Neutral Higgs $H^0 \rightarrow h^0(A^0) l_i^−l_j^+$ decay

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Abstract

We study the lepton flavor violating $H^0 \rightarrow h^0(A^0) l_i^−l_j^+$ and the lepton flavor conserving $H^0 \rightarrow h^0(A^0) l_i^-l_i^+$ ($l_i = \tau, l_j = \mu$) decays in the framework of the general two Higgs doublet model, the so-called model III. We estimate the decay width of LFV (LFC) process at the order of magnitude of $10^{-5} GeV$ ($10^{-4} GeV$), for $m_{H^0} = 150 GeV$, and the intermediate values of the coupling $\xi_{N,\tau\mu}^E \sim 5 GeV$ ($\xi_{N,\tau\tau}^E \sim 30 GeV$). The experimental result of the process under consideration can ensure comprehensive information about the standard model Higgs boson $H^0$ and the model III free parameters.

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1 Introduction

The standard model (SM) of electroweak interactions is based on the existence of the CP even Higgs boson ($H^0$). Its possible detection in future collider experiments will ensure a test for the SM and the strong information about the mechanism of the electroweak symmetry breaking, the Higgs mass and the top Higgs Yukawa coupling. The search for the Higgs boson is one of the prime goals of LHC.

The light Higgs boson, $m_{H^0} \leq 130 \text{GeV}$, mainly decays into $b\bar{b}$ pair [1]. However its detection is difficult due to the QCD background and the $t\bar{t}H^0$ channel, where the Higgs boson decays to $b\bar{b}$, is the most promising one [2]. The supersymmetric QCD contribution to $H^0b\bar{b}$ has been analyzed at one loop in the Minimal Supersymmetric Model (MSSM) in the decoupling limit in [3].

For a heavier Higgs boson $m_{H^0} \sim 180 \text{GeV}$, the suitable production exist via gluon fusion and the leading decay mode is $H^0 \rightarrow WW \rightarrow l^+l^−\nu\nu$ [4, 5]. In [5], it is stated that this decay mode gives three order times larger events compared to the mode $H^0 \rightarrow ZZ^* \rightarrow l^+l^-l'^+l'^−$. In this work two new cuts have been employed to separate the irreducible continuum background production. The decay $H^0 \rightarrow A^0A^0$ has been studied in the minimal supersymmetric model (MSSM) including one-loop corrections and the decay width is obtained at the order of magnitude of $10^{-2}\text{GeV}$.

The flavor violating (FV) interactions are important in the sense that they do not exist in the SM and their analysis ensure comprehensive information about the physics beyond the SM. The lepton FV (LFV) $H^0$ decays have been studied in series of works in the literature. $H^0 \rightarrow \tau\mu$ decay is an example for LFV decays and it has been studied in [6, 7]. In [6] a large BR, at the order of magnitude of $0.1 - 0.01$, has been estimated in the framework of the 2HDM. In [7] its BR was obtained in the interval $0.001 - 0.01$ for the Higgs mass range $100 - 160(\text{GeV})$, for the LFV parameter $\kappa_{\mu\tau} = 1$. The work in [8] was due to the observable CP violating asymmetries in the leptonic flavor changing $H^0$ decays with branching ratios (BRs) of the order of $10^{-6} - 10^{-5}$. The LFV $H^0 \rightarrow l_il_j$ decay has been studied also in [9].

In our work we analyze the LFV $H^0 \rightarrow h^0l_i^-l_j^+$, $H^0 \rightarrow A^0l_i^-l_j^+$ and the lepton flavor conserving (LFC) $H^0 \rightarrow h^0l_i^-l_i^+$, $H^0 \rightarrow A^0l_i^-l_i^+$ ($l_i = \tau, l_j = \mu$) decays in the framework of the general 2HDM, the so-called model III. These processes can exist at the tree level in the model III and provide wide information about the free parameters of the model, since their decay widths depend on the masses of the new particles, namely $m_{h^0}, m_{A^0}$ and the leptonic Yukawa couplings. In our analysis, we observe the decay width at the order of magnitude of $10^{-5}\text{GeV}$,
for outgoing τ and μ leptons, for the LFV process. In the case of LFC decay, the decay width reaches of $10^{-3}$ GeV, for the appropriate choice of the free parameters, for outgoing τ τ leptons. These numbers are sensitive to the Yukawa coupling for $\tau - \mu$ ($\tau - \tau$) transitions, the new Higgs boson masses $m_{h^0}$ and $m_{A^0}$, and the SM Higgs mass $m_{H^0}$. Therefore their experimental investigations will provide a crucial information about the SM Higgs and the model III free parameters.

