

# COLLIDER PHENOMENOLOGY FOR SUPERSYMMETRY WITH LARGE $\tan \beta$

Howard Baer<sup>1</sup>, Chih-hao Chen<sup>2</sup>, Manuel Drees<sup>3</sup>, Frank Paige<sup>4</sup>  
and Xerxes Tata<sup>5</sup>

<sup>1</sup>*Department of Physics, Florida State University, Tallahassee, FL 32306 USA*

<sup>2</sup>*Davis Institute for High Energy Physics, University of California, Davis, CA 95616 USA*

<sup>3</sup>*APCTP, 207-43 Cheongryangri-dong, Tongdaemun-gu, Seoul 130-012 Korea*

<sup>4</sup>*Brookhaven National Laboratory, Upton, NY 11973 USA*

<sup>5</sup>*Department of Physics and Astronomy, University of Hawaii, Honolulu, HI 96822 USA*

(February 1, 2008)

## Abstract

If the parameter  $\tan \beta$  of the minimal supersymmetric model is large, then  $b$  and  $\tau$  Yukawa interactions are important. These can significantly modify the masses and decays of sparticles. We describe new calculations which allow a reliable exploration of large  $\tan \beta$  values, and discuss implications for collider experiments. For large values of  $\tan \beta$ , charginos and neutralinos may dominantly decay to  $\tau$ -leptons or  $b$ -quarks. The usual cross sections for multilepton signatures may be greatly reduced, but SUSY may be detectable via new signals involving  $\tau$ 's or  $b$ 's in the final state.

Weak scale supersymmetry [1] is one of the most promising candidates for physics beyond the Standard Model (SM). The minimal supersymmetric model (MSSM) provides a well-motivated framework for investigations of the experimental consequences of weak scale supersymmetry. The MSSM is essentially the supersymmetrized version of the Standard Model (SM), with  $R$ -parity assumed to be conserved. Supersymmetry breaking is incorporated by including soft supersymmetry-breaking interactions consistent with the assumed symmetries. Within the minimal supergravity (mSUGRA) framework, which has been adopted for many phenomenological analyses, the large number of independent soft breaking parameters are related by renormalization group (RG) evolution to universal scalar and gaugino masses ( $m_0$  and  $m_{1/2}$ ) and one universal trilinear coupling ( $A_0$ ), all specified at the scale  $M_X \sim 2 \times 10^{16}$  GeV; these, together with  $\tan\beta = v_u/v_d$  and the sign of the Higgsino mass parameter  $\mu$  completely specify the model.

In many studies of SUSY phenomenology involving cascade decays of sparticles at colliders, only small to moderate values of  $\tan\beta$ , i.e.,  $\tan\beta \sim 1$ –10, have been considered [1]. Partly, this was because event generation programs such as ISAJET [2] did not include all effects of bottom and tau Yukawa couplings. The third generation Yukawa couplings are given by

$$f_t = \frac{gm_t}{\sqrt{2}M_W \sin\beta}, \quad f_b = \frac{gm_b}{\sqrt{2}M_W \cos\beta}, \quad f_\tau = \frac{gm_\tau}{\sqrt{2}M_W \cos\beta}.$$

As  $\tan\beta$  becomes large,  $f_b$  and  $f_\tau$  become large and comparable in strength to  $f_t$ . In the MSSM, the parameter  $\tan\beta$  can range as high as  $\tan\beta \simeq 45$ –50 before running into various theoretical and/or experimental constraints. Such large  $\tan\beta$  values are actually preferred in some  $SO(10)$  GUT models with Yukawa unification.

Large values of  $\tan\beta$  affect SUSY phenomenology and impact upon the search for weak scale supersymmetry at collider experiments in several ways:

- Large  $b$  and  $\tau$  Yukawa couplings contribute negatively to the RG running of the  $\tilde{b}_{L,R}$  and  $\tilde{\tau}_{L,R}$  soft masses. In models with a common scalar mass at some high scale, third generation scalar masses will be driven to lower values than masses for the corresponding first and second generation squarks and sleptons. In addition, left-right mixing of stau and sbottom eigenstates can cause a further reduction in the  $\tilde{\tau}_1$  and  $\tilde{b}_1$  masses.
- It is well known that the large top Yukawa coupling drives the Higgs squared mass  $m_{H_u}^2$  to negative values, resulting in radiative breakdown of electroweak symmetry. At large  $\tan\beta$ , the large  $b$  and  $\tau$  Yukawa couplings drive the other Higgs squared mass  $m_{H_d}^2$  to small or negative values as well. This results [3] overall in a *decrease* in mass for the pseudo-scalar Higgs  $m_A$  relative to its value at small  $\tan\beta$ . Since the values of the heavy scalar and charged Higgs boson masses are related to  $m_A$ , these are also reduced.
- For large values of  $\tan\beta$ ,  $b$  and  $\tau$  Yukawa couplings become comparable in strength to the usual gauge interactions, so that Yukawa interaction contributions to sparticle decay rates are non-negligible and can even dominate. This could manifest itself as lepton non-universality in SUSY events. Also, because of the reduction in masses referred

to above, chargino and neutralino decays to stau, sbottom and various Higgs bosons may be allowed, even if the corresponding decays would be kinematically forbidden for small  $\tan\beta$  values. The reduced stau/sbottom/Higgs masses can also increase sparticle branching ratios to third generation particles via virtual effects. These enhanced decays to third generation particles can radically alter [4] the expected SUSY signatures at colliders.

- Tau Yukawa interactions can alter the mean polarization of the  $\tau$ 's produced in chargino and neutralino decays. This, in turn, alters the energy distribution of the visible decay products of the  $\tau$ , and hence the efficiency with which the  $\tau$  signals can be detected.

These considerations motivated us to begin a systematic exploration of how signals for supersymmetry may be altered if  $\tan\beta$  indeed turns out to be very large. To facilitate this analysis, we have made several new calculations (described below) and incorporated these into ISAJET 7.28. ISAJET allows [5] the simulation of supersymmetry for either a general set of input (weak scale) parameters or for the more restrictive mSUGRA parameter set from which these weak scale parameters are computed. Here, we will only discuss the improvements that we have made in ISAJET to allow a reliable analysis for large values of  $\tan\beta$ .

A first step is to obtain reliable predictions for superpartner and Higgs boson masses as a function of parameters. For both MSSM and mSUGRA parameter sets, we have included bottom squark and tau slepton mixing effects. We found that the pseudoscalar mass  $m_A$ , obtained using the 1-loop effective potential, is unstable by up to factors of two against scale variations for relatively low values of scale choice  $Q \sim M_Z$ . This instability would be presumably corrected by inclusion of 2-loop corrections. We find the choice of scale  $Q \sim \sqrt{m_{\tilde{t}_L} m_{\tilde{t}_R}}$  to empirically yield stable predictions of Higgs boson masses in the RG improved 1-loop effective potential (where we include contributions from all third generation particles and sparticles). This scale choice effectively includes some important two loop effects, and yields predictions for light scalar Higgs boson masses  $m_h$  in close accord with the results of Ref. [6].

We illustrate the  $\tan\beta$  dependence of superpartner and Higgs boson masses in Fig. 1, where we have chosen mSUGRA parameters  $(m_0, m_{1/2}, A_0)=(150,150,0)$  GeV. There is little variation in the mass of the  $\tilde{d}_L$  squark, the  $\tilde{e}_R$  slepton or the neutralino  $\tilde{Z}_1$ . The  $\tilde{t}_1$  and  $\tilde{W}_1$  mass varies mainly at low  $\tan\beta$ . However, there is a significant decrease in the  $\tilde{b}_1$  and  $\tilde{\tau}_1$  masses as  $\tan\beta$  increases. The mass decrease is so severe that for  $\tan\beta \sim 38$ ,  $m_{\tilde{W}_1} > m_{\tilde{\tau}_1}$  so that the two body decays  $\tilde{W}_1 \rightarrow \tilde{\tau}_1 \nu_\tau$  and  $\tilde{Z}_2 \rightarrow \tilde{\tau}_1 \tau$  become kinematically accessible. Being the only allowed two body modes, these dominate chargino and neutralino decays. Even more noteworthy is the drastic decrease in the pseudoscalar Higgs mass  $m_A$ , which drops from  $m_A \sim 400$  GeV at  $\tan\beta = 2$  to less than 40 GeV for  $\tan\beta \sim 47$ . For even larger values of  $\tan\beta$ ,  $m_A^2 < 0$ , so that electroweak symmetry breaking is not correctly obtained. A slightly stronger upper bound on  $\tan\beta$  comes from non-observation of  $Z \rightarrow hA$  events at the  $10^{-4}$  level in experiments at LEP [7]. For these very high values of  $\tan\beta$ , the  $H$  and  $H^\pm$  masses also decrease, so that  $t \rightarrow bH^+$  can occur, potentially in conflict with limits [8] from the CDF experiment. Finally, we note that there is a (hard to see) kink in the  $h$  mass curve at  $\tan\beta = 43$ . Here, the  $H$  and  $h$  masses become equal, and for larger  $\tan\beta$ , these

particles switch roles, so that the light Higgs  $h$  mass decreases along with the curve for the pseudoscalar  $A$ .

