yukawa superpotential does not permits intergenerational couplings for the Higgs superfield, then the phenomenology of the flavor-Higgs sector of the models is quite simple: there are no FCNC mediated by scalars, although a rich phenomenology associated with the multiple Higgs particles will arise.

On the other hand, one can provide a more theoretically compelling construction for the flavor sector of such model, based upon a minimal family symmetry. This attractive approach makes use of the simplest horizontal $\mathrm{U}(1)_H$ symmetry to generate a realistic flavor structure of both fermions and sfermions, via proper powers of a single suppression factor [21]. For convenience, we define the suppression factor $\epsilon = \langle S\rangle/\Lambda$ to have a similar size as the Wolfenstein-parameter λ in the CKM matrix, i.e., $\epsilon \simeq \lambda \simeq 0.22$ [23]. Here, $\langle S\rangle$ denotes the vacuum expectation value of a singlet scalar S, responsible for spontaneous $\mathrm{U}(1)_H$ breaking, and Λ is the scale at which the $\mathrm{U}(1)_H$ breaking is mediated to light fermions. In general, the supermultiplets of three-family fermion/sfermions may carry different $\mathrm{U}(1)_H$ charges. The Yukawa lagrangian, which is obtained from the superpotential of the model, is given by:

$$\mathcal{L}_Y = \bar{U}_i Y^u_{ij} H^u_\alpha Q_j - \bar{D}_i Y^d_{ij} H^d_\alpha Q_j - \bar{E}_i Y^l_{ij} H^d_\alpha L_j\,, \tag{4.1}$$

where $H^{u,d}_\alpha$ $(\alpha = 1,2,3)$ denote the three Higgs pairs of the model.

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Q_1	Q_2	Q_3	$\overline{u}_1$	$\overline{u}_2$	$\overline{u}_3$	$\overline{d}_1$	$\overline{d}_2$	$\overline{d}_3$	H_a	H_a	S
h_1	h_2	h_3	α_1	α_2	α_3	β_1	β_2	β_3	ξ	ξ'	γ
4	3	0	3	0	0	4	3	3	0	0	-1

Table 4: Quantum number assignments are derived with $\tan\beta \sim O(1)$.

We choose to work in a basis where only $H_3^{u,d} = H_{u,d}$ acquires a v.e.v.,($\langle H^0_{u,d}\rangle = v_{u,d}$). Then, assuming that all Higgs pairs have vanishing charges under the flavor symmetry $\mathrm{U}(1)_F$, we can induce Yukawa couplings that satisfy current data on quark-masses and CKM angles (which can all be counted in powers of $\lambda = 0.2$), with the set of $\mathrm{U}(1)_H$ quantum numbers that appear in table 4. We are also considering here $\tan\beta \sim O(1)$.

For instance, the resulting up-quark mass-matrix takes the form of

$$M_u \sim \frac{v_u}{\sqrt{2}} \begin{pmatrix} \lambda^7 & \lambda^4 & \lambda^4 \\ \lambda^6 & \lambda^3 & \lambda^3 \\ \lambda^3 & 1 & 1 \end{pmatrix}, \tag{4.2}$$

which gives the correct spectrum indeed.

On the other hand, since the neutral lepton sector is less constrained, and only recently the experimental facilities have started to provide data on the neutrino sector [9], we choose to work only with the two-flavor case, namely with the tau and muon leptons. Again, working in the basis where only $H_3^{u,d} = H^{u,d}$ acquires a v.e.v., the charged lepton mass matrix is: $M_l = \frac{v_d}{\sqrt{2}} Y^l$. Then, using the following flavor-symmetry charges: $(h_2, h_3) = (2,2)$ and $(\beta_2, \beta_3) = (3,1)$, for the lepton doublet and singlet, respectively, we obtain the following charged lepton mass matrix:

$$M_l \sim \frac{v_d}{\sqrt{2}} \begin{pmatrix} \lambda^5 & \lambda^5 \\ \lambda^3 & \lambda^3 \end{pmatrix}, \tag{4.3}$$

This mass matrix can be diagonalized by a simple 2x2 rotation matrix parameterized by a mixing angle θ_l, and it can be verified that this gives the correct order of magnitude for the charged lepton masses, namely $m_\mu \simeq m_\tau \lambda^2 \simeq \lambda^5 v_d$. Then, the "Yukawa matrices" that generate Higgs-lepton interactions for the remaining Higgs doublets $H^d_{1,2}$, which do not contribute to lepton masses, are given to leading order by:

$$Y^l_{1,2} = \frac{v_d}{\sqrt{2}} \begin{pmatrix} O(\lambda^5) & O(\lambda^5) \\ z_{1,2}\lambda^3 & \lambda^3 \end{pmatrix}. \tag{4.4}$$

