KA-TP-19-2001
hep-ph/0106027
June 2001

Distinguishing Higgs models in $H \to b\bar{b}/H \to \tau^+\tau^-$

Jaume Guasch *, Wolfgang Hollik, Siannah Peñaranda †
Institut für Theoretische Physik, Universität Karlsruhe,
Kaiserstraße 12, D–76128 Karlsruhe, Germany

Abstract

We analyze the ratio of branching ratios $R = BR(H \to b\bar{b})/BR(H \to \tau^+\tau^-)$ of Higgs boson decays as a discriminant quantity between supersymmetric and non-supersymmetric models. This ratio receives large renormalization-scheme independent radiative corrections in supersymmetric models at large $\tan\beta$, which are absent in the Standard Model or Two-Higgs-doublet models. These corrections are insensitive to the supersymmetric mass scale. A detailed analysis in the effective Lagrangian approach shows that, with a measurement of $\pm 21\%$ accuracy, the Large Hadron Collider can discriminate between models if the CP-odd Higgs boson mass is below 900 GeV. An e^+e^- Linear Collider at 500 GeV center of mass energy can discriminate supersymmetric models up to a CP-odd Higgs mass of ~ 1.8 TeV.

PACS: 14.80.Cp, 14.80.Bn, 14.60.Jv, 12.15.Lk

*Supported by the European Union under contract Nr. HPMF-CT-1999-00150.
†Supported by *Fundación Ramón Areces.*
electronic address: guasch@particle.physik.uni-karlsruhe.de, hollik@particle.physik.uni-karlsruhe.de, siannah@particle.physik.uni-karlsruhe.de

The existence of the scalar Higgs boson of the Standard Model (SM) is still waiting for experimental confirmation. Last LEP results, suggesting a light neutral Higgs particle with a mass about 115 GeV are encouraging [1], but we will have to wait the news from the hadron colliders, the upgraded Fermilab Tevatron or the upcoming Large Hadron Collider (LHC) at CERN, to see this result either confirmed or dismissed. For intermediate masses above the LEP limit and below 180 GeV there is a chance for the Tevatron [2], but for higher masses up to 1 TeV one needs the LHC [3]. However, even if a neutral scalar boson is discovered, the question will still be open: whether it is the Higgs particle of the minimal Standard Model (SM) or whether there is an extended Higgs structure beyond the SM. In this paper we approach this question by investigating the neutral Higgs sector of various types of models. In many extensions of the SM the Higgs sector is enlarged, containing several neutral Higgs bosons as well as charged ones [4]. At present, supersymmetric (SUSY) models have become the theoretically favored scenarios, with the Minimal Supersymmetric Standard Model (MSSM) as the most-predictive framework beyond the SM [5]. The Higgs sector of the MSSM contains two Higgs doublets. Its properties at the tree-level are determined by just two free parameters, conventionally chosen as the ratio of the vacuum expectation values (*vevs*) of each doublet, $\tan\beta = v_2/v_1$, and the mass of the CP-odd neutral Higgs boson, M_{A^0}. This simple structure is known to receive large radiative corrections, which have been computed up to two-loop order [6]; a definite prediction is the existence of a light neutral scalar boson with mass below 130 GeV. It is also well known that the SUSY one-loop corrections to the tree-level couplings of Higgs bosons to bottom quarks can be significant for large values of $\tan\beta$, and that they do not decouple in the limit of a heavy supersymmetric spectrum [7–14], opposite to their behaviour in electroweak gauge boson physics [15].

These one-loop corrections can be translated directly into a redefinition of the relation between the b-quark Yukawa coupling (entering production and decay processes) and the physical (pole) mass of the b-quark, with important phenomenological implications e.g. for the branching ratios of SUSY Higgs-boson decays into heavy fermions.

Following this path we consider in this letter the ratio of branching ratios of a neutral Higgs boson H,

$$R = \frac{BR(H \to b\bar{b})}{BR(H \to \tau^+\tau^-)} \ , \tag{1}$$

analyzing in detail the Yukawa-coupling effects and their phenomenological consequences. In the SM, after accounting for the leading QCD corrections, one has $R^{\rm SM} = 3\, m_b^2(M_H)/m_\tau^2$, where $m_b(Q)$ is the b-quark running mass based on the QCD evolution, and m_τ is the τ-lepton mass. For $M_H = 115$ GeV we have $R^{\rm SM} \simeq 8$. Some other, small, QCD contributions are neglected here. Actually, the result for the leading QCD corrections is much more general in the sense that it is valid for any Higgs model in which the Higgs sector follows the family structure of the SM, like the Two-Higgs-Doublet-Model (2HDM) of type I and II, or the MSSM as far as the Standard QCD correction is considered.

