Flavour violating gluino and squark decays @ LHC

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Outline

- Introduction
- Squark generation mixing in the MSSM
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- Quark flavour violating (QFV) three-body decays of gluino
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- Summary and conclusions

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- If weak scale SUSY is realized in Nature, gluinos and squarks will be observed @ the LHC with high statistical significance for masses up to O(1) TeV
- The decays of gluinos and squarks are ussually assumed to be quark-flavour conserving (QFC)
- The squark are, however, not necessarily quark-flavour eigenstates. Flavour mixing in the squark sector may be stronger than in the quark sector. QFV decays can then occur with significant rates

QFV in the MSSM

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no new sources of QFV; in the super CKM-basis the squarks undergo the same rotations as the quarks all flavour-violating entries related to the CKM matrix (e.g. $\tilde{\chi}_i^\pm \tilde{q}_j \tilde{q}_k \sim V q_j q_k'$)

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- In the following we assume NMFV

NMFV in the MSSM

- The flavour-violating terms are contained in the mass matrices of the squarks at the electroweak scale

$$\mathcal{M}^2_{\tilde{q}} \quad = \quad \begin{pmatrix} \mathcal{M}^2_{\tilde{q}\,LL} & (\mathcal{M}^2_{\tilde{q}\,RL})^\dagger \\ \mathcal{M}^2_{\tilde{q}\,RL} & \mathcal{M}^2_{\tilde{q}\,RR} \end{pmatrix}, \quad q = u, d.$$

- The 3×3 soft-breaking matrices can introduce flavour violating (off-diagonal) terms, e.g. in the up-squark sector

$$\begin{aligned}
(\mathcal{M}^2_{\tilde{u}\,LL})_{\alpha\beta} &= M^2_{Q_u\,\alpha\beta} + \left[(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W)\cos 2\beta\; m_Z^2 + m_{u_\alpha}^2\right]\delta_{\alpha\beta} \\
(\mathcal{M}^2_{\tilde{u}\,RR})_{\alpha\beta} &= M^2_{U\,\alpha\beta} + \left[(\frac{2}{3}\sin^2\theta_W)\cos 2\beta\; m_Z^2 + m_{u_\alpha}^2\right]\delta_{\alpha\beta} \\
(\mathcal{M}^2_{\tilde{u}\,RL})_{\alpha\beta} &= (v_2/\sqrt{2})T_{U\,\beta\alpha} - m_{U_\alpha}\mu^* \cot\beta\;\delta_{\alpha\beta}
\end{aligned}$$

- After diagonalization with a 6×6 rotation matrix $R^{\tilde{u}}$, the mass eigenstates are obtained $\tilde{u}_i = R^{\tilde{u}}_{i\alpha}\tilde{u}_{0\alpha}$, where $R^{\tilde{u}}\mathcal{M}^2_{\tilde{u}}R^{\tilde{u}\dagger} = \mathrm{diag}(m_{\tilde{u}_1}, ..., m_{\tilde{u}_6})$, with $m_{\tilde{u}_i} < m_{\tilde{u}_j}$ for $i < j$

NMFV in the MSSM

- Dimentionless QFV parameters are introduced, in the up-type squark sector ($\alpha \neq \beta$)

$$
\begin{aligned}
\delta^{LL}_{\alpha\beta} &\equiv M^2_{Q\alpha\beta} / \sqrt{M^2_{Q\alpha\alpha} M^2_{Q\beta\beta}} \\
\delta^{uRR}_{\alpha\beta} &\equiv M^2_{U\alpha\beta} / \sqrt{M^2_{U\alpha\alpha} M^2_{U\beta\beta}} \\
\delta^{uRL}_{\alpha\beta} &\equiv (v_2/\sqrt{2}) T_{U_{\beta\alpha}} / \sqrt{M^2_{U\alpha\alpha} M^2_{Q\beta\beta}}
\end{aligned}
$$

- Analogously in the down-type squark sector

$$
\begin{aligned}
\delta^{dRR}_{\alpha\beta} &\equiv M^2_{D\alpha\beta} / \sqrt{M^2_{D\alpha\alpha} M^2_{D\beta\beta}} \\
\delta^{dRL}_{\alpha\beta} &\equiv (v_2/\sqrt{2}) T_{D_{\beta\alpha}} / \sqrt{M^2_{D\alpha\alpha} M^2_{Q\beta\beta}}
\end{aligned}
$$

- From the vacuum stability conditions, the trilinear coupling matrices are constrained as follows

$$\begin{aligned} |T_{U\alpha\alpha}|^2 &< 3\, Y_{U\alpha}^2\, (M_{Q\alpha\alpha}^2 + M_{U\alpha\alpha}^2 + m_2^2)\ , \\ |T_{D\alpha\alpha}|^2 &< 3\, Y_{D\alpha}^2\, (M_{Q\alpha\alpha}^2 + M_{D\alpha\alpha}^2 + m_1^2)\ , \\ |T_{U\alpha\beta}|^2 &< Y_{U\gamma}^2\, (M_{Q\alpha\alpha}^2 + M_{U\beta\beta}^2 + m_2^2)\ , \\ |T_{D\alpha\beta}|^2 &< Y_{D\gamma}^2\, (M_{Q\alpha\alpha}^2 + M_{D\beta\beta}^2 + m_1^2)\ , \end{aligned}$$

where $\alpha, \beta = 1, 2, 3,\ \alpha \neq \beta;\ \gamma = \mathrm{Max}(\alpha, \beta)$ and

$$\begin{aligned} m_1^2 &= (m_{H^\pm}^2 + m_Z^2 \sin^2\theta_W)\sin^2\beta - \frac{1}{2}m_Z^2, \\ m_2^2 &= (m_{H^\pm}^2 + m_Z^2 \sin^2\theta_W)\cos^2\beta - \frac{1}{2}m_Z^2. \end{aligned}$$

$Y_{U\alpha}$ and $Y_{D\alpha}$ are the Yukawa couplings of the up-type and down-type quarks.

