Phenomenology of Non-Minimal Flavour Violating Supersymmetry at the LHC

Björn Herrmann
LPSC Grenoble

in collaboration with G. Bozzi, B. Fuks, and M. Klasen

[Bozzi, Fuks, BjHe, Klasen, Nucl. Phys. B (2007); Fuks, BjHe, Klasen, *in preparation*]

EURO-GDR SUSY
Bruxelles, November 13, 2007

Outline

Non-Minimal Flavour Violation (NMFV)

- Squark mass matrices in constrained minimal flavour violation: $\Delta_{ij}^{qq'} = 0$

$$M^2_{\tilde{Q}} = \left(\begin{array}{ccc|ccc} M^2_{LL,1} & \Delta^{12}_{LL} & \Delta^{13}_{LL} & m_1 m_{LR,1} & \Delta^{12}_{LR} & \Delta^{13}_{LR} \\ \Delta^{21}_{LL} & M^2_{LL,2} & \Delta^{23}_{LL} & \Delta^{21}_{LR} & m_2 m_{LR,2} & \Delta^{23}_{LR} \\ \Delta^{31}_{LL} & \Delta^{32}_{LL} & M^2_{LL,3} & \Delta^{31}_{LR} & \Delta^{32}_{LR} & m_3 m_{LR,3} \\ \hline m_1 m_{RL,1} & \Delta^{12}_{RL} & \Delta^{13}_{RL} & M^2_{RR,1} & \Delta^{12}_{RR} & \Delta^{13}_{RR} \\ \Delta^{21}_{RL} & m_2 m_{RL,2} & \Delta^{23}_{RL} & \Delta^{21}_{RR} & M^2_{RR,2} & \Delta^{23}_{RR} \\ \Delta^{32}_{RL} & \Delta^{32}_{RL} & m_3 m_{RL,3} & \Delta^{31}_{RR} & \Delta^{32}_{RR} & M^2_{RR,3} \end{array} \right)$$

Non-Minimal Flavour Violation (NMFV)

- Squark mass matrices in constrained minimal flavour violation: $\Delta_{ij}^{qq'} = 0$

$$M^2_{\tilde{Q}} = \left(\begin{array}{ccc|ccc} M^2_{LL,1} & \Delta^{12}_{LL} & \Delta^{13}_{LL} & m_1 m_{LR,1} & \Delta^{12}_{LR} & \Delta^{13}_{LR} \\ \Delta^{21}_{LL} & M^2_{LL,2} & \Delta^{23}_{LL} & \Delta^{21}_{LR} & m_2 m_{LR,2} & \Delta^{23}_{LR} \\ \Delta^{31}_{LL} & \Delta^{32}_{LL} & M^2_{LL,3} & \Delta^{31}_{LR} & \Delta^{32}_{LR} & m_3 m_{LR,3} \\ \hline m_1 m_{RL,1} & \Delta^{12}_{RL} & \Delta^{13}_{RL} & M^2_{RR,1} & \Delta^{12}_{RR} & \Delta^{13}_{RR} \\ \Delta^{21}_{RL} & m_2 m_{RL,2} & \Delta^{23}_{RL} & \Delta^{21}_{RR} & M^2_{RR,2} & \Delta^{23}_{RR} \\ \Delta^{32}_{RL} & \Delta^{32}_{RL} & m_3 m_{RL,3} & \Delta^{31}_{RR} & \Delta^{32}_{RR} & M^2_{RR,3} \end{array} \right)$$

- New sources of flavour violation when embedding SUSY in larger structures
  $\longrightarrow$ Convenient parametrization: 24 NMFV-parameters $\lambda_{ij}^{qq'}$ [Gabbiani *et al.* (1989, 1996)]

$$\Delta_{ij}^{qq'} = \lambda_{ij}^{qq'} M_{ii,q} M_{jj,q'} \neq 0$$

Non-Minimal Flavour Violation (NMFV)

- Squark mass matrices in constrained minimal flavour violation: $\Delta_{ij}^{qq'} = 0$

$$M_{\tilde{Q}}^2 = \left(\begin{array}{ccc|ccc} M^2_{LL,1} & \Delta^{12}_{LL} & \Delta^{13}_{LL} & m_1 m_{LR,1} & \Delta^{12}_{LR} & \Delta^{13}_{LR} \\ \Delta^{21}_{LL} & M^2_{LL,2} & \Delta^{23}_{LL} & \Delta^{21}_{LR} & m_2 m_{LR,2} & \Delta^{23}_{LR} \\ \Delta^{31}_{LL} & \Delta^{32}_{LL} & M^2_{LL,3} & \Delta^{31}_{LR} & \Delta^{32}_{LR} & m_3 m_{LR,3} \\ \hline m_1 m_{RL,1} & \Delta^{12}_{RL} & \Delta^{13}_{RL} & M^2_{RR,1} & \Delta^{12}_{RR} & \Delta^{13}_{RR} \\ \Delta^{21}_{RL} & m_2 m_{RL,2} & \Delta^{23}_{RL} & \Delta^{21}_{RR} & M^2_{RR,2} & \Delta^{23}_{RR} \\ \Delta^{32}_{RL} & \Delta^{32}_{RL} & m_3 m_{RL,3} & \Delta^{31}_{RR} & \Delta^{32}_{RR} & M^2_{RR,3} \end{array} \right)$$