The ratio (1) is very interesting from both the experimental and the theoretical side. It is a clean observable, measurable in a counting experiment, with only small systematic errors since most of them are canceled in the ratio. The only surviving systematic effect results

from the efficiency of τ- and b-tagging. From the theoretical side, it is independent of the production mechanism of the decaying neutral Higgs boson and of the total width; hence, new-physics effects affecting the production cross-section do not appear in the ratio (1). For the same reason, this observable is insensitive to unknown high order QCD corrections to Higgs boson production.

Another theoretical point of view is of interest: When one finds large radiative corrections to a certain process (e.g. $H \to b\bar{b}$), one may wonder if their effects would be absorbed by a proper redefinition of the parameters in some renormalization scheme, such that these effects disappear. Since the ratio (1) only depends on the ratio of the masses, there is no other parameter (e.g. $\tan\beta$) that could absorb these large corrections.

The partial decay width $\Gamma(h \to b\bar{b})$ of the lightest supersymmetric neutral Higgs particle has been the subject of several studies in the literature. Besides the complete one-loop corrections [16], comprehensive studies of the one- and two-loop SUSY-QCD corrections are available in Ref. [8] and [17], respectively. Implications for Higgs-boson searches from SUSY effects in the $hb\bar{b}$ vertex (together with their effective Lagrangian description) can be found in [9, 10]. The decoupling properties of the SUSY-QCD corrections to $\Gamma(h \to b\bar{b})$ have been extensively discussed in [13]. The effects on $BR(h \to \tau^+\tau^-)$ were presented in [18]. Analyses of the observable R can be found in [11, 19].

In the MSSM, the Higgs boson couplings to down-type fermions receive large quantum corrections, enhanced by $\tan\beta$. In the case of the $t\bar{b}H^+$ vertex, these corrections have been resummed to all orders of perturbation theory with the help of the effective Lagrangian formalism in Ref. [9]. The effective Lagrangian of the MSSM Higgs couplings to down-type fermions can be written as follows,

$$\mathcal{L}_{\text{eff}} = h_b \left(-\varepsilon_{ij} H_1^i L^j B_R + \Delta_B H_2^i L^i B_R \right) , \tag{2}$$

where H_1 and H_2 are the two Higgs-doublets of the MSSM, L is the $SU(2)_L$ fermion-doublet, B_R is the right-handed down-type fermion,[1] and h_b is the b-quark Yukawa coupling, related to the corresponding running mass at the tree level by $h_b = m_b/v_1$. H_2 is the doublet responsible for giving masses to the up-type fermions, and the second term in (2) only appears when radiative corrections are taken into account (encoded in the quantity Δ_B) due to breaking of SUSY. On the other hand, in the most general 2HDM such terms are permitted also at the tree level. However, they would lead to large Flavour Changing Neutral Currents in the light-quark sector of the model, and hence they are usually explicitly forbidden by a postulated ad-hoc symmetry, which leads to the so called 2HDM of Type I and Type II.

Given the effective Lagrangian (2), with the *vev* v_i of the Higgs doublet H_i, the b-quark mass is given by [2]

$$m_b = h_b(v_1 + \Delta_B\, v_2) = h_b v_1\, (1 + \Delta_B\, \tan\beta) \equiv h_b v_1\, (1 + \Delta m_b) \ . \tag{3}$$

[1] Here, and in the following, we use the third generation quark notation as a generic one.

[2] Notice that in the case of vanishing tree-level Yukawa coupling, the bottom quark mass would be generated by the non-decoupling terms like Δ_B in (3) [20].