- Strong constraints on mixing involving the first generation from precision measurements of K and B meson decays
- Only mixing between **second and third generation** squarks considered. Despite the constraints from B physics still allows appreciable mixing
- SUSY mass limits from direct collider searches
- Electroweak precision and low-energy measurements

$$\mathrm{B}(b \to s\gamma) = (3.37 \pm 0.23).10^{-4}$$

$$\Delta M_{B_s} = (17.725 \pm 0.049)\ \mathrm{ps}^{-1}$$

$$\Delta\rho\ (\mathrm{SUSY}) < 0.0012$$

$$\mathrm{B}(b \to s\mu^+\mu^-) = (1.60 \pm 0.50).10^{-6}$$

$$\mathrm{B}(B_s \to \mu^+\mu^-) < 4.2.10^{-9}$$

QVF three-body decays of gluino

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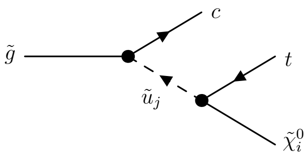
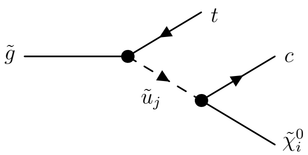
* All squarks are heavier than the gluino $\Longrightarrow$ only three-body decays to quark pairs + chargino/neutralino possible

* Squark generation mixing occurs **only** between the 2^{nd} and 3^{rd} generation

- $\Longrightarrow$ One has the following QFV three-body decays into quarks and neutralino

$$\tilde{g} \to c\,\bar{t}\,\tilde{\chi}_i^0,\, \bar{c}\,t\,\tilde{\chi}_i^0\,,\ \tilde{g} \to s\,\bar{b}\,\tilde{\chi}_i^0,\, \bar{s}\,b\,\tilde{\chi}_i^0\,.$$





- We will mainly focus on decays into the lightest neutralino, $\tilde{\chi}_1^0$

- Basic MSSM input parameters (at the weak scale and real)

$$\{\tan\beta,\ m_{A^0},\ M_1,\ M_2,\ M_3,\ \mu,\ M^2_{Q\alpha\beta},\ M^2_{U\alpha\beta},\ M^2_{D\alpha\beta},\ T_{U\alpha\beta},\ T_{D\alpha\beta}\}$$

- Quark-flavour violating parameters

$$M^2_{Q\alpha\beta},\ M^2_{U\alpha\beta},\ M^2_{D\alpha\beta},\ T_{U\alpha\beta},\ T_{D\alpha\beta},\ \alpha \neq \beta$$

- Reference scenario

M_1	M_2	M_3	μ	$\tan\beta$	m_{A^0}
139 GeV	264 GeV	800 GeV	1000 GeV	10	800 GeV

	$\alpha=\beta=1$	$\alpha=\beta=2$	$\alpha=\beta=3$
$M^2_{Q\alpha\beta}$	$(3150)^2$ GeV^2	$(3100)^2$ GeV^2	$(3050)^2$ GeV^2
$M^2_{U\alpha\beta}$	$(3000)^2$ GeV^2	$(2200)^2$ GeV^2	$(2150)^2$ GeV^2
$M^2_{D\alpha\beta}$	$(3000)^2$ GeV^2	$(2990)^2$ GeV^2	$(2980)^2$ GeV^2

- All constraints are satisfied, $T_{\{U,D\}\alpha\alpha} = 0$

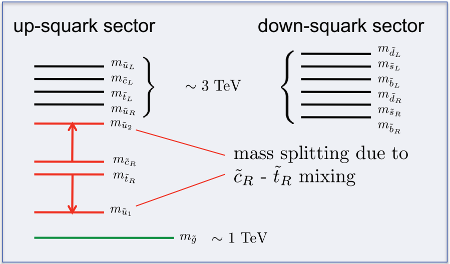
QVF three-body decays of gluino

Physical output

- The numerical calculations of the decay BRs and physical masses are performed with Spheno v3.0
- Physical masses of the SUSY particles in the reference scenario chosen (Fairly insensitive to the QFV parameters)

Particle	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	$m_{\tilde{\chi}_1^+}$	$m_{\tilde{\chi}_2^+}$	$m_{\tilde{g}}$
Ph. mass [GeV]	139	281.3	1017.9	1021.7	281.5	1022.7	975

Particle	m_{h^0}	m_{H^0}	m_{A^0}	m_{H^+}
Ph. mass [GeV]	121.1	800.3	800	804



- QFV left-right mixing is not relevant for our study

* We show this for the left-right mixing parameter δ_{23}^{uRL}

  Due to the vacuum stability condition we have

  $$|T_{U32}|^2 \lesssim Y_{U3}^2(M_{Q33}^2 + M_{U22}^2 + m_2) \approx M_{Q33}^2 + M_{U22}^2 \approx \mathrm{O}(10\mathrm{TeV}^2),$$

  because $Y_{U3} \approx 1$ and $m_2 \ll M_{Q33}^2 + M_{U22}^2$.

  $$\Longrightarrow |\delta_{23}^{uRL}| = \frac{v_2}{\sqrt{2}} \frac{|T_{U32}|}{\sqrt{M_{U22}^2 M_{Q33}^2}} \lesssim \frac{v_2}{\sqrt{2}} \sqrt{\frac{M_{U22}^2+M_{Q33}^2}{M_{U22}^2 M_{Q33}^2}} \approx 0.1$$