We have included the factors $z_{1,2}$ to parameterize the $O(1)$ coefficients left undetermined by the FN approach. After rotating to the lepton mass-eigenstate basis, we obtain the following Higgs-lepton interaction lagrangian:

$$\mathcal{L}_{\mathrm{int}} = \frac{\lambda^3(1+z_i)}{\sqrt{2}} \bar{\tau} H^d_i \tau + \frac{\lambda^3(z_i - 1)}{\sqrt{2}} \bar{\tau} H^d_i \mu + \mathrm{h.c.} \tag{4.5}$$

which includes Higgs-FV interactions for tau-mu and Higgs-FC interactions for the tau. Now, these interactions can be transmitted to the light MSSM-like Higgs boson of the model, by a mixing mechanism, namely we only need to assume that the neutral states resulting from H_1^d and H_2^d mix with MSSM-like CP-even Higgs state [37]. This mixing can be treated as a small perturbation, and one can expect that it does not affect significantly the remaining properties of the light Higgs boson. Furthermore, we can assume that the lightest state arising from $H_{1,2}$ dominates this mixing, which can be parameterized by another mixing angle $\sin\chi_l = \epsilon_l$, in such a way that the LFV Higgs coupling can be written as:

$$\mathcal{L}_{\rm int} = \frac{g m_\tau \sin\alpha}{\sqrt{2} m_W \cos\beta}\left[-\epsilon_l \frac{(1-z_1)}{\sin\alpha}\bar{\tau}\mu + \left(1-\epsilon_l\frac{(1+z_1)}{\sin\alpha}\right)\bar{\tau}\tau + \text{h.c.}\right] h^0\,, \tag{4.6}$$

where we have substituted λ^3 by the appropriate power of the tau mass.

Finally, to use the same notation as in Eq. (24), we can write the corresponding expressions for the LFV form factors $(F_{L,R})$, as follows:

$$F_L = F_R = -\frac{g m_\tau \epsilon_l (1-z_1)}{\sqrt{2} m_W \cos\beta}\,. \tag{4.7}$$

Then we can analyze the Higgs branching ratio that results from this coupling. Before doing that we briefly mention that because this model has an structure similar to the THDM-III [18], LFV decays of tau and muon, such as $\tau \to \mu + \gamma$ or $\tau \to \mu\mu\mu$, will only give mild constrains on the parameters $\epsilon_l, z_{1,2}$, similar to those obtained for the THDM-III [13], then it is possible that strongest bounds on the parameters will come from the search for the LFV Higgs decays itself.

For the numerical study, we assume that the decay modes of the light Higgs boson include $h \to b\bar{b}, c\bar{c}, gg, WW^*$. Since z_1 must be of order unity, we consider two values $z_1 = 0.75, 0.9$. As shown in table 5, for $z_1 = 0.75, 0.9$ and $\epsilon_l = 0.1$, the decay branching ratio $\text{Br}[h \to \tau\mu]$ can be of the order 7×10^{-2}, over a large part of the SUSY parameter space, while for $\epsilon_l = 0.05$ the B.r. still can reach values of the order 10^{-2}, especially for large values of $\tan\beta$ ($\simeq 20$) and when the mass of the lightest Higgs boson h^0 is around 115 – 120 GeV. These results for the LFV B.R.'s are larger than those obtained in the MSSM, because now the LFV Higgs couplings are tree-level effects; thus, the loop corrections, where the truly SUSY aspects of the model will show up, can be safely neglected.

Comparing our results with the minimum B.R. of the LFV Higgs $h \to \tau\mu$, that can be detected at future hadron colliders (shown in table 3), one can see that there is a significant region of parameters where such a LFV Higgs signal can be found. In fact, the rates obtained in this model for $z_1 = 0.75$ are at the reach of Tevatron Run-2. While the LHC, can also have a great sensitivity to discover the LFV decay channel $h \to \tau\mu$ in largest portions of parameter space, and test the model predictions. The future Linear Collider, with a high luminosity, is also expected to have a good sensitivity to detect this channel [17].

