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Flavour violating squark and gluino decays at LHC

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We study the effects of squark generation mixing on squark and gluino production and decays at LHC in the Minimal Supersymmetric Standard Model (MSSM) with focus on the mixing between second and third generation squarks. Taking into account the constraints from B-physics experiments we show that various regions in parameter space exist where decays of squarks and/or gluinos into quark flavour violating (QFV) final states can have large branching ratios. Here we consider both fermionic and bosonic decays of squarks. Rates of the corresponding QFV signals, e.g. $pp \to t t \bar{c} \bar{c}$ missing-E_T X, can be significant at LHC (14 TeV).

We find that the inclusion of flavour mixing effects can be important for the search of squarks and gluinos and the determination of the underlying model parameters of the MSSM at LHC.

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1. Introduction

If weak scale supersymmetry (SUSY) is realized in nature, gluinos and squarks will have high production rates for masses up to O(1) TeV at LHC. The main decay modes of gluinos and squarks are usually assumed to be quark-flavour conserving (QFC). However, squark generation mixing can induce quark-flavour violating (QFV) decays of gluinos and squarks. In this article based on [1, 2] we study the effects of squark generation mixing on squark and gluino production and decays at LHC in the general Minimal Supersymmetric Standard Model (MSSM) with focus on the mixing between second and third generation squarks.

2. MSSM with QFV

We take the basic MSSM parameters defined at the scale Q = 1 TeV (except for m_{A^0} being the pole mass) as follows: $\tan\beta, m_{A^0}, M_{1,2,3}, \mu, M^2_{Q\alpha\beta}, M^2_{U\alpha\beta}, M^2_{D\alpha\beta}, T_{U\alpha\beta}$ and $T_{D\alpha\beta}$ (α,β = 1,2,3 = *u,c,t* or *d,s,b*), where $\tan\beta = \langle H_2^0\rangle / \langle H_1^0\rangle$, m_{A^0} is the CP odd Higgs boson mass, $M_{1,2,3}$ are the U(1), SU(2), SU(3) gaugino masses, μ is the higgsino mass parameter, $M^2_{Q\alpha\beta}$ is the left squark soft-SUSY-breaking mass matrix, $M^2_{U\alpha\beta}$ [$M^2_{D\alpha\beta}$] is the right up-type [down-type] squark soft-SUSY-breaking mass matrix, $T_{U\alpha\beta}$ [$T_{D\alpha\beta}$] is the trilinear coupling matrix of up-type [down-type] squarks and the Higgs bosons. The QFV parameters in our study are M^2_{Q23} ($\tilde{c}_L$ - $\tilde{t}_L$ mixing term), M^2_{U23} ($\tilde{c}_R$ - $\tilde{t}_R$ mixing term), T_{U23} ($\tilde{c}_L$ - $\tilde{t}_R$ mixing term) and T_{U32} ($\tilde{c}_R$ - $\tilde{t}_L$ mixing term). We work in the super-CKM basis of squarks. We define the following QFV parameters:

$$\delta^{LL}_{23} \equiv M^2_{Q23} / \sqrt{M^2_{Q22} M^2_{Q33}}, \quad \delta^{uRR}_{23} \equiv M^2_{U23} / \sqrt{M^2_{U22} M^2_{U33}}, \quad \delta^{uRL}_{23} \equiv (v_2/\sqrt{2}) T_{U32} / \sqrt{M^2_{U22} M^2_{Q33}}$$

and $\delta^{uRL}_{32} \equiv (v_2/\sqrt{2}) T_{U23} / \sqrt{M^2_{U33} M^2_{Q22}}$, where $v_2/\sqrt{2} \equiv \langle H_2^0 \rangle$.

3. Constraints on the MSSM parameters

The following constraints are taken into account in our analysis in order to respect experimental and theoretical constraints [3]: constraints from the B-physics experiments (such as $b \to s\gamma$, ΔM_{Bs} and $B_s \to \mu^+\mu^-$), LHC limits on sparticle masses [4], constraints from the LHC data on the Standard Model (SM)-like Higgs boson [5], the experimental limit on SUSY contributions to the electroweak ρ parameter, and vacuum stability conditions on the trilinear couplings. Respecting the LHC limits on squark and gluino masses [4], we assume a gluino mass of about 1 TeV in our analysis.