The next step is to properly evaluate the various sparticle and Higgs boson branching fractions for large  $\tan\beta$ . We have, therefore, re-calculated the branching fractions for the  $\tilde{g}$ ,  $\tilde{b}_i$ ,  $\tilde{t}_i$ ,  $\tilde{\tau}_i$ ,  $\tilde{\nu}_\tau$ ,  $\tilde{W}_i$ ,  $\tilde{Z}_i$ ,  $h$ ,  $H$ ,  $A$  and  $H^\pm$  particles and sparticles including sbottom and stau mixing as well as effects of  $b$  and  $\tau$  Yukawa interactions. For Higgs boson decays, we use the formulae in Ref. [9]. We have recalculated the decay widths for  $\tilde{g} \rightarrow t\tilde{b}\tilde{W}_i$  and  $\tilde{g} \rightarrow b\tilde{b}\tilde{Z}_i$ . These have been calculated previously by Bartl *et. al.* [10]; our results agree with theirs if we use pole fermion masses to calculate the Yukawa couplings. In ISAJET, we use the running Yukawa couplings evaluated at the scale  $Q = m_{\tilde{g}}$  ( $m_t$ ) to compute decay rates for the gluino ( $\tilde{W}_i, \tilde{Z}_i$ ). This seems a more appropriate choice, and it significantly alters the decay widths when effects of  $f_b$  are important. The  $\tilde{Z}_i \rightarrow \tau\tilde{\tau}\tilde{Z}_j$  and  $\tilde{Z}_i \rightarrow b\tilde{b}\tilde{Z}_j$  decays take place via eight diagrams ( $\tilde{f}_{1,2}$ ,  $\tilde{f}_{1,2}$ ,  $Z$ ,  $h$ ,  $H$  and  $A$  exchanges). We have calculated these decays (neglecting  $b$  and  $\tau$  masses except in the Yukawa couplings and in the phase space integration). We have also computed the widths for decays  $\tilde{W}_i \rightarrow \tilde{Z}_j\tau\nu$  which are mediated by  $W$ ,  $\tilde{\tau}_{1,2}$ ,  $\tilde{\nu}_\tau$  and  $H^\pm$  exchanges.

To illustrate the importance of the Yukawa coupling effects, we show selected branching ratios of the  $\tilde{W}_1$ ,  $\tilde{Z}_2$  and  $\tilde{g}$  in Fig. 2*a-c* respectively. In all frames we take  $\mu > 0$ . Frames *a*) and *b*) are for the mSUGRA case  $(m_0, m_{1/2}, A_0) = (150, 150, 0)$  GeV. For low  $\tan\beta$  we see that the  $\tilde{W}_1 \rightarrow e\nu\tilde{Z}_1$  and  $\tilde{W}_1 \rightarrow \tau\nu\tilde{Z}_1$  branching ratios are very close in magnitude, reflecting the smallness of  $f_\tau$ . For  $\tan\beta \gtrsim 10$ , these branchings begin to diverge, with the branching to  $\tau$ 's becoming increasingly dominant. For  $\tan\beta > 40$ , the two body mode  $\tilde{W}_1 \rightarrow \tilde{\tau}_1\nu$  opens up and quickly dominates. Since this decay is followed by  $\tilde{\tau}_1 \rightarrow \tau\tilde{Z}_1$ , the end product of chargino decays here are almost exclusively tau leptons plus missing energy.

