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The decays $\tilde{g} \to \tilde{t}_1\,\bar{b}\,W^-$ and $\tilde{g} \to \tilde{t}_1\bar{c}$ and phenomenological implications in supersymmetric theories

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Abstract: We show that the decay $\tilde{g} \to \tilde{t}_1\,\bar{b}\,W^-$ is important and can even be dominant in the region of parameter space where it is kinematically allowed. We discuss phenomenological implications within the Minimal Supersymmetric Standard Model and models with broken R-parity. We consider the flavour diagonal case as well as a possible mixing between squarks of different generations. In the latter case also the decay $\tilde{g} \to \tilde{t}_1\bar{c}$ is potentially important. We show that the decay $\tilde{g} \to \tilde{t}_1\,\bar{b}\,W^-$ is sensitive to the stop mixing angle. Furthermore we demonstrate that in scenarios with a higgsino-like LSP the gluino decays mainly into final states containing top quarks or a light stop if allowed by kinematics.

Keywords: Supersymmetric Effective Theories, Beyond Standard Model, Supersymmetric Standard Model.

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Contents

1. Introduction

At the Tevatron as well as at the future Large Hadron Collider (LHC) the search for supersymmetric particles is among the main topics of their experimental programs. Here the strongly interacting supersymmetric partners of quarks and gluons, squarks and gluinos, are expected to have the largest cross sections. Their production as well as their decays have therefore been intensively studied in recent years [1, 2, 3].

In these studies it has been assumed that the gluino $\tilde{g}$ decays either into $q\tilde{q}_i$ if kinematically allowed or into $q\bar{q}\tilde{\chi}^0_i$, $q'\bar{q}\tilde{\chi}^\pm_j$ and $g\tilde{\chi}^0_i$ otherwise. Here $\tilde{q}_i$, $\tilde{\chi}^0_i$, $\tilde{\chi}^\pm_j$ denote squarks, neutralinos and charginos, respectively. These decay modes have been used in the searches for gluinos (see e.g. [4] and references therein). However, there exists also the possibility that the gluino decays via a three body decay into the lighter stop, namely: $\tilde{g} \to \tilde{t}_1\, \bar{b}\, W^-$. The necessary mass hierarchy $m_{\tilde{q}}, m_{\tilde{t}_1} + m_t > m_{\tilde{g}} > m_{\tilde{t}_1} + m_W + m_b$ can be obtained e.g. in the minimal supergravity model as will be shown below. In the case that this mass hierarchy is realized in nature there are further gluino decays, violating flavour, into $\tilde{t}_1\bar{c}$. To our knowledge this interesting possibilities have not been treated so far in the literature.

In this paper we discuss the decays $\tilde{g} \to \tilde{t}_1\, \bar{b}\, W^-$ and $\tilde{t}_1\bar{c}$ and possible signatures. Our framework is mainly the Minimal Supersymmetric Standard Model (MSSM) [5] with conserved R-parity. However, we also discuss possible implications of R-parity violation for the signatures of these two decay modes. The paper is organized as follows: in the next section we present our conventions as well as the formulas for the gluino decays. In section 3 we present our numerical results for various scenarios, with and without R-parity. Finally in section 4 we present our conclusions.

2. Conventions and the formulas for the widths

The parameters relevant to our discussions are the soft susy breaking mass parameters for the squarks M_{Q_i}, M_{U_i}, M_{D_i}, the trilinear parameters $A_{t,b}$, the gaugino mass parameters $M_{1,2}$, the gluino mass $m_{\tilde{g}}$, the higgsino mass parameter μ and the ratio of the Higgs vacuum expectation values $\tan\beta = v_2/v_1$. Here i is a generation index.

We give the formulas for complex parameters to be as general as possible although later in the numerical discussions we confine ourselves to real parameters to reduce the numbers of free parameters. It is well known that in the third generation left and right squarks mix due to the presence of the large Yukawa couplings. We give here for completeness the formulas for the mass matrix matrices as well as for the mass-eigenstates. Neglecting a possible generation mixing the mass matrices read as:

$$M^2_{\tilde{q}} = \begin{pmatrix} M^2_{\tilde{q},LL} & M^2_{\tilde{q},RL} \\ M^2_{\tilde{q},LR} & M^2_{\tilde{q},RR} \end{pmatrix} \qquad (q = b, t) \tag{2.1}$$

with

$$\begin{aligned}
M^2_{\tilde{t},LL} &= M^2_{Q,3} + m_t^2 + \left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\cos 2\beta\, m_Z^2 && (2.2)\\
M^2_{\tilde{t},LR} &= \left(M^2_{\tilde{t},RL}\right)^* = m_t(A_t - \mu^*\cot\beta) && (2.3)\\
M^2_{\tilde{t},RR} &= M^2_{U,3} + m_t^2 + \frac{2}{3}\sin^2\theta_W\cos 2\beta\, m_Z^2 && (2.4)\\
M^2_{\tilde{b},LL} &= M^2_{Q,3} + m_b^2 - \left(\frac{1}{2} - \frac{1}{3}\sin^2\theta_W\right)\cos 2\beta\, m_Z^2 && (2.5)\\
M^2_{\tilde{t},LR} &= \left(M^2_{\tilde{t},RL}\right)^* = m_b(A_b - \mu^*\tan\beta) && (2.6)\\
M^2_{\tilde{t},RR} &= M^2_{D,3} + m_b^2 - \frac{1}{3}\sin^2\theta_W\cos 2\beta\, m_Z^2 && (2.7)
\end{aligned}$$

The mass eigenstates $\tilde{q}_i$ are $(\tilde{q}_1, \tilde{q}_2) = (\tilde{q}_L, \tilde{q}_R)\mathcal{R}^{\tilde{q}T}$ with

$$\mathcal{R}^{\tilde{q}} = \begin{pmatrix} e^{i\varphi_{\tilde{q}}}\cos\theta_{\tilde{q}} & \sin\theta_{\tilde{q}} \\ -\sin\theta_{\tilde{q}} & e^{-i\varphi_{\tilde{q}}}\cos\theta_{\tilde{q}} \end{pmatrix}, \tag{2.8}$$

$$\begin{aligned}
\cos\theta_{\tilde{q}} &= \frac{-|M^2_{\tilde{q},LR}|}{\sqrt{|M^2_{\tilde{q},LR}|^2 + (m^2_{\tilde{q}_1} - M^2_{\tilde{q},LL})^2}}, \qquad \sin\theta_{\tilde{q}} = \frac{M^2_{\tilde{q},LL} - m^2_{\tilde{q}_1}}{\sqrt{|M^2_{\tilde{q},LR}|^2 + (m^2_{\tilde{q}_1} - M^2_{\tilde{q},LL})^2}},\\
\varphi_{\tilde{q}} &= \arg(M_{\tilde{q},LR})\,. && (2.9)
\end{aligned}$$

The mass eigenvalues are

$$m^2_{\tilde{q}_{1,2}} = \frac{1}{2}\left((M^2_{\tilde{q},LL} + M^2_{\tilde{q},RR}) \mp \sqrt{(M^2_{\tilde{q},LL} - M^2_{\tilde{q},RR})^2 + 4|M^2_{\tilde{q},LR}|^2}\right). \tag{2.10}$$

The decay $\tilde{g} \to \tilde{t}_1\, \bar{b}\, W^-$ proceeds via top-quark exchange and sbottom exchange as shown in figure 1. The relevant part of the lagrangian is given by:

$$\begin{aligned}
\mathcal{L} = {}& \lambda^a_{rs}\bar{b}_r\left(c_L^{\tilde{b}_i}P_L + c_R^{\tilde{b}_i}P_R\right)\tilde{g}^a\tilde{b}_{i,s} + \lambda^a_{rs}\bar{t}_r\left(c_L^{\tilde{t}_i}P_L + c_R^{\tilde{t}_i}P_R\right)\tilde{g}^a\tilde{t}_{i,s} + \\
& + , C_{tb}W^+_\mu\bar{t}\gamma^\mu b + d_{ij}W^+_\mu\left(i\tilde{b}_i\partial^\mu\tilde{t}^*_j - i\tilde{t}^*_j\partial^\mu\tilde{b}_i\right) + \text{h.c.} && (2.11)
\end{aligned}$$

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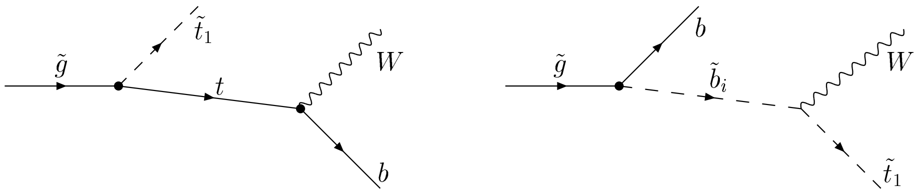

Figure 1: Feynman graphs for the decay $\tilde{g} \to \tilde{t}_1\, \bar{b}\, W^-$.

