Abstract

An analysis of supersymmetric contributions to $R_b$ in supergravity grand unification with non-universal boundary conditions on soft SUSY breaking in the scalar sector is given. Effects on $R_b$ of Planck scale corrections on gaugino masses are also analysed. It is found that there exist regions of the parameter space where positive corrections to $R_b$ of size $\sim 1\sigma$ can be gotten. The region of the parameter space where enhancement of $R_b$ occurs is identified.

Prediction of the full sparticle spectrum for the maximal $R_b$ case is given.

The analysis has implications for the discovery of supersymmetric particles at colliders.

The Standard Model(SM) predicts a value of $R_b$ of

$$R_b^{SM} = 0.2159, m_t = 175\, \text{GeV}$$  \hspace{1cm} (1)

with $\delta R_b/\delta m_t = -0.0002$. The experimental value of $R_b$ has been in a state of flux over the past couple of years. The experimental analyses in 1994-95 indicated $R_b = 0.2208 \pm 0.0024$. However, more recently $R_b^{exp}$ has drifted downwards, and currently, assuming the value of $R_c$ at its SM value of $R_c = 0.172$, one finds [1]
\[ R_{b}^{exp} = 0.2178 \pm 0.0011 \]  

which is about 1.8\( \sigma \) higher than the SM value. The possibility of a discrepancy between \( R_{b}^{exp} \) and the SM value has aroused much interest, since if valid the result would signal the onset of new physics beyond the SM. There have been several analyses recently to understand the possible origin of potentially large \( R_{b} \) corrections. Specifically supersymmetric contributions to this process have been analysed within MSSM [2–6]. A variety of other suggestions have also been made, such as corrections from additional \( Z' \) and from additional fermion generations.

In this Letter we give the first analysis of the maximal SUSY corrections within supergravity unification [7,8] with radiative breaking of the electroweak symmetry with non-universal boundary conditions [3 [11]] including Planck scale corrections to the gauge kinetic energy function in supergravity [12]. For comparison with the previous work we also give results for the maximum SUSY corrections in MSSM, and in minimal supergravity. One defines \( R_{b} = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons}) \) and the supersymmetric corrections to \( R_{b} \) by

\[ \Delta R_{b}^{SUSY} = R_{b}^{SM}(m_{t}, m_{b}) - R_{b}^{SM}(0, 0) \]

Numerically \( R_{b}^{SM}(0, 0) = 0.2196 \) and \( \nabla_{b}^{SUSY}(m_{t}, m_{b}) \) is given by

\[ \nabla_{b}^{SUSY}(m_{t}, m_{b}) = \frac{\alpha}{2\pi\sin^{2}\theta_{W}} \left( \frac{v_{L}F_{L} + v_{R}F_{R}}{(v_{L})^{2} + (v_{R})^{2}} \right) \]

where \( v_{L} \) is defined by \( v_{L} = -\frac{1}{2} + \frac{1}{3}\sin^{2}\theta_{W} \), and \( v_{R} \) by \( v_{R} = \frac{1}{3}\sin^{2}\theta_{W} \). In supersymmetric models the quantities \( F_{L,R} \) receive one loop contributions from the charged Higgs, the chargino, the neutralinos and the gluino. The most dominant terms are those arising from the chargino exchange and we exhibit these below [3]

\[
\begin{align*}
F_{L,R}^{\tilde{W}} &= (B_{1}^{\alpha\beta}v_{L,R} - \frac{4}{3}\sin^{2}\theta_{W}C_{24}^{\alpha\beta}L_{\alpha}^{L\beta}L_{\beta}^{L\alpha} + M_{\tilde{W}}^{\alpha\beta}L_{\alpha}^{L\beta}A_{\beta}^{L\beta} + M_{\tilde{Z}}^{\alpha\beta}C_{12}^{\alpha\beta}A_{\alpha}^{L\beta}A_{\beta}^{L\alpha} + \frac{1}{2}O_{\alpha\beta}^{L\beta}L_{\alpha}^{L\beta}A_{\alpha}^{L\beta}) \\
&+ (2C_{24}^{\alpha\beta} - M_{\tilde{Z}}^{\alpha\beta}(C_{12}^{\alpha\beta}C_{23}^{\alpha\beta}) - \frac{1}{2})O_{\alpha\beta}^{R\beta}L_{\alpha}^{L\beta}A_{\alpha}^{L\beta} \end{align*}
\]
where $\alpha, \beta(i, j)$ are the chargino(stop) indices. $B_1, C_0, C_{12}$ etc are given in terms of the Passarino-Veltman functions $[13]$ and $\Lambda^{L,R}_{\alpha\alpha}$ are given by

