Extracting SUSY Parameters from the Higgs Boson Properties

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Abstract. We calculate the ratio of the two branching ratios, $\mathrm{Br}(h \to b\bar{b})$ and $\mathrm{Br}(h \to c\bar{c}) + \mathrm{Br}(h \to gg)$, in the minimal supersymmetric standard model taking into account the SUSY-loop corrections to the Higgs sector and the $hb\bar{b}$ vertex. We show that the heavy Higgs mass can be extracted from the ratio, almost independently of other SUSY parameters, in the region of $\tan\beta \lesssim 10$.

It was pointed out that the CP-odd Higgs mass m_A can be determined by the measurements of the lightest Higgs decay branching ratios in the minimal supersymmetric standard model (MSSM) [1]. Since there is the region of moderate $\tan\beta$ where LHC may not be able to detect the CP-odd Higgs boson, $m_A \gtrsim 200\mathrm{GeV}$ [2], it is important to study such an option to indirectly constrain m_A. Ref. [1] showed that we could extract m_A from the double ratio,

$$R_{br} \equiv \frac{Br(h \to c\bar{c}) + Br(h \to gg)}{Br(h \to b\bar{b})},$$

taking into account the SUSY-loop corrections to the Higgs sector.

Since the dependence of the $h \to b\bar{b}$ and $h \to c\bar{c}$ branching ratios on the mixing angles α and β of the Higgs sector is given by $Br(h \to b\bar{b}) \propto \frac{\sin^2\alpha}{\cos^2\beta}$ and $Br(h \to c\bar{c}) \propto \frac{\cos^2\alpha}{\sin^2\beta}$, the double ratio between $Br(h \to b\bar{b})$ and $Br(h \to c\bar{c})$ becomes $R_c \equiv Br(h \to c\bar{c})/Br(h \to b\bar{b}) \propto 1/(\tan\alpha\tan\beta)^2$, where the scalar-top-quark corrections to the Higgs sector are implicit in $\tan\alpha$ and $\tan\beta$. When the CP-odd Higgs boson is heavy, $m_A \gg m_h \sim m_Z$, and the left-right mixing of the scalar top quarks is small, the double ratio R_c is approximately proportional to $(m_h^2 - m_A^2)^2/(m_Z^2 + m_A^2)^2$. From this expression, you can see that, once we measure the lightest Higgs mass m_h, the double ratio R_c determines m_A. Furthermore, $Br(h \to gg)$, dominantly induced by the top quark exchange, has the same dependence on the mixing angles α and β as the $Br(h \to c\bar{c})$, and therefore we can expect the double ratio R_{br} determines the mass scale of the CP-odd Higgs boson.

In the above discussion, we assume that Higgs-fermion Yukawa couplings are the same as those in the type-II two Higgs doublet model (THDM). Recently, the SUSY-loop corrections to the $hb\bar{b}$ coupling constant have been studied by many authors [3,4]. The one-loop-level coupling of a bottom quark to the neutral Higgs fields is given by

$$\mathcal{L} = f_b \bar{b}_L b_R H_d^0 + \epsilon_b f_b \bar{b}_L b_R H_u^{0*} + h.c., \tag{1}$$

$$\epsilon_b \equiv \frac{2\alpha_S}{3\pi}\mu M_3 f(M_3^2, m_{\tilde{b}_L}^2, m_{\tilde{b}_R}^2) + \frac{f_t^2}{16\pi^2}\mu A_t f(\mu^2, m_{\tilde{t}_L}^2, m_{\tilde{t}_R}^2), \tag{2}$$

$$f(m_1^2, m_2^2, m_3^2) \equiv \frac{1}{m_3^2}\left[\frac{x\log x}{1-x} - \frac{y\log y}{1-y}\right]\frac{1}{x-y}, \quad x \equiv \frac{m_1^2}{m_3^2}, \quad y \equiv \frac{m_2^2}{m_3^2} \tag{3}$$

