Karlsruhe Institute of Technology

Light Up-Type Squarks in the MSSM

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INSTITUTE FOR THEORETICAL PHYSICS

Outline

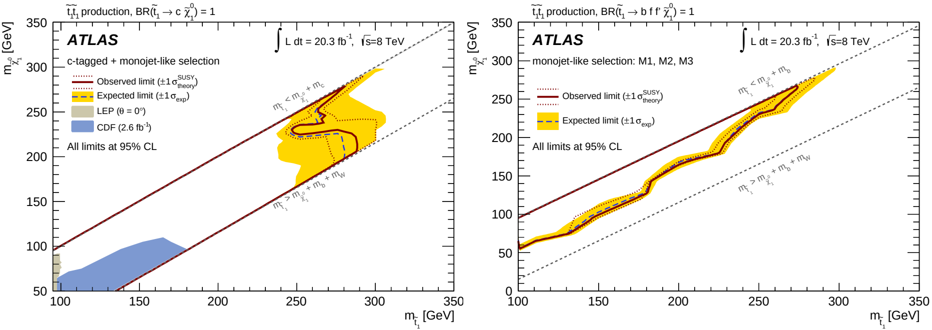
1. Motivation
   - Light Stops and Their Decays
   - Experimental Status
2. Calculation
   - Decays
   - Implementation and Constraints
3. Results

Motivation: Light Stops and Their Decays

Light Stops and Their Decays

- large mass splitting possible for stops
- less fine tuning
- stops accessible at LHC energies
- $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$; $\Delta m < m_W$
- existing work:
  - $\tilde{t}_1 \to c\tilde{\chi}_1^0$ electroweak one-loop process
    [Hikasa, Kobayashi '87][Jahn '98][Mühlleitner, Popenda '11]
  - four-body decay without FV [Boehm, Djouadi, Mambrini '99]
- here:
  - FCNC decay $\tilde{u}_1 \to (c, u)\tilde{\chi}_1^0$ at NLO SUSY-QCD
  - four-body decay $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i f \bar{f}'$ with final state mass effects
- MSSM; LSP: $\tilde{\chi}_1^0$; NLSP: $\tilde{u}_1$
- general flavor structure

Motivation: Experimental Status

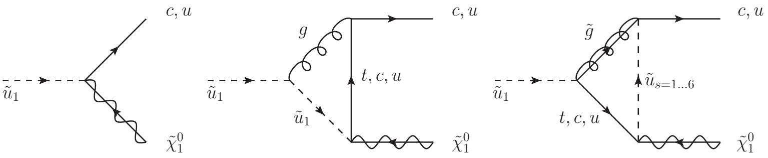


[CERN-PH-EP-2014-141]

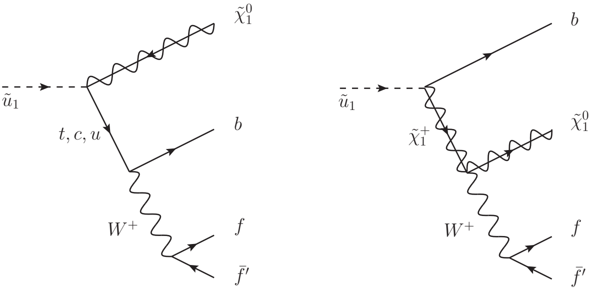
Similar exclusion bounds reported by CMS [CMS PAS SUS-13-009] (only two-body final state)