The paper is organized as follows: In Section II, we present the theoretical expression for the decay widths of the LFV decay $H^0 \rightarrow h^0 l^-_i l^+_j$, $H^0 \rightarrow A^0 l^-_i l^+_j$ and the LFC decay $H^0 \rightarrow h^0 l^-_i l^+_j$, $H^0 \rightarrow A^0 l^-_i l^+_j$ ($l_i = \tau, l_j = \mu$), in the framework of the model III. Section 3 is devoted to discussion and our conclusions.

2 $H^0 \rightarrow h^0(A^0) l^-_i l^+_j$, decays in the two Higgs doublet model

The decay of the SM Higgs $H^0$ into the new neutral Higgs bosons $h^0$ ($A^0$) and the lepton pairs is kinematically allowed. In the case of different flavors as an output in the lepton sector the tree level LFV interactions should be to switch on. For such interactions the model III version of the 2HDM is the simplest candidate. In the model III, the Yukawa lagrangian, including the interaction between the scalar bosons and the leptons, reads

$$\mathcal{L}_Y = \eta_{ij}^E \xi_i^l l_i \phi_1 E_j R + \xi_{ij}^R \phi_2 E_j R + h.c.$$ \hspace{1cm} (1)

where $i, j$ are family indices of leptons, $L$ and $R$ denote chiral projections $L(R) = 1/2 (1 \mp \gamma_5)$, $\phi_i$ for $i = 1, 2$, are the two scalar doublets, $l_i L$ and $E_j R$ are lepton doublets and singlets respectively. In general, there is a mixing between the neutral CP even bosons, $H^0$ and $h^0$, however, by considering the gauge and $CP$ invariant Higgs potential which spontaneously breaks $SU(2) \times U(1)$ down to $U(1)$ as

$$V(\phi_1, \phi_2) = c_1(\phi_1^+ \phi_1 - v^2/2)^2 + c_2(\phi_2^+ \phi_2)^2 + c_3[(\phi_1^+ \phi_1 - v^2/2 + \phi_2^+ \phi_2)^2 + c_4[(\phi_2^+ \phi_1)(\phi_2^+ \phi_2) - (\phi_2^+ \phi_1)(\phi_2^+ \phi_1)] + c_5[Re(\phi_1^+ \phi_2)]^2 + c_6[Im(\phi_1^+ \phi_2)]^2 + c_7,$$ \hspace{1cm} (2)

with constants $c_i, i = 1, ..., 7$, and the doublets $\phi_1$ and $\phi_2$ as

$$\phi_1 = \frac{1}{\sqrt{2}} \left[ \begin{array}{c} 0 \\ v + H^0 \end{array} \right] + \left( \frac{\sqrt{2} \chi^+}{i \chi^0} \right) \; ; \; \phi_2 = \frac{1}{\sqrt{2}} \left( \begin{array}{c} \sqrt{2} H^+ \\ H_1 + iH_2 \end{array} \right),$$ \hspace{1cm} (3)

where only $\phi_1$ has a vacuum expectation value;

$$< \phi_1 > = \frac{1}{\sqrt{2}} \left( \begin{array}{c} 0 \\ v \end{array} \right) \; ; \; < \phi_2 > = 0,$$ \hspace{1cm} (4)
this mixing is switched off. Therefore, $H_1$ and $H_2$ are obtained as the mass eigenstates $h^0$ and $A^0$, respectively.

