$\tan\beta$ Determination From Heavy Higgs Boson Production at Linear Colliders[1]

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Abstract. We study the production at future e^+e^- linear colliders of the heavy neutral Higgs bosons H and A of the minimal supersymmetric standard model in association with top and bottom quarks. The cross sections have a strong dependence on the parameter $\tan\beta$, and thus provide a good way to determine it. At a linear collider with $\sqrt{s} = 0.5 - 1$ TeV and expected integrated luminosities, we find significant sensitivities for determining $\tan\beta$. In the Supergravity scenario, the sensitivity is particularly strong for $\tan\beta \gtrsim 10$, reaching a 15% or better measurement. In the general MSSM scenario, the interplay between the $4b$ and $4t$ channels results in a good determination for $\tan\beta \lesssim 10$, while the sensitivity is weakened for higher values of $\tan\beta$.

The parameter $\tan\beta$ is one of the most important parameters in minimal sypersymmetric standard model (MSSM). It characterizes the relative fraction that the two Higgs doublets contribute to the electroweak symmetry breaking, and it enters all sectors of the theory. The interactions of both the supersymmetric (SUSY) particles and the Higgs bosons depend on $\tan\beta$, and the relations of SUSY particle masses to the soft symmetry breaking parameters of supersymmetry involve $\tan\beta$ [1]. A measurement of $\tan\beta$ from one sector will thereby allow predictions or tests in other sectors. The renormalization group evolution of the Yukawa couplings from the unification scale to the electroweak scale are sensitive to the value of $\tan\beta$. The determination of the $\tan\beta$ value will be useful in distinguishing different unification scenarios in grand unified theories (GUTs). Because of the significance of $\tan\beta$ for the theory and phenomenology of the MSSM, it is important to find processes in which $\tan\beta$ can be best determined. In this talk we present the production of heavy neutral Higgs bosons in association with top and bottom quarks as a sensitive probe to the parameter $\tan\beta$. For details of the analysis see Ref. [2].

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The Higgs couplings of H, A to heavy quarks are given by

$$A\bar{t}t : \frac{-gm_t}{2m_W} \cot\beta\ \gamma_5 \qquad\qquad A\bar{b}b : \frac{-gm_b}{2m_W} \tan\beta\ \gamma_5 \tag{1}$$

$$H\bar{t}t : \frac{-igm_t}{2m_W}\frac{\sin\alpha}{\sin\beta} \approx \frac{igm_t}{2m_W}\cot\beta \qquad\qquad H\bar{b}b : \frac{-igm_b}{2m_W}\frac{\cos\alpha}{\cos\beta} \approx \frac{-igm_b}{2m_W}\tan\beta \tag{2}$$

where the decoupling limit $M_A \gg M_Z$ has been assumed for the approximate forms of $H\bar{t}t, H\bar{b}b$. For the H, A Higgs bosons, $\tan\beta$ is essentially the unique parameter for Higgs-heavy quark couplings. This suggests that studies of the associated production of the Higgs bosons and heavy quarks may effectively determine the $\tan\beta$ parameter.

We study the sensitivity to probe $\tan\beta$ in two scenarios: the minimal Supergravity model (mSUGRA) and the MSSM. At tree level, there are only two parameters m_A and $\tan\beta$ in the MSSM Higgs sector. In a general analysis including radiative corrections, other SUSY parameter are required. In mSUGRA scenario we relate the soft SUSY breaking parameters to the common scalar, fermion and trilinear parameters m_0, $m_{1/2}$ and A_0 at the grand unified scale. In MSSM scenario we choose the soft SUSY breaking parameter to be similar to mSUGRA parameters with $\tan\beta \approx 15$.