Decays - Examples of Feynman Diagrams

Examples for the Two-Body Decay



Examples for the Four-Body Decay



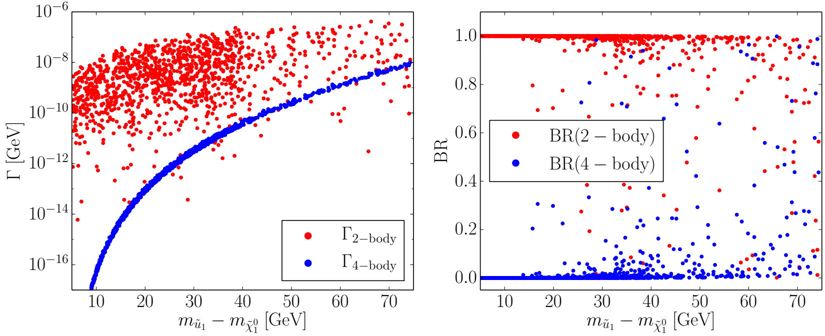
Implementation and Constraints

- implementation of the decays: `SUSYHIT` [Djouadi, Mühlleitner, Spira '12]
- spectrum generator: `SPheno` [Porod '12]
- Higgs decays, BRs, effective couplings: `HDECAY` [Djouadi, Kalinowski, Mühlleitner, Spira '10]
- Higgs observation and exclusion bounds: `HiggsBounds` and `HiggsSignals`
  [Bechtle, Brein, Heinemeyer, Stål, Stefaniak, Weiglein, Williams '13]
- Relic Density, $\Omega_c h^2 < 0.12$: `SuperIso Relic` [Arbey, Mahmoudi '11]
- B-physics observables: `SuperIso` [Mahmoudi '09]
  $BR(b \to X_s \gamma)\,, \quad BR(B \to \tau\nu)\,, \quad BR(B^0_{(s)} \to \mu^+\mu^-)\,, \quad a_\mu$
- constraints on relevant SUSY masses and on the lightest CP-even Higgs boson mass

  $m_{\tilde{u}_1} > 290$ GeV [CERN-PH-EP-2014-141]
  $m_{\tilde{\chi}^0_1} > 200$ GeV [CERN-PH-EP-2014-141]
  $m_{\tilde{g}} > 1.45$ TeV [CMS-SUS-13-007, ATL-PHYS-PROC-2013-179]
  $m_{h^0} = (125.5 \pm 3.0)$ GeV [CMS-HIG-12-028, CERN-PH-EP-2012-218]

Results: Random Scan over $A_t, M_1, m_{\tilde{U}_3}, m_{\tilde{Q}_{L3}}, \tan\beta, m_A$

$$m_{\tilde{Q}_{L1}} = m_{\tilde{Q}_{L2}} \neq m_{\tilde{Q}_{L3}}$$



Results: Random Scan over $A_t, M_1, m_{\tilde{U}_3}, m_{\tilde{Q}_L}, \tan\beta, m_A$

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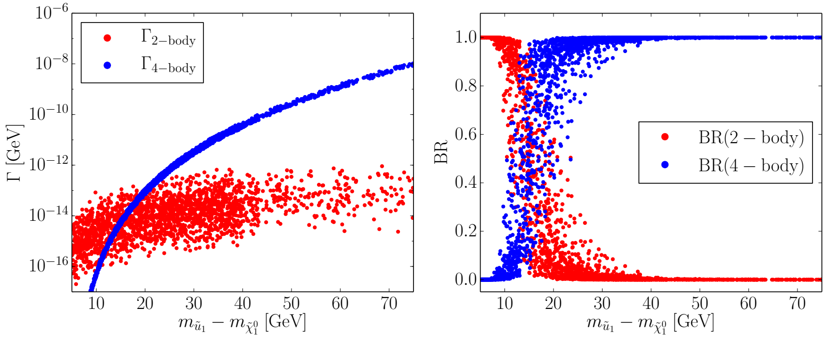

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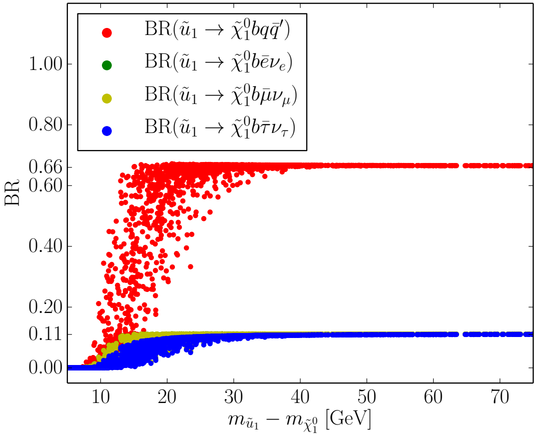
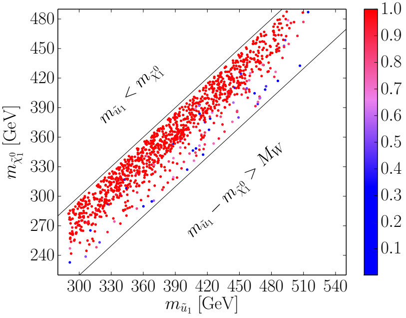
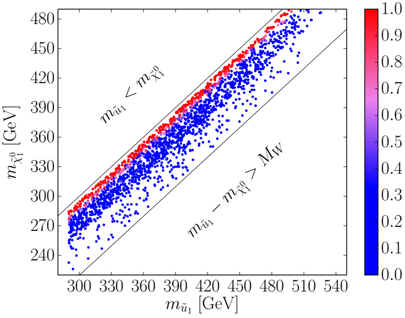


Results: Direct Comparison



Random scan with
$m_{\tilde{Q}_{L1}} = m_{\tilde{Q}_{L2}} \neq m_{\tilde{Q}_{L3}}$



