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Ligth Stop Decays with Flavour Violation

arXiv:1408.4662

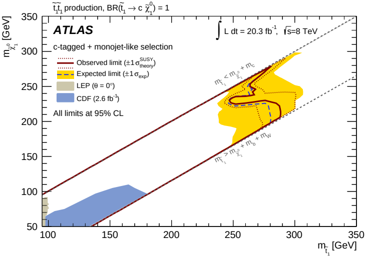
in collaboration with R. Gröber, M. Mühlleitner and A. Wlotzka
Eva Popenda | 24.9.2014

Introduction

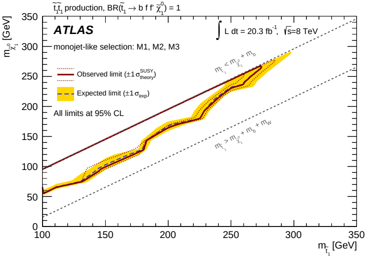
- SUSY searches at the LHC: Squarks of 1st & 2nd generation > 1.5 TeV
  Squarks of 3rd generation can still be light
- Light stop $\tilde{t}_1$ arises naturally: Large mixing between $\tilde{t}_L$ and $\tilde{t}_R$
- Light stops favoured by: Higgs data, reduced fine tuning, relic density

- Lightest SUSY Particle: $\tilde{\chi}^0_1$, Next-to-LSP: $\tilde{t}_1$
- Possible decay/search channels in the low mass region: $m_{\tilde{t}_1} - m_{\tilde{\chi}^0_1} < m_W + m_b$

$\tilde{t}_1 \to c\tilde{\chi}^0_1$



$\tilde{t}_1 \to \tilde{\chi}^0_1 b f \bar{f}'$



[arXiv:1407.0608]

Theoretical Status: $\tilde{u}_1 \to c\tilde{\chi}_1^0$

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- FCNC transition: Forbidden at tree level in SM
- Precision flavour measurements in agreement with CKM picture of SM
- MSSM: In general many new flavour-violating sources

$$\begin{pmatrix} \tilde{u}_1 \\ \vdots \\ \vdots \\ \tilde{u}_6 \end{pmatrix} = \begin{pmatrix} W_{11} & \dots & \dots & W_{16} \\ \vdots & \ddots & & \vdots \\ \vdots & & \ddots & \vdots \\ W_{61} & \dots & \dots & W_{66} \end{pmatrix} \begin{pmatrix} \tilde{u}_L \\ \tilde{c}_L \\ \tilde{t}_L \\ \tilde{u}_R \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}$$

- Solution to New Physics Flavour Puzzle:
  Minimal Flavour Violation: Based on flavour symmetry in quark sector of SM

$$U(3)_{\tilde{Q}_L} \times U(3)_{\tilde{u}_R} \times U(3)_{\tilde{d}_R}$$

  Smaller flavour symmetries: CKM-like pattern, fulfill contraints

$$U(2)_{\tilde{Q}_L} \times U(2)_{\tilde{u}_R} \times U(2)_{\tilde{d}_R}$$

[Barbieri, Buttazzo, Sala & Straub, '14]

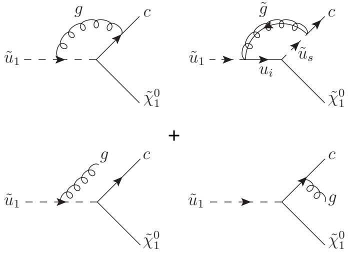
➡ Lightest up-type squark $\tilde{u}_1$ mostly stop-like

Theoretical status: $\tilde{u}_1 \to c\tilde{\chi}_1^0$

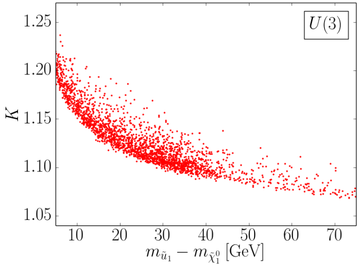
- Coupling $\tilde{t}_1 - c - \tilde{\chi}_1^0$ assumed to vanish at tree level *[Hikasa & Kobayashi, '87]*
  - ➡ Process realized at 1-loop with charged particles in loops
  - ➡ Calculation of 1-loop process in approximation
- Exact 1-loop calculation of charged loops *[Mühlleitner & Popenda, '11]*
  - ➡ Comparison to RGE-invariant MFV approach with tree level coupling