In frame *b*), we see at low  $\tan\beta$  the  $\tilde{Z}_2 \rightarrow e\tilde{e}\tilde{Z}_1$  and  $\tilde{Z}_2 \rightarrow \tau\tilde{\tau}\tilde{Z}_1$  branchings are large ( $\sim 10\%$ ) and equal, again because of the smallness of the Yukawa coupling. Except for parameter regions where the leptonic decays of  $\tilde{Z}_2$  are strongly suppressed,  $\tilde{W}_1\tilde{Z}_2$  production leads to the well known  $3\ell$  ( $= e, \mu$ ) signature for the Tevatron and LHC colliders [1]. As  $\tan\beta$  increases beyond 10, these branchings again diverge, and increasingly  $\tilde{Z}_2 \rightarrow \tau\tilde{\tau}\tilde{Z}_1$  dominates. Also, we see that the  $\tilde{Z}_2 \rightarrow b\tilde{b}\tilde{Z}_1$  branching fraction becomes increasingly dominant for large  $\tan\beta$ . For  $\tan\beta > 40$ ,  $\tilde{Z}_2 \rightarrow \tau\tilde{\tau}_1$  opens up, and becomes quickly close to 100%. Near the edge of parameter space ( $\tan\beta \sim 45$ ), the  $\tilde{Z}_2 \rightarrow \tilde{Z}_1 h$  decay opens up, resulting in a reduction of the  $\tilde{Z}_2 \rightarrow \tau\tilde{\tau}_1$  branching fraction.

Frame *c*) shows several gluino branching fractions for  $(m_0, m_{1/2}, A_0) = (700, 250, 0)$  GeV, for which  $m_{\tilde{g}} \simeq 700$  GeV. For  $\tan\beta \sim 2$ , the  $\tilde{g} \rightarrow t\tilde{t}\tilde{Z}_1$  and  $\tilde{g} \rightarrow t\tilde{b}\tilde{W}_1$  branching fractions dominate the decay. As  $\tan\beta$  increases,  $|\mu|$  decreases so that  $\tilde{g}$  decays into heavier chargino and neutralino states become allowed, and more cascading takes place in the  $\tilde{g}$  decays. We also see from frame *c*) that as  $\tan\beta$  increases, ultimately the  $\tilde{g} \rightarrow b\tilde{b}\tilde{Z}_i$  branching fraction becomes dominant until for very large  $\tan\beta$  the two body mode  $\tilde{g} \rightarrow \tilde{b}_1 b$  opens up. For  $\tan\beta \sim 40$ , the  $\tilde{g} \rightarrow b\tilde{b}\tilde{Z}_i$  branching fraction occurs at 4, 14, 11 and 6% for  $\tilde{Z}_i = \tilde{Z}_1, \tilde{Z}_2, \tilde{Z}_3$  and  $\tilde{Z}_4$ , respectively. We also see from Fig. 2 that for  $\tan\beta \lesssim 10$ , the  $\tau$  and  $b$  Yukawa coupling effects are small, and conclusions from previous SUSY analyses are still valid.

At  $e^+e^-$  colliders, it is possible the  $\tilde{\tau}_1\tilde{\tau}_1$  production could be accessible to experiments, whereas  $\tilde{\mu}\tilde{\mu}$  and  $\tilde{e}\tilde{e}$  would be inaccessible. In this case, SUSY would be revealed as acollinear  $\tau$ -pair events. The energy spectrum of the hadronic decay products of the  $\tau$  lepton depends

on the helicity of the  $\tau$ , so that its measurement could yield information on the left-right mixing of the parent, and hence on  $A_\tau$  and  $\tan\beta$  [11]. For this reason (and also because the detection efficiency for taus at hadron colliders is sensitive to it), we include in ISAJET a calculation of tau polarization resulting from various possible parents:  $\tilde{Z}_i$ ,  $\tilde{W}_i$ ,  $\tilde{\tau}_i$ ,  $\tilde{\nu}_\tau$  and  $H^\pm$ . Exact matrix elements are used for tau lepton decays in ISAJET. Since ISAJET does not include chargino or neutralino spin correlations, an average polarization is computed for three body decays from these sources. This polarization is used in the generation of subsequent decays of the  $\tau$  lepton.