Here r, s are color indices whereas i, j denote the mass eigenstates. The λ^a_{rs} are the Gell-Mann matrices with normalization $\sum_a \mathrm{Tr}(\lambda^a)^2 = 16$. The couplings are given by:

$$\begin{aligned} c_L^{\tilde{q}_i} &= \frac{g_3 R^{\tilde{q}}_{i2} e^{-i\phi_3/2}}{\sqrt{2}}\,, & c_R^{\tilde{q}_i} &= -\frac{g_3 R^{\tilde{q}}_{i1} e^{i\phi_3/2}}{\sqrt{2}} \qquad (q = b, t)\,, \\ d_{ij} &= \frac{g}{\sqrt{2}} \left(R^{\tilde{t}}_{j1} \right)^* R^{\tilde{b}}_{i1} V_{tb}\,, & C_{tb} &= -\frac{g}{\sqrt{2}} V_{tb}\,, \end{aligned} \tag{2.12}$$

Here ϕ_3 is the phase of the gluino mass parameter M_3 and V_{tb} is the (33) element of the CKM matrix. The partial width can be written as

$$\begin{aligned} 256\pi^3 m_{\tilde{g}}^2 \frac{d\Gamma}{ds dt} = & \frac{|C_{tb}|^2}{(s - m_t^2)^2 + m_t^2 \Gamma_t^2} \times \\ & \times \Bigg[|c_R^{\tilde{t}_1}|^2 \Bigg(\left(m_{\tilde{g}}^2 - m_{\tilde{t}_1}^2 \right) \left(m_b^2 + m_{\tilde{g}}^2 - t \right) + \\ & \qquad + \left(m_{\tilde{t}_1}^2 - m_{\tilde{g}}^2 - s \right) \left(u - m_{\tilde{t}_1}^2 - m_b^2 \right) + \\ & \qquad + \frac{1}{m_W^2} \left(m_{\tilde{t}_1}^2 - m_{\tilde{g}}^2 - s \right) \left(s - m_b^2 - m_W^2 \right) \left(t - m_{\tilde{t}_1}^2 - m_W^2 \right) + \\ & \qquad + \frac{m_{\tilde{g}}^2 - m_{\tilde{t}_1}^2}{m_W^2} \left(s - m_b^2 - m_W^2 \right) \left(m_{\tilde{g}}^2 + m_W^2 - u \right) \Bigg) + \\ & + 2\mathrm{Re} \left(c_R^{\tilde{t}_1} \left(c_L^{\tilde{t}_1} \right)^* \right) m_{\tilde{g}} m_t \left(s - 2m_W^2 + m_b^2 + \frac{(s - m_b^2)^2}{m_W^2} \right) + \\ & + |c_L^{\tilde{t}_1}|^2 \Bigg(m_t^2 \left(m_b^2 + m_{\tilde{g}}^2 - t \right) + \\ & \qquad + \frac{m_t^2}{m_W^2} \left(s - m_b^2 - m_W^2 \right) \left(m_{\tilde{g}}^2 + m_W^2 - u \right) \Bigg) \Bigg] + \\ & + \sum_{j=1}^{2} \mathrm{Re} \Bigg[\frac{d_{j1} C_{tb}}{(s - m_t^2 + i m_t \Gamma_t)(t - m_{\tilde{b}_j}^2 - i m_{\tilde{b}_j} \Gamma_{\tilde{b}_j})} \times \\ & \quad \times \Bigg(c_R^{\tilde{b}_j *} c_R^{\tilde{t}_1} \Bigg(2m_{\tilde{g}}^2 \left(m_b^2 + m_{\tilde{g}}^2 - t \right) - 2m_{\tilde{t}_1}^2 \left(u - m_{\tilde{t}_1}^2 - m_b^2 \right) + \\ & \qquad + \frac{t - m_{\tilde{t}_1}^2 - m_W^2}{m_W^2} \left(2st - m_{\tilde{g}}^2 (s + m_W^2 - m_b^2) - 2m_b^2 m_{\tilde{t}_1}^2 \right) \Bigg) + \\ & \qquad + c_R^{\tilde{b}_j *} c_L^{\tilde{t}_1} \Bigg(2m_{\tilde{g}} m_t \left(m_b^2 + m_{\tilde{g}}^2 - t \right) + \end{aligned}$$

$$
\begin{aligned}
&+ \frac{m_{\tilde g} m_t}{m_W^2}\left(s - m_b^2 - m_W^2\right)\left(t - m_{\tilde t_1}^2 - m_W^2\right)\Bigg) + \\
&+ c_L^{\tilde b_j *} c_R^{\tilde t_1}\Bigg(2 m_{\tilde g} m_b \left(m_{\tilde t_1}^2 - m_{\tilde g}^2 - s\right) - \\
&- \frac{m_{\tilde g} m_b}{m_W^2}\left(s - m_b^2 + m_W^2\right)\left(t - m_{\tilde t_1}^2 - m_W^2\right)\Bigg) + \\
&+ c_L^{\tilde b_j *} c_L^{\tilde t_1}\Bigg(2 m_t m_b \left(m_{\tilde t_1}^2 + m_{\tilde g}^2 - s\right) - \\
&- \frac{m_t m_b}{m_W^2}\left(t - m_{\tilde t_1}^2 - m_W^2\right)\left(m_{\tilde g}^2 + m_W^2 - u\right)\Bigg)\Bigg)\Bigg] + \\
&+ \sum_{i,j=1}^{2}\Bigg[\left((c_R^{\tilde b_i})^* c_R^{\tilde b_j} + (c_L^{\tilde b_i})^* c_L^{\tilde b_j}\right)\left(m_b^2 + m_{\tilde g}^2 - t\right) + \\
&+ \left((c_R^{\tilde b_i})^* c_L^{\tilde b_j} + (c_L^{\tilde b_i})^* c_R^{\tilde b_j}\right) 2 m_b m_{\tilde g}\Bigg] \times \\
&\times \frac{d_{i1}^* d_{j1}\left(2t + 2m_{\tilde t_1}^2 - m_W^2\right)}{(t - m_{\tilde b_i}^2 + i m_{\tilde b_i}\Gamma_{\tilde b_i})(t - m_{\tilde b_j}^2 - i m_{\tilde b_j}\Gamma_{\tilde b_j})} \qquad (2.13)
\end{aligned}
$$

with $\kappa(x,y,z) = \sqrt{(x-y-z)^2 - 4yz}$, $s = (p_{\tilde g} - p_{\tilde t_1})^2$, $t = (p_{\tilde g} - p_b)^2$ and $u = (p_{\tilde g} - p_W)^2$. The total width is obtained by integrating in the range

$$
s_{\min} = (m_W + m_b)^2 \ , \quad s_{\max} = (m_{\tilde g} - m_{\tilde t_1})^2 \ , \qquad (2.14)
$$

$$
\begin{aligned}
t_{\min,\max} &= \frac{m_{\tilde g}^2 + m_{\tilde t_1}^2 + m_W^2 + m_b^2 - s}{2} + \frac{(m_{\tilde g}^2 - m_{\tilde t_1}^2)(m_W^2 - m_b^2)}{2s} \mp \\
&\mp \frac{\kappa(s, m_{\tilde g}^2, m_{\tilde t_1}^2)\kappa(s, m_W^2, m_b^2)}{2s} \qquad (2.15)
\end{aligned}
$$