Now, we consider the lepton flavor violating processes $H^0 \rightarrow h^0 l_i^- l_j^+$ and $H^0 \rightarrow A^0 l_i^- l_j^+$ where $l_i, l_j$ are different leptons flavors, $e, \mu, \tau$ (see Fig. 1). The source of the LFV interactions are the Yukawa couplings $\xi_{ij}^E$, which are responsible for the tree level $h^0(A^0) - l_i - l_j$ interactions. These couplings are complex in general and they are the free parameters of the model III version of 2HDM. Notice that, in the following, we replace $\xi$ with $\xi^E_N$ where 'N' denotes the word 'neutral'.

Using the diagram given in Fig. [1], the matrix element square of the process $H^0 \rightarrow h^0 l_i^- l_j^+$ is obtained as

$$|M|^2 = \frac{g^4}{4m_W^4}(A_1 + A_2 + A_3)$$

(5)

where

$$A_1 = \frac{1}{2(m_{H^0}^2 + 2p.k_i)^2} \left\{ m_{l_i}^2 |\tilde{\xi}_{N,ji}^E|^2 \left( 2(p.k_i)^2 + (m_{H^0}^2 - 4m_{l_i}^2)q.k_l + p.k_i (m_{H^0}^2 + 4m_{l_i}^2) \right) + m_{H^0}^2 (m_{l_j} + m_{l_i} - 2m_{l_j} \sin^2 \theta_{ij}) + 4m_{l_i}^2 (m_{l_j} + m_{l_i} - 2m_{l_j} \sin^2 \theta_{ij}) + 4m_{l_j}^2 (p.q) \right\},$$

$$A_2 = \frac{1}{(m_{H^0}^2 + 2p.k_i)^2} \left\{ 2m_{l_i} m_{H^0}^2 |\tilde{\xi}_{N,ji}^E|^2 Im[p_{h^0}] \left( (3m_{l_i} + m_{l_j} - 2m_{l_j} \sin^2 \theta_{ij}) p.k_l + m_{l_i} (m_{H^0}^2 + 4m_{l_i}^2 + 2m_{l_j}^2 + 2m_{l_j} - 2m_{l_j} \sin^2 \theta_{ij} - 2q.(k_l - p)) \right) \right\},$$

$$A_3 = 2m_{h^0}^4 |\tilde{\xi}_{N,ji}^E|^2 Abs[p_{h^0}]^2 \left( m_{l_i} (m_{l_i} + m_{l_j} - 2m_{l_j} \sin^2 \theta_{ij}) + (p - q).k_l \right).$$

(6)

Here

$$p_S = \frac{i}{k^2 - m_S^2 + i m_S \Gamma_S}.$$  

(7)

with the transfer momentum square $k^2$; $p$, $q$, $k_l$ are four momentum of incoming $H^0$, outgoing $h^0$, incoming $l_i^-$ lepton respectively. The angle $\theta_{ij}$ carries the information about the complexity of the Yukawa coupling $\tilde{\xi}_{N,ji}^E$ with the parametrization

$$\tilde{\xi}_{N,ji}^E = |\tilde{\xi}_{N,ji}^E| e^{i \theta_{ij}}.$$  

(8)

Similarly, the matrix element square of the process $H^0 \rightarrow A^0 l_i^- l_j^+$ is obtained as

$$|M|^2 = \frac{g^4}{4m_W^4}(A'_1 + A'_2 + A'_3)$$

(9)
where

\[ A'_1 = \frac{1}{2(m^2_{H^0} + 2p.k_i)^2} \left\{ \frac{m_i^2}{2} |\bar{\xi} E| N_{ji}|^2 \left( 2(p.k_i)^2 + (m^2_{H^0} - 4m_i^2) q.k_i + p.k_i (m^2_{H^0} - 4m_i^2) \right) \right\} \]

\[ + \frac{4m_i(-m_{ij} + 2m_i + 2m_{ij} \sin^2 \theta_{ij} - 2p.q)}{m^2_{H^0} (3m_i - m_{ij} + 2m_{ij} \sin^2 \theta_{ij} - 4m_i p.q)} \right\}, \]