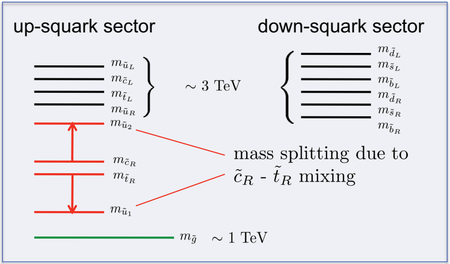
  Analogously, the parameters $\delta_{23}^{uLR}, \delta_{23}^{dRL}, \delta_{23}^{dLR}$ are also constrained to be very small

- Relevant QFV parameters for our study are δ_{23}^{LL} $(\tilde{c}_L - \tilde{t}_L)$, δ_{23}^{uRR} $(\tilde{c}_R - \tilde{t}_R)$, δ_{23}^{dRR} $(\tilde{s}_R - \tilde{b}_R)$

QVF three-body decays of gluino

Numerical results

- Squark and guino masses



- All squarks but $\tilde{u}_1$ are heavy $\Longrightarrow$ gluino decay is dominated by virtual $\tilde{u}_1$ exchange
- $\tilde{u}_1$ is a strong mixture of $\tilde{c}_R$ and $\tilde{t}_R$ $\Longrightarrow$ QFV branching ratio $B(\tilde{g} \to c\bar{t}\tilde{\chi}_1^0)$ can be large

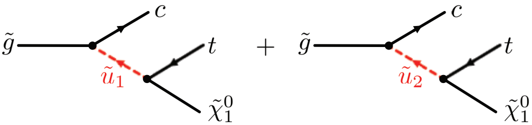
QVF three-body decays of gluino

Numerical results

- Due to the effective $\tilde{c} - \tilde{t}$ mixing

$$\begin{aligned} \tilde{u}_1 &\sim \cos\theta\ \tilde{c}_R + \sin\theta\ \tilde{t}_R \\ \tilde{u}_2 &\sim -\sin\theta\ \tilde{c}_R + \cos\theta\ \tilde{t}_R \end{aligned}$$

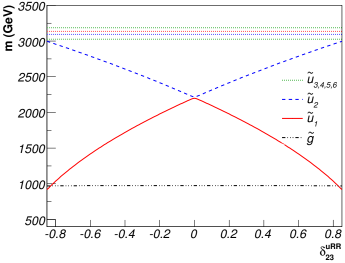
  there can be a strong destructive interferience between $\tilde{u}_1$ and $\tilde{u}_2$ if their masses are similar

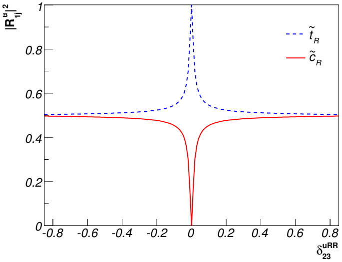


$\sim +\frac{\cos\theta\sin\theta}{p^2 - m^2_{\tilde{u}_1}}$ $\qquad$ $\sim -\frac{\cos\theta\sin\theta}{p^2 - m^2_{\tilde{u}_2}}$

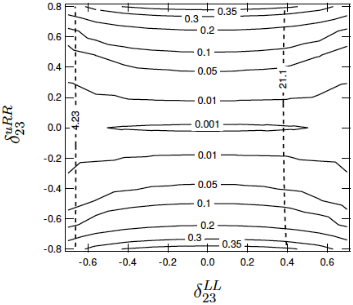
- In order to suppress such cancelations large mass splitting is required and hence large values of the mixing term M^2_{U23} ($\sim \delta^{uRR}_{23}$)

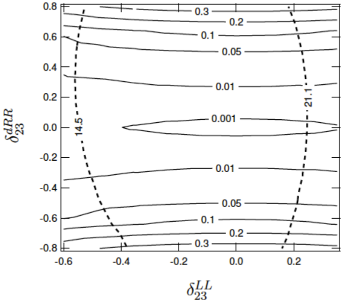
- Up-type squark masses and flavour decomposition of $\tilde{u}_1$ as a function of $\delta_{23}^{uRR}(\tilde{c}_R - \tilde{t}_R)$, all other QFV parameters are zero





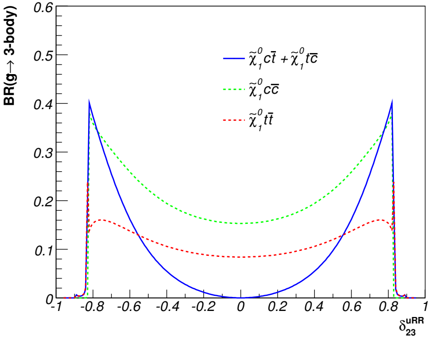
- QFV decay branching ratio $\mathrm{B}(\tilde{g} \to c t \tilde{\chi}_1^0)$ { $\mathrm{B}(\tilde{g} \to \tilde{b} \tilde{\chi}_1^0)$} in the $\delta_{23}^{uRR}\{\delta_{23}^{dRR}\}$ - δ_{23}^{LL} plane



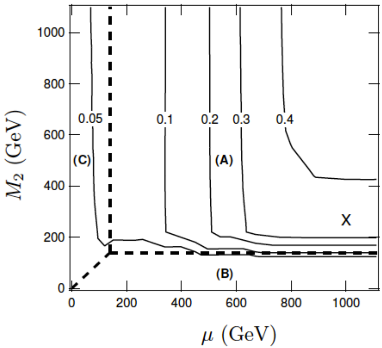


$$\mathrm{B}(\tilde{g} \to c t \tilde{\chi}_1^0) \equiv B(\tilde{g} \to c \bar{t} \tilde{\chi}_1^0) + B(\tilde{g} \to \bar{c} t \tilde{\chi}_1^0)$$
$$\mathrm{B}(\tilde{g} \to s b \tilde{\chi}_1^0) \equiv B(\tilde{g} \to s \bar{b} \tilde{\chi}_1^0) + B(\tilde{g} \to \bar{s} b \tilde{\chi}_1^0)$$