Random scan with
$m_{\tilde{Q}_{L1}} = m_{\tilde{Q}_{L2}} = m_{\tilde{Q}_{L3}}$

Color code: BR of the two-body decay

Conclusion

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- large parameter space leading to a light up-type squark
- $\tilde{u}_1 \to (c, u)\tilde{\chi}^0_1$ and $\tilde{u}_1 \to \tilde{\chi}^0_1 d_i f \bar{f}'$ for $\Delta m < m_W$
- two-body decay strongly dependent on the size of flavor mixing
- four-body decay nearly independent of flavor changing effects
- searches required in both the two-body and the four-body channel
- complete results and further details will be published soon

Thanks for listening!

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Thanks for listening!

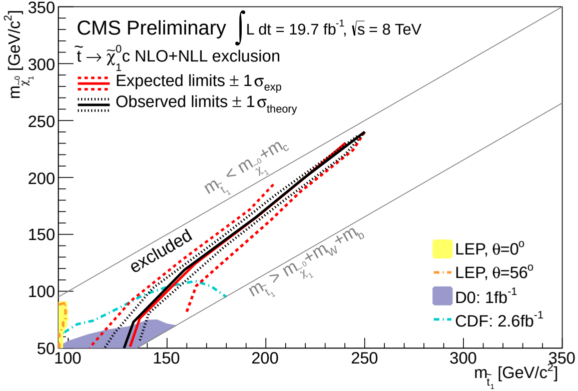
Backup: Scan Range

$$A_t \in [1000, 2000] \text{ GeV}$$
$$m_{\tilde{U}_3} \in [300, 600] \text{ GeV}$$
$$m_{\tilde{Q}_{L3}} \in [1000, 1500] \text{ GeV}$$
$$\tan\beta \in [1, 15]$$
$$M_1 \in [220, 500] \text{ GeV}$$
$$m_A \in [400, 1000] \text{ GeV}$$

All other parameters fixed:

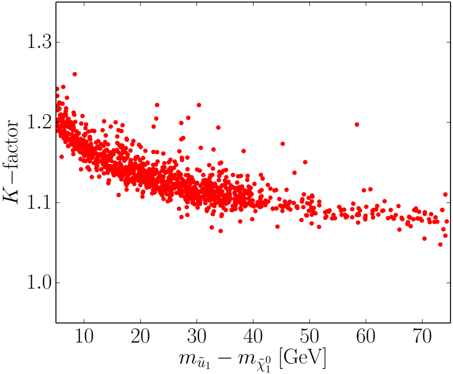
$$M_2 = 650 \text{ GeV}$$
$$M_3 = 1530 \text{ GeV}$$
$$\mu = 900 \text{ GeV}$$
$$m_{\text{Sleptons}} = 1000 \text{ GeV}$$
$$m_{\text{Squarks}} = 1500 \text{ GeV}$$
$$A_d = A_l = 0$$

Backup: CMS Exclusion Limits



[CMS PAS SUS-13-009]

Backup: Random Scan over $A_t, M_1, m_{\tilde{U}_3}, m_{\tilde{Q}_{L3}}, \tan\beta, m_A$



$K = \frac{\Gamma_{NLO}}{\Gamma_{LO}}$, results for $m_{\tilde{u}_1} - m_{\tilde{\chi}_1^0} \in [5, 75]$ GeV

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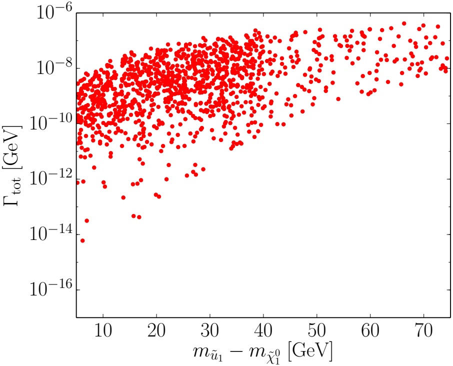

$\Gamma_{\text{tot}} = \Gamma_{\text{2-body}} + \Gamma_{\text{4-body}}$

Backup: Random Scan over $A_t, M_1, m_{\tilde{U}_3}, m_{\tilde{Q}_L}, \tan\beta, m_A$