- New sources of flavour violation when embedding SUSY in larger structures
  $\rightarrow$ Convenient parametrization: 24 NMFV-parameters $\lambda_{ij}^{qq'}$ [Gabbiani *et al.* (1989, 1996)]

$$\Delta_{ij}^{qq'} = \lambda_{ij}^{qq'} M_{ii,q} M_{jj,q'} \neq 0$$

- Diagonalization through 6×6 rotation matrices $(m_{\tilde{q}_1} < \ldots < m_{\tilde{q}_6})$

$$(\tilde{u}_1, \tilde{u}_2, \tilde{u}_3, \tilde{u}_4, \tilde{u}_5, \tilde{u}_6)^T = R^u (\tilde{u}_L, \tilde{c}_L, \tilde{t}_L, \tilde{u}_R, \tilde{c}_R, \tilde{t}_R)^T$$
$$(\tilde{d}_1, \tilde{d}_2, \tilde{d}_3, \tilde{d}_4, \tilde{d}_5, \tilde{d}_6)^T = R^d (\tilde{d}_L, \tilde{s}_L, \tilde{b}_L, \tilde{d}_R, \tilde{s}_R, \tilde{b}_R)^T$$

Constraints on Non-Minimal Flavour Violation

- Scaling of the off-diagonal terms with SUSY breaking scale [Gabbiani *et al.* (1989)]

$$\Delta^{qq'}_{LL} \gg \Delta^{qq'}_{LR,RL} \gg \Delta^{qq'}_{RR}$$

Constraints on Non-Minimal Flavour Violation

- Scaling of the off-diagonal terms with SUSY breaking scale [Gabbiani *et al.* (1989)]

$$\Delta^{qq'}_{LL} \gg \Delta^{qq'}_{LR,RL} \gg \Delta^{qq'}_{RR}$$

- Upper limits on $\lambda^{qq'}_{ij}$ from FCNC
  $\longrightarrow$ Neutral kaon sector, B- and D-meson oscillations, rare decays, electric dipole moments [Gabbiani *et al.* (1996), Ciuchini *et al.* (2007)]

Constraints on Non-Minimal Flavour Violation

- Scaling of the off-diagonal terms with SUSY breaking scale [Gabbiani *et al.* (1989)]

$$\Delta^{qq'}_{LL} \gg \Delta^{qq'}_{LR,RL} \gg \Delta^{qq'}_{RR}$$

- Upper limits on $\lambda^{qq'}_{ij}$ from FCNC
  → Neutral kaon sector, B- and D-meson oscillations, rare decays, electric dipole moments [Gabbiani *et al.* (1996), Ciuchini *et al.* (2007)]

- Constraints: only 2^{nd}-3^{rd}-generation mixing in the left-left sector

$$\lambda^{ct}_{LL} \leq 0.1, \qquad \lambda^{bs}_{LL} \leq 0.1, \qquad \text{other } \lambda^{qq'}_{ij} = 0$$

Constraints on Non-Minimal Flavour Violation

- Scaling of the off-diagonal terms with SUSY breaking scale [Gabbiani *et al.* (1989)]

$$\Delta^{qq'}_{LL} \gg \Delta^{qq'}_{LR,RL} \gg \Delta^{qq'}_{RR}$$

- Upper limits on $\lambda^{qq'}_{ij}$ from FCNC
  → Neutral kaon sector, B- and D-meson oscillations, rare decays, electric dipole moments [Gabbiani *et al.* (1996), Ciuchini *et al.* (2007)]

- Constraints: only 2^{nd}-3^{rd}-generation mixing in the left-left sector

$$\lambda^{ct}_{LL} \leq 0.1, \qquad \lambda^{bs}_{LL} \leq 0.1, \qquad \text{other } \lambda^{qq'}_{ij} = 0$$

- In our analysis: only one new free parameter

$$\lambda^{ct}_{LL} = \lambda^{bs}_{LL} \equiv \lambda$$

  → no large difference allowed due to $SU(2)$ gauge invariance

Low-energy, EW precision and cosmological constraints

- Decay $b \to s\gamma$: NMFV contributes at the one-loop level (as also SM)

$$\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \quad \text{(at } 2\sigma\text{)}$$ [Barbiero *et al.* (2006)]

Low-energy, EW precision and cosmological constraints

- Decay $b \to s\gamma$: NMFV contributes at the one-loop level (as also SM)

$$\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \quad \text{(at } 2\sigma\text{)}$$ [Barbiero *et al.* (2006)]

- Electroweak ρ-parameter: sensitive to squark mass splitting

$$\Delta\rho = 0.00102 \pm 0.00086 \quad \text{(at } 2\sigma\text{)}$$ [Yao *et al.* (2006)]

Low-energy, EW precision and cosmological constraints

- Decay $b \to s\gamma$: NMFV contributes at the one-loop level (as also SM)

$$\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \quad (\text{at } 2\sigma)$$ [Barbiero *et al.* (2006)]

- Electroweak ρ-parameter: sensitive to squark mass splitting

$$\Delta\rho = 0.00102 \pm 0.00086 \quad (\text{at } 2\sigma)$$ [Yao *et al.* (2006)]

- New physics contribution to the anomalous magnetic moment of the muon

$$a_\mu^{SUSY} = (g-2)_\mu^{SUSY} = (22 \pm 10) \times 10^{-10} \quad (\text{at } 2\sigma)$$ [Yao *et al.* (2006)]

$\rightarrow$ squarks contribute only at two-loop level (SM: one-loop)
$\rightarrow$ disfavours $\mu < 0$ in all SUSY models

Low-energy, EW precision and cosmological constraints

- Decay $b \to s\gamma$: NMFV contributes at the one-loop level (as also SM)

$$\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \quad \text{(at } 2\sigma\text{)}$$ [Barbiero *et al.* (2006)]