where ϵ_b is induced by the gluino- and Higgsino-exchange diagrams. In Eq.(1) the second term proportional to ϵ_b is absent at the tree level in the MSSM (and also in the type-II THDM). The b-quark mass and the $hb\bar{b}$ coupling constant are then expressed as,

$$m_b = f_b v_d + f_b \epsilon_b v_u = f_b v \cos\beta \times (1 + \epsilon_b \tan\beta), \quad \mathcal{L}_{hbb} = -\frac{m_b \sin\alpha}{v\cos\beta} \times \left[\frac{1 - \epsilon_b/\tan\alpha}{1 + \epsilon_b \tan\beta}\right].$$

We can see that the effect of the ϵ_b on the b-quark mass and the $hb\bar{b}$ coupling constant becomes significant when $\tan\beta$ is large. In this case the effective theory below the SUSY-breaking scale becomes the general THDM.

The double ratios between the Higgs decay branching ratios are proportional to the following expressions:

$$R_{br} \propto \frac{1}{(\tan\alpha\tan\beta)^2}\left[\frac{(1+\epsilon_b\tan\beta)}{(1-\epsilon_b/\tan\alpha)}\right]^2,$$

$$R_\tau \equiv \frac{Br(h\to\tau^+\tau^-)}{Br(h\to b\bar{b})} \propto \left[\frac{(1+\epsilon_b\tan\beta)}{(1-\epsilon_b/\tan\alpha)}\right]^2.$$

When $\tan\beta$ is large, the effect of ϵ_b on the double ratios, R_{br} and R_τ, becomes significant whereas the ratio R_{br}/R_τ is ϵ_b independent. In addition, if the stop mixing parameter A_t is large, the SUSY-loop corrections to the Higgs sector modify the approximate relation, $1/(\tan\alpha\tan\beta)^2 \sim (m_h^2 - m_A^2)^2/(m_Z^2 + m_A^2)^2$ [4].

We first consider the uncertainties of the decay double ratios for the standard model (SM) Higgs boson due to the SM input parameters; the strong coupling constant $\hat{\alpha}_S(m_Z)$, and the $\overline{\rm MS}$ running quark masses of the bottom and charm quarks, $\hat{m}_b(m_b)$ and $\hat{m}_c(m_c)$. We assume the following center values and errors; $\hat{\alpha}_S(m_Z) = 0.1181 \pm 0.002, \hat{m}_b(m_b) = 4.20 \pm 0.13$ GeV ($\pm 3\%$), $\hat{m}_c(m_c) = 1.25 \pm 0.06$ GeV ($\pm 5\%$). For the $h \to q\bar{q}$ and $h \to gg$ partial widths, we used the same formulas as in Ref. [1]. In the second column in Table 1, we show the SM theoretical uncertainties for the ratios obtained by varying the input parameters in the above range. In the third column, the expected statistical errors of the double ratios are given for the integrated luminosity of 100 fb^{-1} and 500 fb^{-1} obtained by scaling the results of Ref. [5]. Totals of the theoretical and experimental errors for the three double ratios are shown in the forth column for the integrated luminosity of 100 fb^{-1} and 500 fb^{-1} respectively. Assuming the integrated luminosity of 500 fb^{-1}, total errors for the three double ratios are about 10%.

TABLE 1. The errors of the double ratios of the Standard Model Higgs boson due to the theoretical uncertainties of input parameters and experimental errors (%).