We will also consider the possibility of $\tilde g \to \tilde t_1 \bar c$. Using the approximate formulas for scalar top - scalar charm mixing as given in [6] we get:

$$
\Gamma(\tilde g \to \tilde t_1 \bar c) = \frac{\alpha_s}{8}|\epsilon|^2 m_{\tilde g}\left(1 - \frac{m_{\tilde t_1}^2}{m_{\tilde g}^2}\right) \qquad (2.16)
$$

with

$$
\begin{aligned}
\epsilon &= \frac{\Delta_L R_{11}^{\tilde t} + \Delta_R R_{21}^{\tilde t}}{m_{\tilde c_L}^2 - m_{\tilde t_1}^2} &(2.17)\\
\Delta_L &= -\frac{g^2}{16\pi^2}\ln\left(\frac{M_X^2}{m_W^2}\right)\frac{V_{tb}^* V_{cb} m_b^2}{2 m_W^2 \cos^2\beta}\left(M_{Q,2}^2 + M_{D,3}^2 + M_{H_1}^2 + A_b^2\right) &(2.18)\\
\Delta_R &= \frac{g^2}{16\pi^2}\ln\left(\frac{M_X^2}{m_W^2}\right)\frac{V_{tb}^* V_{cb} m_b^2}{2 m_W^2 \cos^2\beta} m_t A_b &(2.19)
\end{aligned}
$$

where M_X is a high scale which we assume to be the Planck mass to get a maximal mixing. M_{H_1} is the soft susy breaking Higgs mass term and V_{tb} and V_{cb} are the respective elements of the CKM matrix. Assuming proper electroweak symmetry breaking one gets at tree

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level $m^2_{H_1} = m^2_{A^0}\sin^2\beta - \cos 2\beta m_Z^2/2 - |\mu|^2$, where m_{A^0} is the mass of the pseudoscalar Higgs boson. The formulas for Δ_L and Δ_R are the result of a single step integration of the corresponding RGEs assuming that the CKM matrix is the only source of flavour violation at the GUT scale. In this approximation the parameters $M^2_{Q,2}$, $M^2_{D,3}$, $M^2_{H_1}$, and A_b can be evaluated at any scale because the induced error would be of higher orders. Therefore the expression should be treated as a rough estimate giving the order of magnitude for the mixing. For definiteness we take the corresponding values of the parameters at the electroweak scale. In addition one should note that this approximation is an expansion in $m_b/(m_W\cos\beta)$. Therefore one expects, that for small $\tan\beta$ the quality of this approximation is better than for large $\tan\beta$.

In principle there is also the possibility that the gluino decays according to $\tilde{g}\to\tilde{t}_1\bar{u}$. However, this decay is suppressed by $|V_{ub}/V_{cb}|^2 \simeq 10^{-2}$ in the approximation used above and will therefore be neglected in the following.

Formulas for the decays $\tilde{g}\to q\bar{q}\tilde{\chi}^0_i$, $\tilde{g}\to q'\bar{q}\tilde{\chi}^\pm_k$ and $\tilde{g}\to g\tilde{\chi}^0_i$ can be found in [2]. Formulas for the cross section for gluino pair production as well as associated gluino-squark production including QCD corrections are given in [7] and for associated gluino-gaugino production including QCD corrections in [8].

3. Numerical results

In this section we present our numerical results for three different frameworks: (i) The MSSM without flavour violation. (ii) The MSSM with minimal flavour violation. In this case we assume that at an high energy scale the only source of flavour violation is given by the CKM matrix. RGE running induces in this case non-vanishing flavour violating couplings couplings between squarks, quarks and gluino. However, these couplings have to be small to respect the bounds on flavour changing neutral currents FCNCs [9]. (iii) A scenario where R-parity is broken by bilinear terms [10]. This class of models resemble in many respects also the case of R-parity violation with trilinear terms [11] violating lepton number as will be shown below.

The parameter space relevant for our discussion is given by: $m_{\tilde{q}}, m_{\tilde{t}_1} + m_t > m_{\tilde{g}} > m_{\tilde{t}_1} + m_W + m_b$. In the following we take the parameters freely without referring to a high scale scheme such as minimal supergravity (mSUGRA) or gauge mediated supersymmetry breaking (GMSB). However, we want to stress that this mass hierarchy can be obtained in mSUGRA. This can be seen by plugging the following approximate solutions of the 1-loop RGEs (see e.g. [12] and references therein) in the inequalities above: $m^2_{\tilde{q}} \simeq M_0^2 + 6.2M^2_{1/2}$, $m_{\tilde{g}} \simeq 3.5M_{1/2}$ and $m^2_{\tilde{t}_1} = 0.43M_0^2 + 4.55M^2_{1/2} + m_t^2 + 0.2M_{1/2}A_0 - M_{1/2}\sqrt{2.25M^2_{1/2} + 1.13M_0^2 + 20.2m_t^2}/2$ where $M_{1/2}$, M_0 and A_0 are the universal gaugino mass parameter, the universal scalar mass and the universal trilinear coupling at the GUT scale.

In all numerical examples below we take $m_{\tilde{g}} = 500\,\text{GeV}$, $m_{\tilde{t}_2} = 660\,\text{GeV}$ and for the first two generation squark mass parameters 600 GeV. Moreover, we fix $A_b = -865\,\text{GeV}$. The relevant Standard Model parameters used are: $m_t = 174.3\,\text{GeV}$, $m_b = 4.6\,\text{GeV}$, $\sin^2\theta_W = 0.2315$, $\alpha_s(m_Z) = 0.118$ and $\alpha(m_Z) = 1/127.9$. The parameters $m_{\tilde{t}_1}$, M_{D_3}, $\tan\beta$, μ and

scenario	$m_{\tilde{t}_1}$ [GeV]	M_{D_3} [GeV]	$\tan\beta$	M_2 [GeV]	μ [GeV]	m_{A^0} [TeV]
1	340	580	6	150	500	1.4
2	380	580	6	150	500	1.4
3	340	580	30	450	150	0.86
4	340	550	6	450	150	1.4
5	340	550	6	1100	600	1.8
6	340	580	30	1100	600	0.86

Table 1: Parameters for various scenarios. In all cases we have taken the squark mass parameters of the first two generations equal to 600 GeV, $A_b = -865$ GeV, $m_{\tilde{t}_2} = 660$ GeV and $m_{\tilde{g}} = 500$ GeV. We use the GUT relation for $M_1 = 5\tan^2\theta_W M_2/3$.

M_2 define the various scenarios discussed below and are specified in table 1. We use the GUT inspired relation $M_1 = 5\tan^2\theta_W M_2/3$ to reduce the number of free parameters. We will mainly discuss the dependence on the stop mixing angle as this is the most interesting parameter giving rise to the strongest dependence. The parameter A_t can be calculated from $m_{\tilde{t}_1}$ and $\cos\theta_{\tilde{t}}$ and we have explicitly checked in all examples that $|A_t| \leq 1$ TeV avoiding problems with possible colour breaking minima.

3.1 The MSSM without flavour violation

In this section we discuss the case of the MSSM without any flavour violation. Before starting with numerical details, we want to note that in practice the $\Gamma(\tilde{g} \to \tilde{t}_1 W b)$ is very well approximated (within an error of 1% and below) by considering solely the top-quark exchange in eq. (2.13) except for the parameter region where the lighter sbottom is nearly on-shell. The reason for this is that angular momentum conservation at the W-$\tilde{t}$-$\tilde{b}$ vertex implies that either the $\tilde{t}$-$\tilde{b}$ subsystem or one of the W-boson squark subsystems form a P-wave. This in turn implies that the sbottom exchange is spin suppressed compared to the top-quark exchange.