\[ A'_2 = \frac{1}{(m^2_{H^0} + 2p.k_i)^2} \left\{ \frac{m_i^2}{2} \frac{m_{ij}^2}{2} |\bar{\xi} E| N_{ji}|^2 \left( 3m_i - m_{ij} + 2m_{ij} \sin^2 \theta_{ij} \right) p.k_i \right\} \]

\[ + \frac{m_i (m^2_{H^0} + 2m_i^2 - 2m_{ij}m_i + 4m_i m_{ij} \sin^2 \theta_{ij} - 2q(k_i - p))}{(m^2_{H^0} + 2p.k_i)^2} \right\} \]

\[ A_3 = 2m_{A^0}^4 \frac{|\bar{\xi} E| N_{ji}|^2}{2} \left( m_i (m_i - m_{ij} + 2m_{ij} \sin^2 \theta_{ij}) + (p - q).k_i \right), \] (10)

where \( q \) is four momentum of outgoing \( A^0 \). Notice that we use the parametrization

\[ \xi_{N,ij}^E = \sqrt{\frac{4G_F}{\sqrt{2}}} \xi_{N,ij}^E, \] (11)

where \( G_F = 1.6637 \times 10^{-5} (GeV^{-2}) \) is the fermi constant. Finally, the decay width \( \Gamma \) is obtained in the \( H^0 \) boson rest frame using the well known expression

\[ d\Gamma = \frac{(2\pi)^4}{m_{H^0}} |M|^2 \delta^4(p - \sum_{i=1}^{3} p_i) \prod_{i=1}^{3} \frac{d^3 p_i}{(2\pi)^3 2E_i}, \] (12)

where \( p \) (\( p_i, i=1,2,3 \)) is four momentum vector of \( H^0 \) boson, \( (h^0 (A^0) \) boson, incoming \( l_i^- \), outgoing \( l_j^- \) leptons).

### 3 Discussion

In this section, we study the LFV \( H^0 \rightarrow h^0 (\tau^- \mu^+ + \tau^+ \mu^-) \), \( H^0 \rightarrow A^0 (\tau^- \mu^+ + \tau^+ \mu^-) \) and the LFC \( H^0 \rightarrow h^0 \tau^- \tau^+ \), \( H^0 \rightarrow A^0 \tau^- \tau^+ \) decays in the model III. The source of the LFV interactions are the Yukawa couplings \( \xi_{N,ij}^E \), which are free parameters of the model used, and they should be restricted by using the appropriate experimental measurements. There are various theoretical works to predict the upper limits of these couplings in the literature. The upper limit of the coupling \( \xi_{N,\tau \mu}^E \) has been predicted as \( \sim 0.15 \), by using the experimental result of anomalous magnetic moment of muon in [10]. The low energy limits of the LFV couplings from muon g-2 measurement has been presented in [1]. In this work the upper bound of the LFV coupling \( \lambda_{\mu \tau} \) was predicted in the range \( 1 - 10 \) for type b 2HDM and \( 10 - 100 \) for type a 2HDM, for various values of Higgs masses, \( \tan \beta \) and mixing angle \( \alpha \). Here the well known parametrization
\( \xi_{N,\mu\tau}^E = \lambda_{\mu\tau} \frac{\sqrt{m_{\mu} m_{\tau}}}{v} \) has been used where the numerical value of \( v \) is 246 GeV. The decay width of the LFV \( H^0 \rightarrow \tau^- \mu^+ \) process in the type b 2HDM has been predicted as \( 10^{-2} \lambda^2 (10^{-4} \lambda^2) \) for \( \tan \beta \sim 50 \) (\( \tan \beta \sim 5 \)) and the small mixing between CP even neutral Higgs bosons. Furthermore, the numerical value of the decay width for the LFC \( H^0 \rightarrow \tau^- \tau^+ \) was estimated as \( 10^{-1} \lambda^2 (10^{-3} \lambda^2) \). \[1\] is devoted to the analysis of the LFV \( H^+ \rightarrow W^+ (\tau^- \mu^+ + \tau^+ \mu^-) \) and the LFC \( H^+ \rightarrow W^+ \tau^- \tau^+ \) decays in the framework of the model III. In this work the coupling \( \xi_{N,\tau\mu}^E \) (\( \xi_{N,\tau\tau}^E \)) has been estimated as \( \sim 0.03 \) GeV (\( \sim 0.15 \) GeV) for the range of the decay width \( \Gamma(H^+ \rightarrow W^+ (\tau^- \mu^+ + \tau^+ \mu^-)) \) (\( \Gamma(H^+ \rightarrow W^+ \tau^- \tau^+) \)) \( (10^{-11} - 10^{-5}) \) GeV (\( (10^{-9} - 10^{-4}) \) GeV) and the charged Higgs mass \( 200 \leq m_{H^\pm} \leq 400 \) GeV. Here the Yukawa coupling \( \xi_{N,\tau\tau}^E \) plays the main role in the existence of the LFC decay \( H^0 \rightarrow h^0(A^0) \tau^- \tau^+ \) decay and its prediction would be possible with the future experimental measurement of these decays.

