Flavour violating squark and gluino decays

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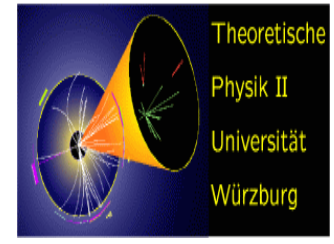


Overview

- SUSY breaking and scenarios
- SPheno as a flavour tool
- low energy constraints
- Squark and gluino decays
- Observables
- Summary and outlook

SUSY breaking

Question:

$$M_{SUSY} > M_{flavour} \qquad \text{or} \qquad M_{flavour} > M_{SUSY}$$

Generically:

$$\int d^2\theta d^2\bar{\theta} c_{ij}^S \frac{S^\dagger S}{M^2} \phi_i^\dagger \phi_j$$

with $M = M_{Planck}, M_{messenger}, \ldots$

Squark mass matrices, super-CKM basis

$$\text{basis} \quad : \quad (\tilde{u}_L, \tilde{c}_L, \tilde{t}_L, \tilde{u}_R, \tilde{c}_R, \tilde{t}_R) \ , \ (\tilde{d}_L, \tilde{s}_L, \tilde{b}_L, \tilde{d}_R, \tilde{s}_R, \tilde{b}_R)$$

$$\mathcal{M}_f^2 = \begin{pmatrix} M^2_{f,\,LL} + F_{f\,LL} + D_{f\,LL} & M^2_{f,\,LR} + F_{f\,LR} \\ \left(M^2_{f,\,LR}\right)^\dagger + F^*_{f\,RL} & M^2_{f,\,RR} + F_{f\,RR} + D_{f\,RR} \end{pmatrix}$$

$$M^2_{d,LL} = K^\dagger M^2_{u,LL} K = M^2_Q$$

$$M^2_{d,LL} = M^2_D \ , \qquad M^2_{u,LL} = M^2_U$$

$$M^2_{d,LR} = v_d (A^d)^* \ , \qquad M^2_{u,LR} = v_u (A^u)^*$$

$$F_{f\,LL,ij} = F_{f\,RR,ij} = m_i^2 \delta_{ij}$$

$$F_{f\,RL,ij} = -\mu m_i \delta_{ij} (\tan\beta)^{-2T_{3,f}}$$

$$D_{f\,LL} = (T_{3,f} - e_f \sin^2\theta_W) \cos(2\beta) m_Z^2$$

$$D_{f\,RR} = e_f \sin^2\theta_W \cos(2\beta) m_Z^2$$

Flavour effects

- FCNC effects
  - K^0-$\bar{K}^0$ mixing, $K \to \pi\nu\nu$, $K \to \pi e^+ e^-$
  - $b \to s\gamma$, $b \to s\mu^+\mu^-$, $B_s \to \mu^+\mu^-$
    $A_{CP}(B_d \to \Phi K_s)$, ΔM_{B_q} $(q = d, s)$
- flavour violating production of SUSY particles (see talk by F. Fuks)
- flavour violating decays of SUSY particles
  - Gluino decays: $\tilde{g} \to c\tilde{t}_1$
  - Squark decays: $\tilde{b}_1 \to s\tilde{\chi}_i^0$

Benchmark points

Strategy: existing benchmark points + flavour violating parameters at the electroweak scale

	$M_{1/2}$ [GeV]	M_0 [GeV]	A_0 [GeV]	$\tan\beta$	μ	m_{A^0}
SP1a'	250	70	-300	10	–	–
I"	350	180	–	35	–	–
γ	340	350	0	20	330	240

(see hep-ph/0511344 and hep-ph/0508198)

focus on mixing between 2^{nd} and 3^{rd} generation

theoretical restriction†:

$$
\begin{aligned}
|A_{D,ij}|^2 &< Y_{D,k}^2(M_{Q,ii}^2 + M_{D,jj}^2 + m_1^2) \\
|A_{U,ij}|^2 &< Y_{U,k}^2(M_{Q,ii}^2 + M_{U,jj}^2 + m_2^2), \qquad k = \max(i,j)
\end{aligned}
$$

† J.A. Casas, S. Dimopoulos, Phys. Lett. B **387** (1996) 107

Tools: SPheno

Generation mixing and all complex phases are included in:

- complete 2-loop SUSY RGEs (including ν_R)
- complete 1-loop SUSY masses
- all 2-body decays of SUSY and Higgs particles at tree-level
- all 3-body decay modes of $\tilde{\chi}_k^0$, $\tilde{\chi}_j^\pm$, $\tilde{g}$, $\tilde{t}_1$
- production of SUSY particles in e^+e^- annihilation several tests passed
- Higgs masses complete 1-loop formulas, in case of real parameters: 2-loop part implemented assuming that there is no generation mixing.
  However: no mixing yet of h^0, H^0, A^0 , but interface to FeynHiggs

Tools: SPheno

- Low energy observables
  - electric and magnetic moments of leptons: a_i, d_i, $[i = e, \mu, \tau]$
  - rare lepton decays: $\mu \to e\gamma$, $\tau \to e\gamma$, $\tau \to \mu\gamma$, $\mu \to eee$, $\tau \to eee$, $\tau \to \mu\mu\mu$
  - $b \to q\gamma$, $A_{CP}(b \to q\gamma)$ $[q = d, s]$
  - $B_q^0 \to \mu^+\mu^-$ $[q = d, s]$
  - $b \to s l^+ l^-$, $b \to s\nu\nu$
  - $B_u \to \tau\nu$
  - $\Delta M_{B_q^0}$ $(q = d, s)$
  - neutron EDM

Tools: SPheno

- Models
  - high scale models
    - mSUGRA, GMSB, AMSB, string inspired models: usual parameters + CKM effects in RGE running and mass calculation
    - at M_{GUT}: specification of all SUSY parameters
  - all MSSM parameters at a user given scale $Q \leq 1$ TeV
- SLHA2 implemented
- Release: January/February 2008

Low energy constraints

for easier comparision of benchmark points

$$\begin{aligned}
\delta_{LL,23} &= \frac{M^2_{Q,23}}{\bar{m}^2_{\tilde{d}}}\ ,\ \delta_{D,RR,23} = \frac{M^2_{D,23}}{\bar{m}^2_{\tilde{d}}}\ ,\ \delta_{D,LR,ij} = \frac{v_1 A_{D,ij}}{\bar{m}^2_{\tilde{d}}} \\
\delta_{U,RR,23} &= \frac{M^2_{U,23}}{\bar{m}^2_{\tilde{d}}}\ ,\ \delta_{U,LR,ij} = \frac{v_2 A_{U,ij}}{\bar{m}^2_{\tilde{d}}} \\
\bar{m}^2_{\tilde{d}} &= \frac{1}{6}\sum_{i=1}^{6} m^2_{\tilde{d}_i}\ ,\ \bar{m}^2_{\tilde{u}} = \frac{1}{6}\sum_{i=1}^{6} m^2_{\tilde{u}_i}
\end{aligned}$$

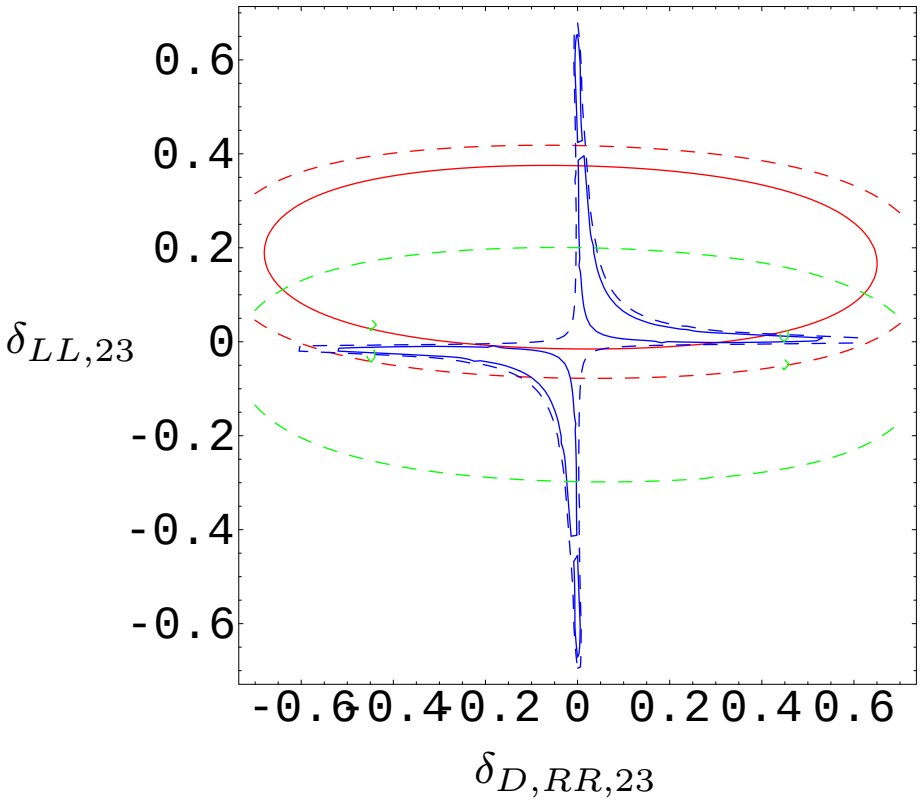
Note: $v_1 \ll v_2 \Rightarrow \delta_{D,LR,ij} \ll \delta_{U,LR,ij}$

