Karlsruhe Institute of Technology

Light Stop Decays

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INSTITUTE FOR THEORETICAL PHYSICS

Outline

Introduction: Supersymmetry

Supersymmetry (SUSY)

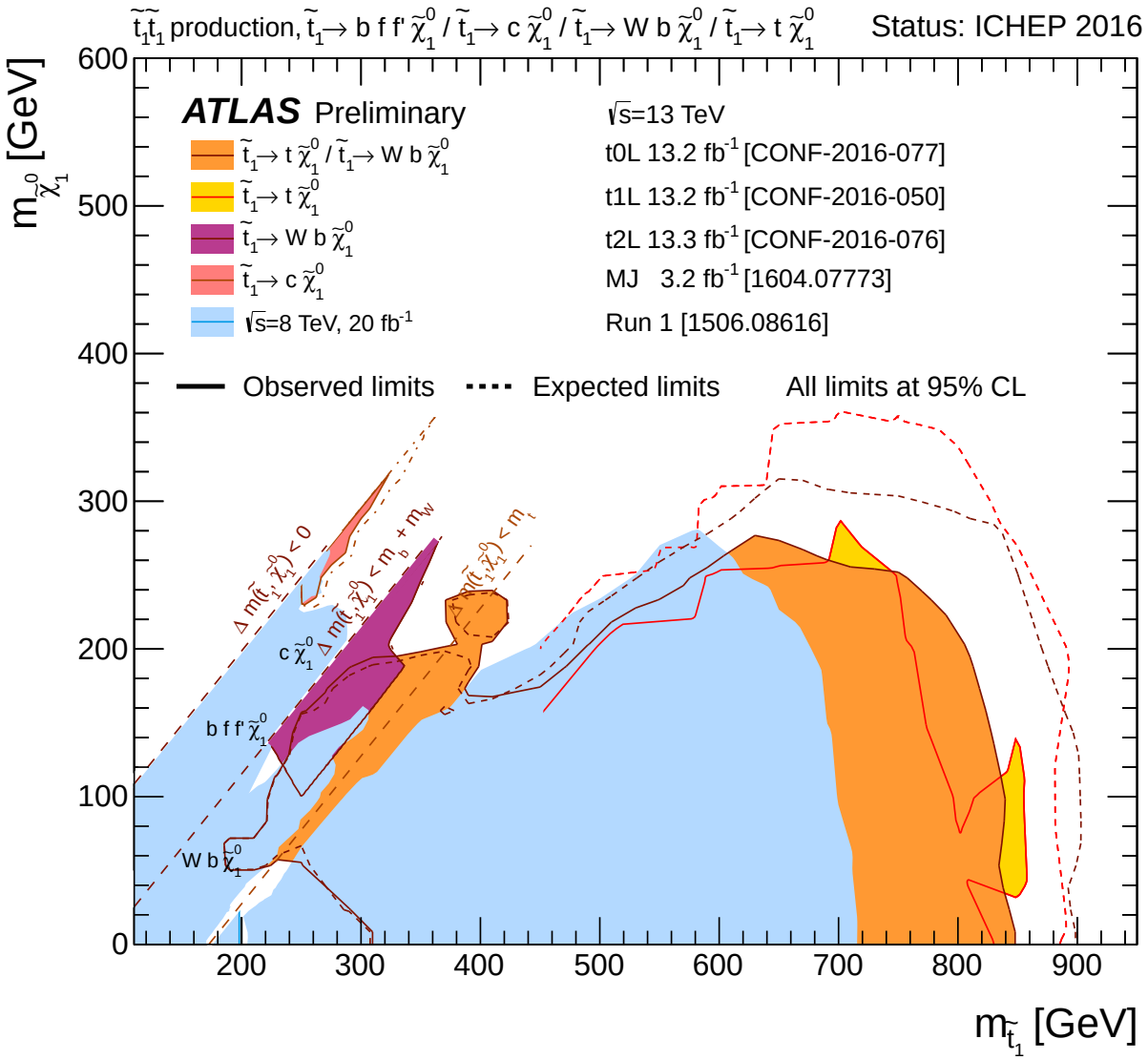
- extension of the Standard Model (SM)
  $\rightarrow$ Dark Matter, gauge coupling unification, stabilization of Higgs mass
- SM gauge group
- enhanced space-time symmetry
- enriched particle spectrum $\rightarrow$ superpartners, extended Higgs sector
- conserved SUSY $\rightarrow$ masses of superpartners = 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
- $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$; $\Delta m < m_t$
- 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]
  - three-body-decay without FV [Porod, Wohrmann '97][Porod '98][Djouadi, Mambrini '00]
- 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
  - three-body decay $\tilde{u}_1 \to \tilde{\chi}_1^0 d_i W$
- general flavor structure
- threshold effects between three- and four-body decay taken into account
- MSSM; LSP: $\tilde{\chi}_1^0$; NLSP: $\tilde{u}_1$