Now we start to analyze the LFV \( H^0 \rightarrow h^0(A^0) (\tau^- \mu^+ + \tau^+ \mu^-) \) and LFC \( H^0 \rightarrow h^0(A^0) \tau^- \tau^+ \) decays. In the numerical calculations we take the total decay widths of \( h^0 \) and \( A^0 \) \( \Gamma_{h^0} = \Gamma_{A^0} \sim 0.1 \) GeV, which is at the same order of magnitude of \( \Gamma_{h^0} \).

In Fig. 2, we present \( \xi_{N,\tau\mu}^E \) dependence of the decay width \( \Gamma \) for the decay \( H^0 \rightarrow h^0(A^0) (\tau^- \mu^+ + \tau^+ \mu^-) \), for the real coupling \( \xi_{N,\tau\mu}^E \), \( m_{H^0} = 150 \) GeV, \( m_{h^0} = 85 \) GeV (\( m_{A^0} = 90 \) GeV). Here the solid (dashed) line represents the case for the output \( h^0 \) (\( A^0 \)). The \( \Gamma \) is at the order of magnitude of \( 10^{-6} - 10^{-5} \) for the range of \( \xi_{N,\tau\mu}^E \), \( 1 \) GeV \( < \xi_{N,\tau\mu}^E < 10 \) GeV and it enhances with the increasing values of the coupling \( \xi_{N,\tau\mu}^E \). The \( \Gamma \) for the output \( h^0 \) is greater than the one for the output \( A^0 \).

Fig. 3 represents the \( m_{H^0} \) dependence of the \( \Gamma \) for the decay \( H^0 \rightarrow h^0(A^0) (\tau^- \mu^+ + \tau^+ \mu^-) \), for the fixed values of \( \xi_{N,\tau\mu}^E = 5 \) GeV, \( m_{h^0} = 85 \) GeV (\( m_{A^0} = 90 \) GeV). The \( \Gamma \) is strongly sensitive to the Higgs mass \( m_{H^0} \) and it enhances with the increasing values of the Higgs mass, as expected.

Fig. 4 is devoted to \( \xi_{N,\tau\tau}^E \) dependence of the decay width \( \Gamma \) for the decay \( H^0 \rightarrow h^0(A^0) \tau^- \tau^+ \), for the real coupling \( \xi_{N,\tau\tau}^E \), \( m_{H^0} = 150 \) GeV, \( m_{h^0} = 85 \) GeV (\( m_{A^0} = 90 \) GeV). Here the solid (dashed) line represents the case for the output \( h^0 \) (\( A^0 \)). The \( \Gamma \) is at the order of magnitude of \( 10^{-4} - 10^{-3} \) for the range of \( \xi_{N,\tau\tau}^E \), \( 20 \) GeV \( < \xi_{N,\tau\tau}^E < 60 \) GeV and it enhances with the increasing values of the coupling \( \xi_{N,\tau\tau}^E \). Similar to the LFV process \( H^0 \rightarrow h^0(A^0) (\tau^- \mu^+ + \tau^+ \mu^-) \), the \( \Gamma \) for the output \( h^0 \) is greater than the one for the output \( A^0 \).

