$H^+ \to W^+ l_i^- l_j^+$ decay in the two Higgs doublet model

E. O. Iltan* and H. Sundu†
Physics Department, Middle East Technical University, Ankara, Turkey
(Received 22 November 2002; published 27 February 2003)

We study the lepton flavor violating (LFV) $H^+ \to W^+ l_i^- l_j^+$ and the lepton flavor conserving (LFC) $H^+ \to W^+ l_i^- l_i^+$ $(l_i=\tau, l_j=\mu)$ decays in the framework of the general two Higgs doublet model, the so-called model III. We estimate the decay width of LFV (LFC) decay at the order of magnitude of 10^{-11}–10^{-5} GeV (10^{-9}–10^{-4} GeV), for 200 GeV$\leq m_{H^\pm} \leq$400 GeV, and intermediate values of the coupling $\bar{\xi}^E_{N,\tau\mu} \sim 5$ GeV ($\bar{\xi}^E_{N,\tau\tau} \sim 30$ GeV). We observe that experimental results for the process under consideration can give comprehensive information about physics beyond the standard model and the existing free parameters.

DOI: 10.1103/PhysRevD.67.035006 PACS number(s): 12.60.Fr, 14.80.Cp

I. INTRODUCTION

The charged Higgs boson carries a distinctive signature of the Higgs sector in models beyond the standard model (SM), such as the two Higgs doublet model (2HDM) and the minimal extension of the standard model (MSSM). Therefore, its discovery will be evidence of the multidoublet structure of the Higgs sector. In the literature, charged Higgs boson decays have been widely studied.

Charged Higgs boson production in hadron colliders was studied in [1] and more systematic calculations of production process at the CERN Large Hadron Collider (LHC) have been presented in [2]. At the LHC the dominant production channel for H^+ is $gb \to H^+ t$. One expects more than 1000 events for a Higgs boson mass $m_{H^+}=400$ GeV, with an integrated luminosity of $L=100$ fb^{-1} [3]. At the Tevatron, the Collider Detector at Fermilab (CDF) and D0 Collaborations have searched for H^+ bosons through the process $p\bar{p} \to t\bar{t}$, with at least one of the top quarks decaying via $t \to H^+ b$. They have excluded the regions with light H^+ [4]. At present the model independent lower limit on the charged Higgs boson mass is $m_{H^+} > 77.4$ GeV [5].

Charged Higgs boson decay into a tau and neutrino was analyzed in [6] and in [7] and it was shown that the dominant decay modes of the charged Higgs boson are $H^+ \to \tau^+ \nu$ and $H^+ \to t\bar{b}$. However, the other candidate for a large branching ratio (BR) is the process $H^+ \to W^+ h^0$, and it has been examined in [8,9]. The analysis in [8] was related to $H^+ \to W^+ h^0$ decay, in the framework of the 2HDM, including loop corrections, and for some reasonable choice of free parameters those corrections could be as large as $\sim$80% of the tree level result. In [9], the chance of detecting the charged Higgs boson of the MSSM at the Large Hadron Collider, in the $W^+ h^0$ mode, was studied and it was concluded that the charged Higgs boson signal overcomes the background for optimum $\tan\beta$ values between 2 and 3. In [10] the above decay was analyzed in the MSSM and the electroweak corrections were obtained. It was observed that, for low $\tan\beta$, these corrections caused an enhancement at the order of 20%.

The work in [11] is devoted to the decays of the charged Higgs boson, including the decays modes $W^+\gamma$ and $W^+ Z$, mostly in the framework of the 2HDM and MSSM. In [12], the analysis of $H^+ \to W^+ \gamma$, $H^+ \to W^+ Z$, and $H^+ \to W^+ h^0$ decays was done in the context of the effective Lagrangian extension of the 2HDM. In this work the BRs were obtained at the order of magnitude of $10^{-5}, 10^{-1}$, and $O(1)$, respectively.

Lepton flavor violating (LFV) interactions are interesting, since they do not exist in the SM and give a strong signal about the new physics beyond. Such decays are of great interest at present and the experimental search has been improved. The $H^0 \to \tau\mu$ decay is an example of a LFV decay and it was studied in [13,14]. In [13] a large BR, at the order of magnitude of 0.1–0.01, was estimated in the framework of the 2HDM. In [14] its BR was obtained in the interval 0.001–0.01 for the Higgs boson mass range 100–160 GeV, for the LFV parameter $\kappa_{\mu\tau}=1$.