- Branching ratios of the decays $\tilde{g} \to ct\tilde{\chi}_1^0$, $\tilde{g} \to c\bar{c}\tilde{\chi}_1^0$ and $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ as functions of δ_{23}^{uRR}, the other QFV parameters are zero



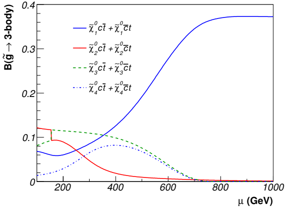
- Squark generation mixing enters also the squark-quark-neutralino couplings
- The neutralino/chargino parameters can also influence the QFV gluino three-body decays
- Contour plot for B($\tilde{g} \to ct\tilde{\chi}_1^0$) in the $\mu - M_2$ plane for $\delta_{23}^{uRR} = 0.8$, the other QFV parameters being zero, Region A: bino-like LSP, Region B: wino-like LSP, Region C: higgsino-like LSP

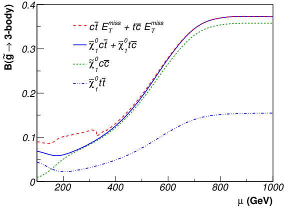


QVF three-body decays of gluino

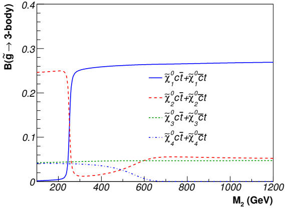
Influence of the neutralino/chargino parameters on the QFV three-body decays of gluino

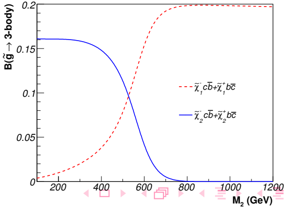
- μ dependence of the QFV and QFC gluino decay branching ratios for $\delta_{23}^{uRR} = 0.8$, the other QFV parameters being zero





- The M_2 dependence of the QFV gluino decay branching ratios for $M_1 = 264$ GeV, $\mu = 600$ GeV, $\delta_{23}^{uRR} = 0.8$, the other QFV parameters being zero





- Weak scale parameters , the corresponding neutralino and chargino masses and some important branching ratios for a scenario with a higgsino-like LSP ($\mu < M_1, M_2$)

M_1	M_2	M_3	μ	$\tan\beta$	m_A^0
139 GeV	264 GeV	800 GeV	120 GeV	10	800 GeV

$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	$m_{\tilde{\chi}_1^+}$	$m_{\tilde{\chi}_2^+}$
87.0 GeV	133.1 GeV	158.3 GeV	310.1 GeV	109.3 GeV	310.1 GeV

$\mathrm{B}(\tilde{g} \to c\bar{t}\tilde{\chi}_1^0)$	$\mathrm{B}(\tilde{g} \to c\bar{t}\tilde{\chi}_2^0)$	$\mathrm{B}(\tilde{g} \to b\bar{c}\tilde{\chi}_1^+)$	$\mathrm{B}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \nu\bar{\nu})$	$\mathrm{B}(\tilde{\chi}_1^+ \to \mu^+\nu_\mu\tilde{\chi}_1^0)$
3.4 %	6.1 %	11.2 %	18.4 %	11.2 %

$\delta_{23}^{uRR} = 0.8$, the other QFV parameters being zero

- Signature from $\tilde{g} \to \tilde{\chi}^{\pm} + b\bar{c}(\bar{b}c) + \mu^{\pm}(e^{\pm}) + E_T^{\text{miss}}$ with $\approx 5\%$ probability

(from MFV $\approx 10^{-4}$)

- Weak scale parameters , the corresponding neutralino and chargino masses and some important branching ratios for a scenario with a wino-like LSP $(M_2 < M_1, \mu)$

M_1	M_2	M_3	μ	$\tan\beta$	m_A^0
400 GeV	300 GeV	800 GeV	350 GeV	10	800 GeV

$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	$m_{\tilde{\chi}_1^+}$	$m_{\tilde{\chi}_2^+}$
275.5 GeV	362.6 GeV	376.4 GeV	433.1 GeV	280.0 GeV	407.1 GeV

$\mathrm{B}(\tilde{g} \to c\bar{t}\tilde{\chi}_1^0)$	$\mathrm{B}(\tilde{g} \to c\bar{t}\tilde{\chi}_2^0)$	$\mathrm{B}(\tilde{g} \to b\bar{c}\tilde{\chi}_1^+)$	$\mathrm{B}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\nu\bar{\nu})$	$\mathrm{B}(\tilde{\chi}_1^+ \to \mu^+\nu_\mu\tilde{\chi}_1^0)$
2.5 %	6.3 %	5.8 %	4.1 %	13.2 %

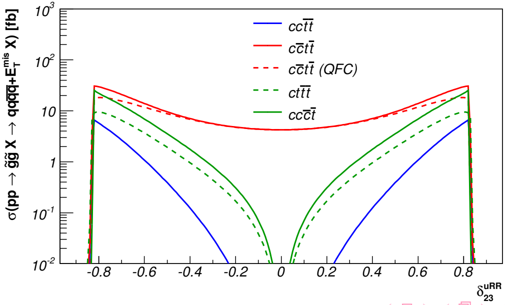
$\delta_{23}^{uRR} = 0.8$, the other QFV parameters being zero

- Signature from $\tilde{g} \to \tilde{\chi}^{\pm} + b\bar{c}(\bar{b}c) + \mu^{\pm}(e^{\pm}) + E_T^{\mathrm{miss}}$ with $\approx 3\%$ probability