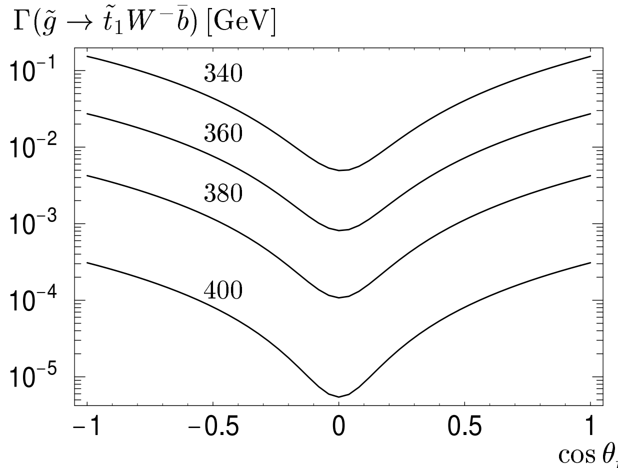

Figure 2: Partial decay width $\Gamma(\tilde{g} \to \tilde{t}_1 W^- \bar{b})$ as a function of $\cos\theta_{\tilde{t}}$ for $m_{\tilde{g}} = 500$ GeV, $\tan\beta = 6$, $m_{\tilde{t}_2} = 660$ GeV, $M_{D_3} = 580$ GeV, $A_b = -865$ GeV, $m_{\tilde{t}_1} = 340$, 360, 380 and 400 GeV.

In figure 2 we show the partial width $\Gamma(\tilde{g} \to \tilde{t}_1 W b)$ as a function of $\cos\theta_{\tilde{t}}$ for $m_{\tilde{t}_1} = 340$, 360, 380 and 400 GeV. One encounters a strong dependence on $\cos\theta_{\tilde{t}}$ independent of the mass. This is due to the fact that the W-boson couples only to left-handed fermions and correspondingly only to left sfermions. In case of $\cos\theta_{\tilde{t}} = 0$ the lighter stop is a pure right state and the decay is only possible due to a "spin-flip" of the exchanged top quark.

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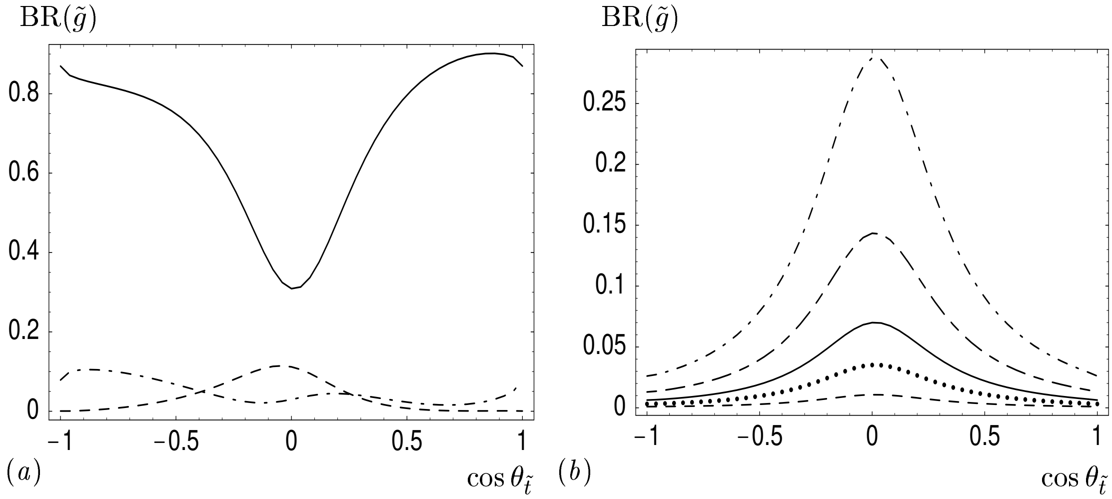

Figure 3: Gluino branching ratios for scenario 1 of table 1. In (a) the lines correspond to $\tilde{g} \to \tilde{t}_1 W^- \bar{b} + \bar{\tilde{t}}_1 W^+ b$ (full line), $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$ (dashed line) and $\tilde{g} \to t\bar{b}\tilde{\chi}^-_1 + \bar{t}b\tilde{\chi}^+_1$ (dashed dotted line). In (b) the lines correspond to $\tilde{g} \to b\bar{b}\tilde{\chi}^0_1$ (dashed line), $\tilde{g} \to b\bar{b}\tilde{\chi}^0_2$ (dotted line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_1$ (full line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_2$ (long short dashed line), and $\tilde{g} \to \sum_{q,q'} q\bar{q}'\tilde{\chi}^-_1 + \bar{q}q'\tilde{\chi}^-_1$ (dashed dotted line). q and q' are summed over u, d, c, s.

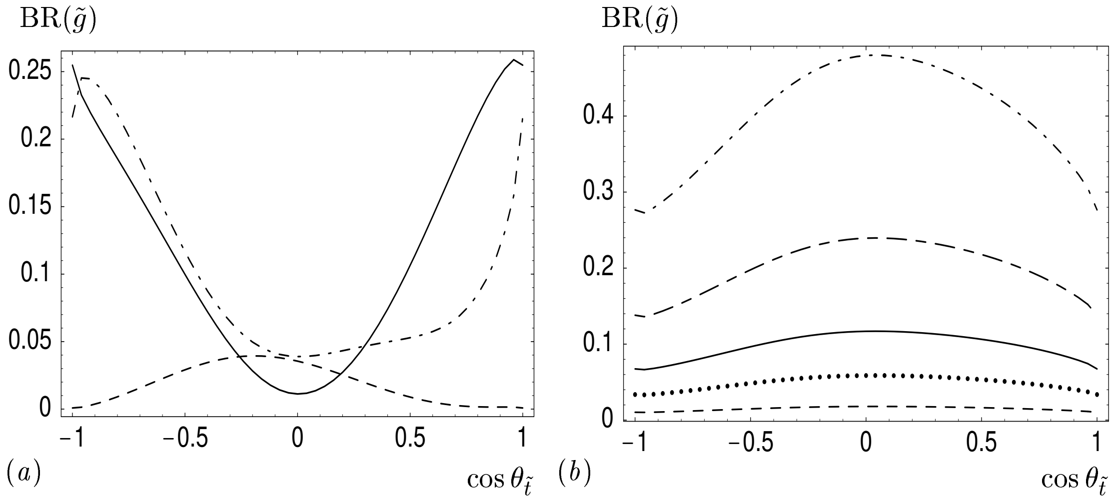

Figure 4: Gluino branching ratios for scenario 2. The parameters are specified in table 1 and in the text. In (a) the lines correspond to $\tilde{g} \to \tilde{t}_1 W^- \bar{b} + \bar{\tilde{t}}_1 W^+ b$ (full line), $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$ (dashed line) and $\tilde{g} \to t\bar{b}\tilde{\chi}^-_1 + \bar{t}b\tilde{\chi}^+_1$ (dashed dotted line). In (b) the lines correspond to $\tilde{g} \to b\bar{b}\tilde{\chi}^0_1$ (dashed line), $\tilde{g} \to b\bar{b}\tilde{\chi}^0_2$ (dotted line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_1$ (full line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_2$ (long short dashed line), and $\tilde{g} \to \sum_{q,q'} q\bar{q}'\tilde{\chi}^-_1 + \bar{q}q'\tilde{\chi}^-_1$ (dashed dotted line). q and q' are summed over u, d, c, s.