$$\Lambda^L_{\alpha\alpha} = T_{i1}V^*_{\alpha1} - \frac{m_t}{\sqrt{2}M_W \sin \beta}T_{i2}V^*_{\alpha2}$$

$$\Lambda^R_{\alpha\alpha} = -\frac{m_b}{\sqrt{2}M_W \cos \beta}T_{i1}U^*_{\alpha2}$$

where $\tan \beta = \langle H_2 \rangle / \langle H_1 \rangle$ is the ratio of the Higgs VEV’s, $O^{L,R}_{\alpha\beta}$ are defined by

$$O^L_{\alpha\beta} = -\cos^2 \theta_W \delta_{\alpha\beta} + \frac{1}{2} U^*_{\alpha2} U_{\beta2}$$

$$O^R_{\alpha\beta} = -\cos^2 \theta_W \delta_{\alpha\beta} + \frac{1}{2} V^*_{\alpha2} V_{\beta2},$$

where $U_{\alpha\beta}, V_{\alpha\beta}$ are the matrices that diagonalize the chargino mass matrix and $T_{ij}$ is the matrix that diagonalizes the stop mass matrix, i.e,

$$\begin{pmatrix} \tilde{t}_2 \\ \tilde{t}_1 \end{pmatrix} = \begin{pmatrix} \cos \theta_\tilde{t} & \sin \theta_\tilde{t} \\ -\sin \theta_\tilde{t} \cos \theta_\tilde{t} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

To set the stage for the analysis in supergravity unification we discuss first the general features that lead to a large $\Delta R_b$ contribution in SUSY models. The maximum contribution to $\Delta R_b^{SUSY}$ comes from the terms involving light masses in Eq. (5). So a large $\Delta R_b^{SUSY}$ will require light $\tilde{\chi}_1^\pm, \tilde{t}_1$ $[2, 8]$ and for low $\tan \beta$ $M_{\tilde{\chi}_2} \approx M_{\tilde{\chi}_1} \{3\}$ which is possible for $M_2 \approx -\mu$, where $M_2$ is the SU(2) gaugino mass and $\mu$ is the Higgs mixing parameter (for an overview of large $\tan \beta$ case see Ref. $[3]$). Further, $\Lambda^L_{ij}$’s and $O^{L,R}_{ij}$’s that give large weights to the dominant terms in Eq.(5) lead to a large $\Delta R_b^{SUSY}$. Large weights for the dominant terms require a large $\Lambda^L_{11}(\Lambda^L_{12})$ and a large negative $O^L_{11}(O^L_{22})$ implying a large $T_{12}, V_{12}(V_{22})$ and a small $U_{12}(U_{22})$ for $\tan \beta < 1 (\tan \beta > 1)$. We find that for $\tan \beta > 1 \Delta R_b^{SUSY}$ is maximum for $\theta_\tilde{t} \approx -9^o$ and a $\tilde{\chi}_2^\pm$ which is mixture of a large up-higgsino and a gaugino state($|V_{22}| > 0.9, |U_{22}| < 0.1$). Our results are in accord with the analysis of Ref.$[3]$ except for $\theta_\tilde{t}^{opt}$ where our value supports the result of Ref.$[2]$. Our best value of $\Delta R_b$ in MSSM then is $\Delta R_b^{SUSY} \leq 0.0028$ for $\tan \beta \geq 1.16$, comparable with previous determinations $[3, 6]$. Although, as discussed above, one can generate a significant $\Delta R_b^{SUSY}$ correction in MSSM, it is not a priori clear what part of the parameter space, if any, which gives large corrections is compatible with the constraints of grand unification and radiative breaking of the electro-weak symmetry. This is the issue we address in this Letter. The analysis
we carry out includes radiative breaking of the electroweak symmetry, constraints to avoid
color and charge breaking, experimental constraints on the superparticle spectrum and the
$b \rightarrow s + \gamma$ experimental constraint as given by the CLEO Collaboration \[14\]. We also include
the constraint arising from the decay $t \rightarrow \tilde{t}_1 \tilde{\chi}_i^0$ and assume that the branching ratio of the
top decay into stops satisfies $B(t \rightarrow \tilde{t}_1 \tilde{\chi}_i^0) < 0.4$. We discuss first the minimal supergravity
case which is parameterized by $m_0, m_{1/2}, A_0$ and $\tan \beta$, where $m_0$ is the universal scalar
mass, $m_{1/2}$ is the universal gaugino mass, and $A_0$ is the universal trilinear coupling. We find
that the maximal supersymmetric contribution to $R_b$ is $\Delta R_{b^{SUSY}} = 0.0002$ over the entire
parameter space investigated. Our result is in accord with previous analyses \[3\] where it was
also found that the minimal supergravity grand unification does not produce a significant
correction to $R_b$.