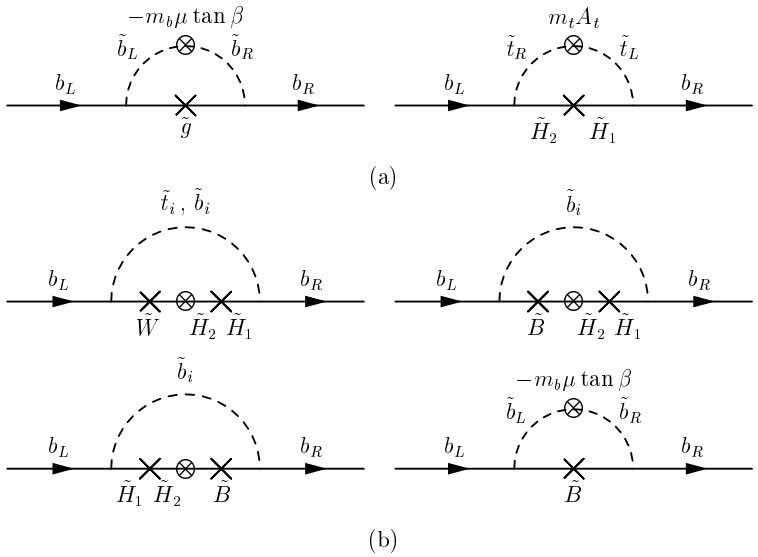


Figure 1: Diagrams contributing to Δm_b – eq. (5). The cross means a mass insertion, and the cross with a circle the coupling with H_2. The diagrams contributing to Δm_τ are those equivalent to **(b)**.

We now can relate the known quark mass to the Yukawa coupling via

$$h_b = \frac{m_b}{v_1}\frac{1}{1+\Delta m_b} = \frac{m_b}{v\cos\beta}\frac{1}{1+\Delta m_b}, \qquad v = (v_1^2+v_2^2)^{1/2}\,. \tag{4}$$

Δm_b is a non-decoupling quantity that encodes the leading radiative corrections. The expression (3) contains the resummation of all possible $\tan\beta$ enhanced corrections of the type $(\alpha_{(s)}\tan\beta)^n$ [9]. Similarly to the b case, the relation between m_τ and the τ-lepton Yukawa coupling h_τ is also modified by a quantum correction Δm_τ, in analogy to (4).

The explicit form of Δm_b and Δm_τ at the one-loop level can be obtained approximately by computing the supersymmetric loop diagrams at zero external momentum ($M_{SUSY} \gg m_b\,, m_\tau$), as given in Fig. 1 for Δm_b. The dominant diagrams are those of Fig. 1a, but in order to have a precise evaluation we are including the entire set in our result, which is given by

$$\begin{aligned}
\Delta m_b \;\simeq\;& \mu\tan\beta\left\{\frac{2\alpha_S}{3\pi}M_{\tilde{g}}\,I(M_{\tilde{b}_1},M_{\tilde{b}_2},M_{\tilde{g}}) + \frac{Y_t}{4\pi}A_t\,I(M_{\tilde{t}_1},M_{\tilde{t}_2},\mu)\right.\\
&+\;\frac{\alpha}{4\pi}\Bigg(-\frac{M_2}{s_W^2}\Big(\left[c_t^2\;I(M_{\tilde{t}_1},M_2,\mu)+s_t^2\;I(M_{\tilde{t}_2},M_2,\mu)\right]\\
&\quad+\frac{1}{2}\left[c_b^2\;I(M_{\tilde{b}_1},M_2,\mu)+s_b^2\;I(M_{\tilde{b}_2},M_2,\mu)\right]\Big)\\
&\quad-\frac{M_1}{3\,c_W^2}\Big(\frac{1}{3}I(M_{\tilde{b}_1},M_{\tilde{b}_2},M_1)+\frac{1}{2}\left[c_b^2\;I(M_{\tilde{b}_1},M_1,\mu)+s_b^2\;I(M_{\tilde{b}_2},M_1,\mu)\right]\\
&\quad+\left[s_b^2\;I(M_{\tilde{b}_1},M_1,\mu)+c_b^2\;I(M_{\tilde{b}_2},M_1,\mu)\right]\Big)\Bigg)\Bigg\}\,.
\end{aligned} \tag{5}$$

The diagrams contributing to Δm_τ are those equivalent to Fig. 1b replacing $b \to \tau$, $\tilde{b} \to \tilde{\tau}$, $\tilde{t} \to \tilde{\nu}_\tau$. Explicitly, they read

$$\begin{aligned}\Delta m_\tau &\simeq \mu \tan\beta \frac{\alpha}{4\pi}\Bigg\{ -\frac{M_2}{s_W^2}\left(I(M_{\tilde{\nu}_\tau}, M_2, \mu) + \frac{1}{2}\left[c_\tau^2\ I(M_{\tilde{\tau}_1}, M_2, \mu) + s_\tau^2\ I(M_{\tilde{\tau}_2}, M_2, \mu)\right]\right) \\ &+\frac{M_1}{c_W^2}\Big(I(M_{\tilde{\tau}_1}, M_{\tilde{\tau}_2}, M_1) + \frac{1}{2}\left[c_\tau^2\ I(M_{\tilde{\tau}_1}, M_1, \mu) + s_\tau^2\ I(M_{\tilde{\tau}_2}, M_1, \mu)\right] \\ &- \left[s_\tau^2\ I(M_{\tilde{\tau}_1}, M_1, \mu) + c_\tau^2\ I(M_{\tilde{\tau}_2}, M_1, \mu)\right]\Big)\Bigg\}. \end{aligned} \tag{6}$$