Here: SUSY-QCD corrections to $\tilde{u}_1 \to c\tilde{\chi}_1^0$ *[Gröber, Mühlleitner, Popenda & Wlotzka, '14]*

$$\Gamma^{\text{NLO}} = \Gamma^{\text{LO}} + \Gamma^{\text{virt}} + \Gamma^{\text{real}}$$



$$K = \Gamma^{\text{NLO}}/\Gamma^{\text{LO}}$$

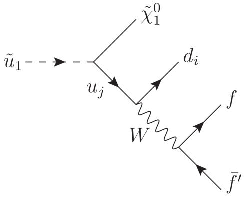


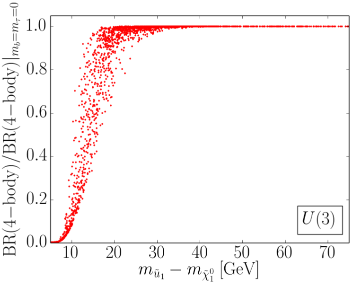
Theoretical status: $\tilde{u}_1 \to q\tilde{\chi}_1^0 f\bar{f}'$

- Four-body decays $\tilde{t}_1 \to b\tilde{\chi}_1^0 f\bar{f}'$ *[Böhm, Djouadi & Mambrini, '99]*

Here:

- Allow for FCNC couplings at tree level: $\tilde{u}_1 \to q\tilde{\chi}_1^0 f\bar{f}'$ with $q = d, s, b$ and $f, f' = d, s, b, u, c, e, \mu, \tau, \nu_e, \nu_\mu, \nu_\tau$
- Take into account mass dependence of 3rd generation fermions





- Dominating Feynman diagramm
- FV effects negligible

Implementation and Constraints

- Both decays implemented in `SUSY-HIT` [http://www.itp.kit.edu/∼maggie/SUSY-HIT]
- Spectrum from `SPheno` [Porod '03, Porod & Straub '12]
- No strict MFV but

$$300\text{ GeV} < M_{\tilde{t}_R} < 600\text{ GeV} \qquad 1\text{ TeV} < A_t < 2\text{ TeV}$$

Constraints on points of random scan:

- Higgs data: [Bechtle, Brein, Heinemeyer, Stal, Stefaniak, Weiglein, Williams, '08-'13]
  `HiggsBounds`: Compatibility with non-observation of SUSY Higgs bosons
  `HiggsSignals`: Compatibility of SM-like Higgs Boson with data
  `HDECAY`: Effective couplings & decay widths [Djouadi, Kalinoswki, Spira & Zerwas, '91-'98]
- Relic density: $\Omega_c h^2(\tilde{\chi}_1^0) < 0.12$ [Planck collaboration, '13]
  Calculated with `SuperIsoRelic` [Arbey & Mahmoudi, '09,'11]
- B meson branching ratios
  Calculated with `SuperIso` [Mahmoudi, '07,'08]
- SUSY searches

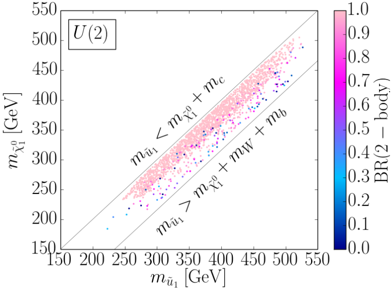
$$m_{\tilde{g}} = 1450\text{ GeV} \qquad m_{\tilde{q}_{1,2}} > 900\text{ GeV}$$

[ATLAS, 1405.7875; CMS-PAS-SUS-13-019]

Results: Random Scan

2 different symmetries in squark sector

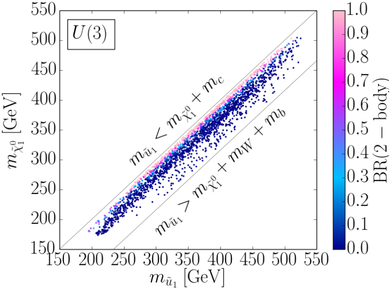
$U(2)_{\tilde{Q}_L} \times U(3)_{\tilde{u}_R} \times U(3)_{\tilde{d}_R}$