	Theoretical error	Experimental error (100/500) fb^{-1}	Total error (100/500) fb^{-1}
$R_{br} = \frac{Br(h->c\bar{c})+Br(h->gg)}{Br(h->b\bar{b})}$	8.6	15.0/6.7	17.3/10.9
$R_{\tau} = \frac{Br(h->\tau^+\tau^-)}{Br(h->b\bar{b})}$	7.6	10.0/4.5	12.6/8.8
$R_{br}/R_{\tau} = \frac{Br(h->c\bar{c})+Br(h->gg)}{Br(h->\tau^+\tau^-)}$	4.1	19.5/8.7	19.9/9.6

We present the double ratios as functions of M_A for typical SUSY parameters. For this purpose we introduce the SUSY-breaking scale M_S and set the soft masses for squarks as $m^2_{\tilde{q}_L} = m^2_{\tilde{t}_R} = m^2_{\tilde{b}_R} = M^2_S$, and the squark mixing parameters as $A_t = X_t M_S$ and $A_b = 0$, where X_t is a dimensionless parameter. Then we can calculate the Higgs masses $m_{h,H}$, the mixing angle α and the radiatively induced coupling ϵ_b in Eq.(2) from the parameter set ($\tan\beta$, M_A, M_S, X_t, M_3, μ). In our numerical calculation, we solve the renormalization group equations of the Higgs sector given in Ref. [6] to obtain the Higgs boson masses and the mixing angle α.

In Fig.1 we plot the double ratios R_{br} and R_τ in the upper and lower rows respectively for $\tan\beta = 10$, 30, and 50 as functions of M_A. We set (M_3, μ) to (300GeV, 300GeV) and solve M_S such that the lightest Higgs mass m_{h^0} becomes 120GeV for each M_A with fixing the ratio X_t. For the present parameter set, R_{br} has the maximum (minimum) value when X_t is set to -2 (2.5) and R_τ has the maximum (minimum) value at $X_t = -1.6$ (2.5) in the range of $-2.5 \leq X_t \leq 2.5$. The dependence of X_t comes from both the induced coupling ϵ_b and the mixing angle α. The shaded regions in the graphs for $\tan\beta = 10, 30$ show the constrained region of the CP-odd Higgs mass assuming that R_{br} were determined with the 10% accuracy. We can see that M_A is well (weakly) constrained by R_{br}, when $\tan\beta$=10 (30). When R_{br} receives the significant corrections, R_τ also receives corrections of the similar magnitude. For moderate $\tan\beta \sim$10, both the ratios R_{br} and R_{br}/R_τ are approximately proportional to $(m_h^2 - m_A^2)^2/(m_Z^2 + m_A^2)^2$.

To summarize, we estimated the theoretical uncertainties due to the SUSY-loop corrections on the double ratios between the branching fractions of the lightest Higgs boson. In the region of moderate $\tan\beta \sim 10$, where LHC will not be able to detect the CP-odd Higgs boson of $m_A \gtrsim 200$GeV [2], we can constrain the range of the CP-odd Higgs mass from the ratios, R_{br} and R_{br}/R_τ. On the other hand, if LHC detects the CP-odd Higgs boson, we may be able to obtain information on the SUSY sector by the branching ratios of the Higgs boson at the future LC.