Our work is devoted to the analysis of the LFV $H^+ \to W^+ l_i^- l_j^+$ and the lepton flavor conserving (LFC) $H^+ \to W^+ l_i^- l_i^+$ $(l_i=\tau, l_j=\mu)$ decays in the framework of the general 2HDM, the so-called model III. This LFV decay occurs through the chain processes, $H^+ \to W^+ (h^{0*}, A^{0*}) \to W^+ l_i^- l_j^+$, where h^0, A^0 are CP even neutral Higgs bosons beyond the SM. This decay is rich in the sense that its decay width depends on the masses of the new particles, namely, $m_{H^\pm}, m_{h^0}, m_{A^0}$, the leptonic Yukawa couplings, and total decay widths $\Gamma_{h^0}, \Gamma_{A^0}$. In our analysis, we observe large values, at the order of magnitude of 10^{-4} GeV, for the decay width of the process, for outgoing τ and μ leptons. This is informative in the determination of the upper limits of the Yukawa couplings for LFV interactions and also in the prediction of the new Higgs boson masses and the total decay widths of the new neutral Higgs bosons.

We also analyze the LFC $H^+ \to W^+ l_i^- l_i^+$ $(l_i=\tau)$ decay in model III. We observe that the decay width of the process reaches the value 10^{-3} GeV, depending on an appropriate choice of the free parameters. This analysis allows a prediction for the leptonic constant, which is responsible for the τ-τ transition.

The paper is organized as follows. In Sec. II, we present a

*Email address: eiltan@heraklit.physics.metu.edu.tr
†Email address: sundu@metu.edu.tr

theoretical expression for the decay width of the LFV decay $H^+ \to W^+ l_i^- l_j^+$ and the LFC decay $H^+ \to W^+ l_i^- l_i^+$, $l_i = \tau, l_j = \mu$, in the framework of model III. Section III is devoted to discussion and our conclusions.

II. THE CHARGED HIGGS $H^+ \to W^+ l_i^- l_j^+$ DECAY IN THE TWO HIGGS DOUBLET MODEL

In this section, we derive the expressions for the LFV $H^+ \to W^+ l_i^- l_j^+$ and LFC $H^+ \to W^+ l_i^- l_i^+$ ($l_i = \tau, l_j = \mu$) decays in the general 2HDM, the so-called model III. The leptonic part of the process can be regulated by the Yukawa interaction in the leptonic sector

$$\mathcal{L}_Y = \eta_{ij}^E \overline{l}_{iL} \phi_1 E_{jR} + \xi_{ij}^E \overline{l}_{iL} \phi_2 E_{jR} + \text{H.c.}, \tag{1}$$

where i,j are family indices of leptons, L and R denote the chiral projections $L(R) = 1/2(1 \mp \gamma_5)$, ϕ_i ($i = 1,2$), are the two scalar doublets, and l_{iL} and E_{jR} are the lepton doublets and singlets, respectively. On the other hand the $H^+ \to W^+$ transition is possible with the help of scalar bosons, the SM Higgs boson H^0, and the CP even (odd) new particle h^0 (A^0). The part of the Lagrangian that is responsible for these transitions is the so-called kinetic term

$$(D_\mu \phi_i)^+ D^\mu \phi_i = \left(\partial_\mu \phi_i^+ + i \frac{g'}{2} B_\mu \phi_i^+ + i \frac{g}{2} \phi_i^+ \frac{\vec{\tau}}{2} \vec{W}_\mu \right) \times \left(\partial^\mu \phi_i - i \frac{g'}{2} B^\mu \phi_i - i \frac{g}{2} \phi_i \frac{\vec{\tau}}{2} \vec{W}^\mu \right). \tag{2}$$