- Electroweak ρ-parameter: sensitive to squark mass splitting

$$\Delta\rho = 0.00102 \pm 0.00086 \quad \text{(at } 2\sigma\text{)}$$ [Yao *et al.* (2006)]

- New physics contribution to the anomalous magnetic moment of the muon

$$a_\mu^{SUSY} = (g-2)_\mu^{SUSY} = (22 \pm 10) \times 10^{-10} \quad \text{(at } 2\sigma\text{)}$$ [Yao *et al.* (2006)]

$\longrightarrow$ squarks contribute only at two-loop level (SM: one-loop)
$\longrightarrow$ disfavours $\mu < 0$ in all SUSY models

- Dark matter candidate: LSP neutral in charge and colour [Ellis *et al.* (1984)]

Low-energy, EW precision and cosmological constraints

- Decay $b \to s\gamma$: NMFV contributes at the one-loop level (as also SM)

$$\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4} \quad \text{(at } 2\sigma\text{)}$$ [Barbiero *et al.* (2006)]

- Electroweak ρ-parameter: sensitive to squark mass splitting

$$\Delta\rho = 0.00102 \pm 0.00086 \quad \text{(at } 2\sigma\text{)}$$ [Yao *et al.* (2006)]

- New physics contribution to the anomalous magnetic moment of the muon

$$a_\mu^{SUSY} = (g-2)_\mu^{SUSY} = (22 \pm 10) \times 10^{-10} \quad \text{(at } 2\sigma\text{)}$$ [Yao *et al.* (2006)]

$\to$ squarks contribute only at two-loop level (SM: one-loop)
$\to$ disfavours $\mu < 0$ in all SUSY models

- Dark matter candidate: LSP neutral in charge and colour [Ellis *et al.* (1984)]

- Dark matter relic density:

$$0.094 < \Omega_{CDM} h^2 < 0.136 \quad \text{(at } 2\sigma\text{)}$$ [Hamann *et al.* (2007)]

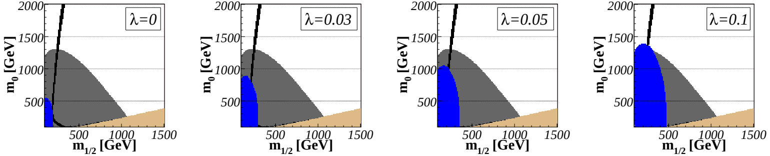
Constraints on NMFV in mSUGRA

- Inspect mSUGRA scenario

  → Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]

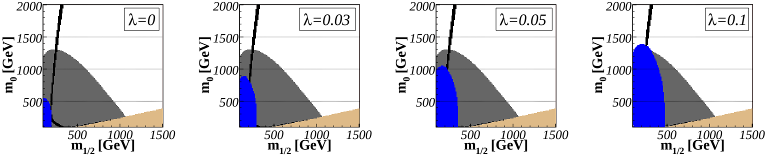
Constraints on NMFV in mSUGRA

- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  $\rightarrow$ Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



Constraints on NMFV in mSUGRA

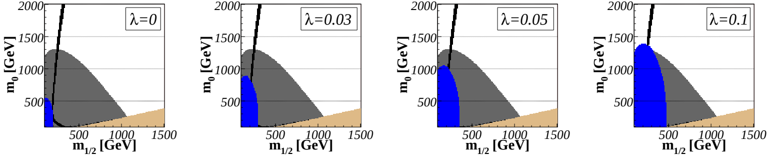
- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  $\longrightarrow$ Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions

Constraints on NMFV in mSUGRA

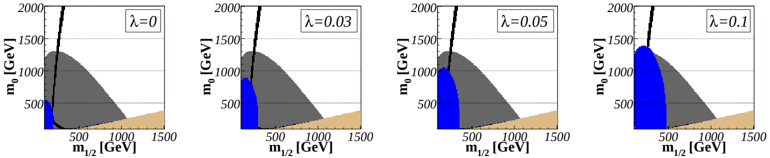
- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  $\longrightarrow$ Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions
- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)

Constraints on NMFV in mSUGRA

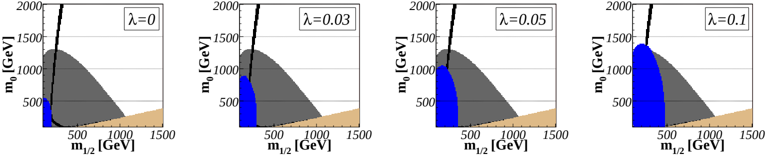
- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  $\longrightarrow$ Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions
- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)
- Region leading to charged LSP (beige)

Constraints on NMFV in mSUGRA

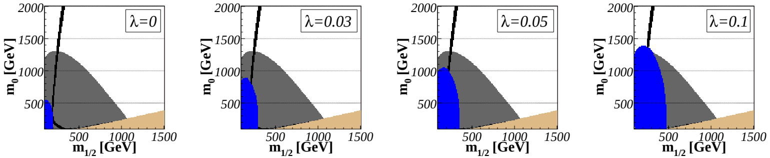
- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  $\longrightarrow$ Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions
- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)
- Region leading to charged LSP (beige)
- Region favoured by Ω_{CDM} (black)
  $\longrightarrow$ sensitivity to NMFV very small

Constraints on NMFV in mSUGRA

- Inspect mSUGRA scenario for $\tan\beta = 10$, $\mu > 0$, $A_0 = 0$, and $0 \leq \lambda \leq 0.1$
  → Spectrum and constraints calculated using `SPheno 2.2.3`, `FeynHiggs 2.5.1`, and modified `DarkSUSY 4.1` [Porod (2003), Heinemeyer *et al.* (2000), Gondolo *et al.* (2004)]