$M_{\tilde{Q}_{L,11}} = M_{\tilde{Q}_{L,22}} = 1.5$ TeV

$M_{\tilde{Q}_{L,33}} \in [1, 1.5]$ TeV

$U(3)_{\tilde{Q}_L} \times U(3)_{\tilde{u}_R} \times U(3)_{\tilde{d}_R}$



$M_{\tilde{Q}_{L,11}} = M_{\tilde{Q}_{L,22}} = M_{\tilde{Q}_{L,33}} \in [1, 1.5]$ TeV

➡ Assumtion of $BR = 1$ is wrong for both decays over large parts of parameter space

Results: Re-interpretation of exclusion bounds

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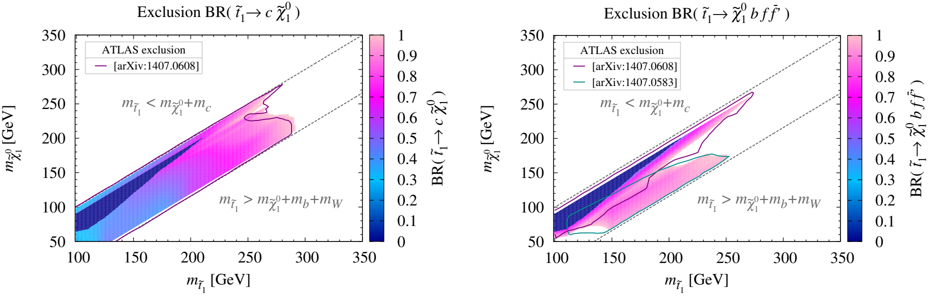

- Stop masses with a BR above the one associated with colour code are excluded
- If $BR = 1$: reproduce current exclusion bounds
- If $BR < 1$: exclusion bounds are weakened

Conclusions

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Summary

- Stops can still be light
- Dominant decays in the low mass region:

$$\tilde{u}_1 \to c\tilde{\chi}_1^0 \qquad\qquad \tilde{u}_1 \to b\tilde{\chi}_1^0 f\bar{f}'$$

- Experimental analyses assume $BR = 1$
- Here: SUSY-QCD corrections to $\tilde{u}_1 \to c\tilde{\chi}_1^0$
  FCNC coupling + 3rd generation masses to $\tilde{u}_1 \to q\tilde{\chi}_1^0 f\bar{f}'$
- BR's are likely to deviate from 1
- Currently existing exclusion bounds are weakened

➡ Large range of light stop masses still allowed

On-shell Renormalization

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- Quark mass counterterm:

$$m^0_{u_i} = m_{u_i} + \delta m_{u_i}$$

- Quark and squark field counterterms:

$$q^{L/R}_{(0)i} = (\delta_{ij} + \delta Z^{L/R}_{ij})\; q^{L/R}_j \qquad \tilde{q}^{(0)}_i = (\delta_{ij} + \delta Z^{\tilde{q}}_{ij})\; \tilde{q}_j$$

- Quark and squark mixing matrices counterterms:

$$U^{L/R}_{(0)ij} = (\delta_{in} + \delta u^{L/R}_{in})\; U^{L/R}_{nj} \qquad \tilde{W}^{(0)}_{ij} = (\delta_{in} + \delta \tilde{w}_{in})\; \tilde{W}_{nj}$$

Bare and renormalized matrices unitary ➡ Counterterms anti-hermitian

$$\delta u^{L/R} = \frac{1}{4}(\delta Z^{L/R} - \delta Z^{L/R\dagger}) \qquad \delta \tilde{w} = \frac{1}{4}(\delta Z^{\tilde{q}} - \delta Z^{\tilde{q}\dagger})$$

[Denner & Sack, '90]
[Degrassi, Gambino & Slavich, '06]

Feynman-'t Hooft gauge: Coincides with gauge independent result

[Yamada, '01]

Parameter choice and Random scan

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$$1 \leq \tan\beta \leq 15 \qquad 150\text{ GeV} \leq M_A \leq 1\text{ TeV}$$

$$75\text{ GeV} \leq M_1 \leq 900\text{ GeV} \qquad M_2 = 650\text{ GeV} \qquad M_3 = 1530\text{ GeV}$$