Here ϕ_1 and ϕ_2 are chosen as

$$\phi_1 = \frac{1}{\sqrt{2}} \left[\begin{pmatrix} 0 \\ v + H^0 \end{pmatrix} + \begin{pmatrix} \sqrt{2} \chi^+ \\ i \chi^0 \end{pmatrix} \right], \quad \phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} H^+ \\ H_1 + i H_2 \end{pmatrix}, \tag{3}$$

where only ϕ_1 has a vacuum expectation value,

$$\langle \phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix}, \quad \langle \phi_2 \rangle = 0. \tag{4}$$

By considering the gauge and CP invariant Higgs potential which spontaneously breaks SU(2)×U(1) down to U(1) as

$$\begin{aligned} V(\phi_1, \phi_2) = {} & c_1 (\phi_1^+ \phi_1 - v^2/2)^2 + c_2 (\phi_2^+ \phi_2)^2 + c_3 [(\phi_1^+ \phi_1 \\ & - v^2/2) + \phi_2^+ \phi_2]^2 + c_4 [(\phi_1^+ \phi_1)(\phi_2^+ \phi_2) \\ & - (\phi_1^+ \phi_2)(\phi_2^+ \phi_1)] + c_5 [\text{Re}(\phi_1^+ \phi_2)]^2 \\ & + c_6 [\text{Im}(\phi_1^+ \phi_2)]^2 + c_7, \end{aligned} \tag{5}$$

with constants $c_i, i = 1, \ldots, 7$, H_1 and H_2 are obtained as the

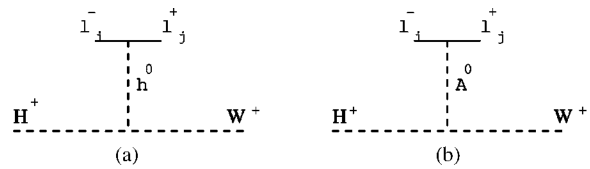

FIG. 1. Tree level diagrams contribute to $\Gamma(H^+ \to W^+ l_i^- l_j^+)$, $i = e, \mu, \tau$, decay in the model III version of 2HDM. Solid lines represent leptons; dashed lines represent the H^+, W^+, h_0, and A_0 fields.

mass eigenstates h^0 and A^0, respectively, since no mixing occurs between two CP even neutral bosons H^0 and h^0 in the tree level and the internal new scalars h^0 and A^0 play the main role in both $H^+ \to W^+ l_1^- l_2^+$ and $H^+ \to W^+ l_1^- l_1^+$ decays (see Fig. 1).

Now, we consider the lepton flavor changing process $H^+ \to W^+ l_i^- l_j^+$ where l_i, l_j are different leptons flavors e, μ, τ. This process is driven by the flavor changing interaction in the leptonic sector and the strength of this interaction is carried by the Yukawa couplings ξ_{ij}^E, which are the free parameters of the model III version of the 2HDM. They can have complex entries in general and be restricted by using experimental measurements. Notice that, in the following, we replace ξ^E with ξ_N^E where "N" denotes the "neutral."

The vertex function for $H^+ \to W^+$ is connected to the $l_i^- l_j^+$ outgoing leptons by intermediate h^0 and A^0 bosons and the matrix element squared of the process $H^+ \to W^+ l_i^- l_j^+$ is obtained as

$$\begin{aligned} |M|^2 = {} & \frac{g^2}{2} h (\{[(m_{l_j} + m_{l_i})^2 - k^2] |A^2|^2 + [(m_{l_j} - m_{l_i})^2 - k^2] \\ & \times |B^2|^2\} |p_{h^0}|^2 + \{[(m_{l_j} + m_{l_i})^2 - k^2] |A'^2|^2 \\ & + [(m_{l_j} - m_{l_i})^2 - k^2] |B'^2|^2\} |p_{A^0}|^2 - 4 m_{l_j} m_{l_i} \\ & \times \text{Im}[(AA'^* - BB'^*) p_{h^0} p_{A^0}^*] - 2 (m_{l_j}^2 + m_{l_i}^2 - k^2) \\ & \times \text{Im}[(A A'^* + BB'^*) p_{h^0} p_{A^0}^*]) \end{aligned} \tag{6}$$

where

$$h = \frac{k^2 + (m_{H^\pm}^2 - m_W^2)^2 - 2k^2 (m_{H^\pm}^2 + m_W^2)^2}{m_W^2}, \tag{7}$$