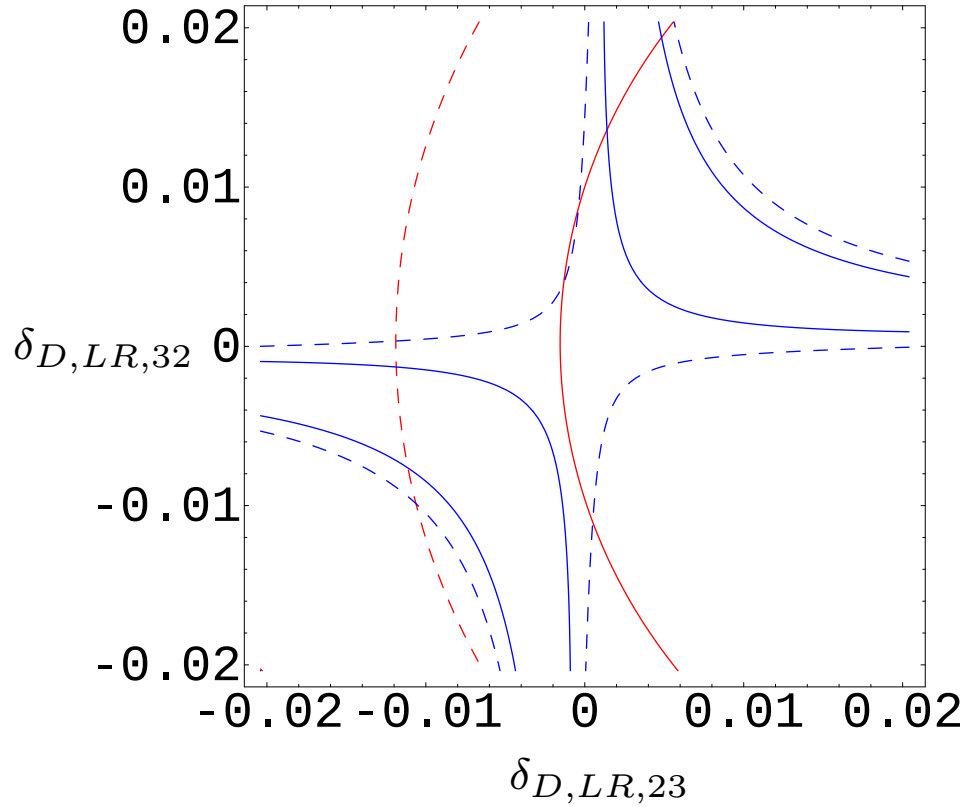
Main effects of low energy observables:

$$\begin{aligned}
b \to s\gamma &\quad\Rightarrow\quad \delta_{Q,LR} \\
\Delta M_{B_q} &\quad\Rightarrow\quad \delta_{LL}\delta_{Q,RR} \\
B_u \to \tau\nu\ ,\ B_s \to \mu^+\mu^- &\quad\Rightarrow\quad \tan\beta\ ,\ m_{H^+}
\end{aligned}$$

see e.g. Buras, Gabbiani, Masiero, Piai, Romanino, Silvestrini . . .