In the above expressions we have introduced shorthand notations for the functions of the Weinberg angle $s_W \equiv \sin\theta_W$, $c_W \equiv \cos\theta_W$, the top quark Yukawa coupling $Y_t = \frac{g^2 m_t^2}{8\pi m_W^2 \sin\beta^2}$, and sine and cosine of the sfermion mixing angles $s_{t,b}$, $c_{t,b}$, and s_τ, c_τ. For further conventions and notation see Refs. [7, 15]. The fine structure constants, α_S and α, have to be evaluated at the SUSY mass scale. The function I is given by,

$$I(a,b,c) = \frac{a^2 b^2 \ln(a^2/b^2) + b^2 c^2 \ln(b^2/c^2) + c^2 a^2 \ln(c^2/a^2)}{(a^2-b^2)(b^2-c^2)(a^2-c^2)}. \tag{7}$$

Although partial results for the expressions (5), (6) have been given several times in the literature [9–12], the subleading terms have not been given so far in a complete version.[3] We have checked the results in (5), (6) using *FeynArts 3* and *FormCalc* [21].

If we impose that all the SUSY masses, and also the supersymmetric Higgs mass parameter μ, are approximately of the same scale, M_{SUSY},

$$M_{\tilde{f}}\,(\tilde{f} \equiv \tilde{t}, \tilde{b}, \tilde{\tau}, \tilde{\nu}) \sim M_g \sim M_1 \sim M_2 \sim \mu \sim M_{SUSY}\,,$$

we find that:

$$\begin{aligned}\Delta m_b &\simeq \mathrm{sign}(\mu)\tan\beta\left\{ \frac{\alpha_S}{3\pi} - \frac{\alpha}{16\pi s_W^2}\left(3 + \frac{11}{9}\frac{s_W^2}{c_W^2}\right) + \frac{Y_t}{8\pi}\,\frac{A_t}{M_{SUSY}}\right\}, \\ \Delta m_\tau &\simeq -\mathrm{sign}(\mu)\tan\beta\,\frac{\alpha}{16\pi s_W^2}\left(3 - \frac{s_W^2}{c_W^2}\right)\ . \end{aligned} \tag{8}$$

Notice that these two quantities are independent of the SUSY mass scale M_{SUSY} since they only depend on $\tan\beta$ and the ratio A_t/M_{SUSY}.

From the effective Lagrangian (2), the b-quark coupling to each of the MSSM neutral Higgs bosons [10] is also derived:

$$\begin{aligned} h^0 b\bar{b} &: C_{hbb} = h_b \sin\alpha\left(1 - \frac{\Delta m_b}{\tan\beta\tan\alpha}\right) = \frac{m_b \sin\alpha}{v\cos\beta}\Delta_{hbb}\ , \\ H^0 b\bar{b} &: C_{Hbb} = -h_b\cos\alpha\left(1 + \frac{\Delta m_b \tan\alpha}{\tan\beta}\right) = -\frac{m_b\cos\alpha}{v\cos\beta}\Delta_{Hbb}\ , \\ A^0 b\bar{b} &: C_{Abb} = -ih_b\sin\beta\left(1 - \frac{\Delta m_b}{\tan\beta^2}\right) = -im_b\tan\beta\Delta_{Abb}\ . \end{aligned} \tag{9}$$

[3] Notice a sign difference in Δm_τ with [10].

Notice that, although Δm_b is basically a non-decoupling quantity, the CP-even mixing angle behaves as $\tan\alpha \to -1/\tan\beta$ in the *decoupling regime* of the MSSM Higgs sector (i.e. $M_{A^0} \gg M_Z$) and the $h^0 b\bar{b}$ coupling reaches the SM value $C_{hbb} \to m_b/v$. A very detailed analysis of this decoupling behaviour (at one-loop order) can be found in Ref. [13].