and

$$p_S = \frac{i}{k^2 - m_S^2 + i m_S \Gamma_S} \tag{8}$$

with the transfer momentum squared k^2. Γ_S is the total decay width of the S boson, for $S = h^0 A^0$. In eq. (6) the factors A, A', B, B' are functions of the Yukawa couplings

$$A = -\frac{i}{2\sqrt{2}}(\xi^E_{N,l_j l_i} + \xi^{*E}_{N,l_i l_j}),$$

$$A' = \frac{1}{2\sqrt{2}}(\xi^E_{N,l_j l_i} - \xi^{*E}_{N,l_i l_j}),$$

$$B = -\frac{i}{2\sqrt{2}}(\xi^E_{N,l_j l_i} - \xi^{*E}_{N,l_i l_j}),$$

$$B' = \frac{1}{2\sqrt{2}}(\xi^E_{N,l_j l_i} + \xi^{*E}_{N,l_i l_j}). \tag{9}$$

Finally, the decay width Γ is obtained in the $H^\pm$ boson rest frame using the well known expression

$$d\Gamma = \frac{(2\pi)^4}{m_{H^\pm}} |M|^2 \, \delta^4\left(p - \sum_{i=1}^{3} p_i\right) \prod_{i=1}^{3} \frac{d^3 p_i}{(2\pi)^3 2E_i}, \tag{10}$$

where p $(p_i, i=1,2,3)$ is the four-momentum vector of the H^+ boson (W^+ boson; incoming l_j and outgoing l_i leptons).

III. DISCUSSION

This section is devoted to analysis of the charged Higgs decays $H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-)$ and $H^+ \to W^+\tau^-\tau^+$. The Yukawa couplings $\xi^E_{N,\tau\mu}$ $(\xi^E_{N,\tau\tau})$ play the main role in the leptonic part of the LFV $H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-)$ [LFC $H^+ \to W^+(l_\tau^- l_\tau^+)$] process. These couplings are free parameters of the model used and they should be restricted by respecting the appropriate experimental measurements. The upper limit of the coupling $\xi^E_{N,\tau\mu}$ has been predicted as ~ 0.15, by using the experimental result for the anomalous magnetic moment of the muon in [15]. However, the strength of the coupling $\xi^E_{N,\tau\tau}$ is an open problem and waiting for new experimental results in the leptonic sector. Furthermore, the total decay widths of h^0 and A^0 are unknown parameters and we expect that they are at the same order of magnitude of $\Gamma_{H^0} \sim 0.1$–1.0 GeV, where H^0 is the SM Higgs boson.

Notice that the couplings $\xi^E_{N,\tau\tau}$ and $\xi^E_{N,\tau\mu}$, are complex in general and in the following we use the parametrization

$$\xi^E_{N,ij} = \sqrt{\frac{4G_F}{\sqrt{2}}}\bar{\xi}^E_{N,ij}, \tag{11}$$

where $G_F = 1.6637 \times 10^{-5}$ GeV^{-2} is the Fermi constant. In our numerical calculations, we take $m_W = 80$ GeV.

At this stage, we would like to discuss the various charged Higgs boson decays which are dominant and can be used in the calculation of the BRs. The candidates for these decay modes of the charged Higgs boson are $H^+ \to W^+ h^0$, $H^+ \to \tau^+\nu$, and $H^+ \to t\bar{b}$ [6–9]. The total decay width of the charged Higgs boson is approximated by

$$\Gamma_{tot}(H^+) = \Gamma(H^+ \to W^+ h^0) + \Gamma(H^+ \to t\bar{b}) + \Gamma(H^+ \to \tau^+\nu) + \Gamma(H^+ \to c\bar{s}).$$