Fig. 5 represents the \( m_{H^0} \) dependence of the \( \Gamma \) for the decay, for the fixed values of \( \xi_{N,\tau\tau}^E = 30 \) GeV, \( m_{h^0} = 85 \) GeV (\( m_{A^0} = 90 \) GeV). The \( \Gamma \) is strongly sensitive to the Higgs mass \( m_{H^0} \) and it enhances with the increasing values of the Higgs mass. It reaches to \( \sim 10^{-3} \) GeV for the
values of \( m_{H^0}, m_{A^0} \sim 160 \text{GeV} \). The experimental measurement of this process can give strong clues about the upper limit of the coupling \( \bar{\xi}_{E,N,\tau\tau}^E \) and the Higgs mass \( m_{H^0} \).

Finally, we study the \( m_{h^0} (m_{A^0}) \) dependence of these LFV and LFC decays and present in the Fig. [8, 9]. The \( m_{h^0} \) dependence of the \( \Gamma \) is presented in Fig. [8]. The solid (dashed) line represents the \( \Gamma \) of the LFV (LFC) decay, for \( \bar{\xi}_{E,N,\tau\mu}^E = 5 \text{GeV} \) \( (\bar{\xi}_{E,N,\tau\tau}^E = 30 \text{GeV}) \), \( m_{H^0} = 150 \text{GeV} \). The decay widths increase with the decreasing values of \( m_{h^0} \) and this is informative in the determination of the Higgs mass \( m_{h^0} \). We present the \( m_{A^0} \) dependence of the \( \Gamma \) in Fig. [9]. The solid (dashed) line represents the \( \Gamma \) of the LFV (LFC) decay, for \( \bar{\xi}_{E,N,\tau\mu}^E = 5 \text{GeV} \) \( (\bar{\xi}_{E,N,\tau\tau}^E = 30 \text{GeV}) \), \( m_{H^0} = 150 \text{GeV} \). Similar to the \( m_{h^0} \), the decay widths increase with the decreasing values of \( m_{A^0} \) and it can give a strong clue for the Higgs mass \( m_{A^0} \).

Now, we consider the coupling \( \bar{\xi}_{E,N,ij}^E \) complex (see eq. (8)) and study the \( \sin \theta_{ij} \) dependence of the decay width. We observe that the decay width is not sensitive to the complexity of the coupling \( \bar{\xi}_{E,N,ij}^E \).

At this stage we would like to summarize our results:

- We predict the decay width \( \Gamma(H^0 \to h^0(A^0) (\tau^+ \mu^+ + \tau^- \mu^-)) \) \( (\Gamma(H^0 \to h^0(A^0) \tau^- \tau^+) \) in the interval \( (10^{-6} - 10^{-5}) \text{GeV} \) \( (10^{-4} - 10^{-3}) \text{GeV} \), for \( 100 \text{GeV} \leq m_{H^0} \leq 160 \text{GeV} \), at the intermediate values of the coupling \( \bar{\xi}_{E,N,\tau\mu}^E \sim 5 \text{GeV} \) \( (\bar{\xi}_{E,N,\tau\tau}^E \sim 30 \text{GeV}) \). The future experimental measurement of the processes under consideration can ensure strong information about the the upper limit of the coupling \( \bar{\xi}_{E,N,\tau\mu}^E \) \( (\bar{\xi}_{E,N,\tau\tau}^E) \) and the Higgs mass \( m_{H^0} \).

- We observe that the decay widths \( \Gamma(H^0 \to h^0(A^0) (\tau^+ \mu^+ + \tau^+ \mu^-)) \) and \( \Gamma(H^0 \to h^0(A^0) \tau^- \tau^+) \) are strongly sensitive to the Higgs masses, \( m_{h^0} \) and \( m_{A^0} \), respectively. This observation is useful in the determination of the new Higgs masses \( m_{h^0} \) and \( m_{A^0} \).