Now we analyze the deviation of the ratio (1) from the SM value, caused by the SUSY radiative corrections, for each of the MSSM neutral Higgs bosons $\phi = h, H, A$, in terms of the quantity

$$\frac{R^{\rm MSSM}(\phi)}{R^{\rm SM}} = \frac{1}{R^{\rm SM}} \frac{3C^2_{\phi bb}}{C^2_{\phi\tau\tau}} = \left(\frac{\Delta_{\phi bb}}{\Delta_{\phi\tau\tau}}\right)^2 , \tag{10}$$

which is a function depending only on $\tan\beta$, $\tan\alpha$, Δm_b and Δm_τ, and encoding all the genuine SUSY corrections. The contributions from QCD are the same as in the SM, and they cancel in (10). Differences in the electroweak corrections can occur only from loops with Higgs particles, and they can usually be neglected. In a MSSM-like Higgs sector, the Higgs-boson loop contributions are very small compared to the rest of the corrections. Large corrections from the Higgs boson sector can only arise in models in which the splitting between the Higgs bosons masses is much larger than that of the MSSM.[4] If this situation were to be found in the experiments, the MSSM would be excluded without any further analysis. Moreover, the contributions from the Higgs sector are very similar for the ϕbb and $\phi\tau\tau$ vertices, and they will mostly cancel in $R^{\rm MSSM}(\phi)$. The genuine SUSY corrections, on the other hand, present sizeable differences between the ϕbb and $\phi\tau\tau$ couplings, even in the case of similar squark and slepton spectra:

- the SUSY-QCD corrections mediated by gluinos is only present in Δm_b [1st term in (5)], yielding the by far dominant contribution to (10);
- there exists a contribution from the chargino sector to Δm_b resulting from mixing in the stop sector [2nd term in (5)], whereas a corresponding term is not present in Δm_τ due to the absence sneutrino mixing;
- the contribution from the $\tilde{B}$ loops is different in both cases because of the different hypercharges.

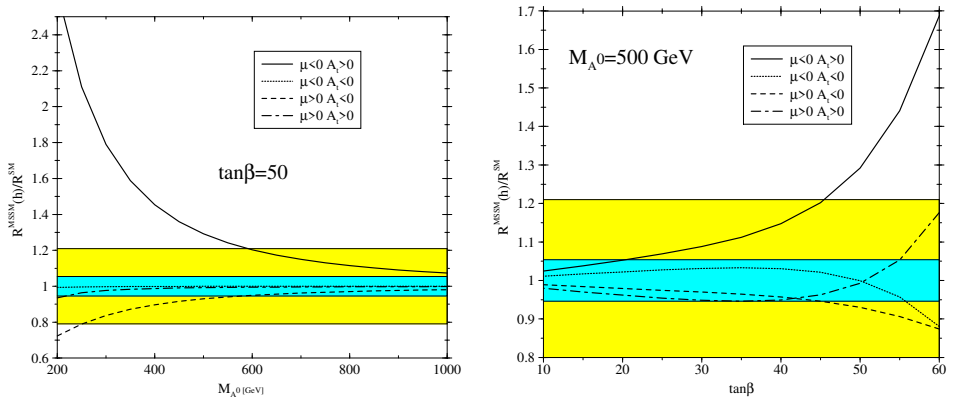
In the following we concentrate on the case of the lightest CP-even Higgs boson, h^0. The ratio R defined in (1), written in terms of the non-decoupling quantities Δm_b and Δm_τ and normalized to the SM value, reads

$$\frac{R^{\rm MSSM}(h)}{R^{\rm SM}} = \frac{(1+\Delta m_\tau)^2\,(-\cot\alpha\Delta m_b + \tan\beta)^2}{(1+\Delta m_b)^2\,(-\cot\alpha\Delta m_\tau + \tan\beta)^2} . \tag{11}$$

In Fig. 2 we present numerical results for the expression (11). The SUSY spectrum has been taken to be around 1.5 TeV, namely,

$$M_{\tilde{g}} = M_{\tilde{b}_1} = M_{\tilde{t}_1} = M_{\tilde{\tau}_1} = M_2 = |\mu| = A_b = A_\tau = |A_t| = 1.5\,{\rm TeV} ,$$

[4] A similar situation in the $t\bar{b}H^-$ coupling can be seen comparing the SUSY Higgs sector contributions [7] with the 2HDM ones [22].