- Region favoured by a_μ (grey)
  → reduced squark two-loop vs. slepton one-loop contributions
- Region excluded by $b \to s\gamma$ (blue)
  → very sensitive to NMFV (same loop-level as SM contributions)
- Region leading to charged LSP (beige)
- Region favoured by Ω_{CDM} (black)
  → sensitivity to NMFV very small
- $\Delta\rho$ excludes only very high SUSY masses (not shown)

Benchmark points for mSUGRA

- We propose the following allowed benchmark points [Bozzi, Fuks, BjHe, Klasen (2007)]

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan\beta$	sgn(μ)	λ bounds
A	700	200	0	10	+	[0; 0.05]
B	100	400	0	10	+	[0; 0.10]
C	230	590	0	30	+	[0; 0.05]
D	600	700	0	50	+	[0; 0.05]

Benchmark points for mSUGRA

- We propose the following allowed benchmark points [Bozzi, Fuks, BjHe, Klasen (2007)]

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan\beta$	sgn(μ)	λ bounds
A	700	200	0	10	+	[0; 0.05]
B	100	400	0	10	+	[0; 0.10]
C	230	590	0	30	+	[0; 0.05]
D	600	700	0	50	+	[0; 0.05]

$\rightarrow$ benchmark points also allowed for cMFV scenarios ($\lambda = 0$)
and MFV scenarios ($\lambda \in [0, 0.005 \ldots 0.01]$)

Benchmark points for mSUGRA

- We propose the following allowed benchmark points [Bozzi, Fuks, BjHe, Klasen (2007)]

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan\beta$	sgn(μ)	λ bounds
A	700	200	0	10	+	[0; 0.05]
B	100	400	0	10	+	[0; 0.10]
C	230	590	0	30	+	[0; 0.05]
D	600	700	0	50	+	[0; 0.05]

$\rightarrow$ benchmark points also allowed for cMFV scenarios ($\lambda = 0$) and MFV scenarios ($\lambda \in [0, 0.005...0.01]$)

- In this talk: focus on benchmark point B
  $\rightarrow$ "collider-friendly"
  ($m_{\tilde{l}} \sim 200 - 300$, $m_{\tilde{\chi}} \sim 150 - 550$, $m_{\tilde{q}} \sim 650 - 850$, $m_{\tilde{g}} \sim 900$ GeV)

Benchmark points for mSUGRA

- We propose the following allowed benchmark points [Bozzi, Fuks, BjHe, Klasen (2007)]

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan\beta$	sgn(μ)	λ bounds
A	700	200	0	10	+	[0; 0.05]
B	100	400	0	10	+	[0; 0.10]
C	230	590	0	30	+	[0; 0.05]
D	600	700	0	50	+	[0; 0.05]

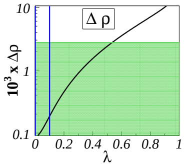
$\rightarrow$ benchmark points also allowed for cMFV scenarios ($\lambda = 0$) and MFV scenarios ($\lambda \in [0, 0.005...0.01]$)

- In this talk: focus on benchmark point B
  $\rightarrow$ "collider-friendly"
  ($m_{\tilde{l}} \sim 200 - 300$, $m_{\tilde{\chi}} \sim 150 - 550$, $m_{\tilde{q}} \sim 650 - 850$, $m_{\tilde{g}} \sim 900$ GeV)
  $\rightarrow$ numerical study of constraints, squark mass splitting and flavour content, squark and gaugino production cross sections

Point B: Constraints

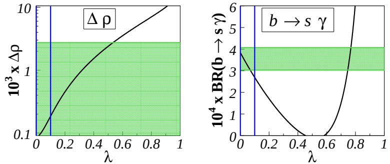
- $a_\mu^{SUSY} \simeq 14 \times 10^{-4}$ independent of λ (not shown)

Point B: Constraints



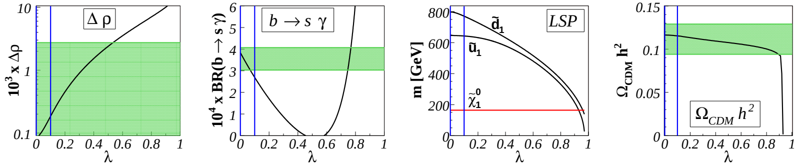
- $a_\mu^{SUSY} \simeq 14 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\rightarrow$ large allowed range ($\lambda \leq 0.52$), due to important experimental errors

Point B: Constraints



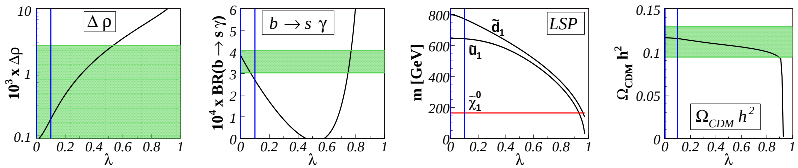
- $a_\mu^{SUSY} \simeq 14 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\rightarrow$ large allowed range ($\lambda \leq 0.52$), due to important experimental errors
- Very stringent constraint from $b \rightarrow s\gamma$
  $\rightarrow$ small error band and very sensitive to λ
  $\rightarrow$ 2^{nd} allowed region disfavoured by $B \rightarrow X_s\mu\mu$ [Gambino *et al.* (2005)]

Point B: Constraints



- $a_\mu^{SUSY} \simeq 14 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.52$), due to important experimental errors
- Very stringent constraint from $b \rightarrow s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \rightarrow X_s \mu\mu$ [Gambino *et al.* (2005)]
- Small mass difference between LSP and NLSP at large λ
  $\longrightarrow$ $\Omega_{CDM} h^2$ falls due to important coannihilations
  and light squark propagated annihilation processes