The rest of this Letter is devoted to a discussion of $R_b$ in supergravity unification with
non-universal soft SUSY breaking. While the simplest supergravity models are based on
universal soft SUSY breaking, the general framework of the theory \[7,8\] allows for the ex-
istence of non-universalities via a generational dependent Kahler potential \[9\]. The non-
universalities that affect $R_b$ most sensitively are the non-universalities in the Higgs sector
and in the third generation sector. For this reason we shall focus in the present analysis
on the non-universalities in these sectors and assume universality in the remaining sectors.
It has recently been shown that the non-universalities in the Higgs sector and in the third
generation sector are strongly coupled because of the large top Yukawa coupling \[11\]. This
phenomenon will play an important role in our analysis. It is convenient to parameterize
the non-universalities in the Higgs sector by $\delta_{H_1}, \delta_{H_2}$ where $m_{H_1}^2(0) = m_{0}^2(1 + \delta_{H_1})$, and
$m_{H_2}^2(0) = m_{0}^2(1 + \delta_{H_2})$. Similarly we parameterize the non-universalities in the third gen-
eration sector by $\delta_{\tilde{t}_L}$ and $\delta_{\tilde{t}_R}$ where $m_{\tilde{t}_L}^2(0) = m_{0}^2(1 + \delta_{\tilde{t}_L})$, and $m_{\tilde{t}_R}^2(0) = m_{0}^2(1 + \delta_{\tilde{t}_R})$.
We also include in the analysis Planck scale corrections which arise via corrections to the
gauge kinetic energy, i.e., $-\frac{1}{4} f_{\alpha\beta} F_{\mu\nu}^\alpha F^{\beta\mu\nu}$, where $f_{\alpha\beta}$ contains the corrections from the Planck
scale. Planck corrections in $f_{\alpha\beta}$ contribute to gauge coupling unification in supergravity
GUT \[12\] and also generate corrections to the gaugino masses which can be parameterized by \( M_i = \frac{a_i}{a_G} (1 + c' M_P n_i) m_{\frac{1}{2}} \), where \( M \) is the GUT mass, \( M_P \) is the Planck mass, \( c' \) parameterizes the Planck scale correction and \( n_i \) are subgroup indices \[12\]. Thus for the non-minimal model we have the set of parameters \( c', \delta_{H_1}, \delta_{H_2}, \delta_{\tilde{t}_L}, \) and \( \delta_{\tilde{t}_R} \), in addition to the parameters of the minimal model.