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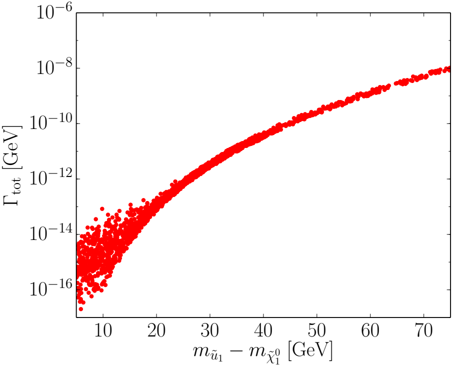
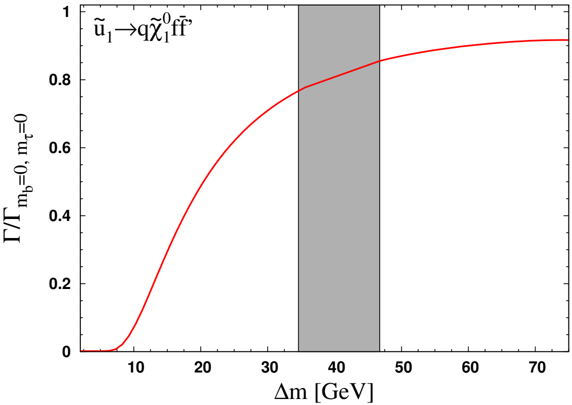
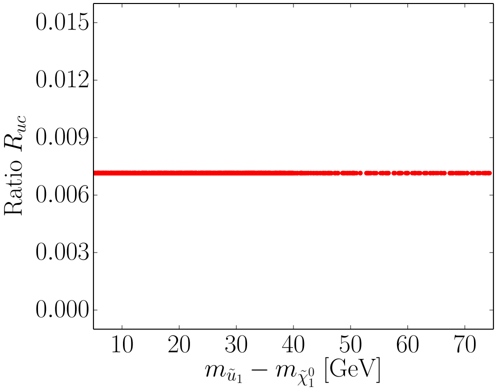


$$\Gamma_{\text{tot}} = \Gamma_{\text{2-body}} + \Gamma_{\text{4-body}}$$

Backup: Effect of Massive Final State Particles



Backup: Relative Size of the Decay into $u\tilde{\chi}_1^0$ and $c\tilde{\chi}_1^0$



$$R_{uc} = \frac{\Gamma_{u\tilde{\chi}_1^0}}{\Gamma_{c\tilde{\chi}_1^0}}$$

Backup: Phenomenological MSSM

Definition:

[Djouadi *et al* '99]

- General MSSM with R-parity conservation and real parameters
- Minimal Flavor Violation, soft SUSY breaking masses and trilinear couplings are diagonal in flavor space
- trilinear couplings for the first two generations of sfermions can be neglected
- soft SUSY breaking masses for the first two generations of sfermions coincide

$$\begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix} = \begin{pmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{pmatrix} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix}$$

$$\longrightarrow \quad \begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \\ \tilde{f}_3 \\ \tilde{f}_4 \\ \tilde{f}_5 \\ \tilde{f}_6 \end{pmatrix} = \begin{pmatrix} F_{11} & \dots & \dots & \dots & F_{16} \\ \vdots & \ddots & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ F_{61} & \dots & \dots & \dots & F_{66} \end{pmatrix} \begin{pmatrix} \tilde{f}_{1L} \\ \tilde{f}_{2L} \\ \tilde{f}_{3L} \\ \tilde{f}_{1R} \\ \tilde{f}_{2R} \\ \tilde{f}_{3R} \end{pmatrix}$$

Backup: Lagrangian for the Squark-Quark-Neutralino Interaction

$$\mathcal{L}_{\bar{u}\tilde{u}\tilde{\chi}^0,L} = \underbrace{Q^L_{1il}\bar{u}^{(0)}_i \tilde{u}^{(0)}_{iR}\mathcal{P}_L\tilde{\chi}^0_l}_{\mathcal{L}_1} + \underbrace{Q^L_{2l}\bar{u}^{(0)}_i m^{\dagger(0)}_{ij}\tilde{u}^{(0)}_{jL}\mathcal{P}_L\tilde{\chi}^0_l}_{\mathcal{L}_2}$$

$$Q^L_{1il} := -ge^{u_i}_{Rl} = g\sqrt{2}Q_{u_i}t_W Z_{l1} \quad \text{and} \quad Q^L_{2l} := -\frac{gZ_{l4}}{\sqrt{2}m_W s_\beta}$$

$$Q^R_{1il} := -ge^{u_i}_{Ll} = -g\sqrt{2}[Z_{l1}t_W(Q_{u_i} - I^3_{u_i}) + Z_{l2}I^3_{u_i}] \quad \text{and} \quad Q^R_{2l} := -\frac{gZ_{l4}}{\sqrt{2}m_W s_\beta}$$