Non-minimal flavour-violation for supersymmetric particle production and decays at hadron colliders.

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Outline

Outline

Non-minimal flavour violation

[Gabbiani, Gabrielli, Masiero, Silvestrini (1996)]

- In the SuperCKM basis, the squared squark mass matrices are

$$M^2_{\tilde{Q}} = \begin{pmatrix} M^2_{LL,1} & \Delta^{12}_{LL} & \Delta^{13}_{LL} & m_1\, m_{LR,1} & \Delta^{12}_{LR} & \Delta^{13}_{LR} \\ \Delta^{21}_{LL} & M^2_{LL,2} & \Delta^{23}_{LL} & \Delta^{21}_{RL} & m_2\, m_{LR,2} & \Delta^{23}_{LR} \\ \Delta^{31}_{LL} & \Delta^{32}_{LL} & M^2_{LL,3} & \Delta^{31}_{RL} & \Delta^{32}_{RL} & m_3\, m_{LR,3} \\ m_1\, m_{RL,1} & \Delta^{12}_{RL} & \Delta^{13}_{RL} & M^2_{RR,1} & \Delta^{12}_{RR} & \Delta^{13}_{RR} \\ \Delta^{21}_{LR} & m_2\, m_{RL,2} & \Delta^{23}_{RL} & \Delta^{21}_{RR} & M^2_{RR,2} & \Delta^{23}_{RR} \\ \Delta^{31}_{LR} & \Delta^{32}_{LR} & m_3\, m_{RL,3} & \Delta^{31}_{RR} & \Delta^{32}_{RR} & M^2_{RR,3} \end{pmatrix}.$$

  * The off-diagonal elements are 24 new free parameters, parameterized by

$$\Delta^{qq'}_{ij} = \lambda^{qq'}_{ij}\, M_{ii,q} M_{jj,q'}.$$

  * Diagonalization through 6×6 rotation matrices R^u and R^d.

- Physical eigenstates given by

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

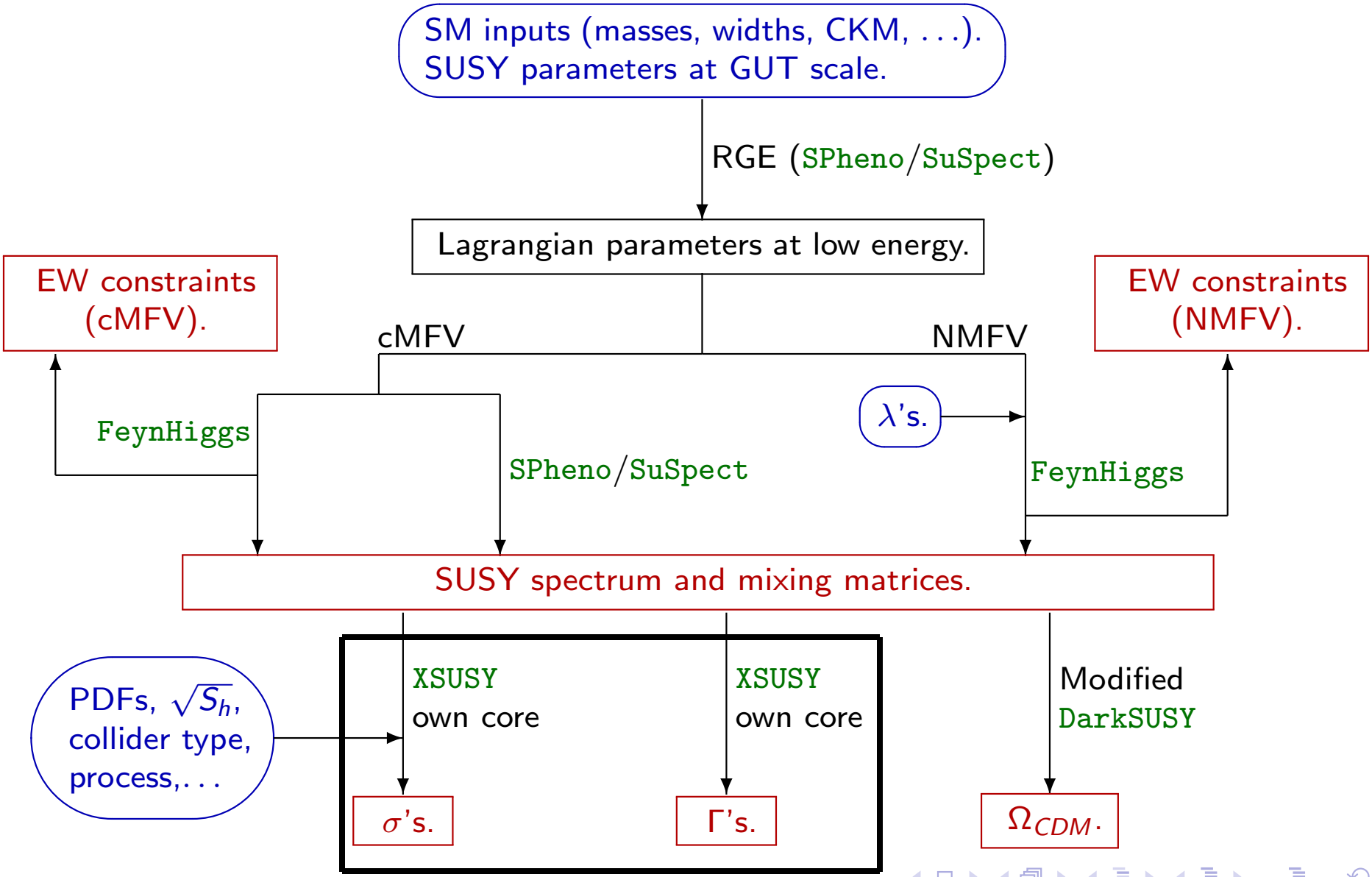
Some questions...