If  $\tilde{W}_1\tilde{W}_1$  pair production is accessible, then for large  $\tan\beta$  a non-universality in  $e/\mu/\tau$  content of signal events might be observed. The angular distribution of taus should make it possible to distinguish between chargino and stau events, even if other signals such as  $\ell + \tau + \cancel{E}_T$  or  $j + \tau + \cancel{E}_T$  are suppressed. Likewise, if  $\tilde{Z}_1\tilde{Z}_2$  is the only reaction accessible, enhanced decays to  $b$ 's or  $\tau$ 's may be evident. Finally, for mSUGRA models with low values of  $\tan\beta$ , the  $H$ ,  $A$  and  $H^\pm$  are expected to be very heavy. An intriguing prospect at large  $\tan\beta$  is that, since the additional Higgs bosons can be quite light, that  $hZ$ ,  $HZ$ ,  $hA$ ,  $HA$  and  $H^\pm H^\mp$  might all be at least kinematically accessible. The neutral Higgs bosons will usually decay to  $b\bar{b}$  pairs, while for the charged Higgs boson, the decay  $H^\pm \rightarrow \tau\nu_\tau$  frequently dominates.

Turning to hadron colliders, we recall that the best bound on gluino and squark masses comes from an analysis of jets +  $\cancel{E}_T$  events [12] at the Fermilab Tevatron; very similar bounds have been obtained from analyses of jets+2 $\ell$  +  $\cancel{E}_T$  events [13]. For  $\tan\beta \lesssim 10$ , the isolated trilepton signal from  $\tilde{W}_1\tilde{Z}_2 \rightarrow 3\ell$  potentially offers the greatest SUSY reach at the integrated luminosity [1] that should be available at the Main Injector. As  $\tan\beta$  grows, we see from Fig. 2 that the branching fraction of  $\tilde{W}_1$  and especially  $\tilde{Z}_2$  into  $e$ 's and  $\mu$ 's diminishes greatly. Thus, the clean  $3\ell$  signal is considerably reduced from its value for low values of  $\tan\beta$  examined in earlier studies. However, a host of new signal channels can potentially be used for large  $\tan\beta$  studies. Event topologies such as  $\ell\tau\tau$ ,  $\ell\bar{\ell}\tau$ ,  $bb\tau$ ,  $b\tau\tau$  and  $3\tau$  (with, possibly, like-sign and like-flavour  $\ell$  or  $\tau$  pairs in the event) are possibilities for Fermilab Tevatron experiments accumulating  $\gtrsim 2 \text{ fb}^{-1}$  of integrated luminosity.

We have calculated the Tevatron signal and background in the  $\ell\tau\tau$  and  $\ell\bar{\ell}\tau$  channels for the mSUGRA point chosen in Fig. 2a and b with  $\tan\beta = 45$ . Already with just basic acceptance cuts, we found the combined signal (17 fb) to be observable at  $5\sigma$  level above SM background (28 fb) provided  $\gtrsim 2.4 \text{ fb}^{-1}$  of integrated luminosity is collected. In our analysis, a  $\tau$  is identified if it is a 1 or 3 isolated charge prong hadronic jet with  $E_T > 15 \text{ GeV}$ ,  $M < 1.8 \text{ GeV}$  and net charge of  $\pm 1$ . Isolated leptons are required to have  $p_T > 10 \text{ GeV}$ ; some  $\ell$ ,  $j$  and  $\cancel{E}_T$  trigger requirements are also imposed. SM backgrounds from  $t\bar{t}$ ,  $W + j$ ,  $Z + j$ ,  $WW$  and  $WZ$  were included in our assessment of the signal, and QCD jets with  $E_T = 15$  ( $\geq 50$ ) GeV were misidentified as  $\tau$ 's 0.5% (0.1%) of the time [14]. These calculations indicate that the  $\ell\tau\tau$  and  $\ell\bar{\ell}\tau$  signals should be observable for some regions of parameter space where the canonical  $3\ell$  signal fails. Hence, we strongly urge our experimental colleagues to keep in mind that SUSY signals at large  $\tan\beta$  might be considerably different from general expectations: *identification of signals with isolated  $\tau$ 's should be a priority for Run 2* [15].

At the CERN LHC, observable SUSY signals at low  $\tan\beta$  values are expected in various multijet plus multilepton plus  $\cancel{E}_T$  channels. For large  $\tan\beta$ , rates for many of these leptonic signals are expected to decrease, but as for the Tevatron, rates for events containing  $b$ -jets

and isolated hadronic  $\tau$ 's should increase, partly due to enhanced production of Higgs bosons  $H$  and  $A$  in gluino and squark cascade decays.

In summary, if  $\tan\beta$  is large, SUSY may manifest itself via events rich in  $\tau$  leptons and  $b$ -jets; signals in conventional leptonic channels may be much reduced! The detection of these novel signals, especially at hadron colliders, could require the development of new algorithms for efficiently identifying isolated  $\tau$  leptons, possibly in events containing several jets.

