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Some results on the distinction of Higgs boson models*

Jaume Guasch [a], Wolfgang Hollik [b], Siannah Peñaranda [b] †

[a] *Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland*
[b] *Max-Planck-Institut für Physik, Föhringer Ring 6, D-80805 München, Germany*

Abstract

We present results on the analysis of 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. A detailed analysis in the effective Lagrangian approach shows how one could discriminate between models at the Large Hadron Collider and the e^+e^- Linear Collider at 500 GeV center of mass energy.

The search for a Higgs boson is nowadays the main objective of High Energy Physics experiments. Even if a neutral scalar boson is discovered in present or future colliders, 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. We approach this question by investigating the neutral Higgs sector of various types of models. In particular, we consider the ratio of branching ratios of a neutral Higgs boson H,

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

and we analyze in detail the Yukawa-coupling effects and their phenomenological consequences [1]. This ratio receives large renormalization-scheme independent radiative corrections in supersymmetric (SUSY) models at large $\tan\beta$, which are absent in the SM or Two-Higgs-doublet models (THDM). These corrections are insensitive to the supersymmetric mass scale. We consider in our analysis the effective Lagrangian approach by relating the quark mass to the Yukawa coupling via Δm_f, the non-decoupling quantity that encodes the leading radiative corrections,

$$h_f = \frac{m_f(Q)}{v_1}\frac{1}{1+\Delta m_f} = \frac{m_f(Q)}{v\cos\beta}\frac{1}{1+\Delta m_f}, \qquad v = (v_1^2+v_2^2)^{1/2} \,. \tag{2}$$

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†electronic address: jaume.guasch@psi.ch, hollik@mppmu.mpg.de, siannah@mppmu.mpg.de

Here the resummation of all possible $\tan\beta$ enhanced corrections of the type $(\alpha_{(s)}\tan\beta)^n$ [2] are included. The leading part of the (potentially) non-decoupling contributions proportional to A_b can be absorbed in the definition of the effective Yukawa coupling at low energies and only subleading effects survive [3]. Therefore, expression (2) contains all leading potentially large radiative effects.

Notice that 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 cancel 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. Besides, since this ratio only depends on the ratio of the masses, there is no other parameter (e.g. $\tan\beta$) that could absorb the large quantum corrections.

The normalized value of the ratio of the Higgs boson decay rates into $b-$quarks and $\tau-$leptons (1) to the $R^{\rm SM}$ expectation is used to distinguish a general THDM from the Minimal Supersymmetric Standard Model (MSSM). We analyze the deviation of this ratio from the SM value, caused by the SUSY radiative corrections, for each of the MSSM neutral Higgs bosons $\phi = h, H, A$. This normalized value is a function depending only on $\tan\beta$, $\tan\alpha$, Δm_b and Δm_τ, and encoding all the genuine SUSY corrections. 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 ($M_{SUSY} \gg m_b\,, m_\tau$) [1]. 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} [1] [1].

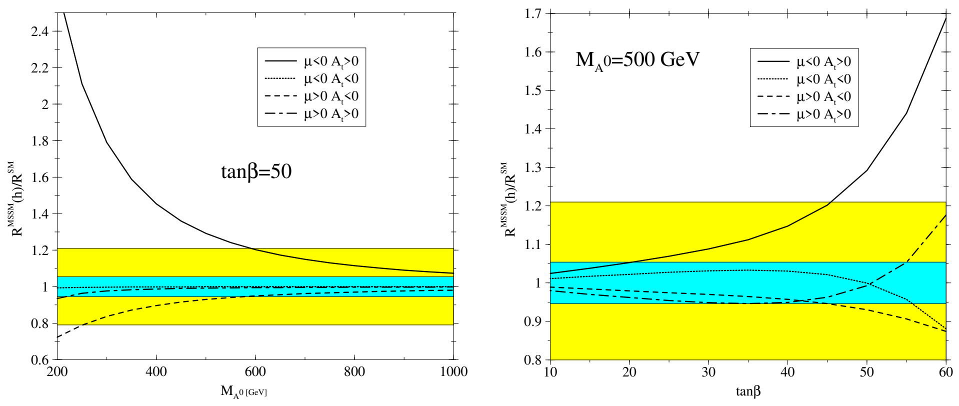
The genuine SUSY corrections present sizeable differences between the ϕbb and $\phi\tau\tau$ couplings, even in the case of similar squark and slepton spectra: the SUSY-QCD corrections mediated by gluinos are only present in Δm_b, yielding the by far dominant contribution to the normalized value of R; there exists a contribution from the chargino sector to Δm_b resulting from mixing in the stop sector, 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.