* Are NMFV SUSY models experimentally viable?
  ⇒ Analysis of the allowed parameter space.
  ⇒ Electroweak and cosmological constraints, ...

* Are hadron colliders sensible to NMFV?
  ⇒ Dependence of the production cross sections on flavour violation.
  ⇒ Dependence of the decay widths on flavour violation.

⇒ Development of a tool: XSUSY

... and answers


SM inputs (masses, widths, CKM, ...).
SUSY parameters at GUT scale.
RGE (SPheno/SuSpect)
Lagrangian parameters at low energy.
EW constraints (cMFV).
EW constraints (NMFV).
cMFV
NMFV
FeynHiggs
SPheno/SuSpect
λ's.
FeynHiggs
SUSY spectrum and mixing matrices.
PDFs, √S_h, collider type, process,...
XSUSY own core
XSUSY own core
Modified DarkSUSY
σ's.
Γ's.
Ω_CDM.

Simplified NMFV scenario

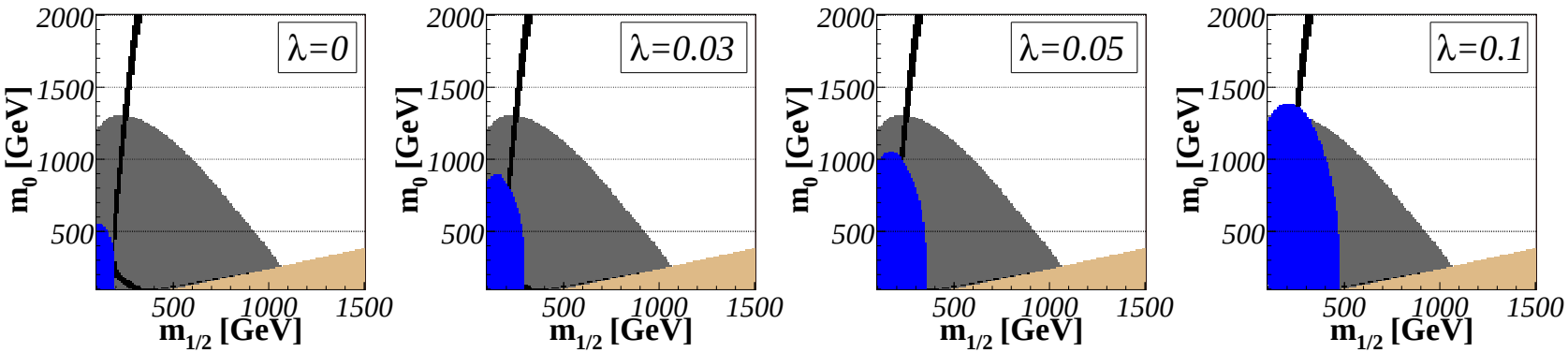
- The squared squark mass matrices are approximated