- We observe that the decay width \( \Gamma(H^0 \to h^0(A^0) (\tau^- \mu^+ + \tau^+ \mu^-)) \) \( (\Gamma(H^0 \to h^0(A^0) \tau^- \tau^+) \) is not sensitive to the possible complexity of the Yukawa coupling.

Therefore, the experimental and theoretical analysis of these decays would ensure strong information about the SM Higgs boson, and the new physics beyond the SM.

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Figure 1: Tree level diagrams contribute to $\Gamma(H^0 \rightarrow h^0(A^0)l^-_i l^+_j)$, $i = e, \mu, \tau$ decay in the model III version of 2HDM. Solid lines represent leptons, dashed lines represent the $H^0$, $h^0$ and $A^0$ fields.
Figure 2: $\bar{\xi}_{N,\tau\mu}^E$ dependence of the decay width $\Gamma$ for the decay $H^0 \rightarrow h^0(A^0)(\tau^-\mu^+ + \tau^+\mu^-)$, for the real coupling $\bar{\xi}_{N,\tau\mu}^E$, $m_{H^0} = 150\, GeV$, $m_{A^0} = 85\, GeV$ ($m_{A^0} = 90\, GeV$). Here solid (dashed) line represents the case for the output $h^0 (A^0)$. 
Figure 3: The $m_{H^0}$ dependence of the $\Gamma$ for the decay $H^0 \to h^0(A^0)(\tau^-\mu^+ + \tau^+\mu^-)$, for the fixed values of $\xi_{N,\tau\mu}^E = 5 GeV$, $m_{h^0} = 85 GeV$ ($m_{A^0} = 90 GeV$). Here solid (dashed) line represents the case for the output $h^0 (A^0)$.

Figure 4: $\xi_{N,\tau\tau}^E$ dependence of the decay width $\Gamma$ for the decay $H^0 \to h^0(A^0)\tau^-\tau^+$, for the real coupling $\xi_{N,\tau\tau}^E$, $m_{H^0} = 150 GeV$, $m_{h^0} = 85 GeV$ ($m_{A^0} = 90 GeV$). Here solid (dashed) line represents the case for the output $h^0 (A^0)$. 
Figure 5: $m_{H^0}$ dependence of the $\Gamma$ for the decay $H^0 \rightarrow h^0(A^0)\tau^-\tau^+$, for the fixed values of $\bar{\xi}_{N,\tau\tau} = 30 \text{ GeV}$, $m_{h^0} = 85 \text{ GeV}$ ($m_{A^0} = 90 \text{ GeV}$). Here solid (dashed) line represents the case for the output $h^0$ ($A^0$).

Figure 6: The $m_{h^0}$ dependence of the $\Gamma$ of the LFV $H^0 \rightarrow h^0(\tau^-\mu^+ + \tau^+\mu^-)$ and LFC $H^0 \rightarrow h^0\tau^-\tau^+$ decays. The solid (dashed) line represents the $\Gamma$ of the LFV (LFC) decay, for $\bar{\xi}_{N,\tau\mu} = 5 \text{ GeV}$ ($\bar{\xi}_{N,\tau\tau} = 30 \text{ GeV}$), $m_{H^0} = 150 \text{ GeV}$. 
Figure 7: $m_{A^0}$ dependence of the $\Gamma$ of the LFV $H^0 \rightarrow A^0 (\tau^- \mu^+ + \tau^+ \mu^-)$ and LFC $H^0 \rightarrow A^0 \tau^- \tau^+$ decays. The solid (dashed) line represents the $\Gamma$ of the LFV (LFC) decay, for $\bar{\xi}_{E,\tau\mu} = 5 \, GeV$ ($\bar{\xi}_{E,\tau\tau} = 30 \, GeV$), $m_{H^0} = 150 \, GeV$. 