SPS1a', low energy constraints





full lines: $BR(b \to s\gamma) = 2.7 \cdot 10^{-4}$, $|\Delta_{M_{B_s}}| = 13.5$ ps^{-1} , $BR(b \to s l^+ l^-) = 1.05 \cdot 10^{-6}$

dashed lines: $BR(b \to s\gamma) = 4.3 \cdot 10^{-4}$, $|\Delta_{M_{B_s}}| = 21.1$ ps^{-1} , $BR(b \to s l^+ l^-) = 2.15 \cdot 10^{-6}$

Fine tuning

Some of regions shown require cancellations between different contributions! $\Rightarrow$ fine tuning?

Majority: yes, allow only individual δs satisfying data
$\Rightarrow \delta_x \lesssim 10^{-3} - 10^{-1}$

But: in exact SUSY: cancellations between large contributions are „natural", e.g.

$$A_t(b \to s\gamma) + A_{H^+}(b \to s\gamma) + A_{\tilde{\chi}_i^+}(b \to s\gamma) = 0$$

Gluino and squarks decays

1. $m_{\tilde{g}} > m_{\tilde{q}_i}$

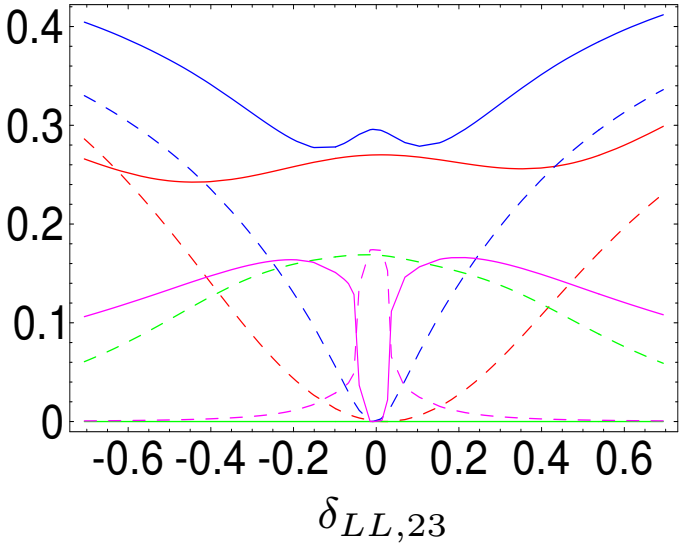
$$
\begin{aligned}
\tilde{g} &\to d_j\,\tilde{d}_i\,, \;\; \tilde{g} \to u_j\,\tilde{u}_i \\
\tilde{u}_i &\to u_j\tilde{\chi}^0_k\,, d_j\tilde{\chi}^+_l\,, \;\; \tilde{d}_i \to d_j\tilde{\chi}^0_k\,, u_j\tilde{\chi}^-_l \\
\tilde{u}_i &\to Z\tilde{u}_k\,, \; H^0_r\tilde{u}_k\,, \; W^+\tilde{d}_j\,, \; H^+\tilde{d}_j \\
\tilde{d}_i &\to Z\tilde{d}_k\,, \; H^0_r\tilde{d}_k\,, \; W^-\tilde{u}_j\,, \; H^-\tilde{u}_j
\end{aligned}
$$

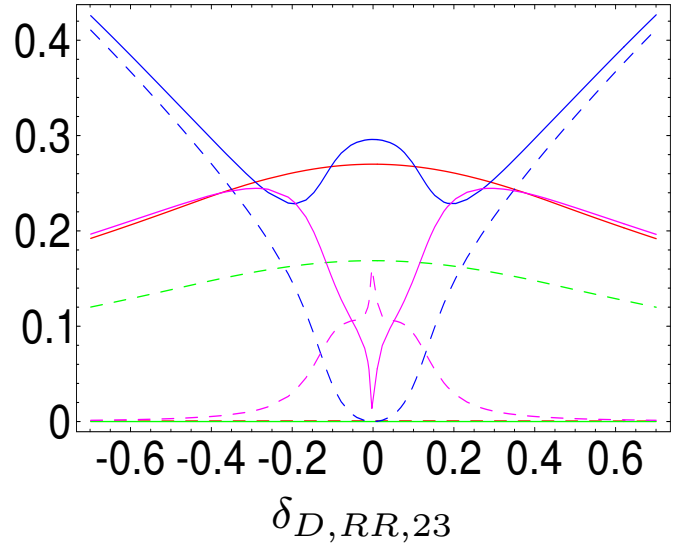
$(H^0_r = (h^0, H^0, A^0),\, k < i,\, j = 1, \ldots, 6)$