In figures 3 and 4 we show the gluino branching ratios as a function of $\cos\theta_{\tilde{t}}$ for $m_{\tilde{t}_1} = 340$ and $380\,\mathrm{GeV}$. In the first example the decay $\tilde{g} \to \tilde{t}_1 W b$ (full line) dominates for most of the range. We want to note that this is not a kinematical effect because $m_{\tilde{t}_1} + m_b + m_W \simeq 2m_t + m_{\tilde{\chi}^0_1} > m_t + m_b + m_{\tilde{\chi}^\pm_1}$. In the second case the decay $\tilde{g} \to \tilde{t}_1 W b$ is about as important as $\tilde{g} \to tb\tilde{\chi}^\pm_1$ despite the fact that it is kinematically suppressed compared to the final states with the lighter chargino.

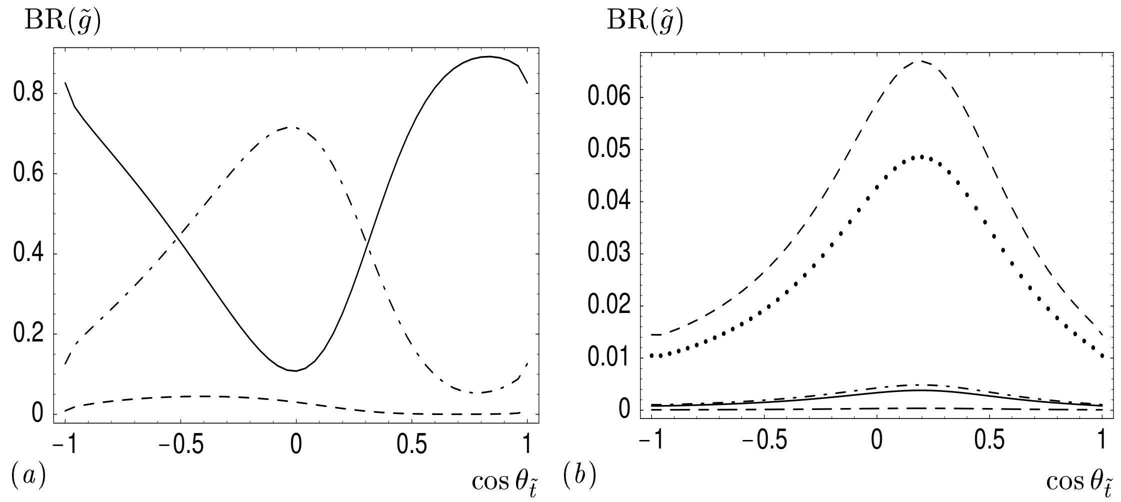

Figure 5: Gluino branching ratios for scenario 3. The parameters are specified in table 1. In (a) the lines correspond to $\tilde{g} \to \tilde{t}_1 W^- \bar{b} + \bar{\tilde{t}}_1 W^+ b$ (full line), $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ (dashed line) and $\tilde{g} \to t\bar{b}\tilde{\chi}_1^- + \bar{t}b\tilde{\chi}_1^+$ (dashed dotted line). In (b) the lines correspond to $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ (dashed line), $\tilde{g} \to b\bar{b}\tilde{\chi}_2^0$ (dotted line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}_1^0$ (full line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}_2^0$ (long short dashed line), and $\tilde{g} \to \sum_{q,q'} q\bar{q}'\tilde{\chi}_1^- + \bar{q}q'\tilde{\chi}_1^-$ (dashed dotted line). q and q' are summed over u, d, c, s.

In both cases the asymmetry in $\cos\theta_{\tilde{t}}$ is mainly due to interference effects in the width for $\tilde{g} \to tb\tilde{\chi}_1^{\pm}$ between stop and sbottom contributions. Together with information from stop production and decays [13] this asymmetry can be used to get information on the sign of $\cos\theta_{\tilde{t}}$. Note that this is asymmetry is not physical in the sense that it can be measured but is given by the structure of the theory implying that the experimental findings together with the consistency of the theory tells one which sign of $\cos\theta_{\tilde{t}}$ is realized in nature. In addition we want to note that the branching ratio for the final state $t\bar{t}\tilde{\chi}_1^0$ is maximal near $\cos\theta_{\tilde{t}} = 0$ because in this case the right stop contributes most. We have checked that the behaviour shown hardly depends on $\tan\beta$.

The situation is somewhat different in scenarios where the $|\mu| \ll |M_{1,2}$ as can be seen in figures 5 and 6. Independent of $\tan\beta$ the channels $\tilde{g} \to \tilde{t}_1 W b$ (full line) and $\tilde{g} \to tb\tilde{\chi}_1^{\pm}$ (dashed dotted) line show a strong dependence on $\cos\theta_{\tilde{t}}$. The reason is that the W-boson couples the left states whereas the higgsino-like chargino couples mainly to the right stop giving rise to the peak of $\tilde{g} \to tb\tilde{\chi}_1^{\pm}$ near $\cos\theta_{\tilde{t}} = 0$. The asymmetry in the sign of $\cos\theta_{\tilde{t}}$ can be traced back to stop-chargino-bottom coupling which reads as $-gR^{\tilde{t}*}_{11}V_{j1} + Y_t R^{\tilde{t}*}_{12}V_{j1}$. Here the relative sign (in case of complex parameters relative phase) between $R^{\tilde{t}}_{11}$ and $R^{\tilde{t}}_{12}$ gives rise to the asymmetry. In both cases the final state $t\bar{t}\tilde{\chi}_1^0$ is less important because the lightest neutralino is to a large extent a down-type higgsino and the decay into the second lightest neutralino, which is mainly a up-type higgsino, is kinematically suppressed. This ordering is beside kinematics also the reason for $\mathrm{BR}(\tilde{g} \to b\bar{b}\tilde{\chi}_1^0) > \mathrm{Br}(\tilde{g} \to b\bar{b}\tilde{\chi}_2^0)$ in these scenarios. We want to stress here that for small $\tan\beta$ the gluino mainly decays into modes containing at least one top or a stop in higgsino-like scenarios as can be seen in figure 6.

The signature of $\tilde{g} \to \tilde{t}_1 W b$ clearly depends on the decay modes of the lighter stop. In the examples studied here $\tilde{t}_1$ decays mainly into $b\tilde{\chi}_1^+$ and the chargino decays further

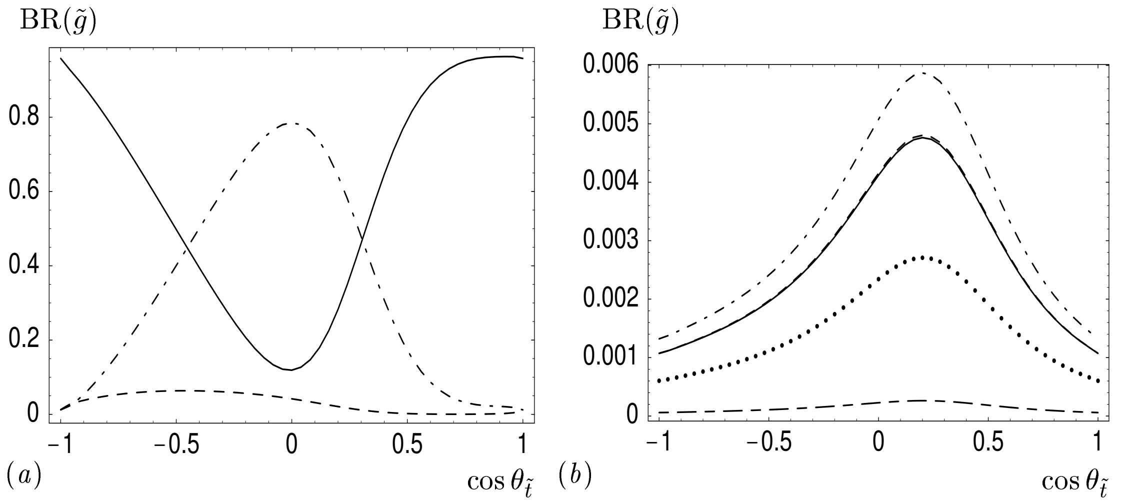

Figure 6: Gluino branching ratios for scenario 4. The parameters are specified in table 1. In (a) the lines correspond to $\tilde{g} \to \tilde{t}_1 W^- \bar{b} + \bar{\tilde{t}}_1 W^+ b$ (full line), $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$ (dashed line) and $\tilde{g} \to t\bar{b}\tilde{\chi}^-_1 + \bar{t}b\tilde{\chi}^+_1$ (dashed dotted line). In (b) the lines correspond to $\tilde{g} \to b\bar{b}\tilde{\chi}^0_1$ (dashed line), $\tilde{g} \to b\bar{b}\tilde{\chi}^0_2$ (dotted line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_1$ (full line), $\tilde{g} \to \sum_q q\bar{q}\tilde{\chi}^0_2$ (long short dashed line), and $\tilde{g} \to \sum_{q,q'} q\bar{q}'\tilde{\chi}^-_1 + \bar{q}q'\tilde{\chi}^-_1$ (dashed dotted line). q and q' are summed over u, d, c, s.