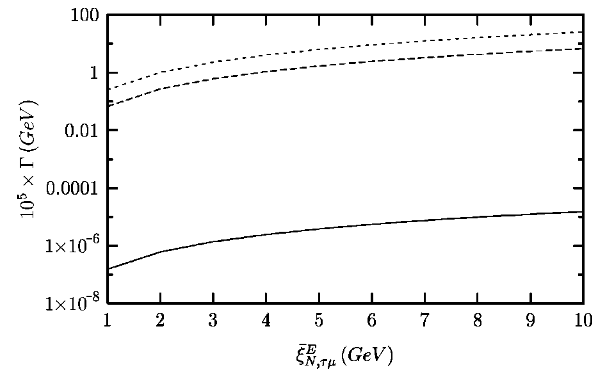

FIG. 2. $\bar{\xi}^E_{N,\tau\mu}$ dependence of the decay width $\Gamma(H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-))$, for real coupling $\bar{\xi}^E_{N,\tau\mu}$, $\Gamma_{A^0} = \Gamma_{h^0} = 0.1$ GeV $m_{h^0} = 85$ GeV and $m_{A^0} = 90$ GeV. Here the solid (dashed, small-dashed) line represents the case for the mass value $m_{H^\pm} = 200(300,400)$ GeV.

Here we present the various BRs of the charged Higgs boson decays:

$$\mathrm{BR}(H^+ \to t\bar{b}) < 1,$$

$$\mathrm{BR}(H^+ \to \tau^+\nu) < 0.1,$$

$$\mathrm{BR}(H^+ \to W^+ h^0) < 0.01,$$

$$\mathrm{BR}(H^+ \to \mu^+\nu) = < 0.001,$$

$$BR(H^+ \to c\bar{s}) < 0.0001 \tag{12}$$

have been obtained, for $\tan\beta \sim 10$ and $m_{H^+} \sim 400$ GeV, in the MSSM [9]. These results are strongly sensitive to the choice of $\tan\beta$, and increasing values of $\tan\beta$ make $H^+ \to \tau^+\nu$ and $H^+ \to \mu^+\nu$ more dominant compared to the decay $H^+ \to W^+ h^0$. In [12], $H^+ \to W^+ h^0$ was predicted at the order of $O(1)$, in the context of the effective Lagrangian extension of the 2HDM.

Now we start to analyze the three-body decay $H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-)$. In Fig. 2, we present the $\bar{\xi}^E_{N,\tau\mu}$ dependence of the decay width Γ for the decay H^+

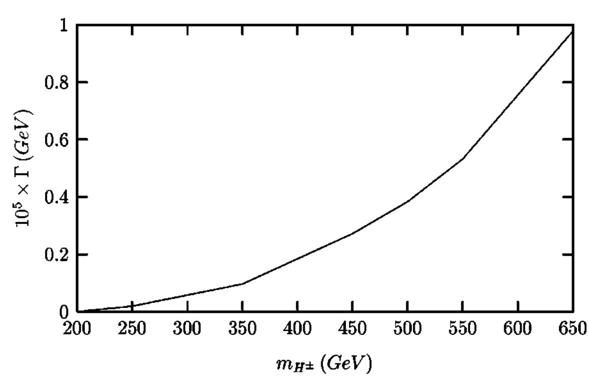

FIG. 3. The $m_{H^\pm}$ dependence of the decay width $\Gamma(H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-))$ for the fixed values of $\bar{\xi}^E_{N,\tau\mu} = 1$ GeV, $\Gamma_{A^0} = \Gamma_{h^0} = 0.1$ GeV, $m_{h^0} = 85$ GeV, and $m_{A^0} = 90$ GeV.

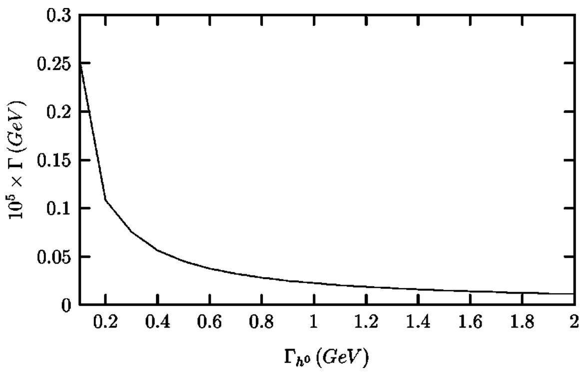

FIG. 4. Γ_{h^0} dependence of the decay width $\Gamma(H^+ \to W^+(\tau^-\mu^+ + \tau^+\mu^-))$ for $\Gamma_{A^0}=\Gamma_{h^0}$, $\bar{\xi}^E_{N,\tau\mu}=1$ GeV, $m_{H^\pm}=400$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV.