In Fig.(1) we display \( R_b \) in the Standard Model and the maximal \( R_b \) that can be achieved in supergravity models with universal and non-universal boundary conditions. As discussed above the supersymmetric contributions for the universal case are always small, maximally \( \Delta R_b^{SUSY} = 0.0002 \). However, for the non-universal case one can get much larger contributions. Thus for \( \mu < 0 \) the maximal \( \Delta R_b^{SUSY} \) is 0.0011, and for \( \mu > 0 \) the maximal \( \Delta R_b^{SUSY} \) is 0.0008. As discussed earlier the maximal \( \Delta R_b^{SUSY} \) is associated with a relatively light chargino \( \tilde{\chi}_1^\pm \) and a relatively light stop \( \tilde{t}_1 \). In Fig.(2) we display the correlation between the light chargino mass and the light stop mass for the maximal \( \Delta R_b^{SUSY} \) for the case \( \mu < 0 \) and a similar analysis holds for the case \( \mu > 0 \). We find that the maximal \( \Delta R_b^{SUSY} \) decreases systematically with increasing mass of the light stop and the light chargino, and one cannot maintain a \( \sim 1\sigma \) correction to the SM value with both the light stop and the light chargino above 100 GeV. Thus if the experimental lower limits on the light chargino and the light stop exceed 100 GeV, then the maximal \( \Delta R_b^{SUSY} \) in supergravity grand unification with inclusion of non-universalities is not in excess of 0.0006. Further, if both the chargino and the light Higgs lie above 100 GeV, then \( \Delta R_b^{SUSY} \) reduces to a value similar to what one has in the minimal case.

We have also computed the full supersymmetric spectrum for some typical cases where \( \Delta R_b^{SUSY} \) is large. We exhibit in Table 1 the mass spectra of the supersymmetric particles which maximize \( R_b \) for 6-discrete sets of chargino-stop masses for the \( \mu < 0 \) case. We find that in all cases \( \delta_{H_2} = -\delta_{H_1} = 1.15 - 1.17 \) and \( \delta_{\tilde{t}_L} \simeq -\delta_{\tilde{t}_R} = 0.25 - 0.35 \). The relative signs of the non-universalities, i.e., opposite signs for \( \delta_{H_1} \) and \( \delta_{H_2} \) and for \( \delta_{\tilde{t}_L} \) and \( \delta_{\tilde{t}_R} \) can be easily understood by looking at the non-universality correction to \( \mu^2 \) and to the stop
masses. The correction to $\mu^2$ is given by \( \Delta \mu^2 = (t^2 - 1)^{-1} (\delta_{H_1} (\delta_{H_2} + \frac{D_0}{2} \delta) t^2) \), where $t = \tan \beta$, $\delta = \delta_{H_2} + \delta_{\tilde{t}_L} + \delta_{\tilde{t}_R}$, and $D_0 = 0$ determines the position of the Landau pole singularity \([11]\). For $m_t = 175$ GeV, $M_G = 10^{16}$ GeV, one has $D_0 = 0.27$. One finds then that a $\delta_{H_1} < 0$ and a $\delta_{H_2} > 0$ gives a negative contribution to $\mu^2$ and makes $|\mu|$ small, which is what is needed as can be seen in Table 1. The correction to $m_{\tilde{t}_L}^2$ and $m_{\tilde{t}_R}^2$ are given by \( \Delta m_{\tilde{t}_L}^2 = m_0^2 (\delta_{\tilde{t}_L} + \frac{D_0}{6} \delta) \), and \( \Delta m_{\tilde{t}_R}^2 = m_0^2 (\delta_{\tilde{t}_R} + \frac{D_0}{3} \delta) \). Here for values of $\delta_{H_2}$, $\delta_{\tilde{t}_L}$ and $\delta_{\tilde{t}_R}$ indicated, e.g. for $\delta_{H_2} = 1.15$, $\delta_{\tilde{t}_L} = -\delta_{\tilde{t}_R} = 0.25$, one finds $\Delta m_{\tilde{t}_L}^2 = 0.11 m_0^2$ and $\Delta m_{\tilde{t}_R}^2 = -0.53 m_0^2$. Since $\tilde{t}_1 \approx \tilde{t}_R$, one finds then that the sign of the non-universalities is such as to split the $\tilde{t}_1 - \tilde{t}_2$ masses, making $\tilde{t}_1$ lighter and $\tilde{t}_2$ heavier. This effect enhances the value of $R_\text{b}$. The analysis shows that most of the corrections to $R_\text{b}$ come from the non-universalities in the scalar sector, and $c'$ is seen not to play a significant role, i.e., the effect of $c'$ on $\Delta R_{\text{SUSY}}^\text{b}$ is less than 5%. In Fig. 3 we present the same analysis as in Fig. 1 but as a function of the top mass. Numerical results for $m_t = 175$ GeV are summarized in Table 2. We note that the upper limit of $R_{\text{b}}^{\text{SUSY}} \leq 0.0011$ in the non-universal case is mostly due to the fact that one needs a high value of $\tan \beta$ to obtain low values of $M_{\tilde{t}_1}, \mu$ and $M_{\tilde{\chi}^\pm}$ using radiative breaking.