On the other hand, this model also predicts corrections to the Higgs-tau couplings, which can be tested at NLC. Table 5 shows the resulting deviation of the Higgs width $(h \to \tau^+\tau^-)$ from the MSSM value, defined as:

$$\Delta\Gamma_{h\tau\tau} = \frac{\Gamma_{h_{E_6}\tau\tau}}{\Gamma_{h_{MSSM}\tau\tau}}\,. \tag{4.8}$$

m_A	z_1	$B.R.(h \to \tau\mu) \times 10^3$	$\Delta\Gamma_{h\tau\tau}$
100 GeV	0.75	(0.19, 0.16, 0.15)	(0.69, 0.72, 0.74)
	0.90	(0.03, 0.027, 0.024)	(0.66, 0.69, 0.71)
150 GeV	0.75	(0.64, 0.17, 0.56)	(0.44, 0.29, 0.04)
	0.90	(0.10, 0.27, 0.90)	(0.40, 0.15, 0.01)
200 GeV	0.75	(1.40, 4.80, 17.0)	(0.23, 0.03, 0.95)
	0.90	(0.22, 0.76, 2.70)	(0.19, 0.07, 1.30)
250 GeV	0.75	(1.90, 7.20, 15.0)	(0.13, 0.06, 2.0)
	0.90	(0.31, 1.10, 3.90)	(0.10, 0.13, 2.60)
300 GeV	0.75	(2.40, 8.80, 29.0)	(0.09, 0.16, 2.80)
	0.90	(0.38, 1.40, 4.60)	(0.05, 0.27, 3.50)

Table 5: Values of $B.R.(h \to \tau\mu)$ and $\Delta\Gamma_{h\tau\tau}$ that arise for $z_1 = 0.75, 0.9$ and $\epsilon_l = 0.1$. Results in each parenthesis correspond to $\tan\beta = 5, 10, 20$.

This table shows that $\Delta\Gamma_{h\tau\tau}$ can easily be above 0.08, which according to current studies, could be measurable at the NLC [3]. Furthermore, we notice that the values of $\Delta\Gamma_{h\tau\tau}$ obtained for $z_1 = 0.9$ are slightly larger than those corresponding to $z_1 = 0.75$, while the LFV Higgs decay $h \to \tau\mu$ is larger for $z_1 = 0.75$. LHC on the other hand, can detect the LFV Higgs signal for both values of z_1.

5. Conclusions

Within the SM, the Higgs boson has fermion couplings proportional to the fermion mass, thus it knows about flavor. In this paper, we have shown that a more flavored Higgs boson arises when the flavor structure encoded in supersymmetric extensions of the standard model is transmitted to the Higgs sector. The flavor-Higgs transmission mechanism can have a radiative or mixing origin, as it is illustrated with several examples, and can produce interesting Higgs signatures that can be probed at future high-energy colliders. In this paper we have focused on the possibility of testing such flavor-Higgs mediation mechanism through the LFV Higgs decay $h \to \tau\mu$.

Within the minimal SUSY extension of the SM (MSSM), the flavor mediation mechanism is of *radiative* type, as it is realized through gaugino-sfermion loops, which transmit the flavor structure of the soft-breaking sector to the Higgs bosons. In particular, we evaluated the contributions from the general trilinear A-terms both to the Higgs LFV and LFC vertices. Our results for the branching ratio of the LFV Higgs mode $h \to \tau\mu$, give $B.R. \simeq 4 \times 10^{-4}$, which is several orders of magnitude larger than the SM estimate, and about one-half of the value required to obtain a 3σ effect at the LHC. This result is quite motivating to look for further improvements in the search strategy to discriminate the signal from the SM backgrounds and to combine several running years to enhance the luminosity.

On the other hand, as an example of flavor mediation through *mixing*, we have discussed an E_6-inspired multi-Higgs model, supplemented with an abelian flavor symmetry, where large LFV-Higgs effects are also found to arise, though in this case at tree-level. We find that even Tevatron can detect the LFV Higgs mode $h \to \tau\mu$ for some values of the model parameters. While LHC can provide further information on the flavor structure of the model for other values of such parameters. Our results also indicate that deviation from the SM for the Higgs-tau-tau coupling could be measurable at the NLC.

In summary, our results suggest that the Higgs boson that arise in several well motivated supersymmetric models could have a more flavored profile, and the future high-energy colliders should be prepared to allows us to taste it.

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