mainly into $\tilde{\chi}^0_1 q'\bar{q}$ and $\tilde{\chi}^0_1 l\nu$. Depending on the parameters chosen, other 2-body decay modes of $\tilde{t}_1$ can become important [13] or higher order decay modes are important in case all the two-body tree-level decay modes are kinematically forbidden [6, 14]. If for example the decay $\tilde{t}_1$ mode is $\tilde{t}_1 \to bW\tilde{\chi}^0_1$ one gets a final state $\tilde{g} \to W^+W^-b\bar{b}\tilde{\chi}^0_1$. The same final state can be obtained via the chain $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1 \to W^+W^-b\bar{b}\tilde{\chi}^0_1$. Similarly, one can show that for all stop final states one finds a gluino decay into a neutralino or a chargino that contains the same particles in the final state. However, in general the energy distribution as well as the angular distribution of the final state particles will be different, which is of course important for gluino searches and measurement of gluino properties.

3.2 The MSSM with flavour violation

Let us now turn to the case that case that the flavour violating coupling gluino–stop–charm-quark is non-zero. As mentioned in section 2 we use the formulas given in [6] to describe the mixing between top-squarks and the left scalar charm. In figure 7 we display the branching ratios for the scenarios 1 – 4 of table 1. We have checked that the used values for the stop–scalar charm mixing are compatible with the bounds given in [9]. One clearly sees that under the assumption of minimal flavour violation for small $\tan\beta$ the branching ratio is at most 1 – 2 %. However, in case of large $\tan\beta$ this decay mode can be potentially large giving branching ratios up to 20%. In case that this decay is important the main consequence is a reduction in the multiplicity of the final state compared to the other gluino decays.

As mentioned in section 2 the used approximation for the description of the scalar-charm–stop mixing is the result of a single step integration of the corresponding RGEs assuming the CKM matrix is the only source of flavour violation at the high scale. There-

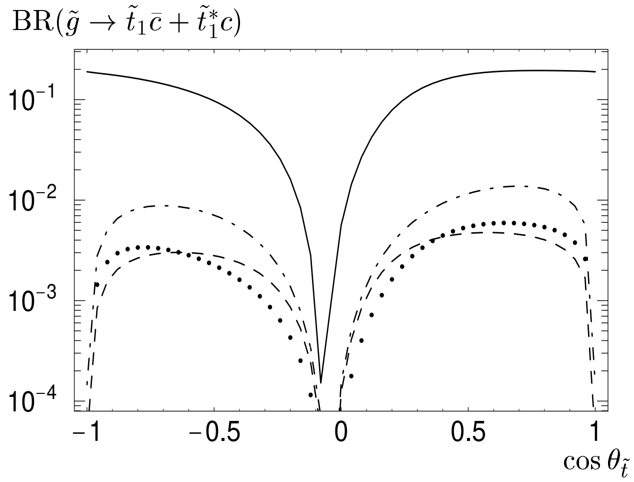

Figure 7: Branching ratio $\tilde{g} \to \tilde{t}_1\bar{c} + \bar{\tilde{t}}_1 c$ as a function of $\cos\theta_{\tilde{t}}$ for scenarios 1 (dashed line), 2 (dashed dotted line), 3 (full line) and 4 (dotted line). The parameters are given in table 1 and in the text.

fore, the results obtained above should not be taken literally but as a demonstration of the expected order of magnitude under the assumptions above. Clearly, additional flavour violation in the squark sector at the high scale could enlarge the branching ratio for the decay $\tilde{g} \to \tilde{t}_1\bar{c}$. However, it cannot be much larger than 20% because otherwise the experimental bounds from low energy physics [9] will be violated. Moreover, in case of additional flavour violation in the squark sector also the $\tilde{g} \to \tilde{t}_1\bar{u}$ could be potentially large because there is not necessarily a suppression of the form $|V_{ub}/V_{cb}|^2$ in such a case.

3.3 R-parity violation

In this section we are going to study scenarios where R-parity is broken. Here we focus on the model where one adds bilinear terms to the superpotential as well as to the soft SUSY breaking part [10]. This class of models can successfully explain the neutrino mass hierarchy as well as the neutrino mixing angles (see [15] and references therein). It also resembles in many respects the models with explicit lepton number violating trilinear couplings λ and λ' [11]. This can easily be seen by a rotation of the superfields where one transforms the bilinear terms in the superpotential into trilinear terms[1] leading to $\lambda_{ijk} \propto \epsilon_i Y^E_{jk}/\mu$ and $\lambda'_{ijk} \propto \epsilon_i Y^D_{jk}/\mu$ [16]. Here Y^E and Y^D are the lepton and down-quark Yukawa couplings and ϵ_i are the parameters of the bilinear terms violating lepton number in the superpotential.

In what follows we study the scenarios discussed above as well as scenarios where the stop is the LSP and the gluino is the next heavier supersymmetric particle. The latter two scenarios can e.g. be obtained in GMSB scenarios [17] or in string scenarios [18]. In the bilinear model the data from neutrino experiments imply relatively small R-parity violating couplings, e.g. $|\epsilon_i/\mu| \simeq O(10^{-3})$ [15] (for a discussion on gluino decays and production in the case of larger R-parity violating parameters see [19, 20] and references therein). This implies that branching ratios for the gluino decays in scenarios 1 – 4 are practically the

[1]This still leaves bilinear terms in the soft SUSY breaking part of the lagrangian.

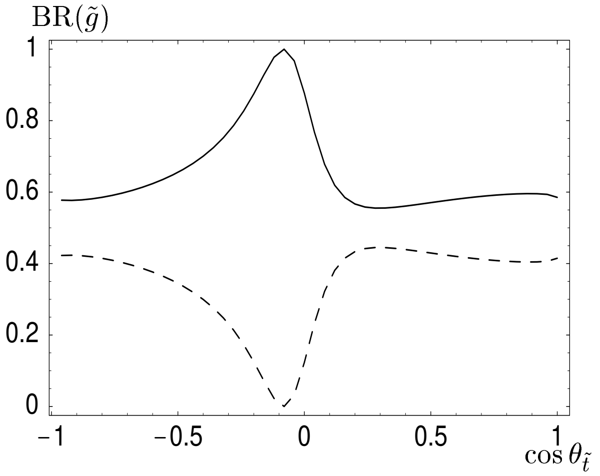

Figure 8: Gluino branching ratio for scenarios 6 of table 1. The lines correspond to $\tilde{g} \to \tilde{t}_1 W^- \bar{b} + \bar{\tilde{t}}_1 W^+ b$ (full line) and $\tilde{g} \to \tilde{t}_1 \bar{c} + \bar{\tilde{t}}_1 c$ (dashed line).

same as in the R-parity conserving case because the R-parity violating decay modes have a branching ratio of at most $O(10^{-7})$. However, now the lightest neutralino will decay further giving rise to additional jets and leptons in the final state [21, 22] compared to the R-parity conserving case (for recent discussions of neutralino decays with trilinear R-parity couplings see e.g. [23]).