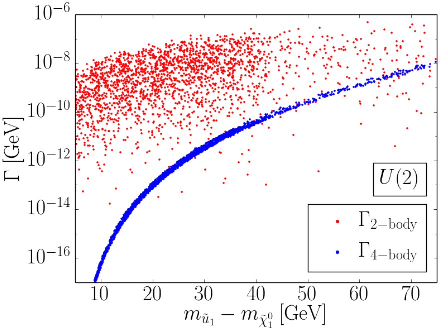
$$\mu = 900\text{ GeV}$$

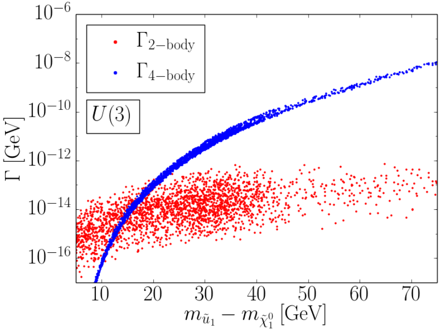
$$\begin{array}{ccccccc} M_{\tilde{E}_R} & = & M_{\tilde{L}_{1,2,3}} & = & 1\text{ TeV} & & A_E = 0\text{ TeV} \\ M_{\tilde{U}_R} & = & M_{\tilde{D}_R} & = & 1.5\text{ TeV} & & A_U = A_D = 0\text{ TeV} \end{array}$$

$$300\text{ GeV} \leq M_{\tilde{t}_R} \leq 600\text{ GeV} \qquad 1\text{ TeV} \leq A_t \leq 2\text{ TeV}$$

$$\begin{array}{rcl} \mathcal{B}(B_s^0 \to \mu^+\mu^-) & = & (2.9 \pm 0.7) \times 10^{-9} \\ \mathcal{B}(B^0 \to \mu^+\mu^-) & < & 8.1 \times 10^{-10} \text{ at } 95\% \text{ CL} \\ \mathcal{B}(B^+ \to \tau^+\nu_\tau) & = & (1.05 \pm 0.25) \times 10^{-4} \\ \mathcal{B}(B \to X_s\gamma) & = & (355 \pm 24 \pm 9) \times 10^{-6} \end{array}$$

Partial decay widths





Total decay widths

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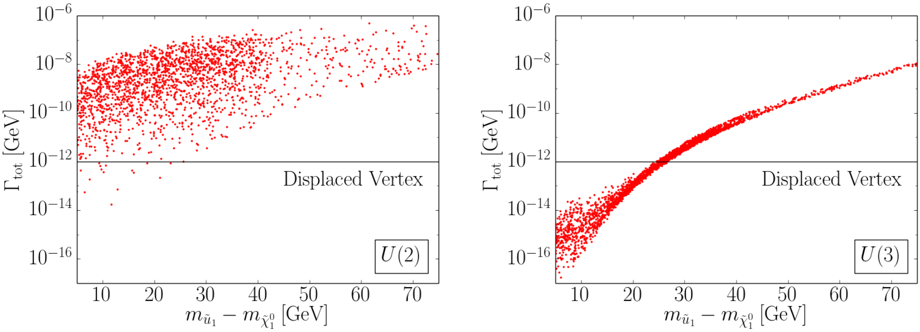
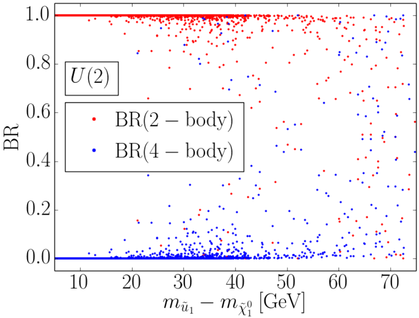
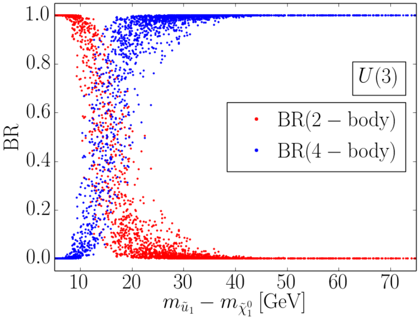


Branching ratios





Final states in 4-body decay