$$M^2_{\tilde{Q}} = \begin{pmatrix} M^2_{LL,1} & 0 & 0 & m_1\, m_{LR,1} & 0 & 0 \\ 0 & M^2_{LL,2} & \lambda M_{LL,2} M_{LL,3} & 0 & m_2\, m_{LR,2} & 0 \\ 0 & \lambda M_{LL,2} M_{LL,3} & M^2_{LL,3} & 0 & 0 & m_3\, m_{LR,3} \\ m_1\, m_{RL,1} & 0 & 0 & M^2_{RR,1} & 0 & 0 \\ 0 & m_2\, m_{RL,2} & 0 & 0 & M^2_{RR,2} & 0 \\ 0 & 0 & m_3\, m_{RL,3} & 0 & 0 & M^2_{RR,3} \end{pmatrix} .$$

- One single parameter λ both for up-type and down-type sectors.
- mSUGRA framework.
- Constraints from FCNC: satisfied if $\lambda \leq 0.1$.
  [Ciuchini, Masiero, Paradisi, Silvestrini, Vempati, Vives (2007)]
- What about other electroweak and cosmological constraints ?

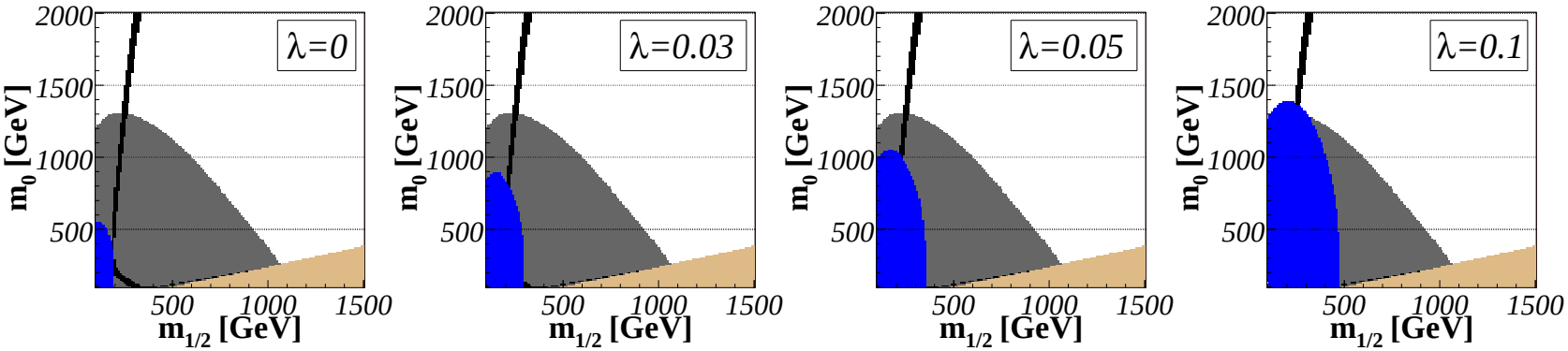
Outline

mSUGRA parameter space analysis: EW constraints



- $\tan\beta = 10, \mu > 0, A_0 = 0$ GeV, $0 \leq \lambda \leq 0.1$. [Bozzi, BF, Herrmann, Klasen (2007)]
- Region favoured by a_μ @2σ (grey)
  - $a_\mu^{\mathrm{SUSY}} = (22 \pm 10) \times 10^{-10}$ (BNL data vs SM) [PDG (2006)].
  - Squarks contribute at the two-loop level only.
    $\Rightarrow$ Reduced squark vs. slepton one-loop contributions.
- Region excluded by $b \to s\gamma$ @2σ (blue)
  - $\mathrm{BR}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$ [Barbiero *et al.* (2006)].
  - NMFV contributes at the one-loop level (same as the SM contributions).
    $\Rightarrow$ Very sensitive to λ.
- Region excluded by $\Delta\rho$ @2σ (not shown)
  - $\Delta\rho = 0.00102 \pm 0.00086$ (fits of EWPO) [PDG (2006)].
  - Sensitive to squark mass splitting [Veltman (1977)], influence on m_W, $\sin^2\theta_W$.
  - Very heavy scalar and gaugino masses excluded.