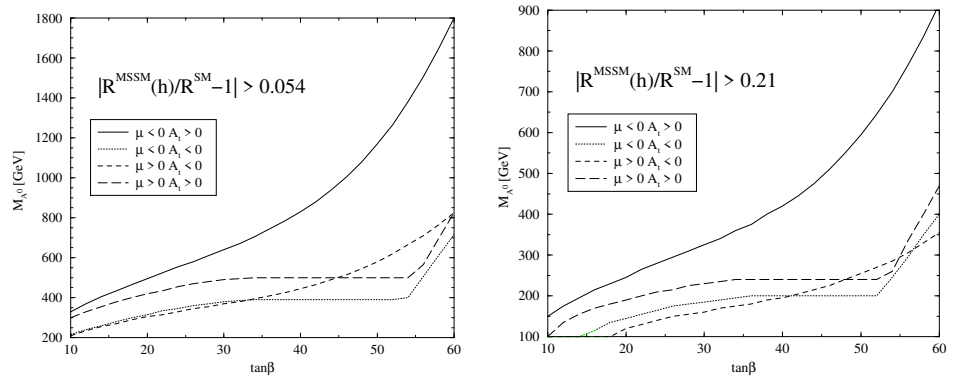
(a) (b)

Figure 2: Deviation of $R^{\rm MSSM}(h)$ with respect to the SM value, as a function of **a)** M_{A^0}, and **b)** $\tan\beta$, for various choices of the SUSY parameters. The light-shaded region shows the $\pm 21\%$ deviation with respect to the SM, and the dark-shaded one the $\pm 5.4\%$.

and we assume the usual GUT relation $M_1 = 5/3 M_2 s_W^2/c_W^2$ and maximal mixing in the $\tilde{b}$ and $\tilde{\tau}$ sector, $\theta = \pm\pi/4$. Our convention here is $M_{\tilde{f}_1} < M_{\tilde{f}_2}$. The rest of the parameters are fixed by the $SU(2)_L$ symmetry. As a consequence, a certain splitting of order $\sim 15\%$ is generated in the sfermion sector. Nevertheless the approximate expressions (8) give an accuracy better that 10% in Δm_τ and in Δm_b for $A_t > 0$. For $A_t < 0$ the approximation for Δm_b is much worse, giving deviations of $\sim 23\%$ for large $\tan\beta$. For definiteness, we also list the following values used for the SM parameters: $m_t = 175\,\text{GeV}$, $m_b = 4.62\,\text{GeV}$, $m_\tau = 1.777\,\text{GeV}$ [23]. The CP-even mixing angle is computed including the leading corrections up to two-loop order by means of the program *FeynHiggsFast* [24].

The decoupling behaviour with M_{A^0} becomes apparent in Fig. 2a. We also clearly see in Fig. 2 that $R^{\rm MSSM}(h)$ deviates significantly from the reference value $R^{\rm SM}$. In some favorable cases, i.e. small M_{A^0}, large $\tan\beta$, $\mu < 0$ and $A_t > 0$, the ratio (11) can be as large as two. Clearly, a moderate-precision measurement of this quantity would give clear signs of a Higgs boson belonging to a SUSY model. For the LHC we estimate that this quantity can be measured to a 21% accuracy. By looking at the associate WW-fusion Higgs boson production $qq \to W^*W^* \to H$, the $BR(H \to \tau^+\tau^-)/BR(H \to \gamma\gamma)$ is measurable with an accuracy of order 15% [25]. On the other hand, for the associated Higgs-boson production with a top quark ($pp \to t\bar{t}H$) the ratio $BR(H \to b\bar{b})/BR(H \to \gamma\gamma)$ can be performed with a similar precision [26]. From these two independent measurements one determines R with the error quoted above. If one were able to make both measurements using the same Higgs-boson production process, the error might be decreased. The $\pm 21\%$ deviation region is marked as a light-shaded region in the figures. As for a future e^+e^- Linear Collider (LC) running at 500 GeV center-of-mass energy, the simulation shows that the ratio of the effective Yukawa couplings, $h_b/h_\tau (\equiv \sqrt{R})$, can be measured with an accuracy of 2.7% [27]. The corresponding band of $\pm 5.4\%$ accuracy in (11) is shown as a dark-shaded region.