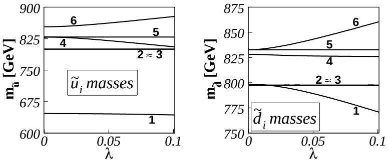
Point B: Constraints



- $a_\mu^{SUSY} \simeq 14 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.52$), due to important experimental errors
- Very stringent constraint from $b \to s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \to X_s \mu\mu$ [Gambino *et al.* (2005)]
- Small mass difference between LSP and NLSP at large λ
  $\longrightarrow$ $\Omega_{CDM} h^2$ falls due to important coannihilations
  and light squark propagated annihilation processes

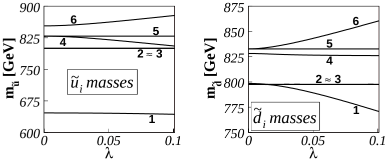
$\Longrightarrow$ Allowed region close to (c)MFV: $0 \lesssim \lambda \lesssim 0.1$

Point B: Mass splitting and flavour content



[Bozzi, Fuks, BjHe, Klasen (2007)]

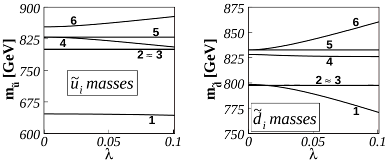
Point B: Mass splitting and flavour content



[Bozzi, Fuks, BjHe, Klasen (2007)]

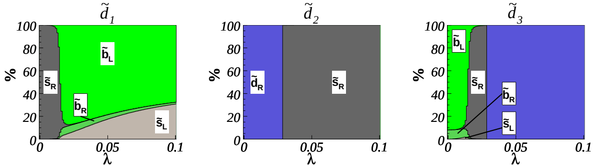
- Hermitian squark mass matrices depend continously on the single parameter λ
  $\longrightarrow$ their eigenvalues do not cross (avoided crossings)
  $\longrightarrow$ exchange of the flavour content between the involved eigenstates

Point B: Mass splitting and flavour content

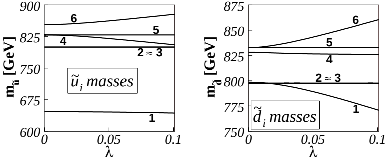


[Bozzi, Fuks, BjHe, Klasen (2007)]

- Hermitian squark mass matrices depend continously on the single parameter λ
  $\rightarrow$ their eigenvalues do not cross (avoided crossings)
  $\rightarrow$ exchange of the flavour content between the involved eigenstates

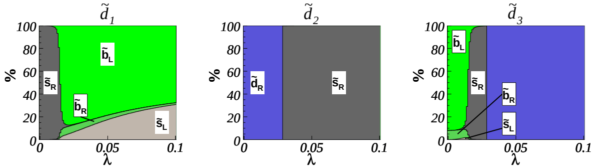


Point B: Mass splitting and flavour content



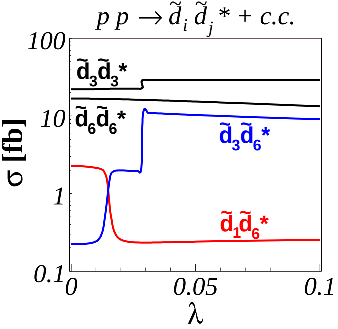
[Bozzi, Fuks, BjHe, Klasen (2007)]

- Hermitian squark mass matrices depend continously on the single parameter λ
  $\rightarrow$ their eigenvalues do not cross (avoided crossings)
  $\rightarrow$ exchange of the flavour content between the involved eigenstates



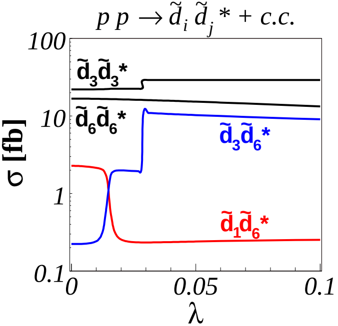
- Large mixing between 2^{nd} and 3^{rd} generations, even for small λ

Point B: Squark-antisquark pair production at the LHC

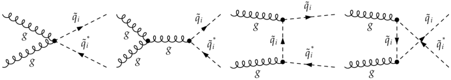


[Bozzi, Fuks, BjHe, Klasen (2007)]

Point B: Squark-antisquark pair production at the LHC

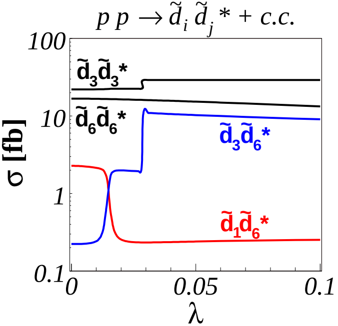


[Bozzi, Fuks, BjHe, Klasen (2007)]

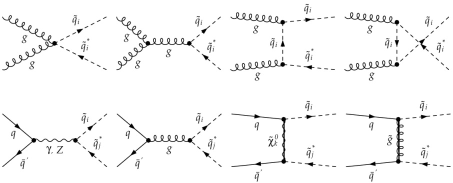


- Diagonal pairs dominated by gluon fusion diagrams
  $\longrightarrow$ strong production, i.e. large cross section
  $\longrightarrow$ low sensitivity to λ due to flavour independent $g\tilde{q}\tilde{q}$ vertex