#### ACKNOWLEDGMENTS

We thank A. Bartl, M. Bisset, D. Castaño and W. Porod for valuable discussions. This research was supported in part by the U. S. Department of Energy under contract numbers DE-FG05-87ER40319, DE-FG03-91ER40674, DE-AC02-76CH00016, and DE-FG-03-94ER40833.

## REFERENCES

- [1] For recent reviews, see H. Baer *et. al.*, hep-ph/9503479, to appear in *Electroweak Breaking and Physics Beyond the Standard Model*, T. Barklow *et. al.*, Editors (World Scientific, to appear); Snowmass 96 Supersymmetry Working Group Report, J. Bagger *et. al.*, hep-ph/9612359 and sub-group reports cited therein.
- [2] F. Paige and S. Protopopescu, in *Supercollider Physics*, p. 41, ed. D. Soper (World Scientific, 1986); H. Baer, F. Paige, S. Protopopescu and X. Tata, in *Proceedings of the Workshop on Physics at Current Accelerators and Supercolliders*, ed. J. Hewett, A. White and D. Zeppenfeld, (Argonne National Laboratory, 1993), hep-ph/9305342.
- [3] M. Drees and M. Nojiri, Nucl. Phys. **B369**, 54 (1992).
- [4] H. Baer, X. Tata and J. Woodside, Phys. Rev. **D42**, 1568 (1990); A. Bartl *et. al.*, Phys. Rev. **D43**, 2214 (1991); H. Baer *et. al.*, Phys. Rev. **D50**, 2148 (1994).
- [5] H. Baer, C-H. Chen, R. Munroe, F. Paige and X. Tata, Phys. Rev. **D51**, 1046 (1995).
- [6] M. Carena, M. Quiros, C.E.M. Wagner, Nucl. Phys. **B461**, 407 (1996); H. Haber, R. Hempfling and A. Hoang, CERN-TH/95-216 (1996), hep-ph/9609331.
- [7] M. Frank in Proceedings of the *International Europhysics Conference on High Energy Physics*, Brussels, Belgium, 1995, J. Lemone, C. Vander Velde and F. Verbeure, Editors (World Scientific, 1996).
- [8] F. Abe *et. al.*, Fermilab preprint 97-058-E (1997), hep-ex/9704003.
- [9] M. Bisset, Ph. D. thesis, Hawaii preprint, UH-511-813-94 (1994).
- [10] A. Bartl, W. Majerotto and W. Porod, Z. Phys. **C64**, 499 (1994); *ibid.* **C68**, 518 (1995) (E).
- [11] M. Nojiri, Phys. Rev. **D51**, 6281 (1995); M. Nojiri, K. Fujii and T. Tsukamoto, Phys. Rev. **D54**, 6756 (1996).
- [12] S. Abachi *et. al.*, Phys. Rev. Lett. **77**, 618 (1995); F. Abe *et. al.*, Fermilab-Pub-97/031-E (1997).
- [13] F. Abe *et. al.*, Phys. Rev. Lett. **76**, 2006 (1996); S. Abachi *et. al.*, Fermilab-Conf-96/254-E (1996).
- [14] M. Hohlmann, Fermilab-Conf-96/330-E (1996).
- [15] For this parameter point, we have also checked that with the cuts of H. Baer *et. al.*, Phys. Rev. **D54**, 5866 (1996) and using  $E_T^c = 100$  GeV, the multijet plus  $\cancel{E}_T$  signal is insensitive to  $\tan\beta$ .