mSUGRA parameter space analysis: cosmol. constraints



- $\tan\beta = 10, \mu > 0, A_0 = 0$ GeV, $0 \leq \lambda \leq 0.1$. [Bozzi, BF, Herrmann, Klasen (2007)]
- Charged LSP (beige)
  - DM candidate $\Leftrightarrow$ Color singlet and electrically neutral [Ellis *et al.* (1984)].
- Region favoured by Ω_{CDM} (black)
  - $0.094 < \Omega_{CDM}\, h^2 < 0.136$ [Hamann, Hannestad, Sloth, Wong (2007)] (WMAP, SDSS, SNLS, Baryon Acoustic Oscillations).
  - Not really sensitive to λ (many processes involved, sum over squark propagators,...)

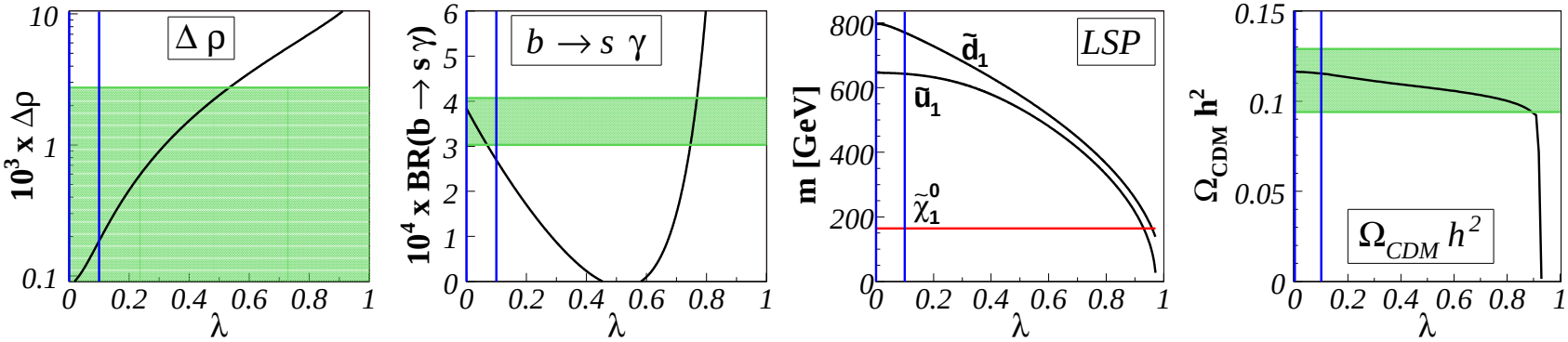
Benchmark points

- (Some) allowed benchmark points:

	m_0 [GeV]	$m_{1/2}$ [GeV]	A_0 [GeV]	$\tan\beta$	sign(μ)	λ bounds
A	700	200	0	10	+	[0;0.05]
B	100	400	0	10	+	[0;0.1]
C	230	590	0	30	+	[0;0.05]
D	600	700	0	50	+	[0;0.05]