QVF three-body decays of gluino

Measurability

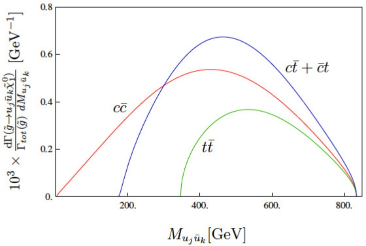
- Production cross section calculated at leading order with WHIZARD/O'MEGA packages, CTEQ6L parton density fit with PDFs factorization scale $Q = m_{\tilde{p}_1+\tilde{p}_2}$, $\alpha_s(Q)$ evaluated at two-loop level
- Dominant production process $pp \to \tilde{g}\tilde{g}X$, with X containing beam jets only
- In our scenario gluino production cross section practically independent on δ_{23}^{uRR}, at the reference point ≈ 170fb (3 fb) for $\sqrt{s}$ =14 TeV (7 TeV)
- Signal rates for $pp \to \tilde{g}\tilde{g}X$ at $\sqrt{s} = 14$ TeV where at least one of the gluinos decays as $\tilde{g} \to c\bar{t}(\bar{c}t)\tilde{\chi}_1^0$, as a function of δ_{23}^{uRR}



QVF three-body decays of gluino

Measurability

- Invariant mass distributions of two up-type quarks from the decay $\tilde{g} \to u_j \bar{u}_k \tilde{\chi}_1^0$, $d\Gamma(\tilde{g} \to u_j \bar{u}_k \tilde{\chi}_1^0)/(\Gamma_{tot}(\tilde{g})\ dM_{u_j \bar{u}_k})$, where $M_{u_j \bar{u}_k}$ is the invariant mass of the two-quark system $u_j \bar{u}_k$, $M^2_{u_j \bar{u}_k} = (p_{u_j} + p_{\bar{u}_k})^2$, $\delta_{23}^{uRR} = 0.8$



- Endpoint at $(m_{\tilde{g}} - m_{\tilde{\chi}_1^0})$, thresholds at $2m_c, m_c + m_t$ and $2m_t$
- No edge structure, in contrast to two-body gluino decays, where the gluino first decays into real squark
- Measuring can help distinguishing QFV from QFC decays

- A typical $\tilde{g}\tilde{g}$ production even contains at least 4 large-p_T jets + large E_T^{miss}
- An event with a QFV gluino decay $\tilde{g} \to c\bar{t}\tilde{\chi}_1^0(\bar{c}t\tilde{\chi}_1^0)$ should contain at least 1 top (anti-top) in the final state to be identified, possibe with $t \to bW^{\pm}$ or c-tagging
- Typical signatures of QFV $\tilde{g}$ pair events are: $t(\text{or } \bar{t}) + 3 \text{ jets} + E_{\text{T}}^{mis} + X$, $t + t \ (\text{or } \bar{t} + \bar{t}) + 2 \text{ jets} + E_{\text{T}}^{mis} + X$ and $t + t + \bar{t} \ (\text{or } \bar{t} + \bar{t} + t) + 1 \text{ jet} + E_{\text{T}}^{mis} + X$, where X contains beam-jets only
- $t + t \ (\text{or } \bar{t} + \bar{t}) + 2\text{jets} + E_{\text{T}}^{mis} + X$ can only be produced in the MSSM with QFV
- Small background

- At the reference point $m_{h^0} = 121.1\ \mathrm{GeV}$
- In order to get $m_{h^0} = 125\ \mathrm{GeV}$ we have to switch on $T_{U33} = h_t A_t = -2350$
- The new elements in the 6×6 up-squark mass matrix are small in comparison with the diagonal ones $\Longrightarrow$ small effect on the flavour decomposition of up-type squarks
- Small influence on the theoretical predictions of B-physics observables
- Small influence on the predictions for the QFV gluino three-body decay BRs

QVF bosonic squark decays

- If kinematically allowed, the following QFV bosonic squark decays are possible

$$\tilde{q}_i \to \tilde{q}_j + h^0, H^0, A^0$$
$$\tilde{q}_i \to \tilde{q}'_j + H^+$$
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with $i, j =$ 1,...,6

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- Furthermore, we will focus on decays into h^0, $\tilde{q}_i \to \tilde{q}_j h^0$, as they offer the best possibility to determine the MSSM trillinear coupling $\tilde{q}_i - \tilde{q}_j - h^0$

QVF bosonic squark decays

- In the super-CKM basis, the Lagrangian including the coupling of up-type squarks to h^0 contains the trilinear couplings $(T_U)_{ij}$ which are explicitly flavour-breaking terms that couple left-handed to right-handed squarks

$$\mathcal{L} \ni -\frac{g_2}{2m_W} h^0 \Big[\tilde{u}^*_{iR}\tilde{u}_{jL}\Big(\mu^* \frac{\sin\alpha}{\sin\beta} m_{u,i}\delta_{ij} + \frac{\cos\alpha}{\sin\beta}\frac{v_2}{\sqrt{2}}(T_U)_{ji}\Big) + \text{h.c.}\Big]$$

- Our QFV parameters are those ones related to the up-type sector

$$\begin{aligned}
\delta^{LL}_{\alpha\beta} &\equiv M^2_{Q\alpha\beta}/\sqrt{M^2_{Q\alpha\alpha}M^2_{Q\beta\beta}} \\
\delta^{uRR}_{\alpha\beta} &\equiv M^2_{U\alpha\beta}/\sqrt{M^2_{U\alpha\alpha}M^2_{U\beta\beta}} \\
\delta^{uRL}_{\alpha\beta} &\equiv (v_2/\sqrt{2})T_{U_{\beta\alpha}}/\sqrt{M^2_{U\alpha\alpha}M^2_{Q\beta\beta}} \\
\delta^{uLR}_{\alpha\beta} &= \delta^{uRL*}_{\beta\alpha}
\end{aligned}$$

for $\alpha, \beta = 2, 3,\ \alpha \neq \beta$

QVF bosonic squark decays

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- For our scenarios the mass of the lightest Higgs $h^0 = 126\ \mathrm{GeV}$ and hence it is SM-like

