Light Stop Decays

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in collaboration with Ramona Gröber, Margarete Mühlleitner and Eva Popenda, arXiv:1408.4662

INSTITUTE FOR THEORETICAL PHYSICS

Outline

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

Introduction: Supersymmetry

Supersymmetry (SUSY)

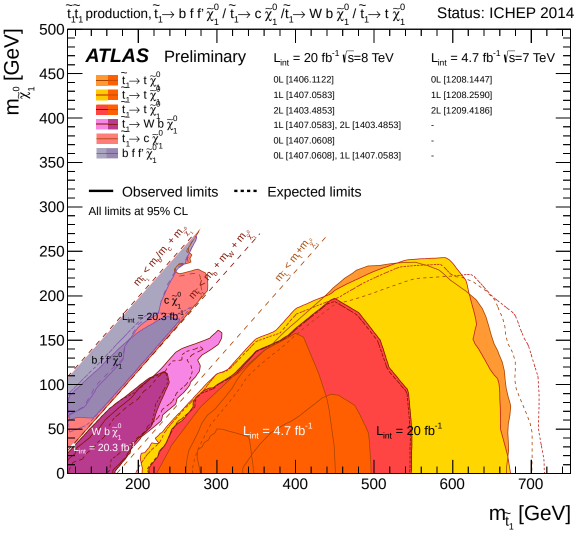
- extension of the Standard Model (SM)
  $\rightarrow$ Dark Matter, gauge coupling unification, stabilization of Higgs mass
- SM gauge group
- enhanced space-time symmetry
- enriched particle spectrum $\rightarrow$ superpartners (s..., ...ino, $\tilde{}$), extended Higgs sector
- conserved SUSY $\rightarrow$ masses of superpartners = masses of SM particles
- soft SUSY breaking terms: general parametrization
- R-parity $\rightarrow$ lightest SUSY particle (LSP) stable, production of SUSY particles in pairs, decays of SUSY particles have odd numbers of SUSY particles in the final state

Introduction: Light Stops and Their Decays

Light Stops and Their Decays

- large mass splitting possible for stops
- light stops compatible with experimental results
- 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
- general flavor structure
- MSSM; LSP: $\tilde{\chi}_1^0$; NLSP: $\tilde{u}_1$

Introduction: Experimental Status



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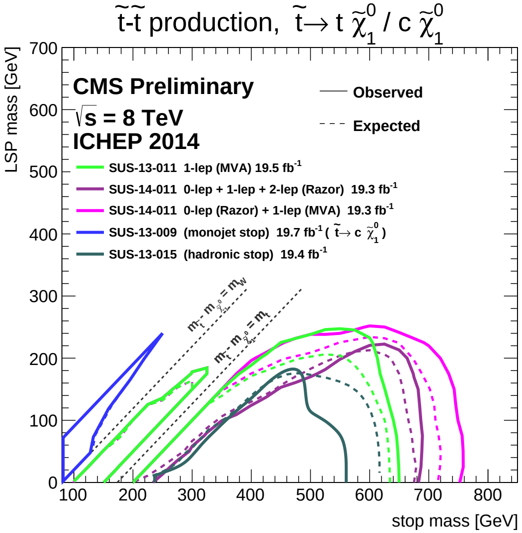
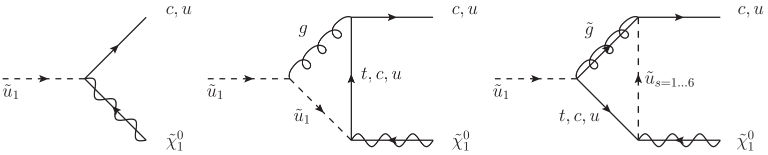
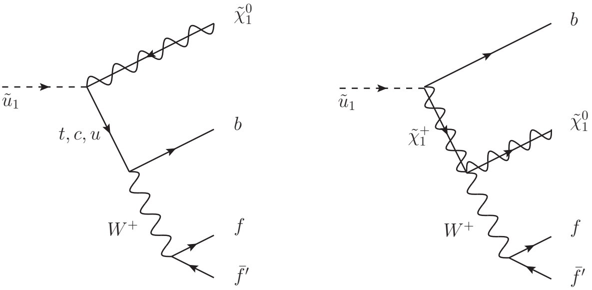