$\to W^+(\tau^-\mu^+ + \tau^+\mu^-)$, for real coupling $\bar{\xi}^E_{N,\tau\mu}$, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV and $m_{A^0}=90$ GeV. Here the solid (dashed, small-dashed) line represents the case for the Higgs boson mass $m_{H^\pm}=200(300,400)$ GeV. Γ is strongly sensitive to the coupling $\bar{\xi}^E_{N,\tau\mu}$, since it is proportional to the square of this coupling. Furthermore, this figure shows that Γ is enhanced with increasing values of the charged Higgs mass, as expected. Γ is at the order of magnitude of 10^{-11} GeV for $m_{H^\pm}=200$ GeV and it is enhanced to the value 10^{-5} GeV for $m_{H^\pm}=400$ GeV, even for intermediate values of $\bar{\xi}^E_{N,\tau\mu}$. Figure 3 represents the $m_{H^\pm}$ dependence of Γ for the fixed values of $\bar{\xi}^E_{N,\tau\mu}=1$ GeV, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV. It is observed that Γ reaches large values at the order of magnitude of 10^{-5} even for the small coupling $\bar{\xi}^E_{N,\tau\mu}=1$ GeV. This is interesting in the determination of the upper limit for the charged Higgs boson mass $m_{H^\pm}$ and also the coupling $\bar{\xi}^E_{N,\tau\mu}$.

In Fig. 4 we present the total decay width Γ_{h^0} dependence of the decay width Γ for $\Gamma_{A^0}=\Gamma_{h^0}$, $\bar{\xi}^E_{N,\tau\mu}=1$ GeV, $m_{H^\pm}=400$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV. Γ is sensitive to Γ_{h^0} and decreases with increasing Γ_{h^0}.

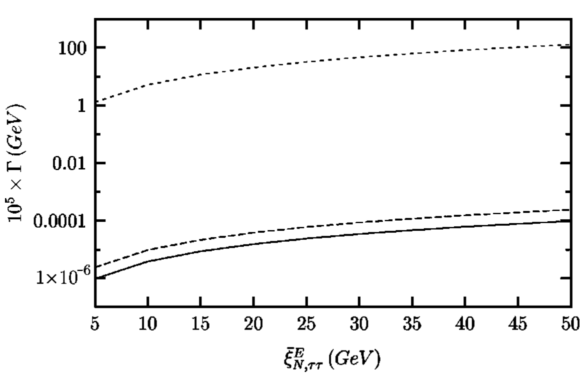

FIG. 5. $\bar{\xi}^E_{N,\tau\tau}$ dependence of the decay width $\Gamma(H^+ \to W^+\,\tau^-\tau^+)$, for real coupling $\bar{\xi}^E_{N,\tau\tau}$, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV. Here the solid (dashed, small-dashed) line represents the case for the mass value $m_{H^\pm}=200(300,400)$ GeV.

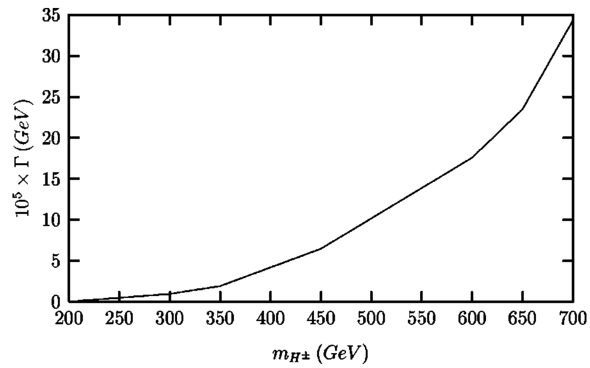

FIG. 6. The $m_{H^\pm}$ dependence of the decay width $\Gamma(H^+ \to W^+\tau^-\tau^+)$ for the fixed values of $\bar{\xi}^E_{N,\tau\tau}=10$ GeV, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV.