2. $m_{\tilde{g}} < m_{\tilde{q}_i}$

$$
\begin{aligned}
\tilde{u}_i &\to u_j\tilde{g}\,, \;\; \tilde{d}_i \to d_j\tilde{g} \\
\tilde{g} &\to d_j\,d_i\,\tilde{\chi}^0_k\,, \;\; u_j\,u_i\,\tilde{\chi}^0_k \\
\tilde{g} &\to u_j\,d_i\,\tilde{\chi}^\pm_l\,, \; \tilde{g} \to g\,\tilde{\chi}^0_k
\end{aligned}
$$

Gluino decays, variations around SPS1a'





full lines

$\tilde{g} \to \tilde{u}_1 t$

$\tilde{g} \to \tilde{u}_2 t$

$\tilde{g} \to \tilde{d}_1 b$

$\tilde{g} \to \tilde{d}_2 b$

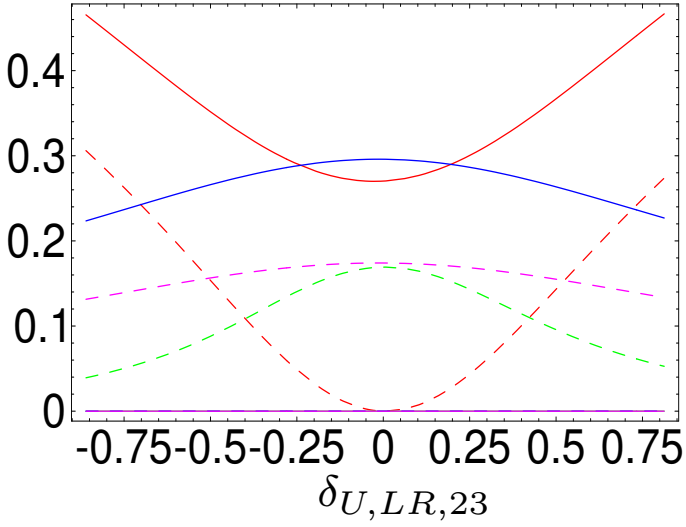
dashed lines

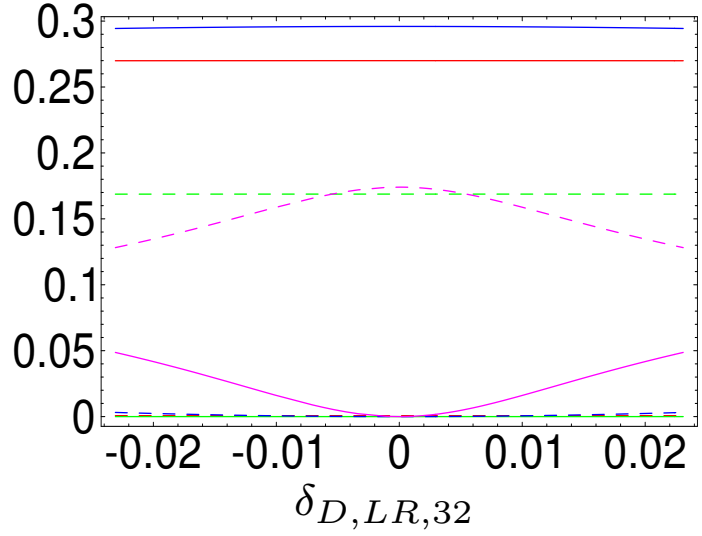
$\tilde{g} \to \tilde{u}_1 c$

$\tilde{g} \to \tilde{u}_2 c$

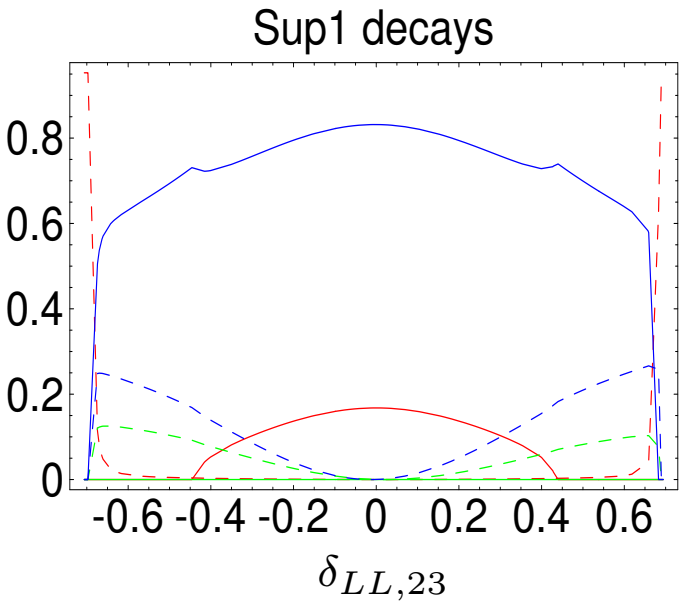
$\tilde{g} \to \tilde{d}_1 s$

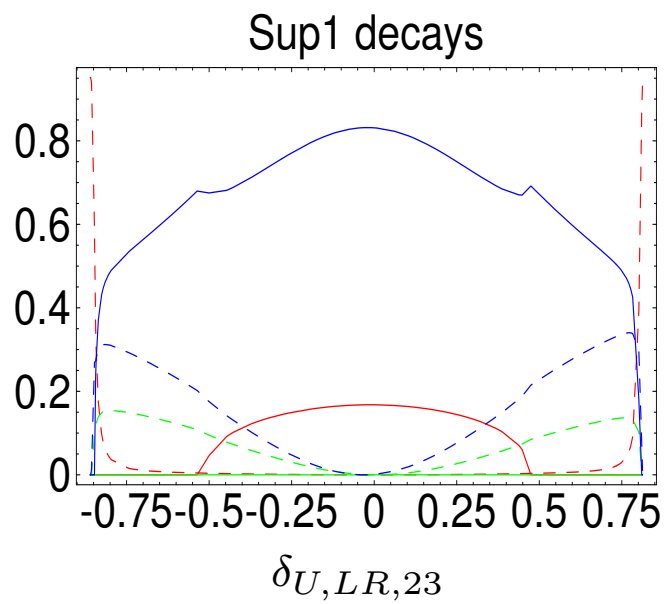
$\tilde{g} \to \tilde{d}_2 s$





Squark decays, variations around SPS1a'