In scenarios 5 and 6 of table 1 the stop is the LSP and the gluino is the next to lightest SUSY particle. Scenario 5 is a low $\tan\beta$ scenario whereas scenario 6 is a large $\tan\beta$ scenario. In the case of small $\tan\beta$ the three-body decay dominates practically with 100%. Moreover, the stop decays mainly into a lepton and a b-quark [24]. Thus, the signature is in this case 2 b-jets, a W-boson and a charged lepton. In the case of large $\tan\beta$ also the decay into $\tilde{t}_1 \bar{c}$ becomes important as can be seen in figure 8. The corresponding signature is in this case a b-jet, a c-jet and a charged lepton. Note, that due to the Majoranna nature of the gluino the final state leptons can have same sign which clearly reduces the Standard Model background.

Let us finally comment on the case of gluino LSP. It decays in these scenarios into the following final states: $q\bar{q}\nu_i$ and $q'\bar{q}l^{\pm}$ and $g\nu_i$. For the scenarios discussed above the width of the gluino varies between O(eV) and O(keV). It turns out that in such a case final states containing top-quarks and/or bottom quarks dominate and that the branching ratios are sensitive to neutrino mixing angles similar to the case of neutralinos [22]. This, however, is beyond the scope of this paper and will be discussed in a dedicated paper [25].

4. Conclusions

We have computed and studied the decays $\tilde{g} \to \tilde{t}_1 W^- \bar{b}$ and $\tilde{g} \to \tilde{t}_1 \bar{c}$. We have demonstrated that the branching ratio of $\tilde{g} \to \tilde{t}_1 W^- \bar{b}$ is large and can even be dominant. This decay does not lead to new final states compared to the decays $\tilde{g} \to t\bar{t}\tilde{\chi}^0_i$ or $\tilde{g} \to tb\tilde{\chi}^{\pm}_j$. However, it leads in general to different energy and angular distributions of the final state particle compared to the decays into a chargino or a neutralino. This is clearly of importance for searches of gluinos at present and future colliders. In addition we have worked out possible signatures in models where R-parity is broken by lepton number violating terms.

Acknowledgments

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References

[1] H. Baer, C. Kao and X. Tata, *New signals for gluinos and squarks of supergravity at the Tevatron collider*, *Phys. Rev.* **D 48** (1993) 2978 [hep-ph/9306248];
R.M. Barnett, J.F. Gunion and H.E. Haber, *Discovering supersymmetry with like sign dileptons*, *Phys. Lett.* **B 315** (1993) 349 [hep-ph/9306204];
M. Guchait and D.P. Roy, *Like sign dilepton signature for gluino production at LHC including top quark and Higgs boson effects*, *Phys. Rev.* **D 52** (1995) 133 [hep-ph/9412329];
H. Baer, C.-H. Chen, F. Paige and X. Tata, *Signals for minimal supergravity at the cern large hadron collider II: multilepton channels*, *Phys. Rev.* **D 53** (1996) 6241 [hep-ph/9512383];
I. Hinchliffe, F.E. Paige, M.D. Shapiro, J. Soderqvist and W. Yao, *Precision susy measurements at LHC*, *Phys. Rev.* **D 55** (1997) 5520 [hep-ph/9610544];
A. Datta, A. Datta and M.K. Parida, *Signatures of non-universal soft breaking sfermion masses at hadron colliders*, *Phys. Lett.* **B 431** (1998) 347 [hep-ph/9801242];
I. Hinchliffe and F.E. Paige, *Measurements in gauge mediated susy breaking models at LHC*, *Phys. Rev.* **D 60** (1999) 095002 [hep-ph/9812233];
U. Chattopadhyay, A. Datta, A. Datta, A. Datta and D.P. Roy, *LHC signature of the minimal sugra model with a large soft scalar mass*, *Phys. Lett.* **B 493** (2000) 127 [hep-ph/0008228];
H. Baer, P.G. Mercadante, X. Tata and Y.-l. Wang, *The reach of the Cern large hadron collider for gauge-mediated supersymmetry breaking models*, *Phys. Rev.* **D 62** (2000) 095007 [hep-ph/0004001];
V. Krutelyov, R. Arnowitt, B. Dutta, T. Kamon, P. McIntyre and Y. Santoso, *Prospect for searches for gluinos and squarks at a tevatron tripler*, *Phys. Lett.* **B 505** (2001) 161 [hep-ph/0011253].

[2] A. Bartl, W. Majerotto, B. Mosslacher, N. Oshimo and S. Stippel, *Gluino and squark decays into heavy top quarks*, *Phys. Rev.* **D 43** (1991) 2214;
A. Bartl, W. Majerotto and W. Porod, *Squark and gluino decays for large* $\tan\beta$, *Z. Physik* **C 64** (1994) 499, erratum *ibid.* **C 68** (1994) 518; H. Baer, C.-H. Chen, M. Drees, F. Paige and X. Tata, *Supersymmetry reach of tevatron upgrades: the large* $\tan\beta$ *case*, *Phys. Rev.* **D 58** (1998) 075008 [hep-ph/9802441];
A. Djouadi and Y. Mambrini, *Three-body decays of susy particles*, *Phys. Lett.* **B 493** (2000) 120 [hep-ph/0007174].

[3] Atlas collaboration, *Technical design report 1999*, vol. II, CERN/LHCC/99-15, Atlas TDR 15; SUGRA Working Group collaboration, S. Abel et al., *Report of the Sugra working group for Run II of the Tevatron*, hep-ph/0003154;
CMS collaboration, S. Abdullin et al., *Discovery potential for supersymmetry in CMS*, *J. Phys.* **G 28** (2002) 469.

JHEP05(2002)030

[4] CDF collaboration, T. Affolder et al., *Search for gluinos and squarks using like-sign dileptons in $p\bar{p}$ collisions $\sqrt{s} = 1.8$ TeV*, *Phys. Rev. Lett.* **87** (2001) 251803 [hep-ex/0106061]; *Search for gluinos and scalar quarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV using the missing energy plus multijets signature*, *Phys. Rev. Lett.* **88** (2002) 041801 [hep-ex/0106001].

[5] H.E. Haber and G.L. Kane, *The search for supersymmetry: probing physics beyond the standard model*, *Phys. Rept.* **117** (1985) 75.

[6] K.-I. Hikasa and M. Kobayashi, *Light scalar top at e^+e^- colliders*, *Phys. Rev.* **D 36** (1987) 724.

[7] W. Beenakker, R. Hopker, M. Spira and P.M. Zerwas, *Squark and gluino production at hadron colliders*, *Nucl. Phys.* **B 492** (1997) 51 [hep-ph/9610490].

[8] E.L. Berger, M. Klasen and T.M.P. Tait, *Next-to-leading order SUSY-QCD predictions for associated production of gauginos and gluinos*, *Phys. Rev.* **D 62** (2000) 095014 [hep-ph/0005196].

[9] F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini, *A complete analysis of fcnc and CP constraints in general SUSY extensions of the standard model*, *Nucl. Phys.* **B 477** (1996) 321 [hep-ph/9604387].

[10] M.A. Díaz, J.C. Romão and J.W.F. Valle, *Minimal supergravity with R-parity breaking*, Nucl. Phys. B **524** (1998) 23.

[11] H. Dreiner, *An introduction to explicit R-parity violation*, *Pramana* **51** (1998) 123.

[12] A. Bartl, T. Gajdosik, E. Lunghi, A. Masiero, W. Porod, H. Stremnitzer and O. Vives, *General flavor blind MSSM and CP-violation*, *Phys. Rev.* **D 64** (2001) 076009 [hep-ph/0103324].