4. QFV gluino 3-body decays

4.1 QFV Scenario

We take the following scenario as our prototype QFV scenario A (All mass parameters are in GeV.) [2]:

$(M_1, M_2, M_3) = (139, 264, 800)$, $\mu = 1000, \tan\beta = 10, m_{A^0} = 800,\ T_{U\alpha\alpha} = T_{D\alpha\alpha} = 0$ (α =1,2,3),

$(M^2_{Q11}, M^2_{Q22}, M^2_{Q33}) = ((3150)^2, (3100)^2, (3050)^2)$

$(M^2_{U11}, M^2_{U22}, M^2_{U33}) = ((3000)^2, (2200)^2, (2150)^2)$

$(M^2_{D11}, M^2_{D22}, M^2_{D33}) = ((3000)^2, (2990)^2, (2980)^2)$.

In this scenario the physical gluino mass (which is fairly insensitive to the QFV parameters) is $m_{\tilde{g}}$ = 975 GeV for which at tree-level $\sigma(pp \to \tilde{g}\tilde{g}X) = 170$ fb at LHC (14 TeV). Note that $m_{\tilde{c}_R} \cong (M^2_{U22})^{1/2}$ = 2200 GeV and $m_{\tilde{t}_R} \cong (M^2_{U33})^{1/2}$ = 2150 GeV, and that all other squarks have masses of about 3 TeV. We add the $\tilde{c}_R$ - $\tilde{t}_R$ mixing parameter M^2_{U23} ($\sim \delta^{uRR}_{23}$) to this scenario, which can induce large mass-splitting between $\tilde{c}_R$ and $\tilde{t}_R$ resulting in a light $\tilde{u}_1$ (the lightest up-type squark). As all squarks other than $\tilde{u}_1$ are very heavy in this large $\tilde{c}_R$ - $\tilde{t}_R$ mixing scenario, gluino decay is dominated by virtual exchange of $\tilde{u}_1$ which is a strong mixture of $\tilde{c}_R$ and $\tilde{t}_R$. Hence the QFV gluino 3-body decay branching ratio $B(\tilde{g} \to ct\tilde{\chi}^0_1) \equiv B(\tilde{g} \to c\bar{t}\tilde{\chi}^0_1) + B(\tilde{g} \to \bar{c}t\tilde{\chi}^0_1)$ can be very large.

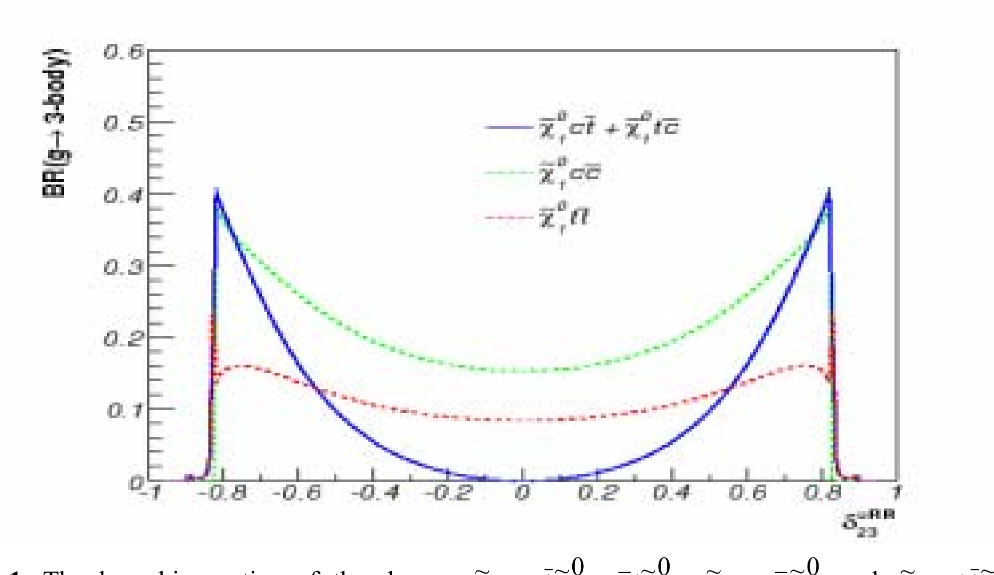

Figure 1: The branching ratios of the decays $\tilde{g} \to c\bar{t}\tilde{\chi}^0_1 + \bar{c}t\tilde{\chi}^0_1$, $\tilde{g} \to c\bar{c}\tilde{\chi}^0_1$ and $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$ as functions of δ^{uRR}_{23} for the scenario A with the other QFV parameters being zero.