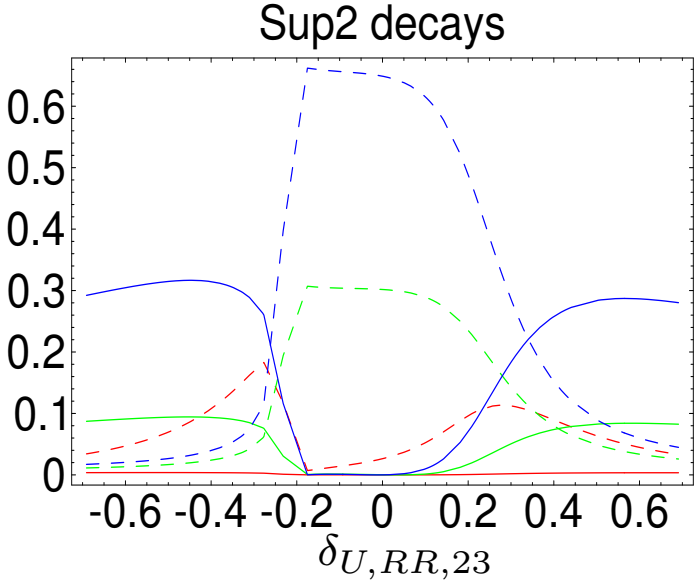


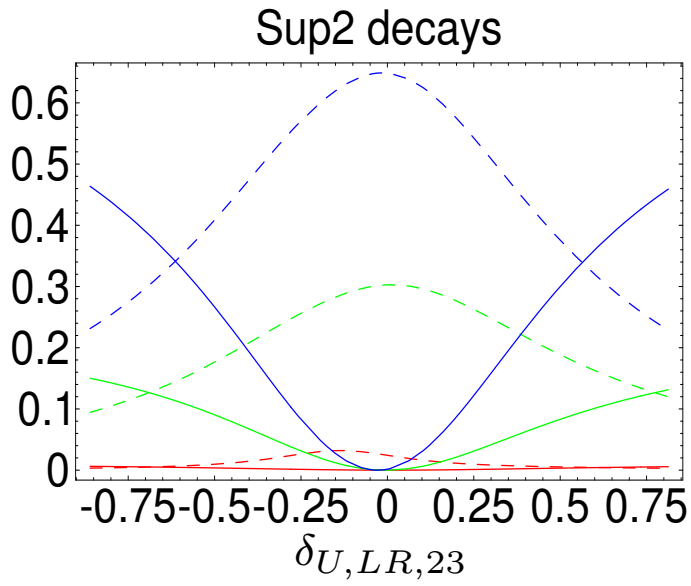
full lines

$\tilde{u}_j \to \tilde{\chi}_1^0 t$
$\tilde{u}_j \to \tilde{\chi}_2^0 t$
$\tilde{u}_j \to \tilde{\chi}_1^+ b$

dashed lines

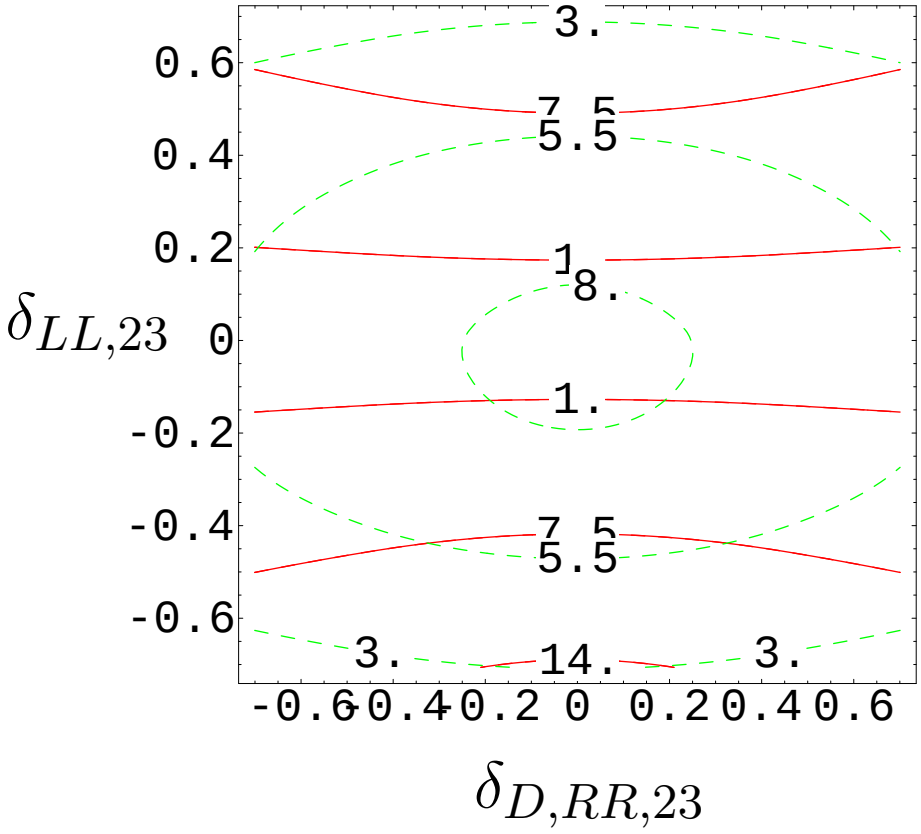
$\tilde{u}_j \to \tilde{\chi}_1^0 c$
$\tilde{u}_j \to \tilde{\chi}_2^0 c$
$\tilde{u}_j \to \tilde{\chi}_1^+ s$