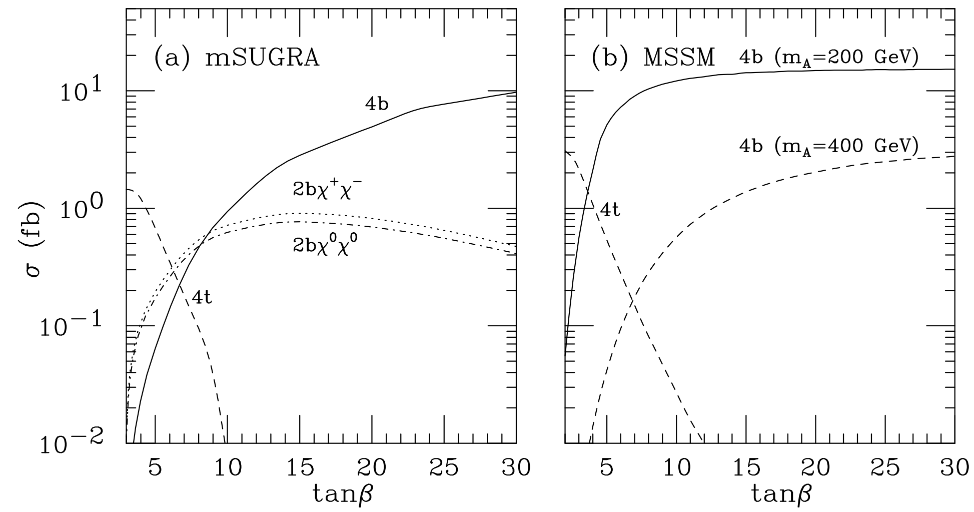

FIGURE 1. Total cross sections with different final states including A, H decays versus $\tan\beta$ at $\sqrt{s} = 1$ TeV, (a) in mSUGRA and (b) in MSSM.

We use the program provided in Ref. [3] for obtaining the branching fractions for the Higgs boson decay. We find that, as $\tan\beta$ increases, the branching fractions of A and H decay into $t\bar{t}$ decrease rapidly and the branching fraction of decays into $b\bar{b}$ increases dramatically. We also calculate the total cross sections of processes $e^+e^- \to A(H)t\bar{t}, A(H)b\bar{b}$. At low $\tan\beta$ the associated production of A (H) with $t\bar{t}$ is dominant but this channel is greatly suppressed at large $\tan\beta$ values. On the other hand the production of A (H) in association with $b\bar{b}$ is small at low $\tan\beta$

and increases rapidly with $\tan\beta$. Concerning the final state signature with the $A(H)$ decays, the $e^+e^- \to t\bar{t}t\bar{t}$ signal is dominant at low $\tan\beta$ due to the $(\cot\beta)^4$ enhancement but at high $\tan\beta$, $e^+e^- \to b\bar{b}b\bar{b}$ becomes dominant because of the $(\tan\beta)^4$ enhancement. We show in Fig. 1(a) the total cross sections at $\sqrt{s} = 1$ TeV versus $\tan\beta$ including the different final states in mSUGRA. For intermediate values of $\tan\beta \sim 5$, the SUSY decay modes, such as $A, H \to \chi^+\chi^-$ and $\chi^0\chi^0$ can be more important. The complementarity of the three final states in different range of $\tan\beta$ can be seen in this figure.

In the MSSM scenario, similar curves for the $4t$ and $4b$ final state signals are shown in Fig. 1(b) for two cases: $m_A = 200$ GeV at $\sqrt{s} = 0.5$ TeV and $m_A = 400$ GeV at $\sqrt{s} = 1$ TeV. Note the $4t$ channel is not open for the case of $m_A = 200$ GeV. As the parameter $\tan\beta$ is varied from small to intermediate to large values, the dominant Higgs signal comes from the three channels $t\bar{t}t\bar{t}$, $b\bar{b}\chi\chi$, $b\bar{b}b\bar{b}$, respectively. Since the sizes of the signal cross sections depend sensitively on $\tan\beta$, a determination of $\tan\beta$ should be possible throughout $\tan\beta$ ranges where there are substantial signal event rates. In our analyses, we employ the $t\bar{t}t\bar{t}$ signal at low $\tan\beta$ and the $b\bar{b}b\bar{b}$ signal at large $\tan\beta$. For the intermediate $\tan\beta$ values, we combine these two channels.

We first consider the mSUGRA scenario at a $\sqrt{s}$ =1 TeV linear collider. In Fig. 2(a), the 95% C.L. constraints on $\Delta\tan\beta$ for 50 fb^{-1} (solid), 100 fb^{-1} (dashes) and 500 fb^{-1} (dotted) are shown versus $\tan\beta$. We find encouraging results for the $\tan\beta$ determination. For instance, with a luminosity of 100 fb^{-1}, $|\Delta\tan\beta| \approx 3$ or better can be reached at the low value of $\tan\beta$, mainly via the $4t$ channel. At the high value of $\tan\beta$, $|\Delta\tan\beta| \approx 5$ can be reached, mainly via the $4b$ channel, which is better than 15% accuracy.