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[2] In this scenario we have m_{h^0} =121.1 GeV. We have , however, confirmed that m_{h^0} can be easily pushed up to the LHC "Higgs signal" range just by taking a sizable T_{U33} without changing our final conclusion.

4.2 Impact of squark generation mixing on gluino 3-body decays

In Fig.1 we show the δ_{23}^{uRR} dependence of $B(\tilde{g} \to ct\tilde{\chi}_1^0)$ for the scenario A. We see that the QFV branching ratio $B(\tilde{g} \to ct\tilde{\chi}_1^0)$ can be very large (up to ~40%) for large δ_{23}^{uRR}. This can lead to remarkable QFV signatures at LHC, such as $pp \to \tilde{g}\tilde{g}X \to (t\bar{c}\tilde{\chi}_1^0)(t\bar{c}\tilde{\chi}_1^0)X \to t\,t\; jet\; jet\, E_T^{mis}\, X$, where E_T^{mis} is missing E_T and X contains beam-jets only. We find that the QFV signal rates such as $\sigma(pp \to \tilde{g}\tilde{g}X \to (t\bar{c}\tilde{\chi}_1^0)(t\bar{c}\tilde{\chi}_1^0)X \to t\,t\; jet\; jet\, E_T^{mis}\, X)$ can be significant for large δ_{23}^{uRR} at LHC(14 TeV) [1].

5.QFV squark bosonic decays

5.1 QFV Scenario

We take the following decoupling Higgs scenario as our prototype QFV scenario B (All mass parameters are in GeV.):

$(M_1, M_2, M_3) = (400,800,1000)$, $\mu = 2400, \tan\beta = 20, m_{A^0} = 1500,$

$(M_{Q11}^2, M_{Q22}^2, M_{Q33}^2) = ((2400)^2, (2360)^2, (1450)^2)$

$(M_{U11}^2, M_{U22}^2, M_{U33}^2) = ((2380)^2, (780)^2, (750)^2)$

$(M_{D11}^2, M_{D22}^2, M_{D33}^2) = ((2380)^2, (2340)^2, (2300)^2)$

with all of $T_{U\alpha\alpha}$ and $T_{D\alpha\alpha}$ being zero, except T_{U33} = -2160.

This is a decoupling Higgs scenario with a large top-trilinear-coupling T_{U33} (i.e. large $\tilde{t}_L$ - $\tilde{t}_R$ mixing term). In this scenario the physical masses of gluino and the lightest MSSM Higgs boson h^0 are $m_{\tilde{g}}$ = 1141 GeV, m_{h^0} = 125.5 GeV, respectively. These masses are fairly insensitive to the QFV parameters. Note that in our decoupling Higgs scenario the h^0 is indeed SM-like and its mass m_{h^0} = 125.5 GeV is in the LHC "Higgs signal" range 123 GeV < m_{h^0} < 129GeV allowing for experimental and theoretical uncertainties [5, 6]. We add the $\tilde{c}_R$ - $\tilde{t}_R$ mixing parameter $M_{U23}^2 (\sim \delta_{23}^{uRR})$ to this scenario, which can induce large mass-splitting between $\tilde{c}_R$ and $\tilde{t}_R$ resulting in two mass eigenstates $\tilde{u}_1$ and $\tilde{u}_2$ with a large mass difference. Here note that $m_{\tilde{c}_R} \cong (M_{U22}^2)^{1/2}$ = 780 GeV and $m_{\tilde{t}_R} \cong (M_{U33}^2)^{1/2}$ = 750 GeV. Hence $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ could be sizable for large δ_{23}^{uRR}. Moreover, in this large $\tilde{t}_L$ - $\tilde{t}_R$ and $\tilde{c}_R$ - $\tilde{t}_R$ mixing scenario, we have $\tilde{u}_{1,2} \sim \tilde{c}_R + \tilde{t}_R (+\tilde{t}_L)$ and $h^0 \sim$ Re(H_2^0) and hence $\tilde{u}_1$-$\tilde{u}_2$-h^0 coupling can be large due to the large $\tilde{t}_L$ - $\tilde{t}_R$ - H_2^0 coupling T_{U33} (= -2160 GeV). This can leads to large QFV branching ratios $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ and $B(\tilde{u}_1 \to c/t\, \tilde{\chi}_1^0)$ and hence large $B(\tilde{u}_2 \to \tilde{u}_1 h^0 \to c/t\, h^0\, \tilde{\chi}_1^0)$.

5.2 Impact of squark generation mixing on squark bosonic decays

In Fig.2 we show the δ_{23}^{uRR} dependence of the QFV branching ratio $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ for the scenario B. It can be very large (up to ~ 47%) for large $\tilde{c}_R$ - $\tilde{t}_R$ mixing parameter δ_{23}^{uRR}.

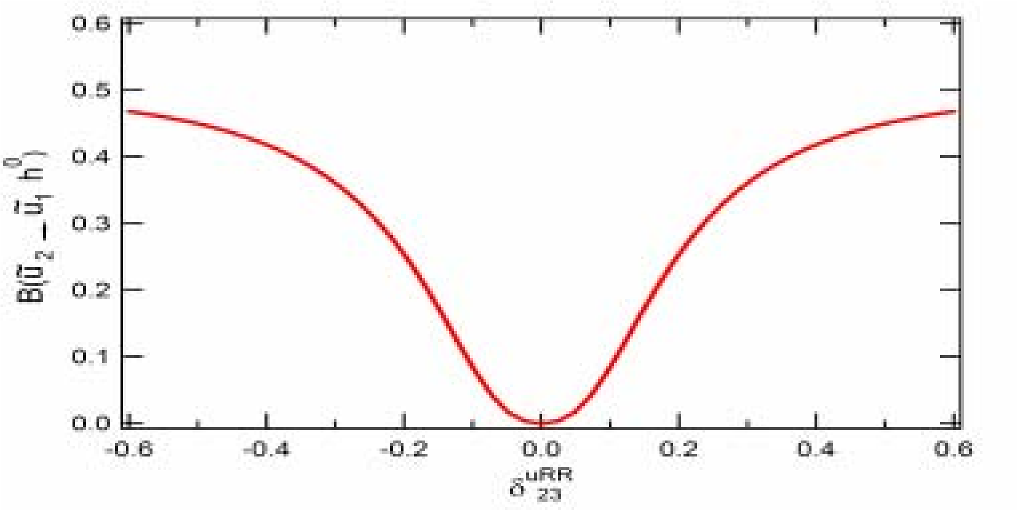

Figure 2: δ_{23}^{uRR} dependence of the QFV branching ratio $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ for the scenario B.

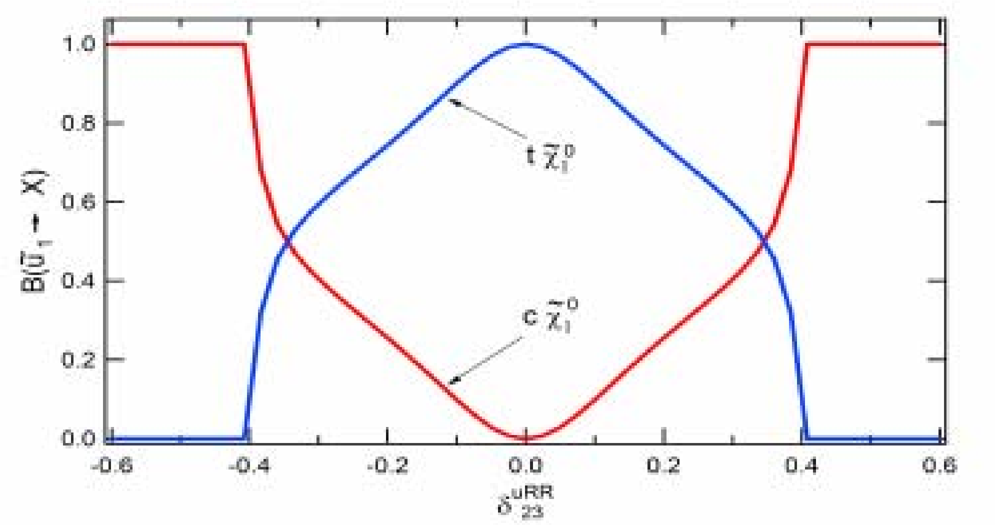

Figure 3: δ_{23}^{uRR} dependence of the QFV branching ratios $B(\tilde{u}_1 \to c/t\ \tilde{\chi}_1^0)$ for the scenario B.

In Fig.3 we show δ_{23}^{uRR} dependence of the QFV branching ratios $B(\tilde{u}_1 \to c/t\ \tilde{\chi}_1^0)$ for the scenario B. They can be very large simultaneously for sizable δ_{23}^{uRR}, which can lead to large QFV effect.

We have also obtained a similar result for δ_{23}^{uRL} ($\tilde{c}_R$ - $\tilde{t}_L$ mixing parameter) dependence of the QFV branching ratios $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ and $B(\tilde{u}_1 \to c/t\ \tilde{\chi}_1^0)$. In Fig.4 we show the δ_{23}^{uRL}

dependence of $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ for the scenario B with $\delta_{23}^{uRR} = 0.32$ and $\delta_{23}^{LL} = 0.015$. It can be very large (up to ~50%) for large negative δ_{23}^{uRL}. The increase of $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ with decrease of δ_{23}^{uRL} ($\sim T_{U32}$) is due to the fact that the contributions of T_{U33} and T_{U32} couplings to the $\tilde{u}_1$-$\tilde{u}_2$-h^0 coupling interfere with each other destructively (constructively) for $T_{U32} > 0$ ($T_{U32} < 0$).

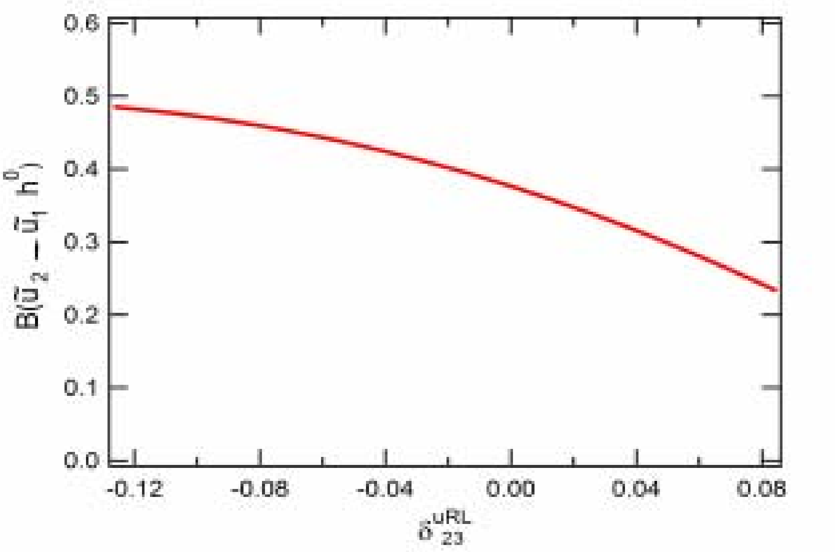

Figure 4: δ_{23}^{uRL} dependence of $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ for the scenario B with δ_{23}^{uRR} = 0.32 and δ_{23}^{LL} = 0.015.

These QFV decays can result in remarkable QFV signatures with a significant rate at LHC (14 TeV), such as $pp \to \tilde{g}\tilde{g}X \to \bar{\tilde{u}}_1 t \tilde{u}_2 \bar{c} X \to \bar{\tilde{u}}_1 t \tilde{u}_1 h^0 \bar{c} X \to \bar{c}\, \tilde{\chi}_1^0\, t\, c\, \tilde{\chi}_1^0\, h^0 \bar{c} X$ ($= t\, c\, \bar{c}\, \bar{c}\, h^0$ $\mathrm{E_T^{mis}}$ X). In our scenario we find that $\sigma(pp \to \tilde{g}\tilde{g}X) \sim$ 150 fb at LHC(14 TeV) and that $B(\tilde{g} \to \tilde{u}_2\, c/t) \equiv B(\tilde{g} \to \tilde{u}_2\, \bar{c}/\bar{t}) + B(\tilde{g} \to \bar{\tilde{u}}_2\, c/t)$ can be large (~ 25%), which leads to a sizable rate of $\tilde{u}_2$ production from gluino production and decays at LHC(14 TeV). Hence QFV squark signal rates can be significant at LHC(14 TeV). Indeed we have found that the QFV signal rates such as $\sigma(pp \to \tilde{g}\tilde{g}X \to t$ 3jets h^0 $\mathrm{E_T^{mis}}$ X) can be significant for large δ_{23}^{uRR} and δ_{23}^{uRL} at LHC (14 TeV) [2].

6. Conclusion

Our analysis suggests the following: One should take into account the possibility of significant contributions from QFV decays in the squark and gluino search at LHC. Moreover, one should also include QFV squark parameters (i.e. squark generation mixing parameters) in the complete determination of the basic MSSM parameters at LHC.

References

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