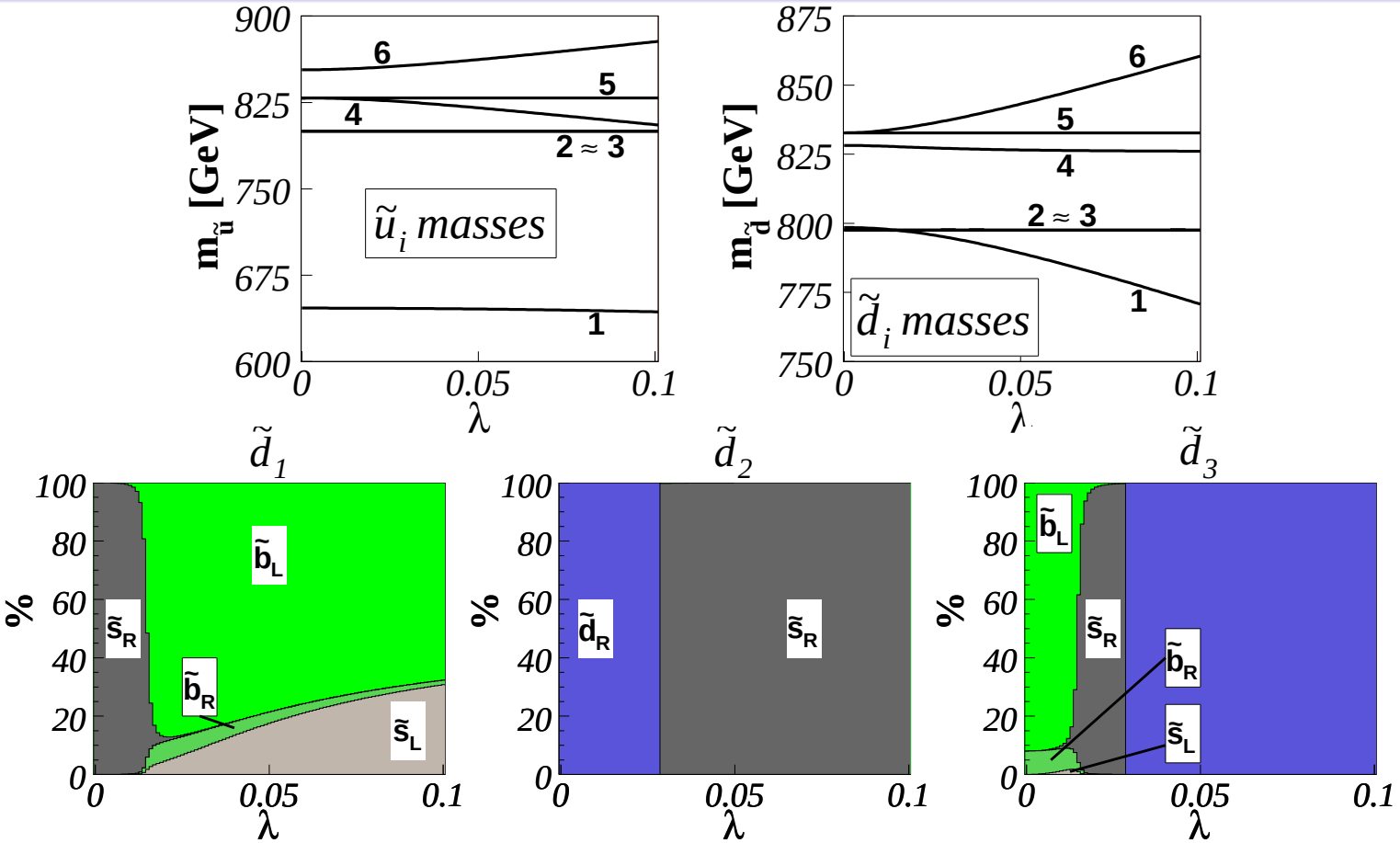
- In this talk: focus on benchmark point B.

Benchmark point BFHK-B: constraints



- $a_\mu^{\mathrm{SUSY}} \simeq 14 \times 10^{-10}$ (for any λ).
  - Included in the PDG's 2σ range of $[2; 42] \times 10^{-10}$.
- $\Delta\rho$ (first figure).
  - Depends strongly on squark flavours, helicities and masses.
  - Large allowed range ($\lambda \leq 0.52$), due to important experimental errors.
- $b \to s\gamma$ (second figure).
  - Very stringent constraint (small error band and large sensitivity on λ).
  - 2^{nd} allowed region disfavoured by $b \to s\mu^+\mu^-$ [Gambino, Haisch, Misiak (2005)].
- Cosmological constraints (third and fourth figures).
  - Small mass difference between LSP and NLSPs at large λ.
    $\Rightarrow \Omega_{CDM}$ falls (co-annihilation and light squark propagated processes).
- Allowed region: close to (c)MFV ($\lambda \lesssim 0.1$).