Prediction of the sparticle spectrum in the non-universal supergravity model depends on the size of $\Delta R_{\text{SUSY}}^\text{b}$ one assumes. If one requires a sizable $\Delta R_{\text{SUSY}}^\text{b}$ correction, which we take here to imply a correction greater than 0.0006, i.e., greater than $\sim \frac{1}{2} \sigma$, then for both signs of $\mu$ the light Higgs will have a mass below 93 GeV, the light chargino and the light stop will have masses around or below 100 GeV, and the gluino mass will lie below 450 GeV (525 GeV) for $\mu < 0 (\mu > 0)$. Thus the entire range of the light chargino and the light stop masses will be fully accessible at the Tevatron in the Main Injector era. Since the light Higgs lies below 93 GeV in this case, it must be visible at LEP II if it achieves its optimum energy of $\sqrt{s} = 192$ GeV and an integrated luminosity of 500 pb$^{-1}$ or at TeV33 with 5-10 fb$^{-1}$ of integrated luminosity \([16]\). Regarding the gluino essentially the entire gluino mass range for $\mu < 0$ and the range up to 450 GeV for $\mu > 0$ could be probed at TeV33 with an integrated luminosity of 100 fb$^{-1}$ \([16]\). Thus the supergravity model with $\Delta R_{\text{SUSY}}^\text{b} > 0.0006$ can be
completely tested in the Higgs, chargino and stop sectors for both signs of $\mu$ at LEP II and at TeV33. It can also be completely (partially) tested in the gluino sector for $\mu < 0 (\mu > 0)$ at TeV33. If no SUSY particles are seen in the mass ranges indicated, then $\Delta R_b^{SUSY}$ must lie below the level of 0.0006, i.e., below $\sim \frac{1}{2}\sigma$.

In this letter we have given the first analysis of the maximal $R_b$ that can be gotten in supergravity unification with non-universal boundary conditions on the soft SUSY breaking parameters. We find maximal $\Delta R_b^{SUSY} \simeq 1\sigma (0.8\sigma)$ for $\mu < 0 (> 0)$ which is significantly smaller than the maximum value one can get in MSSM but significantly larger than the maximum value achievable in minimal supergravity unification. Thus values of $\Delta R_b^{SUSY}$ in MSSM in excess of 0.0011(0.0008) for $\mu < 0 (\mu > 0)$ are in conflict with the twin constraints of grand unification and radiative breaking of the electro-weak symmetry. The $\Delta R_b$ supergravity correction gives a correction to the LEP value of $\alpha_s$ of $\Delta\alpha_s = -4\Delta R_b$ which amounts to a maximal correction of $\Delta\alpha_s = -0.0044 (-0.0032)$ for $\mu < 0 (\mu > 0)$. Recalling the discrepancy between the LEP value of $\alpha_s$ and the DIS value of $\alpha_s$ [15], one finds that supergravity unification with non-universal soft SUSY breaking can bridge the gap maximally only half way between the LEP value and the DIS value of $\alpha_s$. The analysis makes several predictions on the sparticle spectra which can be tested at colliders in the near future. The analysis on maximal $\Delta R_b^{SUSY}$ presented here is also applicable to the class of string models which have the SM gauge group and no extra generations below the GUT scale.