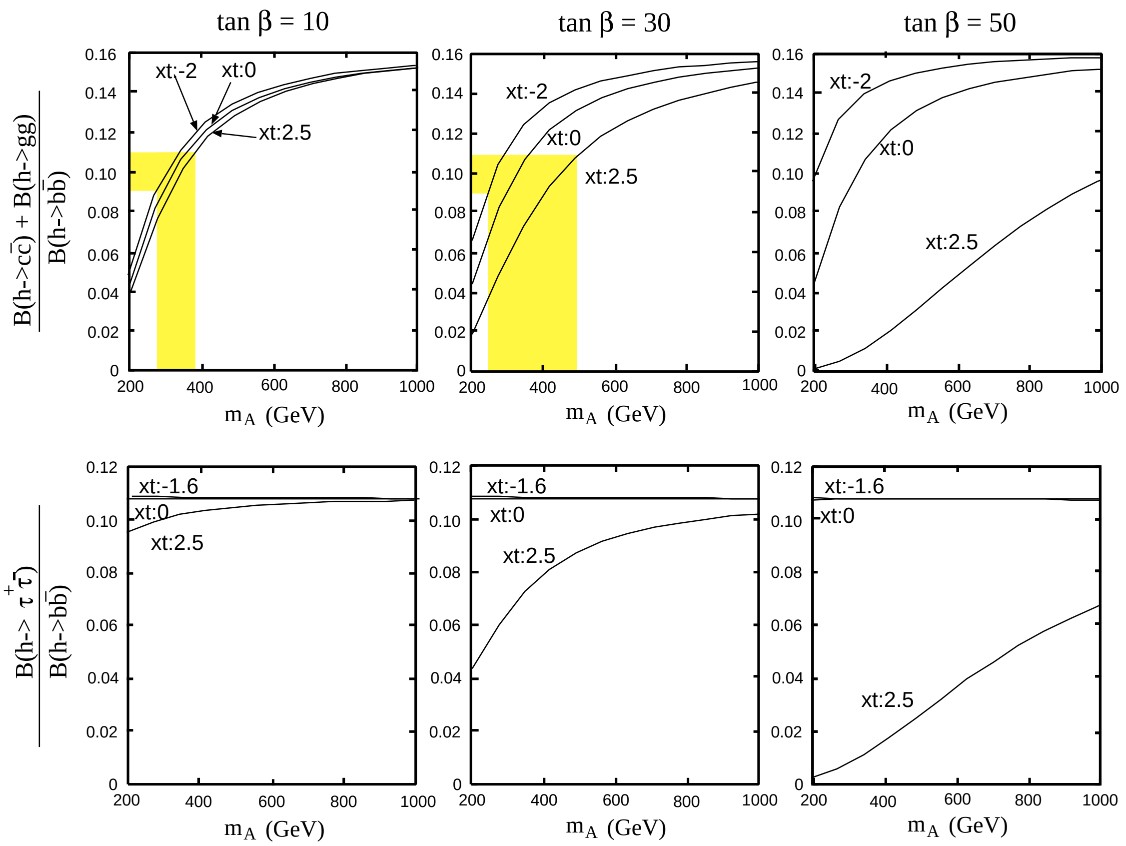

FIGURE 1. R_{br} (upper row) and R_{τ} (lower row) of the 120GeV lightest neutral Higgs boson for $\tan\beta = 10, 30, 50$.

REFERENCES

1. J.Kamoshita, Y.Okada and M.Tanaka, in *Proceedings of the Workshop on Physics and Experiments with Linear Colliders, p.387*, Morioka-Appi, Iwate, Japan 1995 edited by A. Miyamoto *et al.* (World Scientific, Singapore, 1996); *Phys. Lett.* B **391** (1997) 124.
2. E.Richter-Was, D.Froidevaux, F.Gianotti, L.Poggioli, D.Cavalli, S.Resconi, *Int.J.Mod.Phys.* A **13**, (1998) 1371, A.Caner, ICHEP 2000.
3. K.S.Babu and C.Kolda, *Phys. Lett.*B**451**,77 (1999), H.Eberl, K.Hidaka, S.Kraml, W.Majerotto, and Y.Yamada, *Phys.Rev.* D **62**, (2000) 055006, M.Carena, D.Garcia, U.Nierste, and C.E.M.Wagner, *Nucl. Phys.* B **577** (2000) 88, H.E.Haber, M.Herrero, H.E.Logan, S.Peñaranda, S.Rigolin, and D.Temes, hep-ph/0007006.
4. A.Dabelstein, *Nucl. Phys.* B **456**,25 (1995), M.Carena, S.Mrenna, and C.E.M.Wagner, *Phys. Rev.* D **60**, (1999) 075010.
5. I. Nakamura and K. Kawagoe, in *Proceedings of the Workshop on Physics and Experiments with Linear Colliders, p.394*, Morioka-Appi, Iwate, Japan 1995 edited by A. Miyamoto *et al.* (World Scientific, Singapore, 1996); *Phys. Rev.* D **54** (1996) 3634.
6. H. Haber and R. Hempfling, *Phys.Rev.* D **48**, (1993) 4280.