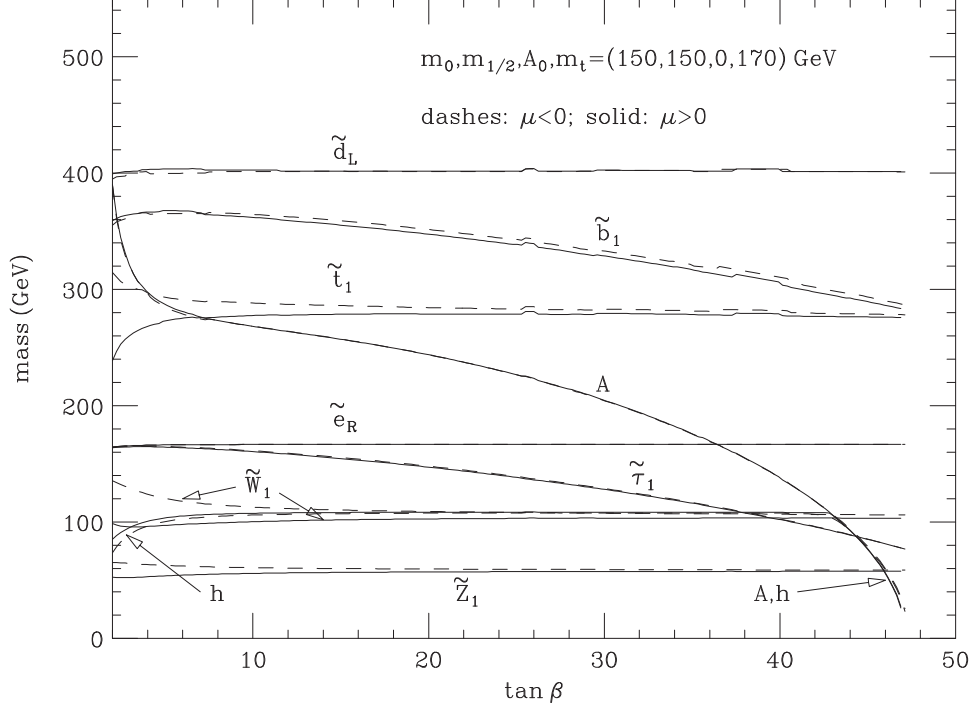


FIG. 1. A plot of various sparticle and Higgs masses versus  $\tan\beta$  for the parameters  $(m_0, m_{1/2}, A_0) = (150, 150, 0)$  GeV, for both signs of the parameter  $\mu$ . We take  $m_t = 170$  GeV.

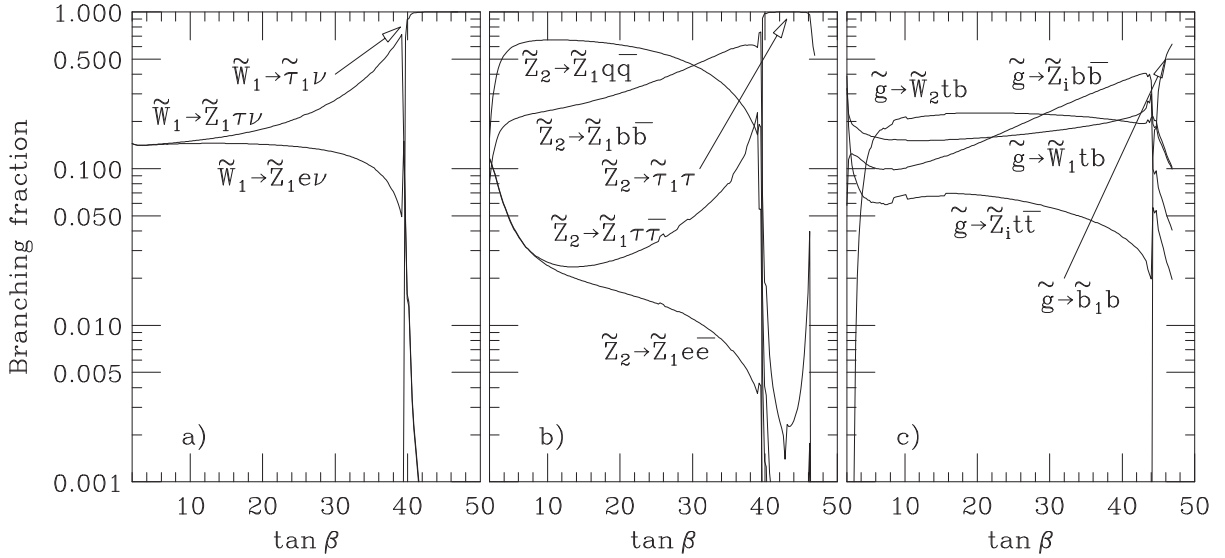


FIG. 2. A plot of sparticle branching fractions versus  $\tan\beta$ . In a) and b), we take the parameters  $(m_0, m_{1/2}, A_0) = (150, 150, 0)$  GeV while c) uses  $(m_0, m_{1/2}, A_0) = (700, 250, 0)$  GeV. In all frames,  $\mu > 0$  and  $m_t = 170$  GeV.