Acknowledgements: This research was supported in part by NSF grant PHY-96020274.
REFERENCES

[1] The LEP Electroweak Working Group, LEPEWWG/96-01(1996).

[2] M. Boulware and D. Finnel, Phys.Rev. D44, 2054(1991); A. Djouadi, et. al., Nucl.Phys. B349, 48(1991); A. Djouadi, M. Drees and H. Konig, Phys.Rev.D48, 3081(1993).

[3] J.D. Wells, C. Kolda and G. Kane, Phys.Lett.B338, 219 (1994); G. Kane, R. Stuart, and J. Wells, Phys. Lett.354, 350(1995); J. Wells and G. Kane, Phys. Rev. Lett. 76, 869(1996).

[4] D. Garcia, R. Jimenez, and Sola, Phys. Lett. B347, 321(1995); E. Ma and D. Ng, Phys. Rev. D53, 255(1996); P. Bambert, et. al., Phys. Rev. D54, 4275(1996); A. Brignole, F. Feruglio, and F. Zwirner, Z.Phys. C71 679(1996).

[5] P.H. Chankowski and S. Pokorski, Nucl. Phys. B475, 3(1996); M. Drees, R.M. Godbole, M. Guchait, S. Raychaudhuri, and D.P. Roy, Phys. Rev. D54, 5598(1996).

[6] X. Wang, J. Lopez and D.V. Nanopoulos, Phys. Rev. D52 4116(1995); J. Ellis, J. Lopez, D. Nanopoulos, Phys. Lett. B372, 95(1996), and (hep-ph/9612376).

[7] A.H. Chamseddine, R. Arnowitt and P. Nath, Phys. Rev. Lett 29. 970 (1982); R. Barbieri, S. Ferrara and C.A. Savoy, Phys.Lett.B119, 343(1982); L. Hall, J. Lykken and S. Weinberg, Phys. Rev. D27, 2359(1983); P. Nath, R. Arnowitt and A.H. Chamseddine, Nucl. Phys.B227, 121(1983).

[8] For a review see, P.Nath,Arnowitt and A.H.Chamseddine , “Applied N=1 Supergravity” (World Scientific, Singapore, 1984); H.P. Nilles, Phys. Rep. 110, 1 (1984); R. Arnowitt and P. Nath, Proc of VII J.A. Swieca Summer School (World Scientific, Singapore 1994).

[9] S.K. Soni and H.A. Weldon, Phys.Lett.B126,215(1983); V.S. Kaplunovsky and J. Louis, Phys. Lett. B306, 268(1993).

[10] D. Matalliotakis and H.P. Nilles, Nucl. Phys. B435, 115(1995); M. Olechowski and S.
Pokorski, Phys.Lett. B344, 201(1995).

[11] P. Nath and R. Arnowitt, NUB-TH-3151/97; CTP-TAMU-03/97; hep-ph/9701301.

[12] T. Dasgupta, P. Mamales, and P. Nath, Phys.Rev. D52, 5366 (1995); D. Ring, S. Urano, and R. Arnowitt, Phys.Rev. D52, 6623(1995).

[13] G. Passarino and T. Veltman, Nucl. Phys. B160, 151 (1979).

[14] M.S. Alam et al. (CLEO Collaboration), Phys. Rev. Lett. 74, 2885 (1995).

[15] M. Shifman, Mod. Phys. Lett. A10, 605(1995); J. Erler and P. Langacker, Phys. Rev. D52, 441(1995).

[16] D. Amidei and R. Brock, " Report of the tev-2000 Study Group", FERMILAB-PUB-96/082.
TABLES

Table 1: Mass spectra of supersymmetric particles.

Table 2: Maximal $\Delta R_0^{SUSY}$ in models vs experiment. The last four entries are from this analysis.

For other determinations of $\Delta R_0^{SUSY}$ in MSSM see Refs. 3, 4, 6.
FIGURES

FIG. 1. Maximum $R_b$ for various models as a function of the light $m_{\tilde{\chi}_1^\pm}$.

FIG. 2. Maximum $R_b$ as a function of $m_{\tilde{\chi}_1^\pm}$ for different $m_{\tilde{t}_1}$ with non-universalities.