Here, we will make the same analysis for the lepton conserving process $H^+ \to W^+\tau^-\tau^+$. Figure 5 denotes the $\bar{\xi}^E_{N,\tau\tau}$ dependence of the decay width Γ, for real coupling, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV. Here the solid (dashed, small-dashed) line represents the case for the mass value $m_{H^\pm}=200(300,400)$ GeV. Γ is strongly sensitive to the coupling $\bar{\xi}^E_{N,\tau\tau}$. It is enhanced with increasing values of the charged Higgs boson mass and it is placed in the interval 10^{-9}–10^{-4} GeV for $200\ \text{GeV} \leq m_{H^\pm} \leq 400$ GeV, at intermediate values of the coupling $\bar{\xi}^E_{N,\tau\tau}$. In Fig. 6, we present the $m_{H^\pm}$ dependence of Γ for $\bar{\xi}^E_{N,\tau\tau}=10$ GeV, $\Gamma_{A^0}=\Gamma_{h^0}=0.1$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV. From the figure it is seen that Γ reaches large values at the order of magnitude of 10^{-4}, even for the small coupling $\bar{\xi}^E_{N,\tau\tau}=10$ GeV. Determination of the upper limit for the coupling $\bar{\xi}^E_{N,\tau\tau}$ would be possible with measurement of the process under consideration.

Figure 7 represents the Γ_{h^0} dependence of the decay width Γ for $\Gamma_{A^0}=\Gamma_{h^0}$, $\bar{\xi}^E_{N,\tau\tau}=10$ GeV, $m_{H^\pm}=400$ GeV, $m_{h^0}=85$ GeV and $m_{A^0}=90$ GeV. Γ is sensitive to Γ_{h^0} and decreases with increasing Γ_{h^0}, as in the LFV process $H^+ \to W^+\tau^-\mu^+$.

Finally, we consider the coupling $\bar{\xi}^E_{N,l_il_j}$ complex

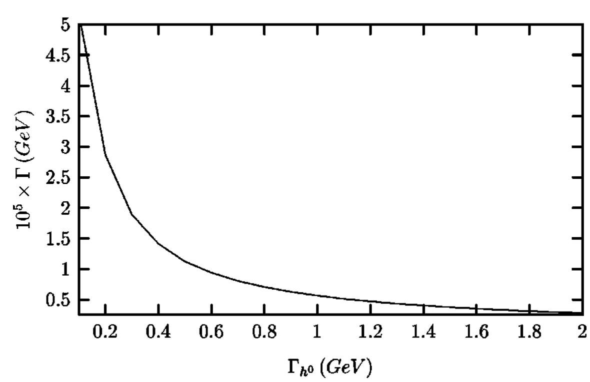

FIG. 7. Γ_{h^0} dependence of the decay width $\Gamma(H^+ \to W^+\,\tau^-\tau^+)$ for $\Gamma_{A^0}=\Gamma_{h^0}$, $\bar{\xi}^E_{N,\tau\tau}=10$ GeV, $m_{H^\pm}=400$ GeV, $m_{h^0}=85$ GeV, and $m_{A^0}=90$ GeV.

$$\overline{\xi}^{E}_{N,l_i l_j} = |\overline{\xi}^{E}_{N,l_i l_j}| e^{i\theta_{l_i l_j}}, \tag{13}$$

and study the $\sin\theta_{l_i l_j}$ dependence of the decay width. We observe that the decay width is not sensitive to the complexity of the coupling $\overline{\xi}^{E}_{N,l_i l_j}$.

At this stage we would like to summarize our results.

We predict the decay width $\Gamma(H^+ \rightarrow W^+(\tau^-\mu^+ + \tau^+\mu^-)$ $[\Gamma(H^+ \rightarrow W^+\tau^-\tau^+]$ in the interval 10^{-11}–10^{-5} GeV ($10^{-9}-10^{-4}$ GeV), for 200 GeV$\leq m_{H^\pm} \leq$400 GeV, at intermediate values of the coupling $\overline{\xi}^{E}_{N,\tau\mu} \sim 5$ GeV ($\overline{\xi}^{E}_{N,\tau\tau} \sim 30$ GeV). With the possible experimental measurement of the processes under consideration, strong clues would be obtained in the prediction of the upper limit of the coupling $\overline{\xi}^{E}_{N,\tau\mu}$ ($\overline{\xi}^{E}_{N,\tau\tau}$) . This result is also informative for the determination of the charged Higgs boson mass $m_{H^\pm}$.