Benchmark point BFHK-B: Mass splitting - flavour content



- Hermitian squark mass matrices depend continuously on the single parameter λ.
  - The eigenvalues do not cross ⇒ avoided crossings.
  - Exchange of the flavour content between the concerned eigenstates.
- Large mixing between 2^{nd} and 3^{rd} generations, even for small λ.

Outline

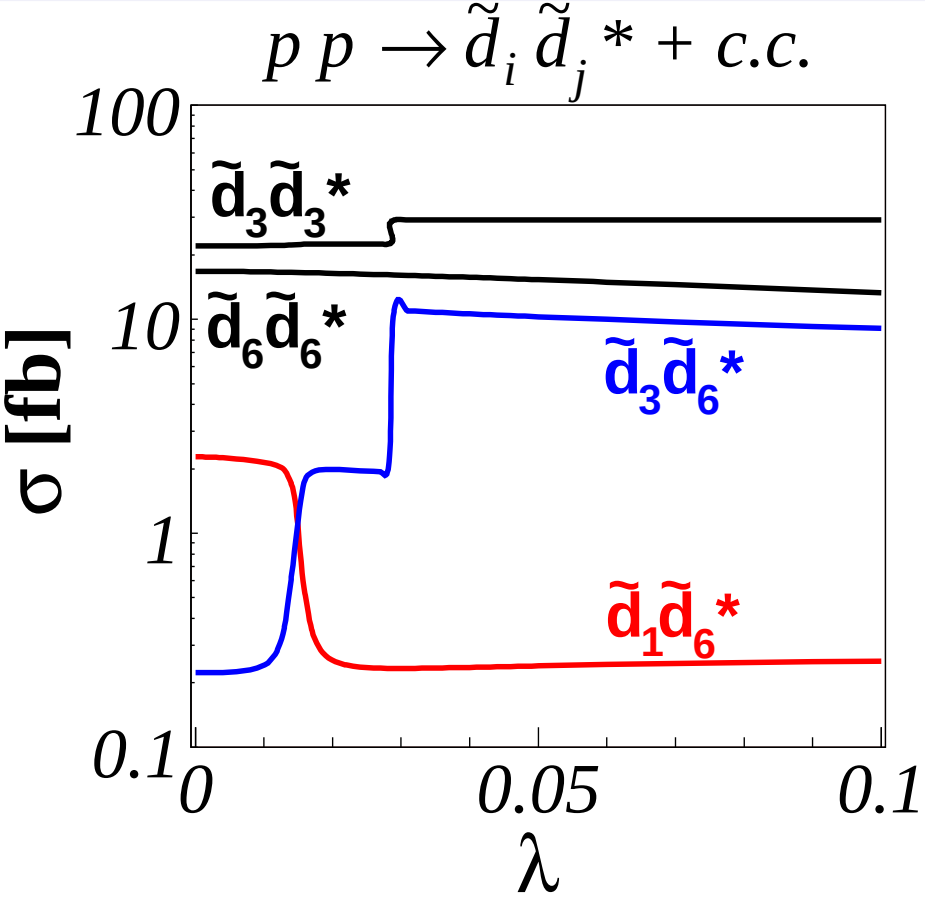
Processes

- Studied (partonic) processes :

$$a_{h_a}(p_a)\, b_{h_b}(p_b) \quad \rightarrow \quad \begin{cases} \tilde{q}_i^{(*)}(p_1)\, \tilde{q}_j'^{(*)}(p_2), \\ \tilde{\chi}_j^{\pm(0)}(p_1)\, \tilde{q}_i^{(*)}(p_2), \\ \tilde{\chi}_i^{\pm(0)}(p_1)\, \tilde{\chi}_j^{\pm(0)}(p_2). \end{cases}$$

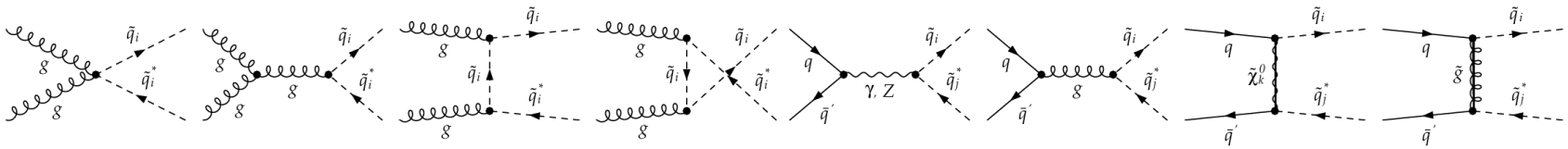
- Heavy flavour content production.
- Leading-order calculations (EW + QCD diagrams).
- LHC collider.