We can now find the regions in the $(\tan\beta, M_{A^0})$ plane in which each experiment can be



(a) (b)

Figure 3: Sensitivity regions on $R^{\rm MSSM}/R^{\rm SM}$ with **a)** 5.4% uncertainty in the measurement; **b)** 21% uncertainty.

sensitive to the SUSY nature of the lightest Higgs boson. We show these regions in Fig. 3a for a 5.4% accuracy measurement, and in Fig. 3b for a 21% one. We see that with a 5.4% measurement one can have sensitivity to SUSY for M_{A^0} up to ~ 1.8 TeV in the most favorable scenario. In less-favored scenarios the sensitivity is kept up to $M_{A^0} \sim 800$ GeV, but there exists also large regions where one is sensitive to SUSY only up to $M_{A^0} \sim 500$ GeV. However, all these masses are well above the threshold production of the heavy Higgs particles for a 500 GeV LC. We stress once again that these conclusions are independent of the scale of the SUSY masses. As long as a 21% accuracy is concerned, feasible e.g. at the LHC, the regions sensitivity are of course much smaller (Fig. 3b). In this case one can probe the SUSY nature of the Higgs boson only if A^0 is lighter that ~ 900 GeV. This means that the heavier MSSM Higgs bosons H^0, A^0 and $H^\pm$ will also be produced at high rates at the LHC. Then, it would be more useful to move our attention to $R^{\rm MSSM}(H/A)$ (corresponding eqs. (9), (10)). We have checked that this quantity is very insensitive to $\tan\alpha$, and so to M_{A^0}. Its numerical value is very close for both types of heavy neutral Higgs bosons. We show the result of this analysis in Fig. 4. A deviation of 21% with respect to the SM value is guaranteed for any scenario with $\tan\beta \gtrsim 20$; hence, the SUSY nature of the Higgs sector can be determined with a moderate-precision measurement.

To summarize, we have proposed the observable $R = BR(H \to b\bar{b})/BR(H \to \tau^+\tau^-)$ to discriminate between SUSY and non-SUSY Higgs models. This observable suffers only little from systematic uncertainties, and is a theoretically *clean* observable. In the MSSM, R is affected by quantum contributions that do not decouple even in the heavy SUSY limit. By assuming a $\pm 5.4\%$ measurement of this ratio for the lightest Higgs boson, to be made at a 500 GeV LC, one is sensitive to the SUSY nature of the lightest Higgs boson h^0 for values of the A^0 mass up to 1.8 TeV. A less precise measurement at $\pm 21\%$ accuracy, feasible at the LHC, is sensitive to SUSY only if $M_{A^0} < 900$ GeV. In this latter case the measurement of R for the heavy Higgs bosons A^0 and H^0 is possible and can give clear evidence for, or against, the SUSY nature of the Higgs bosons. Further confirmation can be obtained by correlating

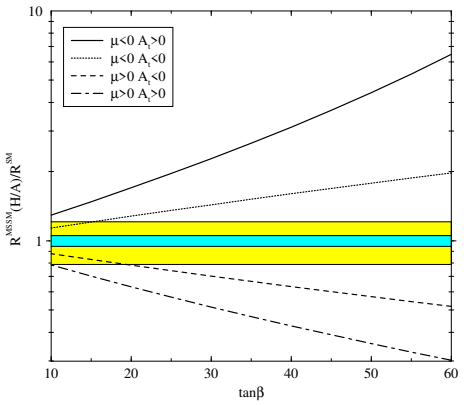


Figure 4: Deviation of $R^{\rm MSSM}(H/A)$ with respect to the SM value, as a function of $\tan\beta$ for various choices of the SUSY parameters. The shaded regions are as in Fig. 2.

these measurements with the production cross-section of charged Higgs bosons [28]. Further simulation analysis of the expected experimental determination are highly desirable.

We are thankful to D. Zeppenfeld for valuable comments.

References

[1] R. Barate *et al.* [ALEPH Collaboration], Phys. Lett. **B495** (2000) 1, hep-ex/0011045; M. Acciarri *et al.* [L3 Collaboration], Phys. Lett. **B495** (2000) 18, hep-ex/0011043; P. Igo-Kemenes for the LEP Working Group on Higgs boson searches, talk given at the LEPC on Nov. 3rd, 2000.

[2] M. Carena *et al.*, "Report of the Tevatron Higgs working group of the Tevatron Run 2 SUSY/Higgs Workshop", hep-ph/0010338.

[3] ATLAS Technical Design Report Vol. II, CERN-LHCC-99-15 (1999); CMS Technical proposal, CERN-LHCC-94-43, 272pp (1994).

[4] J.F. Gunion, H.E. Haber, G.L. Kane, S. Dawson, *The Higgs Hunters' Guide* (Addison-Wesley, Menlo-Park, 1990).

[5] H.P. Nilles, Phys. Rep. **110** (1984) 1; H.E. Haber, G.L. Kane, Phys. Rep. **117** (1985) 75; A.B. Lahanas, D.V. Nanopoulos, Phys. Rep. **145** (1987) 1.