Point B: Squark-antisquark pair production at the LHC

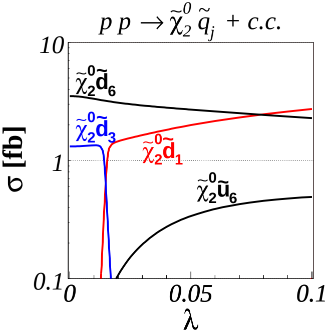


[Bozzi, Fuks, BjHe, Klasen (2007)]



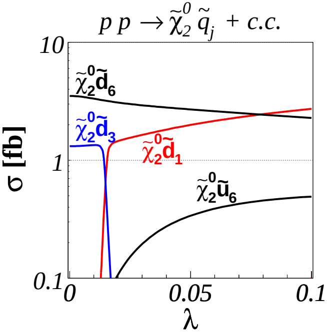
- Diagonal pairs dominated by gluon fusion diagrams
  → strong production, i.e. large cross section
  → low sensitivity to λ due to flavour independent $g\tilde{q}\tilde{q}$ vertex
- Non-diagonal pairs: only $q\bar{q}$ annihilation diagrams
  → sharp transitions with λ, corresponding to avoided crossings and mass flips

Point B: Squark-neutralino production at the LHC

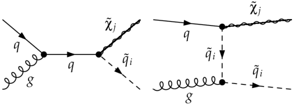


[Bozzi, Fuks, BjHe, Klasen (2007)]

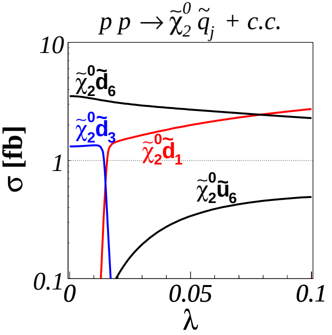
Point B: Squark-neutralino production at the LHC



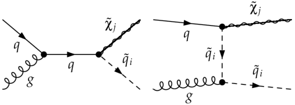
[Bozzi, Fuks, BjHe, Klasen (2007)]



Point B: Squark-neutralino production at the LHC

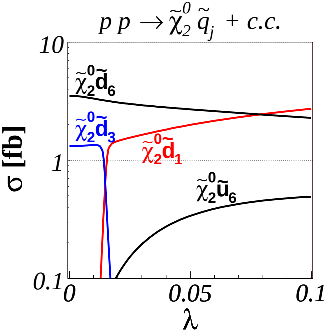


[Bozzi, Fuks, BjHe, Klasen (2007)]

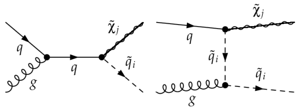


- Semi-strong production (0.1 - 10 fb)

Point B: Squark-neutralino production at the LHC

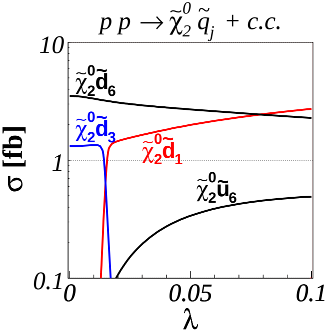


[Bozzi, Fuks, BjHe, Klasen (2007)]

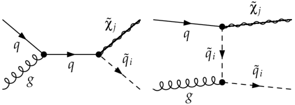


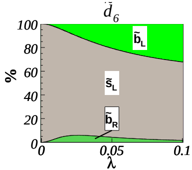
- Semi-strong production (0.1 - 10 fb)
- Quite sensitive to flavour violation due to $q\tilde{q}\tilde{\chi}$ vertex
  $\rightarrow$ avoided crossing / mass-flip between $\tilde{d}_1$ and $\tilde{d}_3$

Point B: Squark-neutralino production at the LHC



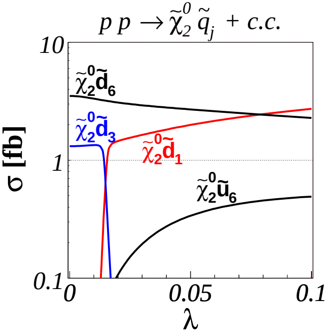
[Bozzi, Fuks, BjHe, Klasen (2007)]



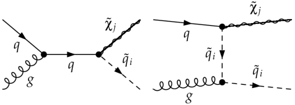


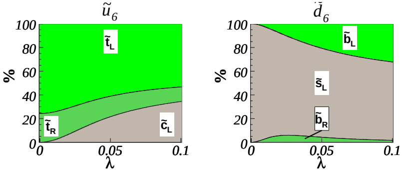
- Semi-strong production (0.1 - 10 fb)
- Quite sensitive to flavour violation due to $q\tilde{q}\tilde{\chi}$ vertex
  $\rightarrow$ avoided crossing / mass-flip between $\tilde{d}_1$ and $\tilde{d}_3$
- $\tilde{d}_6\tilde{\chi}_2^0$ cross section decreases with λ due to strange/bottom content in $\tilde{d}_6$

Point B: Squark-neutralino production at the LHC



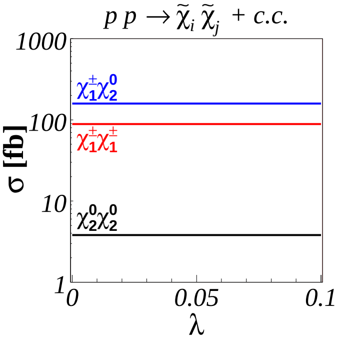
[Bozzi, Fuks, BjHe, Klasen (2007)]