Neutral current squark-antisquark pair production

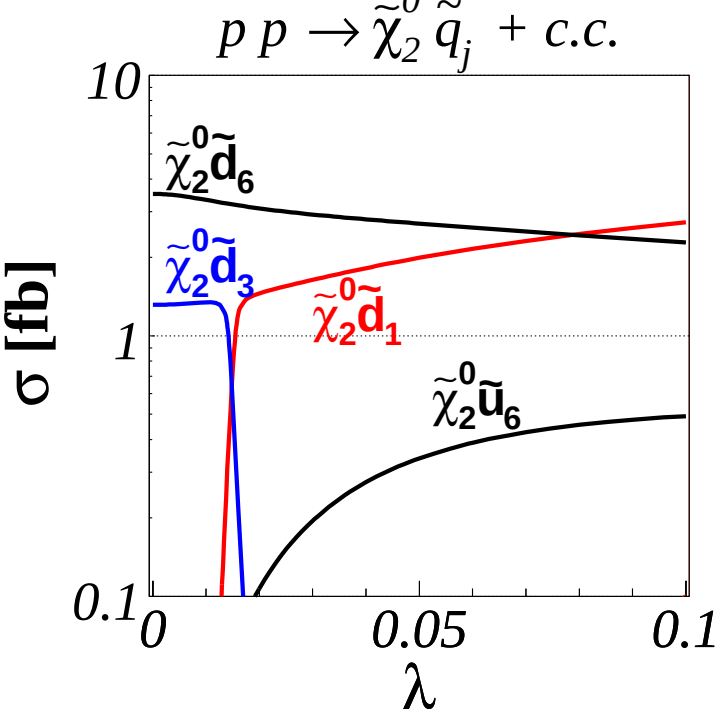


[Bozzi, BF, Herrmann, Klasen (2007)]

- Diagonal pairs:
  - Gluon-fusion initiated diagrams.
  - Strong production
    $\Rightarrow$ Large cross sections.
  - Quite unsensitive to λ
    (flavour-independent $g\tilde{q}\tilde{q}$ vertex).
- Non-diagonal pairs:
  - Only $q\bar{q}$ annihilation diagrams
    (EW + heavy gluino).
  - Show sharp transitions with λ
    (Avoided crossings - mass flips).
    Example: $\tilde{d}_1\tilde{d}_6^*$ and $\tilde{d}_3\tilde{d}_6^*$