[6] M. Carena *et al.*, Nucl. Phys. **B580** (2000) 29, hep-ph/0001002; J.R. Espinosa, R. Zhang, Nucl. Phys. **B586** (2000) 3, hep-ph/0003246, and references therein.

[7] J.A. Coarasa, D. Garcia, J. Guasch, R.A. Jiménez, J. Solà, Eur. Phys. J. **C2** (1998) 373, hep-ph/9607485.

[8] J.A. Coarasa, R.A. Jiménez, J. Solà, Phys. Lett. **B389** (1996) 312, hep-ph/9511402.

[9] M. Carena, D. Garcia, U. Nierste, C.E.M. Wagner, Nucl. Phys. **B577** (2000) 88, hep-ph/9912516.

[10] M. Carena, S. Mrenna, C.E.M. Wagner, Phys. Rev. **D60** (1999) 075010, hep-ph/9808312; *ibid.* **D62** (2000) 055008, hep-ph/9907422.

[11] K. S. Babu, C. Kolda, Phys. Lett. **B451** (1999) 77, hep-ph/9811308.

[12] D. M. Pierce, J. A. Bagger, K. Matchev, R. Zhang, Nucl. Phys. **B491** (1997) 3, hep-ph/9606211; M. Carena, M. Olechowski, S. Pokorski, C.E.M. Wagner, Nucl. Phys. **B426** (1994) 269, hep-ph/9402253; L.J. Hall, R. Rattazzi, U. Sarid, Phys. Rev. **D50** (1994) 7048, hep-ph/9306309.

[13] H.E. Haber *et al.*, Phys. Rev. **D63** (2001) 055004, hep-ph/0007006.

[14] M. J. Herrero, S. Peñaranda, D. Temes, hep-ph/0105097.

[15] A. Dobado, M.J. Herrero, S. Peñaranda, Eur. Phys. J. **C7** (1999) 313, hep-ph/9710313; *ibid.* **C12** (2000) 673, hep-ph/9903211; *ibid.* **C17** (2000) 487, hep-ph/0002134.

[16] A. Dabelstein, Nucl. Phys. **B456** (1995) 25, hep-ph/9503443.

[17] S. Heinemeyer, W. Hollik, G. Weiglein, Eur. Phys. J. **C16** (2000) 139, hep-ph/0003022.

[18] S. Heinemeyer, G. Weiglein, proceedings of *5th International Linear Collider Workshop* (LCWS 2000), Fermilab, Batavia, Illinois, 24-28 Oct 2000, hep-ph/0102117.

[19] M.J. Herrero, Talk at the *XXIX International Meeting on Fundamental Physics*, Sitges, Barcelona, Spain, 5-9 Feb 2001. To appear in the proceedings.

[20] F. Borzumati, G. R. Farrar, N. Polonsky, S. Thomas, Nucl. Phys. **B555** (1999) 53, hep-ph/9902443, and references therein

[21] T. Hahn, hep-ph/0012260; T. Hahn, M. Pérez-Victoria, Comput. Phys. Commun. **118** (1999) 153, hep-ph/9807565; T. Hahn, C. Schappacher, hep-ph/0105349.

[22] J.A. Coarasa, J. Guasch, W. Hollik, J. Solà, Phys. Lett. **B442** (1998) 326, hep-ph/9808278.

[23] D. E. Groom *et al.* [Particle Data Group Collaboration], Eur. Phys. J. **C15** (2000) 1.

[24] S. Heinemeyer, W. Hollik, G. Weiglein, hep-ph/0002213.

[25] D. Zeppenfeld, R. Kinnunen, A. Nikitenko, E. Richter-Was, Phys. Rev. **D62** (2000) 013009, hep-ph/0002036.

[26] F. Gianotti, M. Pepe-Altarelli, Nucl. Phys. Proc. Suppl. **89** (2000) 177, hep-ex/0006016.

[27] *2nd Joint ECFA/DESY Study on Physics and Detectors for a Linear Electron-Positron Collider*, `http://www.desy.de/conferences/ecfa-desy-lc98.html`; *TESLA Technical Design Report* `DESY 2001-011`, Part III: *Physics at an* e^+e^- *Linear Collider*, R. Heuer, D. Miller, F. Richard, P. Zerwas Editors, `http://tesla.desy.de/`.

[28] A. Belyaev, D. Garcia, J. Guasch, J. Solà, hep-ph/0105053.