QVF bosonic squark decays
Scenario A

- Weak scale basic MSSM parameters at $Q = 1$ TeV and physical masses in GeV of the SUSY particles for Scenario A
  $T_{\{U,D\}\alpha\alpha} = 0$, except for $T_{U33} = -2100$ ($\delta^{uRL}_{33} = -0.34$)

M_1	M_2	M_3	μ	$\tan\beta$	m_{A^0}
400 GeV	800 GeV	1000 GeV	2640 GeV	20	1500 GeV

	$\alpha = 1$	$\alpha = 2$	$\alpha = 3$
$M^2_{Q\alpha\alpha}$	$(2400)^2$ GeV^2	$(2360)^2$ GeV^2	$(1450)^2$ GeV^2
$M^2_{U\alpha\alpha}$	$(2380)^2$ GeV^2	$(780)^2$ GeV^2	$(750)^2$ GeV^2
$M^2_{D\alpha\alpha}$	$(2380)^2$ GeV^2	$(2340)^2$ GeV^2	$(2300)^2$ GeV^2

δ^{uLL}_{23}	δ^{uRR}_{23}	δ^{uRL}_{23}	δ^{uLR}_{23}
0.024	0.3	-0.07	0

$m_{\tilde{\chi}^0_1}$	$m_{\tilde{\chi}^0_2}$	$m_{\tilde{\chi}^0_3}$	$m_{\tilde{\chi}^0_4}$	$m_{\tilde{\chi}^+_1}$	$m_{\tilde{\chi}^+_2}$
397	824	2623	2625	825	2625

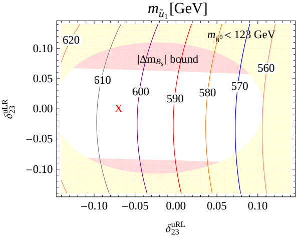
m_{h^0}	m_{H^0}	m_{A^0}	m_{H^+}
126.0	1496	1500	1510

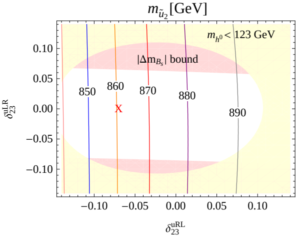
$m_{\tilde{g}}$	$m_{\tilde{u}_1}$	$m_{\tilde{u}_2}$	$m_{\tilde{u}_3}$	$m_{\tilde{u}_4}$	$m_{\tilde{u}_5}$	$m_{\tilde{u}_6}$
1141	605	861	1477	2387	2401	2427

QVF bosonic squark decays

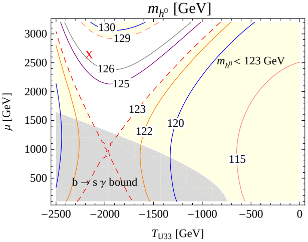
Numerical results, Scenario A

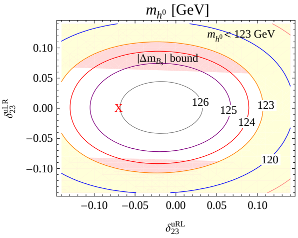
- Dependence of the masses of $\tilde{u}_1$ and $\tilde{u}_2$ on δ_{23}^{uRL} and δ_{23}^{uLR}





- m_{h^0}, as a function of T_{U33} and μ and as a function of δ_{23}^{uRL} and δ_{23}^{uLR}

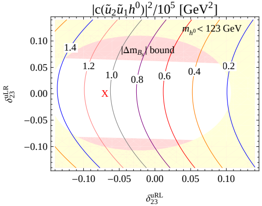


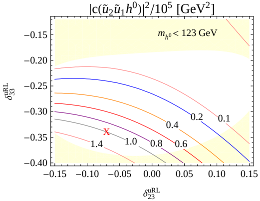


QVF bosonic squark decays

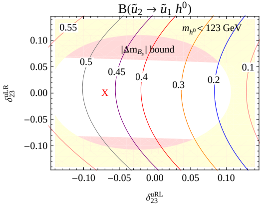
Numerical results, Scenario A

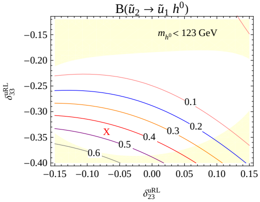
- In the following we concentrate on $\tilde{u}_2 \to \tilde{u}_1 h^0$
- The coupling $|c(\tilde{u}_2 \tilde{u}_1 h^0)|^2$ as a function of δ_{23}^{uRL} and δ_{23}^{uLR} and as a function of δ_{23}^{uRL} and δ_{33}^{uRL}



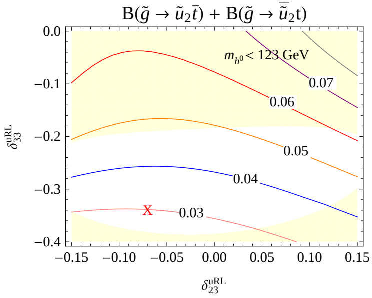


- $B(\tilde{u}_2 \to \tilde{u}_1 h^0)$ as a function of δ_{23}^{uRL} and δ_{23}^{uLR} and as a function of δ_{23}^{uRL} and δ_{33}^{uRL}