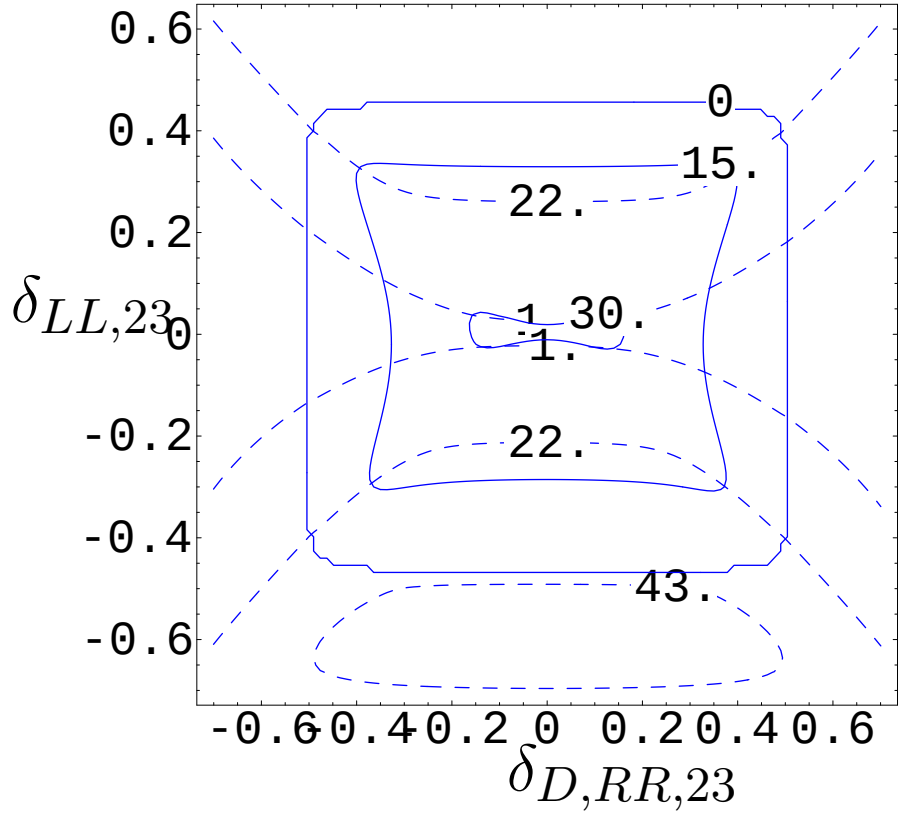


Parameter determination, theoretical dream

BR($\tilde{g} \to t\tilde{u}_1$), BR($\tilde{g} \to \tilde{u}_2 c$)



BR($\tilde{d}_1 \to (c,t)\tilde{\chi}_1^-$)



Parameter determination, practical problems

- cascade decays

$$\tilde{g} \to \bar{b}\tilde{b}_i \to \bar{b}b\tilde{\chi}_2^0 \to \bar{b}bl^+\tilde{l}_R \to \bar{b}bl^+l^-\tilde{\chi}_1^0$$

- same final states with different chains

$$\begin{aligned}\tilde{g} &\to \bar{t}\tilde{t}_i \to \bar{t}b\tilde{\chi}_1^+ \to \bar{b}bW^-\tilde{\chi}_1^+ \\ \tilde{g} &\to \bar{b}\tilde{b}_i \to \bar{b}W^-\tilde{t}_1 \to \bar{b}W^-b\tilde{\chi}_1^+\end{aligned}$$

investigated by Kawagoe, Nojiri, Polesello, Tricomi, . . . for flavour conserving case

$\Rightarrow$ use edges in $m^2_{b\bar{b}}$ or m^2_{bt}, gives hint for $m_{\tilde{b}_i}$, separation of $\tilde{b}_1$ and $\tilde{b}_2$ difficult, additional kinematical information helps

Summary and outlook

- Flavour violating entries $\Rightarrow$ SUSY breaking mechanism
- how to define fine-tuning ?
- MFV scenarios: tiny BRs for flavour violating $\tilde{g}$ and $\tilde{q}$ decays
- Non-MFV scenarios: large flavour violating BRs possible
  $\Rightarrow$ need observables to disentangle cascades or at least parts
- Observables: include effects of decays into gauge and Higgs bosons
- Tools: combine SPheno with Omega/Whizard package (W. Kilian, T. Ohl, J. Reuter)