FIG. 3. Maximum $R_b$ as a function of $M_t$ for different models.
FIG. 1
| Particles | M(GeV) for $\chi^t_1 = 87$ | M(GeV) for $\chi^t_1 = 90$ | M(GeV) for $\chi^t_1 = 95$ | M(GeV) for $\chi^t_1 = 87$ | M(GeV) for $\chi^t_1 = 90$ | M(GeV) for $\chi^t_1 = 95$ |
|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| $M_0$     | 480             | 466             | 466             | 485             | 466             | 451             |
| $M_2$     | 112             | 114             | 125             | 133             | 126             | |
| $M_0$     | 418             | 391             | 366             | 372             | 432             |
| $\chi^0$ | 164             | 165             | 171             | 177             | 174             | |
| $\chi^0$ | 56              | 56              | 60              | 64              | 62              | |
| $\chi^0$ | 79              | 80              | 84              | 89              | 88              | |
| $\chi^0$ | 160             | 161             | 168             | 174             | 170             | |
| $\chi^0$ | 126             | 125             | 124             | 128             | 131             | |
| $h$       | 80              | 75              | 75              | 80              | 77              | |
| $H$       | 489             | 476             | 476             | 495             | 521             | |
| $A$       | 487             | 473             | 473             | 492             | 518             | |
| $H^\pm$  | 493             | 480             | 480             | 499             | 525             | |
| $\mu$     | -96             | -94             | -94             | -100            | -104            | |
| $\delta_{A,1(2)}$ | 603 | 584 | 606 | 584 | 606 | 642 |
| $\delta_{R,1(2)}$ | 597 | 578 | 600 | 578 | 600 | 635 |
| $d_L(g=1,2)$ | 607 | 588 | 611 | 588 | 611 | 646 |
| $b_L$     | 389             | 363             | 363             | 395             | 406             | |
| $d_R(g=1,2,3)$ | 597 | 579 | 601 | 579 | 601 | 636 |
| $\delta_{A,1(2,3)}$ | 419 | 394 | 423 | 391 | 424 | 434 |
| $c_L(g=1-2,3)$ | 493 | 478 | 497 | 478 | 497 | 524 |
| $c_R(g=1-2,3)$ | 485 | 471 | 490 | 471 | 490 | 515 |
| $\beta_L(g=1,2,3)$ | 487 | 473 | 492 | 473 | 492 | 519 |
| $\delta_{1,4}$ | 0.255 | 0.327 | 0.25 | 0.255 | 0.23 | 0.295 |
| $\delta_{c,2}$ | -0.255 | -0.327 | -0.25 | -0.255 | -0.23 | -0.295 |
| $\delta_{B,1}$ | -1.17 | -1.17 | -1.17 | -1.17 | -1.17 | -1.17 |
| $\delta_{B,2}$ | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 |
| $\delta_{C}$ | 1.5 | 0.1 | -0.5 | -0.5 | -0.65 | 0.1 |
| $\tan \beta$ | 3.30 | 3.27 | 3.27 | 3.30 | 3.26 | 3.32 |
| $\Delta MSU^R$ | 0.00857 | 0.00998 | 0.00825 | 0.00060 | 0.000778 | 0.000897 |

Table 1
FIG. 2
| Quantity                                      | Numerical Values               |
|-----------------------------------------------|--------------------------------|
| $R_b^{exp} - R_b^{SM}$                        | 0.0019± 0.0011                  |
| $\Delta R_b^{SUSY(max)} (\text{MSSM})$       | 0.0022 (Ref.[5])                |
| $\Delta R_b^{SUSY(max)} (\text{MSSM})$       | 0.0028                          |
| $\Delta R_b^{SUSY(max)} (\text{minimal SUGRA})$ | 0.0002                          |
| $\Delta R_b^{SUSY(max)} (\text{non-univ SUGRA})$ | 0.0011 ($\mu < 0$)            |
| $\Delta R_b^{SUSY(max)} (\text{non-univ SUGRA})$ | 0.0008 ($\mu > 0$)            |

Table 2:
