SUSY CONTRIBUTIONS TO $R_b$ AND TOP DECAY

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I report on a systematic analysis of the MSSM parameter space to obtain the best SUSY solution to the $R_b$ anomaly within the constraint of top quark decay. Phenomenological implications for top decay and direct stop production at the Tevatron collider are discussed.

The LEP value of $R_b = 0.2202 \pm 0.0016$, obtained by assuming the SM value for $R_c$; shows a 2.8σ excess over the SM prediction of $R_b = 0.2157$ [1]. While it is not possible to explain such a large excess via SUSY, we shall consider a SUSY contribution of half this magnitude, i.e.

$$\delta R_b = 0.0022 \pm 0.0004,$$

(1)
as a viable solution to the $R_b$ anomaly [2]. This will bring the theoretical value of $R_b$ within 1.6σ (90% CL) of the LEP data. Moreover the resulting drop in $\alpha_s(M_Z)$,

$$\delta \alpha_s(M_Z) \simeq -4\delta R_b \simeq -0.01,$$

(2)
will bring its estimate from $\Gamma_{Z_{had}}$ in agreement with the DIS value [3]. We shall assume an optimistic upper limit for the SUSY BR of top decay [2],

$$B_s < 0.4,$$

(3)
whose validity will be discussed below.

In the low tan $\beta$ ($\simeq 1$) region of our interest, the SUSY contribution to $R_b$ comes from the lighter stop

$$\tilde{t}_1 = \cos \theta_t \tilde{t}_R - \sin \theta_t \tilde{t}_L,$$

(4)
and the charginos

$$\tilde{W}_{1L} = V_{i1} \tilde{W}_{L} \pm + \tilde{V}_{i2} \tilde{H}_{L} \pm , \quad \tilde{W}_{1R} = U_{i1} \tilde{W}_{R} \pm + U_{i2} \tilde{H}_{R} \pm .$$

(5)
The dominant SUSY contributions to $Z \rightarrow \tilde{t}\tilde{t}$ come from the triangle diagrams involving lighter stop and chargino exchanges, $\tilde{W}_{1L} \tilde{t}_1 \tilde{t}_L$ and $\tilde{t}_1 \tilde{t}_2 \tilde{W}_1$ [4,5]. The $b$ vertices, common to both the diagrams, are dominated by the $b_L \tilde{W}_{1L} \tilde{t}_1 \tilde{R}$ Yukawa coupling

$$\Lambda_{11}^L \sim -m_t \cos \theta_t V_{12}/\sqrt{2} M_W \sin \beta.$$  

(6)
The $Z$ vertex for the former process is determined by the couplings

$$O_{11}^L \sim \cos 2\theta_W + U_{11}^2 \quad \text{and} \quad O_{11}^R \sim \cos 2\theta_W + V_{11}^2,$$

(7)
while it is suppressed for the latter by the $U(1)$ coupling factor $\sim \sin^2 \theta_W$. Thus the large $b$ vertex (6) favours large higgsino component of $\tilde{W}_1$ corresponding to the higgsino dominated region ($|\mu| \ll M_2$); but the large $Z$ vertex (7) favours large gaugino components of $\tilde{W}_1$ corresponding to the gaugino dominated region ($|\mu| \gg M_2$) [5]. As we shall see below, the combined requirements of large $b$ and $Z$ vertices give the best value of $\delta R_b$ for the mixed region ($|\mu| \sim M_2$) corresponding to a $\tilde{\chi}_1$ dominated LSP, rather than the higgsino dominated region favoured by some earlier works [2].

The SUSY BR for top decay ($t \rightarrow \tilde{t}_1 \tilde{Z}_{1,2}$) is governed by the Yukawa couplings of the lighter neutralinos

$$\tilde{Z}_i = N_i \tilde{B} + N_{i2} \tilde{Z} + N_{i3} \tilde{H}_1 + N_{i4} \tilde{H}_2 ,$$

(8)
i.e.

$$C_i^{L(R)} \sim m_t N_{i4} \cos \theta_t (\sin \theta_t)/M_W \sin \beta .$$

(9)
Thus the higgsino dominated region, corresponding to $\tilde{H}_2$ dominated $\tilde{Z}_1$ and $\tilde{Z}_2$, leads to large values of $B_s$. One gets relatively small $B_s$ in the mixed region, where only $\tilde{Z}_2$ is higgsino dominated. Thus the top decay constraint (3) favours the mixed region over the higgsino dominated one as well.

Figure 1 shows the SUSY contributions to $R_b(\delta R_b)$ and top BR ($B_s$) at tan $\beta = 1.1$ for 3 representative points in the $M_2, \mu$ plane [6], i.e.

$$M_2, \mu = (a)150, -40 \quad (b)60, -60 \quad (c)40, -70 \text{GeV}. \quad (10)$$
The higgsino dominated region (a) is seen to give too small a value of \( \delta R_b \) (\( \lesssim .0014 \)) for \( B_s < 0.4 \). On the other hand one gets acceptable solutions to \( \delta R_b \) (1) for \( B_s < 0.4 \) in the mixed region, represented by the points (b) and (c). The best solutions to \( \delta R_b \) and \( B_s \) are obtained for

\[
m_{\tilde{t}_1} \simeq 60 \text{ GeV} \quad \text{and} \quad \theta_t \simeq -15^\circ,
\]

where the stop mass is below the D0 excluded region \( m_{\tilde{t}_1} \not\sim 65 - 88 \text{ GeV} \) [7]. However, the point (c) also gives acceptable values of \( \delta R_b \) for a relatively large stop mass of 90-100 GeV.

Figure 2 shows the contour plots of \( \delta R_b \) and \( B_s \) in the \( M_2, \mu \) plane for \( \tan \beta = 1.1 \) and 1.4, with the optimal choices of stop mass and mixing (11). The points (a, b, c), shown as bullets, are chosen close to the LEP boundary so as to give the best values of \( \delta R_b \) in their respective regions. The higgsino dominated region, represented by the point a, clearly corresponds to a low \( \delta R_b \) along with an excessively large \( B_s \). One sees a 30-40% increase in \( \delta R_b \) along with a similar fall in \( B_s \) as one goes down to the mixed region, represented by the points b and c. Consequently one gets acceptable values of \( \delta R_b \) (1) for \( B_s = 0.3 - 0.4 \) in this region. By far the best solution to \( \delta R_b \) and \( B_s \) is offered by the point c. But it corresponds to \( M_{\tilde{b}} \simeq 160 \text{ GeV}, (M_{\tilde{W}_1} \simeq 80 \text{ GeV}) \), which is just above the Tevatron gluino mass limit of \( M_{\tilde{g}} \geq 150 \text{ GeV} \) [8], represented by the x-axis. On the other hand the point b corresponds to \( M_{\tilde{g}} \simeq 240 \text{ GeV} \) and \( M_{\tilde{W}_1} \simeq 95 \text{ GeV} \), which are safely above the reaches of Tevatron and LEP-2.

The SUSY BR of

\[
B_s = 0.3 - 0.4
\]

has phenomenological implications for the \( t\bar{t} \) events at Tevatron [9,10]. The isolated lepton plus n-jet events with b-tag [9] come from the SM decay of one top (\( t \rightarrow \ell b\nu \)), while the other undergoes SM or SUSY decay

\[
t \rightarrow bW \rightarrow bq^{\prime},
\]

\[
t \rightarrow \tilde{t}_1\tilde{Z}_1 \rightarrow \tilde{Z}_1 c\tilde{Z}_1 q^{\prime}.
\]

The SUSY decay is characterised by a lower detection efficiency (due to the absence of lepton and b) and fewer visible jets, but a larger missing-\( E_T \) (\( E_T \)). They lead to the following differences with respect to the SM prediction [6].

(i) There is a shift of \( \sim 10\% \) (i.e.3-4) of the above \( t\bar{t} \) events from \( \geq 4 \) jets to the 2 jets channel. Such a shift seems to be favoured by the preliminary CDF data [9], but with large uncertainty.

(ii) The detection efficiency and hence the experimental cross-section in the \( \geq 3 \) jets channel are reduced by a factor

\[
(1 - B_s)(1 - B_s/3) = 2/3 - 1/2.
\]

This is disfavoured by the CDF cross-section.

\[
\sigma_t = 7.5 \pm 1.8 \text{ pb}, \quad m_t = 175.6 \pm 9 \text{ GeV}, \quad (16)
\]

which is already larger than \( \sigma_t^{QCD} (175) \simeq 5.5 \text{ pb} \) [11]. But the 1.6\( \sigma \) (90% CL) lower limits of \( \sigma_t \) and \( m_t \) would correspond to an experimental \( \sigma_t (= 4.5 \text{ pb}) \) of \( \sim 1/2 \) the size of the corresponding \( \sigma_t^{QCD} (160) \simeq 9 \text{ pb} \), as required by (14). This is the basis for the \( B_s \) limit (3). It will be easier to satisfy with the D0 cross-section, \( \sigma_t = 5.3 \pm 1.6 \text{ pb} \) [10].

(iii) There is a 50% enhancement of the large transverse mass (\( M_T(\ell\ell) > 120 \text{ GeV} \)) tail of the above \( t\bar{t} \) events. Similarly one expects a \( \sim 25\% \) deficit in the \( t\bar{t} \) events in the dilepton and double b-tagged channels. Although these are \( \leq 1\sigma \) effects for the current Tevatron luminosity of \( \sim 100 \text{ pb}^{-1} \), they will be 2-3\( \sigma \) effects for the \( \sim -1 \text{ fb}^{-1} \) luminosity expected with the main injector run.

Finally, the large stop mass (90–100 GeV) solution for the point c would correspond to the charged current decay \( t_1 \rightarrow b\tilde{W}_1 \). This would lead to a detectable dilepton signal from stop pair production at Tevatron.

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Fig. 1. SUSY contributions to $R_b$ (solid) and the top BR (dashed) are shown as contour plots in stop mass and mixing angle for $M_2, \mu = (a)150, -40(b)60, -60, (c)40, -70$ GeV with $\tan(\beta) = 1.1$.

Fig. 2. SUSY contributions to $R_b$ (dashed) and top BR (dotted) shown as contour plots in the $M_2, \mu$ plane for stop mass (mixing angle) of 60 GeV (-15°), with $\tan(\beta) = (a) 1.1, (b) 1.4$. The boundary of the region $m_{\tilde{t}_1} < M_{\tilde{Z}_1}$ is not shown in (b).