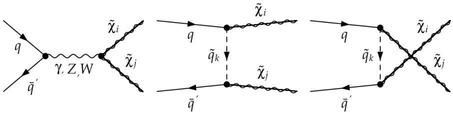


- Semi-strong production (0.1 - 10 fb)
- Quite sensitive to flavour violation due to $q\tilde{q}\tilde{\chi}$ vertex
  → avoided crossing / mass-flip between $\tilde{d}_1$ and $\tilde{d}_3$
- $\tilde{d}_6\tilde{\chi}^0_2$ cross section decreases with λ due to strange/bottom content in $\tilde{d}_6$
- $\tilde{u}_6\tilde{\chi}^0_2$ cross section increases with λ due to charm/top content in $\tilde{u}_6$

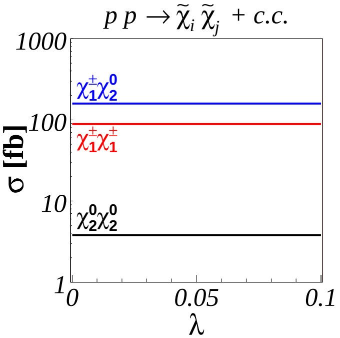
Point B: Gaugino pair production at the LHC



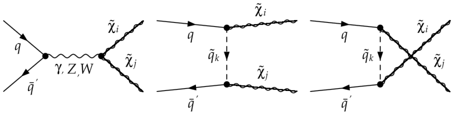
[Bozzi, Fuks, BjHe, Klasen (2007)]



Point B: Gaugino pair production at the LHC

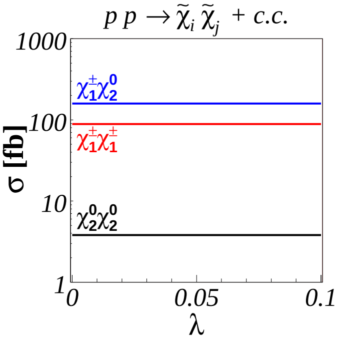


[Bozzi, Fuks, BjHe, Klasen (2007)]

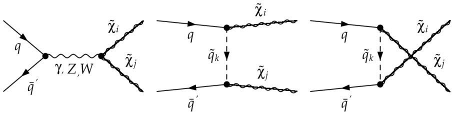


- Large cross sections due to light gauginos

Point B: Gaugino pair production at the LHC



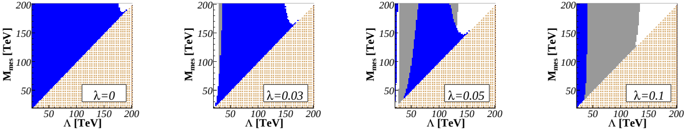
[Bozzi, Fuks, BjHe, Klasen (2007)]



- Large cross sections due to light gauginos
- Insensitive to flavour violation
  → sum over all physical squark states

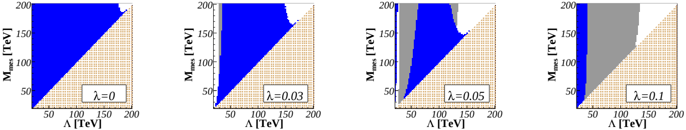
Constraints on NMFV in GMSB

- Inspect GMSB scenario for $\tan\beta = 15$, $\mu > 0$, $N_{\rm mes} = 3$, and $0 \leq \lambda \leq 0.1$



Constraints on NMFV in GMSB

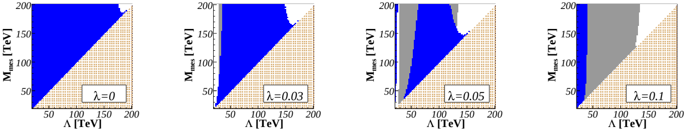
- Inspect GMSB scenario for $\tan\beta = 15$, $\mu > 0$, $N_{\rm mes} = 3$, and $0 \leq \lambda \leq 0.1$



- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)

Constraints on NMFV in GMSB

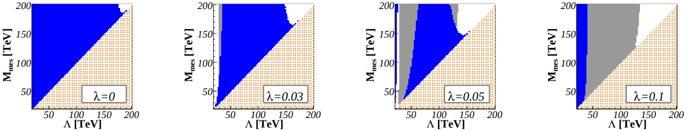
- Inspect GMSB scenario for $\tan\beta = 15$, $\mu > 0$, $N_{\rm mes} = 3$, and $0 \leq \lambda \leq 0.1$



- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)
- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions

Constraints on NMFV in GMSB

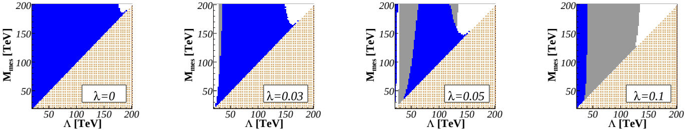
- Inspect GMSB scenario for $\tan\beta = 15$, $\mu > 0$, $N_{\rm mes} = 3$, and $0 \leq \lambda \leq 0.1$



- Region excluded by $b \to s\gamma$ (blue)
  $\longrightarrow$ very sensitive to NMFV (same loop-level as SM contributions)
- Region favoured by a_μ (grey)
  $\longrightarrow$ reduced squark two-loop vs. slepton one-loop contributions
- $\Delta\rho$ excludes only very high SUSY masses (not shown)

Constraints on NMFV in GMSB

- Inspect GMSB scenario for $\tan\beta = 15$, $\mu > 0$, $N_{\rm mes} = 3$, and $0 \leq \lambda \leq 0.1$