- At the reference point B($\tilde{u}_3 \to \tilde{u}_1 h^0$)=22%, can go up to 30%, B($\tilde{u}_3 \to \tilde{u}_2 h^0$)=$10\%$. The branching ratios of $\tilde{u}_3 \to \tilde{u}_1 Z^0$ and $\tilde{u}_3 \to \tilde{u}_2 Z^0$ at the reference point are about 28% and 14%, respectively
- B($\tilde{g} \to \tilde{u}_2 \bar{c}$)+B($\tilde{g} \to \bar{\tilde{u}}_2 c$) and B($\tilde{g} \to \tilde{u}_2 \bar{t}$)+B($\tilde{g} \to \bar{\tilde{u}}_2 t$) as functions of δ_{23}^{uRL} and δ_{33}^{uRL}



- Scenario B, GUT-inspired: $M_1 \approx 0.5\ M_2$, $M_3/M_2 = g_3^2/g_2^2$, where g_2 and g_3 are the SU(2) and SU(3) gauge coupling constants, respectively
- Only M_1, M_2 and M_3 are changed with respect to scenario A, $M_1 = 250$ GeV, $M_2 = 500$ GeV and $M_3 = 1500$ GeV
- Large $m_{\tilde{g}} = 1626$ GeV $\Longrightarrow$ small production cross section
- The dependences of the QFV parameters are similar like in scenario A

QVF bosonic squark decays

Numerical results, Scenario C

- Scenario C, parameters changed with respect to scenario A

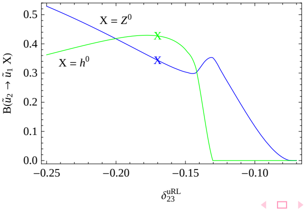
$$M^2_{U22} = (650\ \mathrm{GeV})^2, \quad M^2_{U33} = (1600\ \mathrm{GeV})^2, \quad M^2_{Q33} = (780\ \mathrm{GeV})^2,$$
$$\delta^{uLL}_{23} = 0, \quad \delta^{uRR}_{23} = 0, \quad \delta^{uRL}_{23} = -0.17, \quad \delta^{uRL}_{33} = -0.3$$

- $\delta^{uRL}_{23} (\sim T_{U32})$ much larger than that in Scenario A
- Physical masses and branching ratios

$$m_{\tilde{g}} = 1134\ \mathrm{GeV}, m_{\tilde{u}_1} = 651\ \mathrm{GeV}, m_{\tilde{u}_2} = 800\ \mathrm{GeV}, m_{\tilde{u}_3} = 1580\ \mathrm{GeV}, m_{h^0} = 125.3\ \mathrm{GeV}$$

$$\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 h^0) = 43\%, \mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 Z^0) = 34\%, \mathrm{B}(\tilde{g} \to \tilde{u}_2 \bar{c}) + \mathrm{B}(\tilde{g} \to \bar{\tilde{u}}_2 c) = 8\%,$$
$$\mathrm{B}(\tilde{g} \to \tilde{u}_2 \bar{t}) + \mathrm{B}(\tilde{g} \to \bar{\tilde{u}}_2 t) = 15\%, \mathrm{B}(\tilde{u}_1 \to \tilde{\chi}^0_1 c) = 96\%, \mathrm{B}(\tilde{u}_1 \to \tilde{\chi}^0_1 t) = 4\%$$

- Both $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 h^0)$ and $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 Z^0)$ are very large, leading to the dominance of the QFV bosonic decays of $\tilde{u}_2$.
- δ^{uRL}_{23} dependence of the branching ratios $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 h^0)$ and $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 Z^0)$



QVF bosonic squark decays

Signatures

- Lighter squark states can be produced directly, $pp \to \tilde{u}_1 \bar{\tilde{u}}_1 X$, $pp \to \tilde{u}_2 \bar{\tilde{u}}_2 X$, or via gluino production, $pp \to \tilde{g}\tilde{g}X$, where at least one of the gluino decays into $\tilde{u}_1$ or $\tilde{u}_2$, $\tilde{g} \to \tilde{u}_{1,2}\ u; \tilde{u}_{1,2}\ c; \tilde{u}_{1,2}\ t$, with q being a light quark
- We assume that the t-quark can be identified, but the c-quark not
- Possible signatures expected from the QFV decays of $\tilde{u}_2$ into the lightest Higgs boson h^0, t denotes top or anti-top, j denotes a c-quark jet

processes	final states containing h^0
$pp \to \tilde{u}_2 \bar{\tilde{u}}_2 X$	$2j + h^0 + E_T^{\text{miss}} + X$ (1.4 fb)
	$j + t + h^0 + E_T^{\text{miss}} + X$ (2.8 fb)
	$j + t + 2h^0 + E_T^{\text{miss}} + X$ (1 fb)
	$2j + Z^0 + h^0 + E_T^{\text{miss}} + X$
	$2j + 2h^0 + E_T^{\text{miss}} + X$
	$2t + h^0 + E_T^{\text{miss}} + X$
	$2t + 2h^0 + E_T^{\text{miss}} + X$

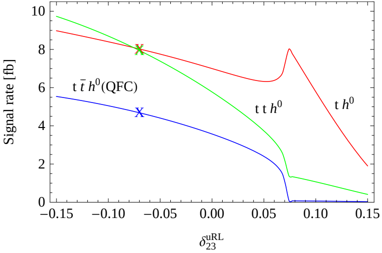
processes	final states containing h^0
$pp \to \tilde{g}\tilde{g}X$	$4j + h^0 + E_T^{\text{miss}} + X$ (2 fb)
	$3j + t + h^0 + E_T^{\text{miss}} + X$ (8 fb)
	$2j + 2t + h^0 + E_T^{\text{miss}} + X$ (4 fb)
	$4j + Z^0 + h^0 + E_T^{\text{miss}} + X$
	$4j + 2h^0 + E_T^{\text{miss}} + X$
	$3j + t + 2h^0 + E_T^{\text{miss}} + X$
	$2j + 2t + 2h^0 + E_T^{\text{miss}} + X$
	$3j + t + Z^0 + h^0 + E_T^{\text{miss}} + X$
	$2j + 2t + Z^0 + h^0 + E_T^{\text{miss}} + X$
	$4t + h^0/Z^0(+h^0/Z^0) + E_T^{\text{miss}} + X$

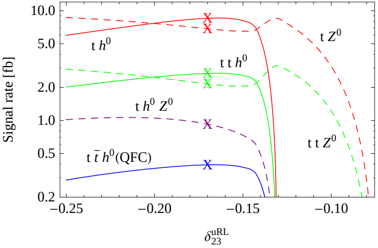
- In scenario A, summing up the cross sections for all QFV final states with at least one h^0 one gets 19 fb $\Longrightarrow$ one could expect about 1900 of such events assuming an integrated luminosity of 100 fb.