Decays - Examples of Feynman Diagrams

Examples for the Two-Body Decay



Examples for the Four-Body Decay

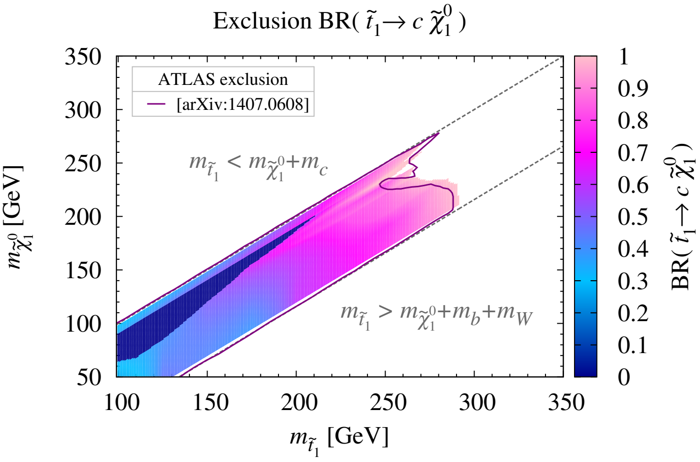


Implementation and Constraints

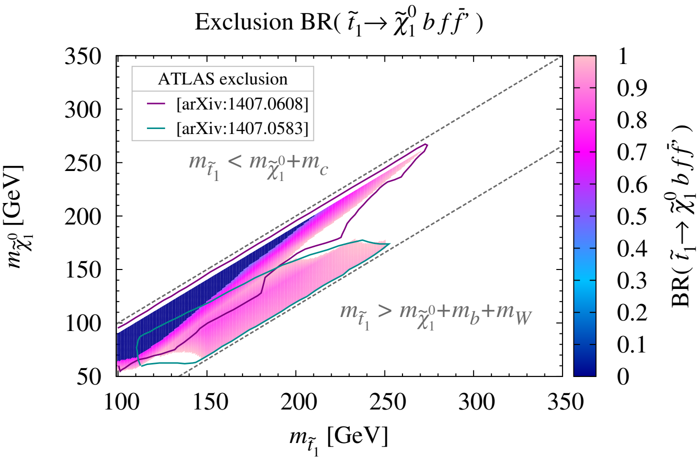
- implementation of the decays: `SUSYHIT` [Djouadi, Mühlleitner, Spira '12]
  [Gröber Mühlleitner, Popenda, AW '14]
- spectrum generator: `SPheno` [Porod '12]
- Higgs decays, BRs, effective couplings: `HDECAY` [Djouadi, Kalinowski, Mühlleitner, Spira '10]
- Higgs observation and exclusion bounds: `HiggsBounds` 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]
  $BR(b \to X_s \gamma)$, $BR(B \to \tau\nu)$, $BR(B^0_{(s)} \to \mu^+\mu^-)$
- constraints on relevant SUSY masses and on the lightest CP-even Higgs boson mass

  $m_{\tilde{g}} > 1.45$ 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]
  $m_{\tilde{u}_1}$, $m_{\tilde{\chi}^0_1}$, $\to$ exclusion limits

Scaled Exclusion Limits

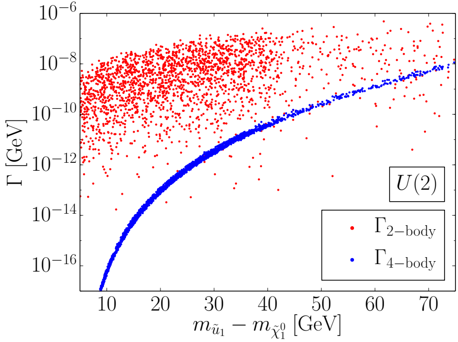


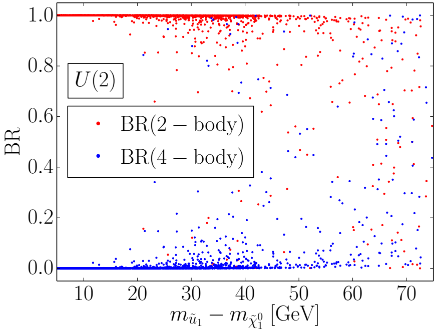
Scaled Exclusion Limits



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

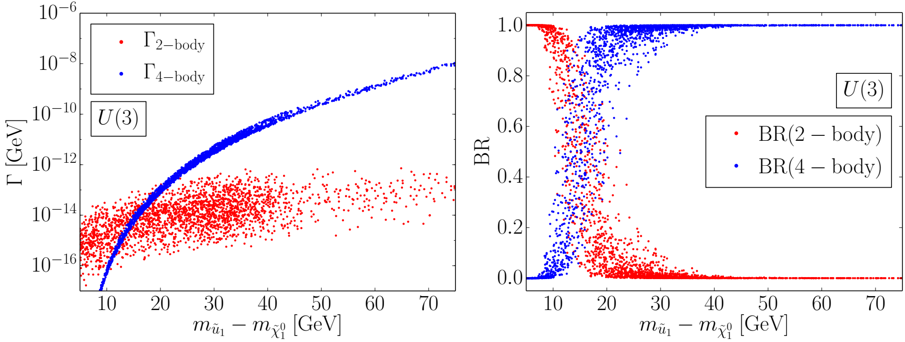
$$m_{\tilde{Q}_{L1}} = m_{\tilde{Q}_{L2}} \neq m_{\tilde{Q}_{L3}}$$





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

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



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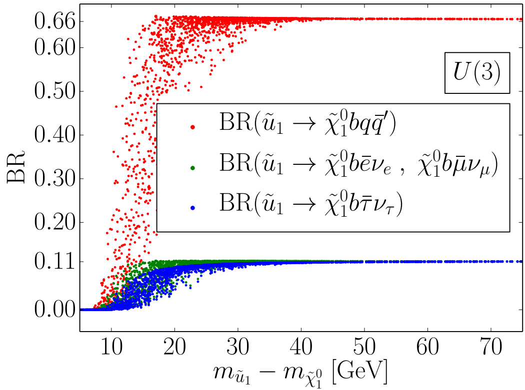
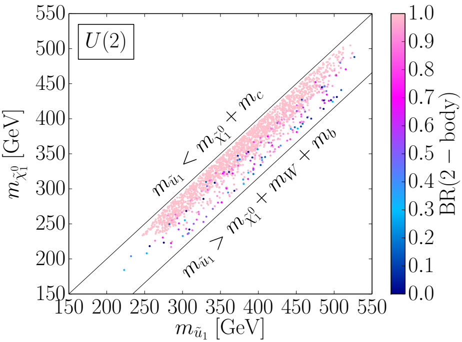
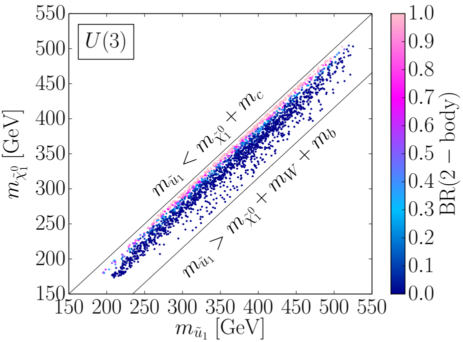


Results: Direct Comparison



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



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

Conclusion

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- large parameter space leading to a light up-type squark ($\approx$ light stop)
- $\tilde{u}_1 \to (c, u)\tilde{\chi}_1^0$ and $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i f \bar{f}'$ 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 can be found in arXiv:1408.4662

Thanks for listening!

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Thanks for listening!

Backup: Scan Range

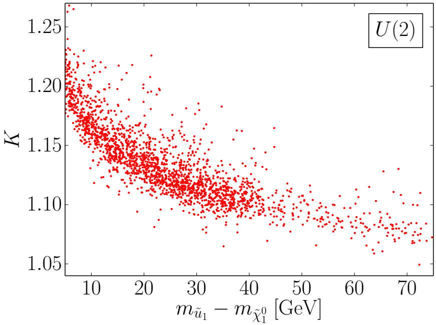
Karlsruhe Institute of Technology

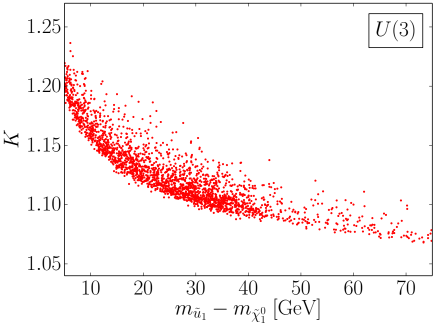
$$
\begin{aligned}
A_t &\in [1000, 2000]\ \text{GeV} \\
m_{\tilde{U}_3} &\in [300, 600]\ \text{GeV} \\
m_{\tilde{Q}_{L3}} &\in [1000, 1500]\ \text{GeV} \\
\tan\beta &\in [1, 15] \\
M_1 &\in [75, 500]\ \text{GeV} \\
m_A &\in [150, 1000]\ \text{GeV}
\end{aligned}
$$

All other parameters fixed:

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

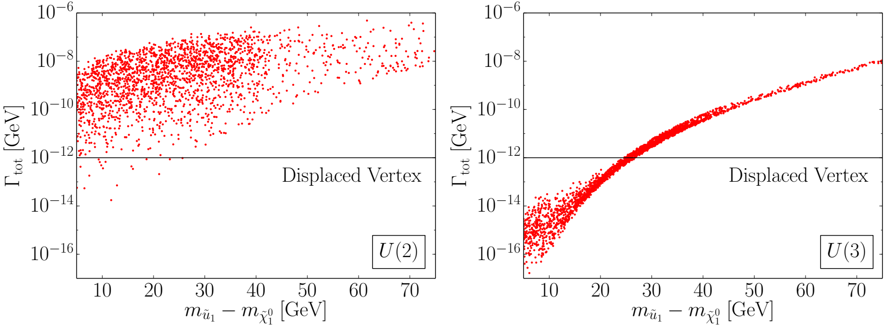
Backup: K-Factor





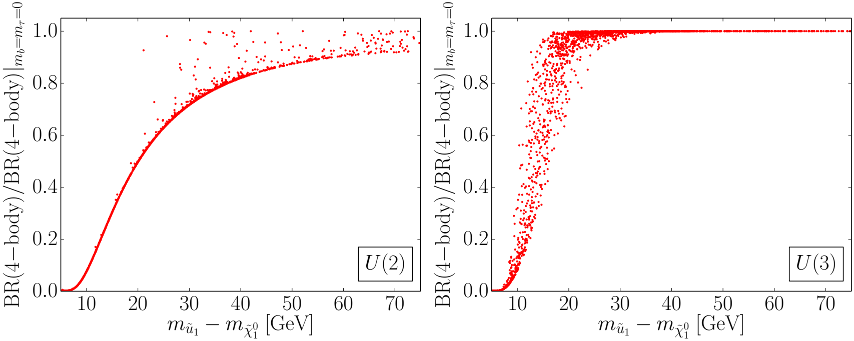
$$K = \frac{\Gamma_{\text{NLO}}}{\Gamma_{\text{LO}}}$$

Backup: Total Decay Width



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

Backup: Effect of Massive Final State Particles



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

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

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

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