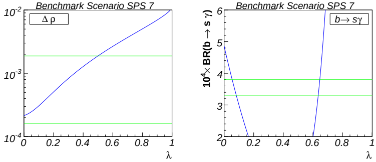
- Region excluded by $b \to s\gamma$ (blue)
  $\to$ very sensitive to NMFV (same loop-level as SM contributions)
- Region favoured by a_μ (grey)
  $\to$ reduced squark two-loop vs. slepton one-loop contributions
- $\Delta\rho$ excludes only very high SUSY masses (not shown)
- Note: $b \to s\gamma$ excludes SPS 7 (and SPS 8) [Allanach *et al.* (2002)]

	Λ (TeV)	M_{mes} (TeV)	N_{mes}	$\tan\beta$	sgn(μ)
SPS 7	40	80	3	15	$+$
SPS 8	100	200	1	15	$+$

Points SPS 7: Constraints and Discussion

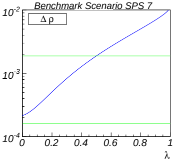
- $a_{\mu}^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)

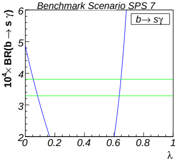
Points SPS 7: Constraints and Discussion



- $a_\mu^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.5$), due to important experimental errors

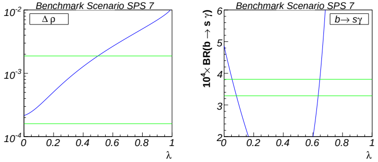
Points SPS 7: Constraints and Discussion





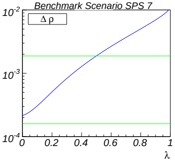
- $a_\mu^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.5$), due to important experimental errors
- Very stringent constraint from $b \to s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \to X_s\mu\mu$ [Gambino *et al.* (2005)]

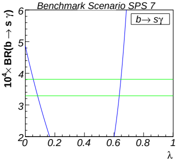
Points SPS 7: Constraints and Discussion



- $a_\mu^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.5$), due to important experimental errors
- Very stringent constraint from $b \to s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \to X_s\mu\mu$ [Gambino *et al.* (2005)]
- Cosmological constraints not yet implemented
  $\longrightarrow$ Gravitino relic density

Points SPS 7: Constraints and Discussion

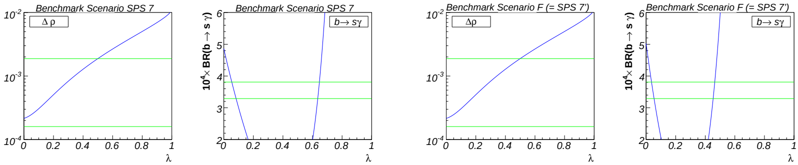




- $a_\mu^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \leq 0.5$), due to important experimental errors
- Very stringent constraint from $b \to s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \to X_s\mu\mu$ [Gambino *et al.* (2005)]
- Cosmological constraints not yet implemented
  $\longrightarrow$ Gravitino relic density

$\Longrightarrow$ Favoured region excludes (c)MFV

Points SPS 7: Constraints and Discussion



- $a_\mu^{SUSY} \simeq 23 \times 10^{-4}$ independent of λ (not shown)
- $\Delta\rho$ depends strongly on squark flavours, helicity and masses
  $\longrightarrow$ large allowed range ($\lambda \lesssim 0.5$), due to important experimental errors
- Very stringent constraint from $b \to s\gamma$
  $\longrightarrow$ small error band and very sensitive to λ
  $\longrightarrow$ 2^{nd} allowed region disfavoured by $B \to X_s\mu\mu$ [Gambino *et al.* (2005)]
- Cosmological constraints not yet implemented
  $\longrightarrow$ Gravitino relic density

$\Longrightarrow$ Favoured region excludes (c)MFV

$\Longrightarrow$ New benchmark point close to SPS 7 allows for λ-interval closer to (c)MFV

Conclusion and Perspectives

- We implement NMFV in MSSM at low energy [Bozzi, Fuks, BjHe, Klasen (2007)]
  → generalized strong and electroweak couplings
  → analytical squark and gaugino production and decay calculation

Conclusion and Perspectives

- We implement NMFV in MSSM at low energy [Bozzi, Fuks, BjHe, Klasen (2007)]
  → generalized strong and electroweak couplings
  → analytical squark and gaugino production and decay calculation
- We propose benchmark points for mSUGRA including NMFV
  → low energy, electroweak precision and cosmological constraints
  → numerical study of squark and gaugino production at LHC

Conclusion and Perspectives

- We implement NMFV in MSSM at low energy [Bozzi, Fuks, BjHe, Klasen (2007)]
  → generalized strong and electroweak couplings
  → analytical squark and gaugino production and decay calculation

- We propose benchmark points for mSUGRA including NMFV
  → low energy, electroweak precision and cosmological constraints
  → numerical study of squark and gaugino production at LHC

- We study GMSB scenarios with NMFV [Fuks, BjHe, Klasen (*in preparation*)]
  → NMFV allows to circumvent constraints
  → cosmological analysis in preparation...

Conclusion and Perspectives

- We implement NMFV in MSSM at low energy [Bozzi, Fuks, BjHe, Klasen (2007)]
  → generalized strong and electroweak couplings
  → analytical squark and gaugino production and decay calculation

- We propose benchmark points for mSUGRA including NMFV
  → low energy, electroweak precision and cosmological constraints
  → numerical study of squark and gaugino production at LHC

- We study GMSB scenarios with NMFV [Fuks, BjHe, Klasen (*in preparation*)]
  → NMFV allows to circumvent constraints
  → cosmological analysis in preparation...

- For details on our code `XSUSY`
  → talk by Benjamin Fuks in "Tools" session this afternoon...