QVF bosonic squark decays

Signatures

- Signal rates for the QFV bosonic squark decay signatures from gluino pair production in Scenario A and in Scenario C as functions of δ_{23}^{uRL} The red solid (dashed) line corresponds to the pure QFV one t final state $3j + t + h^0\ (Z^0) + E_T^{\text{miss}} + X$. The green solid (dashed) line corresponds to the QFV signal events with $2t$ coming from $tt/\overline{tt}/t\bar{t} + 2j + h^0\ (Z^0) + E_T^{\text{miss}} + X$. The blue solid line corresponds to the QFC signal events $t + \bar{t} + 2j + h^0 + E_T^{\text{miss}} + X$. The violet dashed line corresponds to the pure QFV one t final state $3j + t + h^0 + Z^0 + E_T^{\text{miss}} + X$.





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- All constraints from theory and experiments on SUSY particle searches, Higgs searches and precision data in the B meson sector are taken into account
- Mixing is considered only between second and third generations of squarks
- In the case of gluino decays the QFV parameters $\delta_{23}^{uRR}, \delta_{23}^{dRR}$ and δ_{23}^{LL} are important
- We have focused on $\tilde{g} \to c\bar{t}(\bar{c}t)\tilde{\chi}_1^0$ and $\tilde{g} \to s\bar{b}(\bar{c}t)\tilde{\chi}_1^0$ decays, their QFV decay BRs can reach 40% and 35%, respectively
- We have shown that the parameter of the neutralino/chargino sector can have also important influence on the decays studied
- The dominant production process is $pp \to \tilde{g}\tilde{g}X$ and the QFV signatures $pp \to tc\bar{c}\bar{c}E_T^{\text{miss}}X$ and $pp \to tt\bar{c}\bar{c}E_T^{\text{miss}}X$ can be significant at the LHC

QVF bosonic squark decays
Summary

- In the case of $\tilde{u}_2 \to \tilde{u}_1 h^0/Z^0$ the branching ratio $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 h^0)$ can be larger than in the QFC case, and can go up to 60%, and, hence, this decay gives access to the QFV trilinear couplings T_{U32} and T_{U23}
- We have studied the signatures expected from the QFV decay $\tilde{u}_2 \to \tilde{u}_1 h^0$ at LHC with $\sqrt{s} = 14$ TeV in three different scenarios
- We have considered direct $\tilde{u}_2$ production $pp \to \tilde{u}_2 \bar{\tilde{u}}_2 X$ as well as $\tilde{u}_2$ production in $\tilde{g}$ decays via $pp \to \tilde{g}\tilde{g}X$
- The most pronounced QFV signature is $3j + t + h^0 + E_T^{\rm miss} + X$, for example coming from $pp \to \tilde{g}\tilde{g}X \to \tilde{u}_{1,2}\bar{t}\tilde{u}_2\bar{c}X \to \tilde{u}_{1,2}\bar{t}\tilde{u}_1 h^0 \bar{c}X \to c\bar{t}c\bar{c}h^0 E_T^{\rm miss} X$, which can have a cross section up to 8 fb in Scenario A. A further interesting QFV signature coming from gluino pair production is $2j + 2t + h^0 + E_T^{\rm miss} + X$ with a cross section in Scenario A of about 4 fb.

QVF bosonic squark decays
Summary

- In the case of $\tilde{u}_2 \to \tilde{u}_1 h^0/Z^0$ the branching ratio $\mathrm{B}(\tilde{u}_2 \to \tilde{u}_1 h^0)$ can be larger than in the QFC case, and can go up to 60%, and, hence, this decay gives access to the QFV trilinear couplings T_{U32} and T_{U23}
- We have studied the signatures expected from the QFV decay $\tilde{u}_2 \to \tilde{u}_1 h^0$ at LHC with $\sqrt{s} = 14$ TeV in three different scenarios
- We have considered direct $\tilde{u}_2$ production $pp \to \tilde{u}_2 \bar{\tilde{u}}_2 X$ as well as $\tilde{u}_2$ production in $\tilde{g}$ decays via $pp \to \tilde{g}\tilde{g}X$
- The most pronounced QFV signature is $3j + t + h^0 + E_T^{\mathrm{miss}} + X$, for example coming from $pp \to \tilde{g}\tilde{g}X \to \tilde{u}_{1,2}\bar{t}\tilde{u}_2\bar{c}X \to \tilde{u}_{1,2}\bar{t}\tilde{u}_1 h^0 \bar{c}X \to c\bar{t}c\bar{c}h^0 E_T^{\mathrm{miss}} X$, which can have a cross section up to 8 fb in Scenario A. A further interesting QFV signature coming from gluino pair production is $2j + 2t + h^0 + E_T^{\mathrm{miss}} + X$ with a cross section in Scenario A of about 4 fb.
- Our analyses suggest that QFV decays shall be taken into account as they can have an important influence on the search of squarks and gluinos at the LHC as well as on the determination of the MSSM parameters

Thank you for your attention!!!