As for the case of the lightest MSSM 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

$$\frac{R^{\rm MSSM}(h)}{R^{\rm SM}} = \frac{(1+\Delta m_\tau)^2\,(-\cot\alpha\Delta m_b + \tan\beta)^2}{(1+\Delta m_b)^2\,(-\cot\alpha\Delta m_\tau + \tan\beta)^2}\,. \tag{3}$$

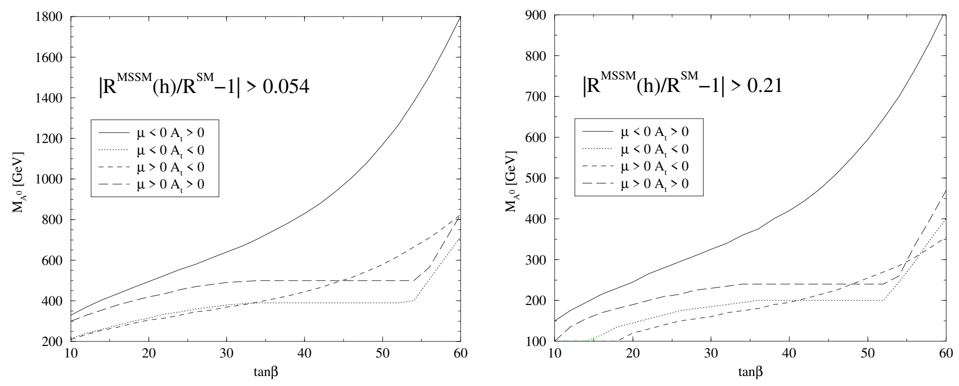
Large deviations from $R = 1$ are expected in the $R^{\rm MSSM}$ for several MSSM parameter combinations as shown in Fig. 1. The SUSY spectrum has been taken to be around 1.5 TeV, namely, $M_{\tilde{g}} = M_{\tilde{b}_1} = M_{\tilde{t}_1} = M_{\tilde{\tau}_1} = M_2 = |\mu| = A_b = A_\tau = |A_t| = 1.5\,{\rm TeV}$, 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, $\theta = \pm\pi/4$. The rest of the parameters are fixed by the $SU(2)_L$ symmetry. As for the SM parameters we have chosen $m_t = 175\,{\rm GeV}$, $m_b = 4.62\,{\rm GeV}$, $m_\tau = 1.777\,{\rm GeV}$ [5]. The

[1] See also [2, 4].



(a) (b)

Figure 1: 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 $\pm 5.4\%$.



(a) (b)

Figure 2: Sensitivity regions on $R^{\rm MSSM}/R^{\rm SM}$ with **a)** 5.4% uncertainty in the measurement; **b)** 21% uncertainty.

CP-even mixing angle is computed including the leading corrections up to two-loop order by means of the program *FeynHiggsFast* [6].

The decoupling behaviour with M_{A^0} becomes apparent in Fig. 1a. In some favorable cases, i.e. small M_{A^0}, large $\tan\beta$, $\mu < 0$ and $A_t > 0$, the ratio (3) 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% [7]. 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 [8]. 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

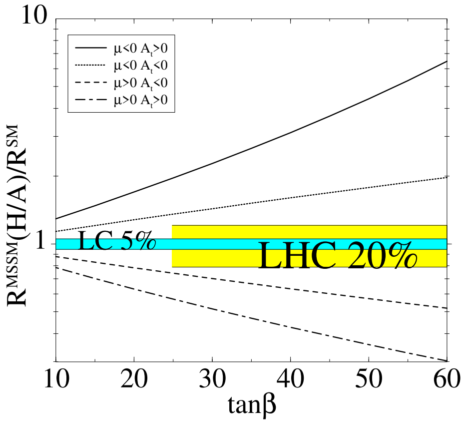


Figure 3: Deviation of $R^{\mathrm{MSSM}}(H/A)$ with respect to the SM value, as a function of $\tan\beta$ for various choices of the SUSY parameters. The shaded regions are as in Fig. 1.

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% [9]. The corresponding band of $\pm5.4\%$ accuracy in (3) is shown as a dark-shaded region.

We have found also the regions in the $(\tan\beta, M_{A^0})$ plane in which each experiment can be sensitive to the SUSY nature of the lightest Higgs boson. We show these regions in Fig. 2a for a 5.4% accuracy measurement, and in Fig. 2b 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 of sensitivity are of course much smaller (Fig. 2b). 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 $R^{\mathrm{MSSM}}(H/A)$. 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. A deviation of 21% with respect to the SM value is guaranteed for any scenario with $\tan\beta \gtrsim 20$ as shown in Fig. 3; hence, the SUSY nature of the Higgs sector can be determined with a moderate-precision measurement. Notice that for the LHC models can be only distinguished for $\tan\beta > 25$ but for th LC cover the entire $\tan\beta$ range.

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 $\pm5.4\%$ measurement of this ratio for the lightest Higgs boson, to be reached 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 $\pm21\%$ accuracy, feasible at the

LHC, is sensitive to SUSY only if $M_{A^0} < 900\,\mathrm{GeV}$. 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 these measurements with the production cross-section of charged Higgs bosons [10]. Further simulation analysis of the expected experimental determination are highly desirable.

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