[13] H. Baer, J. Sender and X. Tata, *The search for top squarks at the Fermilab Tevatron collider*, *Phys. Rev.* **D 50** (1994) 4517 [hep-ph/9404342];
A. Bartl, H. Eberl, S. Kraml, W. Majerotto and W. Porod, *Production of stop, sbottom and stau at LEP2*, *Z. Physik* **C 73** (1997) 469 [hep-ph/9603410];
A. Bartl, H. Eberl, S. Kraml, W. Majerotto, W. Porod and A. Sopczak, *Search of stop, sbottom, τ-sneutrino and stau at an e^+e^- linear collider with $\sqrt{s} = 0.5$ TeV to 2 TeV*, *Z. Physik* **C 76** (1997) 549 [hep-ph/9701336];
ECFA/DESY LC Physics Working Group collaboration, E. Accomando et al., *Physics with e^+e^- linear colliders*, *Phys. Rept.* **299** (1998) 1 [hep-ph/9705442];
A. Bartl, H. Eberl, S. Kraml, W. Majerotto and W. Porod, *Phenomenology of stops, sbottoms, tau sneutrinos, and staus at an e^+e^- linear collider*, *Eur. Phys. J. direct* **C 6** (2000) 1 [hep-ph/0002115].

[14] W. Porod and T. Wöhrmann, *Higher order top squark decays*, *Phys. Rev.* **D 55** (1997) 2907 [hep-ph/9608472];
W. Porod, *More on higher order decays of the lighter top squark*, *Phys. Rev.* **D 59** (1999) 095009 [hep-ph/9812230];
C. Boehm, A. Djouadi and Y. Mambrini, *Decays of the lightest top squark*, *Phys. Rev.* **D 61** (2000) 095006 [hep-ph/9907428];
A. Djouadi and Y. Mambrini, *Three-body decays of top and bottom squarks*, *Phys. Rev.* **D 63** (2001) 115005 [hep-ph/0011364];
A. Djouadi, M. Guchait and Y. Mambrini, *Scalar top quarks at the run II of the Tevatron in the high $\tan\beta$ regime*, *Phys. Rev.* **D 64** (2001) 095014 [hep-ph/0105108];

A. Bartl, T. Kernreiter and W. Porod, *A CP sensitive asymmetry in the three-body decay $\tilde{t}_1 \to b\tilde{\nu}_\tau \tau^+$*, hep-ph/0202198.

[15] J.C. Romão, M.A. Díaz, M. Hirsch, W. Porod and J.W.F. Valle, *A supersymmetric solution to the solar and atmospheric neutrino problems*, *Phys. Rev.* **D 61** (2000) 071703;
M. Hirsch, M.A. Díaz, W. Porod, J.C. Romão and J.W.F. Valle, *Neutrino masses and mixings from supersymmetry with bilinear R-parity violation: a theory for solar and atmospheric neutrino oscillations*, *Phys. Rev.* **D 62** (2000) 113008 [hep-ph/0004115].

[16] J. Ferrandis, *Basis independent study of supersymmetry without R-parity and the ν_τ mass*, *Phys. Rev.* **D 60** (1999) 095012 [hep-ph/9810371].

[17] S. Raby, *Gauge-mediated SUSY breaking with a gluino LSP*, *Phys. Lett.* **B 422** (1998) 158 [hep-ph/9712254].

[18] V.S. Kaplunovsky and J. Louis, *Model independent analysis of soft terms in effective supergravity and in string theory*, *Phys. Lett.* **B 306** (1993) 269 [hep-th/9303040];
A. Brignole, L.E. Ibáñez and C. Muñoz, *Towards a theory of soft terms for the supersymmetric standard model*, *Nucl. Phys.* **B 422** (1994) 125 [hep-ph/9308271], erratum *ibid.* **B 436** (1994) 747;
A. Brignole, L.E. Ibáñez, C. Muñoz and C. Scheich, *Some issues in soft SUSY breaking terms from dilaton/moduli sectors*, *Z. Physik* **C 74** (1997) 157 [hep-ph/9508258].

[19] H.K. Dreiner and G.G. Ross, *R-parity violation at hadron colliders*, *Nucl. Phys.* **B 365** (1991) 597;
H.K. Dreiner, M. Guchait and D.P. Roy, *Like sign dilepton signature for gluino production at LHC with or without R conservation*, *Phys. Rev.* **D 49** (1994) 3270 [hep-ph/9310291];
M. Guchait and D.P. Roy, *Like sign dilepton signature for R-parity violating susy search at the Tevatron collider*, *Phys. Rev.* **D 54** (1996) 3276 [hep-ph/9603219];
A. Bartl, W. Porod, F. de Campos, M.A. García-Jareño, M.B. Magro, J.W.F. Valle and W. Majerotto, *Signatures of spontaneous breaking of R-parity in gluino cascade decays at LHC*, *Nucl. Phys.* **B 502** (1997) 19 [hep-ph/9612436].

[20] M. Chaichian, K. Huitu and Z.H. Yu, *R parity violation in$(t + \bar{t})\tilde{g}$ production at LHC and Tevatron*, *Phys. Lett.* **B 490** (2000) 87 [hep-ph/0007220];
Y. Xi, W.-G. Ma, L.-H. Wan and J.-a. Yi, *Single gluino production in the R-parity lepton number violating MSSM at the LHC*, *Phys. Rev.* **D 64** (2001) 076006 [hep-ph/0107006].

[21] B. Mukhopadhyaya, S. Roy and F. Vissani, *Correlation between neutrino oscillations and collider signals of supersymmetry in an R-parity violating model*, *Phys. Lett.* **B 443** (1998) 191 [hep-ph/9808265];
S.Y. Choi, E.J. Chun, S.K. Kang and J.S. Lee, *Neutrino oscillations and R-parity violating collider signals*, *Phys. Rev.* **D 60** (1999) 075002 [hep-ph/9903465];
A. Bartl, W. Porod, D. Restrepo, J. Romao and J.W.F. Valle, *Neutralino phenomenology at LEP2 in supersymmetry with bilinear breaking of R-parity*, *Nucl. Phys.* **B 600** (2001) 39 [hep-ph/0007157].

[22] W. Porod, M. Hirsch, J. Romão and J.W.F. Valle, *Testing neutrino mixing at future collider experiments*, *Phys. Rev.* **D 63** (2001) 115004 [hep-ph/0011248].

[23] R.M. Godbole, P. Roy and X. Tata, *Tau signals of R-parity breaking at LEP-200*, *Nucl. Phys.* **B 401** (1993) 67 [hep-ph/9209251];
H.K. Dreiner and P. Morawitz, *Signals for supersymmetry at Hera*, *Nucl. Phys.* **B 428** (1994) 31 [hep-ph/9405253], erratum *ibid.* **574** (2000) 874;

JHEP05(2002)030

H. Baer, C. Kao and X. Tata, *Impact of R-parity violation on supersymmetry searches at the Tevatron*, *Phys. Rev.* **D 51** (1995) 2180 [hep-ph/9410283];
E.A. Baltz and P. Gondolo, *Neutralino decay rates with explicit R-parity violation*, *Phys. Rev.* **D 57** (1998) 2969 [hep-ph/9709445];
F. Borzumati, R.M. Godbole, J.L. Kneur and F. Takayama, *Lightest-neutralino decays in R_p-violating models with dominant λ' and λ couplings*, hep-ph/0108244.

[24] A. Bartl, W. Porod, M.A. García-Jareño, M.B. Magro, J.W.F. Valle and W. Majerotto, *New signatures for a light stop at Lep2 in susy models with spontaneously broken R-parity*, *Phys. Lett.* **B 384** (1996) 151 [hep-ph/9606256];
M.A. Díaz, D.A. Restrepo and J.W.F. Valle, *Two-body decays of the lightest stop in supergravity with and without R-parity*, *Nucl. Phys.* **B 583** (2000) 182 [hep-ph/9908286];
D. Restrepo, W. Porod and J.W.F. Valle, *Broken R-parity, stop decays and neutrino physics*, *Phys. Rev.* **D 64** (2001) 055011 [hep-ph/0104040].

[25] M. Hirsch, W. Porod, J.C. Romão and J.W.F. Valle, in preparation.