We observe that the decay width $\Gamma(H^+ \rightarrow W^+(\tau^-\mu^+ + \tau^+\mu^-))$ $[\Gamma(H^+ \rightarrow W^+\tau^-\tau^+)]$ is strongly sensitive to the charged Higgs boson mass $m_{H^\pm}$.

We observe that the decay width $\Gamma(H^+ \rightarrow W^+(\tau^-\mu^+ + \tau^+\mu^-))$ $[\Gamma(H^+ \rightarrow W^+(\tau^-\tau^+)]$ is not sensitive to the possible complexity of the Yukawa coupling.

Therefore, the experimental and theoretical analysis of these decays of the charged Higgs boson would ensure strong hints in the determination of physics beyond the SM and the existing free parameters.

ACKNOWLEDGMENTS

This work was supported by the Turkish Academy of Sciences (EOI-TUBA-GEBIP/2001-1-8).

[1] J.L. Diaz-Cruz and O.A. Sampayo, Phys. Rev. D **50**, 6820 (1994); J. Gunion *et al.*, Nucl. Phys. **B294**, 621 (1987); M.A. Perez and A. Rosado, Phys. Rev. D **30**, 228 (1984).

[2] M. Bisset *et al.*, Eur. Phys. J. C **19**, 143 (2001); A.B. Bendezu and B.A. Kniehl, Phys. Rev. D **63**, 015009 (2001); Z. Fei *et al.*, *ibid.* **63**, 015002 (2001); D.J. Miller *et al.*, *ibid.* **61**, 055011 (2000).

[3] A. Belyaev, D. Garcia, J. Guasch, and J. Sola, J. High Energy Phys. **06**, 059 (2002).

[4] CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **79**, 357 (1997); D0 Collaboration, B. Abbott *et al.*, *ibid.* **82**, 4975 (1999).

[5] ALEPH Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration, and LEP Working Group for Higgs Boson Searches, S. Andriga *et al.*, 2000, http://lephiggs.web.cern.ch/LEPHIGGS/papers; ALEPH Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration, and Working Group for Higgs Boson Searches, P. Bock *et al.*, Report No. CERN-EP-2000-055, 2000.

[6] E. Christove, H. Eberl, W. Majerotto, and S. Kralm, J. High Energy Phys. **12**, 021 (2002); T. Han and D. Marfatia, Phys. Rev. Lett. **86**, 1442 (2000).

[7] V. Barger, R.J.N. Phillips, and D.P. Roy, Phys. Lett. B **324**, 236 (1994); J.F. Gunion and S. Geer, hep-ph/9310333; J.F. Gunion, Phys. Lett. B **322**, 125 (1994); D.J. Miller, S. Moretti, D.P. Roy, and W.J. Stirling, Phys. Rev. D **61**, 055011 (2000); S. Moretti and D.J. Roy, Phys. Lett. B **470**, 209 (1999); K. Odagiri, hep-ph/9901432; S. Raychaudhuri and D.P. Roy, Phys. Rev. D **53**, 4902 (1996).

[8] R. Santos, A. Barosso, and L. Brucher, Phys. Lett. B **391**, 429 (1997).

[9] S. Moretti, Phys. Lett. B **481**, 49 (2000).

[10] Y.S. Yang and C.S. Li, Phys. Lett. B **497**, 101 (2001).

[11] J.L. Diaz-Cruz and M.A. Perez, Phys. Rev. D **33**, 273 (1986); J. Gunion, G. Kane, and J. Wudka, Nucl. Phys. **B299**, 231 (1988); A. Mendez and A. Pomarol, *ibid.* **B349**, 369 (1991); E. Barradas *et al.*, Phys. Rev. D **53**, 1678 (1996); M.C. Peyranere, H.E. Haber, and P. Irulegui, *ibid.* **44**, 191 (1991); S. Kanemura, *ibid.* **61**, 095001 (2000).

[12] J.L. Diaz-Cruz, J.H. Sanhez, and J.J. Toscano, Phys. Lett. B **512**, 339 (2001).

[13] U. Cotti, L. Diaz-Cruz, C. Pagliarone, and E. Vataga, hep-ph/0111236.

[14] T. Han and D. Marfatia, Phys. Rev. Lett. **86**, 1442 (2001).

[15] E. Iltan and H. Sundu, hep-ph/0103105.