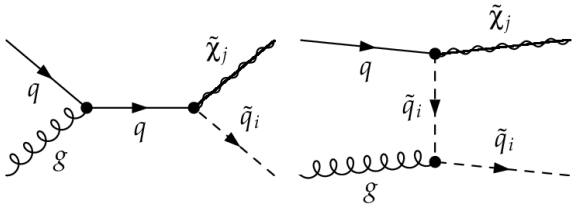


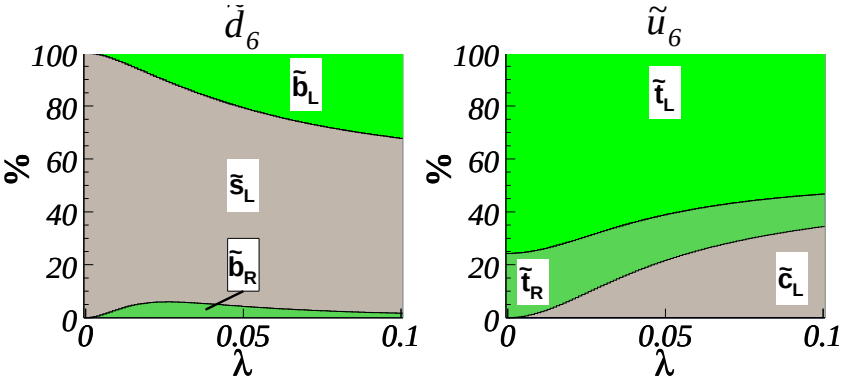
Associated squark-neutralino production



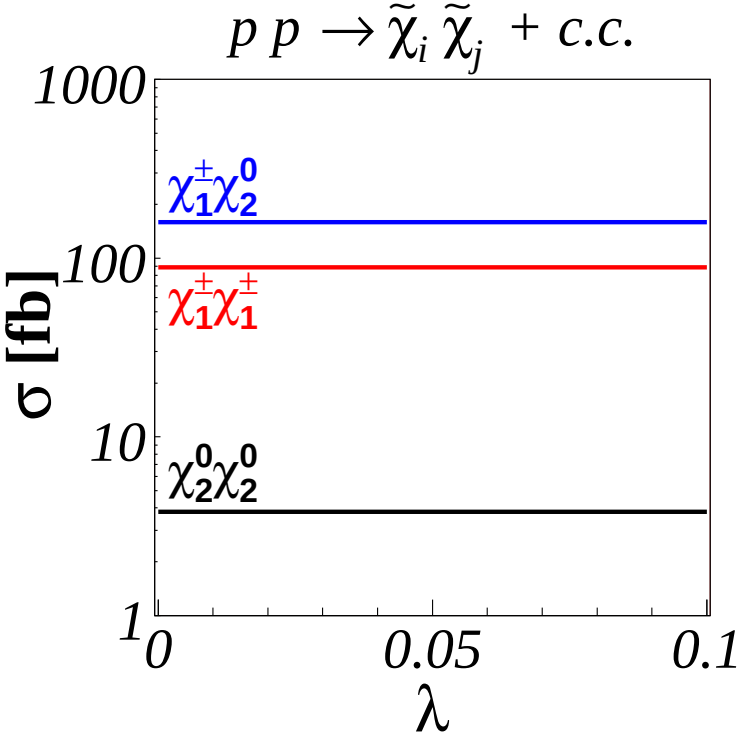
[Bozzi, BF, Herrmann, Klasen (2007)]

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



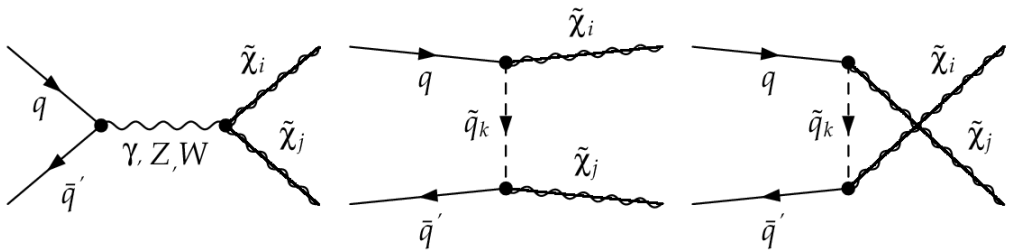


Gaugino-pair production



- Light gauginos
  (rather large cross sections).
- Insensitive to flavour violation
  (sum over all the squark physical states).

[Bozzi, BF, Herrmann, Klasen (2007)]



Outline

Summary and outlook

- Analysis of the NMFV effects in the mSUGRA framework (scans, benchmarks, cross sections,...).
- Implementation of `XSUSY`, a program devoted to NMFV SUSY models.
  - Interface with `DarkSUSY`, `FeynHiggs`, `SPheno` and `SuSpect`.
  - mSUGRA, GMSB and AMSB scenarios implemented.
  - Allows for a detailed analysis of the NMFV parameter space.
  - LO cross sections for (most of) all sparticle pair-production processes.
  - All SUSY particles two-body decays at LO.
  - Current status (v1.8.0): manual ($\sim$ 10%), public version ($\sim$80%).
  - Finalized public version: $\sim$ March 2008.
- To-do list:
  - Three-body decays.
  - Remaining cross sections.
  - Next-to-leading order.
  - Full experimental study
    (heavy-flavour tagging efficiencies, detector resolutions, background,...)
    $\Rightarrow$ Complete understanding of flavour violating effects.
    $\Rightarrow$ Sensitivity of colliders to NMFV.