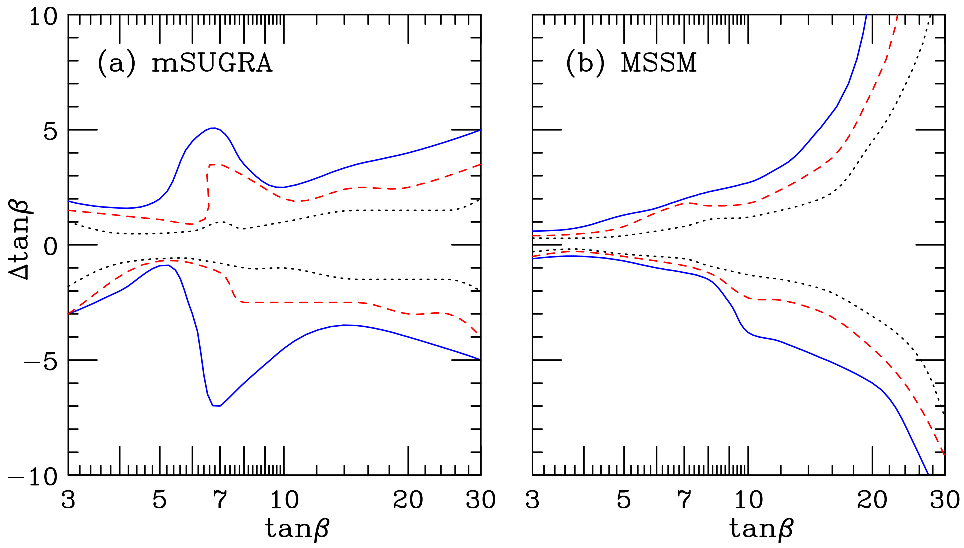

FIGURE 2. Determination of $\tan\beta$ at $\sqrt{s}$ =1 TeV combining both A and H channels; 95% C.L. constraints on the $\tan\beta$ values are shown for 50 fb^{-1} (solid), 100 fb^{-1} (dashes) and 500 fb^{-1} (dotted), (a) in mSUGRA, and (b) in MSSM.

We next consider the MSSM Scenario. For the case with $m_A = 400$ GeV, the constraints on $\tan\beta$ values are shown in Fig. 2(b). We list our $\tan\beta$ constraints in Table 1 based on a 100 fb^{-1} integrated luminosity and compare with the values that we estimate from the results of Ref. [4], where a different statistical procedure of χ^2 was adopted. The results are largely comparable, but our constraints are somewhat stronger, especially for higher values of $\tan\beta$.

TABLE 1. Constraints on values of $\tan\beta$ by 95% C.L. statistical measurement on the cross sections compared with the results estimated from the curves in Ref. [4] based on the $t\bar{b}H^{\pm}$ process.

$\tan\beta$	This analysis	Ref. [4]
3	$2.4 < \tan\beta < 3.6$	$\tan\beta < 5.2$
5	$4.3 < \tan\beta < 6.3$	$3.0 < \tan\beta < 6.0$
10	$6.2 < \tan\beta < 12.7$	$6.5 < \tan\beta$
20	$14 < \tan\beta < 32$	$7.5 < \tan\beta < 90$
30	$18 < \tan\beta < 80$	$8.0 < \tan\beta$

For the mSUGRA scenario, $\tan\beta$ is essentially the only variable after fixing the other soft SUSY breaking parameters. The masses of the H, A Higgs bosons decrease as $\tan\beta$ increases. Thus the corresponding Higgs branching fractions and the production cross sections at a given energy increase with $\tan\beta$, especially for large values. This leads to possible accurate determinations of $\tan\beta$ in mSUGRA, for high values in particular. In contrast, for the MSSM scenario the masses of A and H are independent of $\tan\beta$, and are kept fixed in the analyses. At large $\tan\beta$ values the decay branching fractions and the production cross sections of A or H with $b\bar{b}$ reach a plateau in the MSSM. Consequently the determination of $\tan\beta$ in that range is less effective. The accuracy of $\tan\beta$ determination is generally sufficient to distinguish theories with a low value (~ 2) from a high value (> 30) and thus to provide information on testing certain GUTs scenarios.

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