Introduction: Experimental Status



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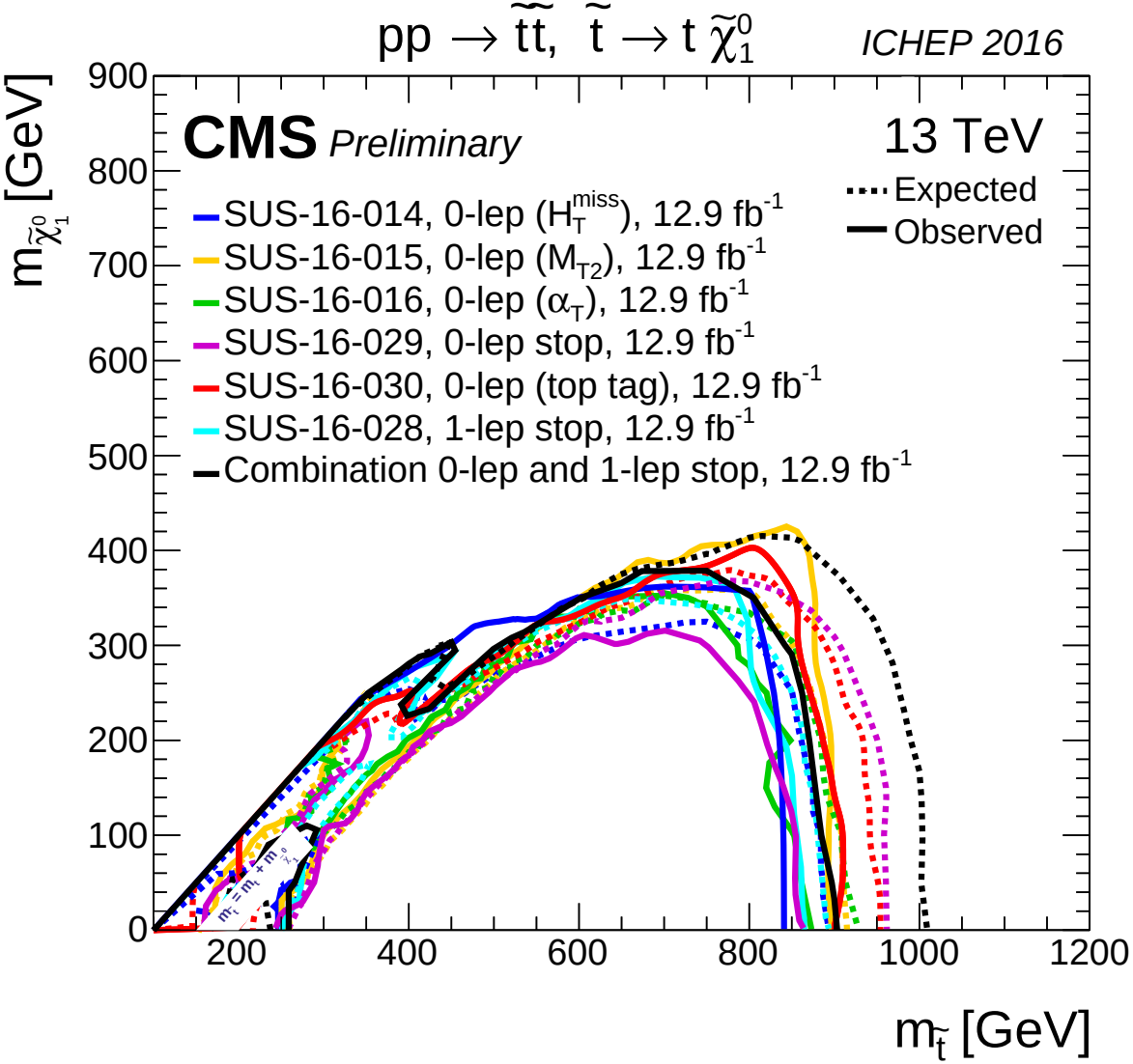

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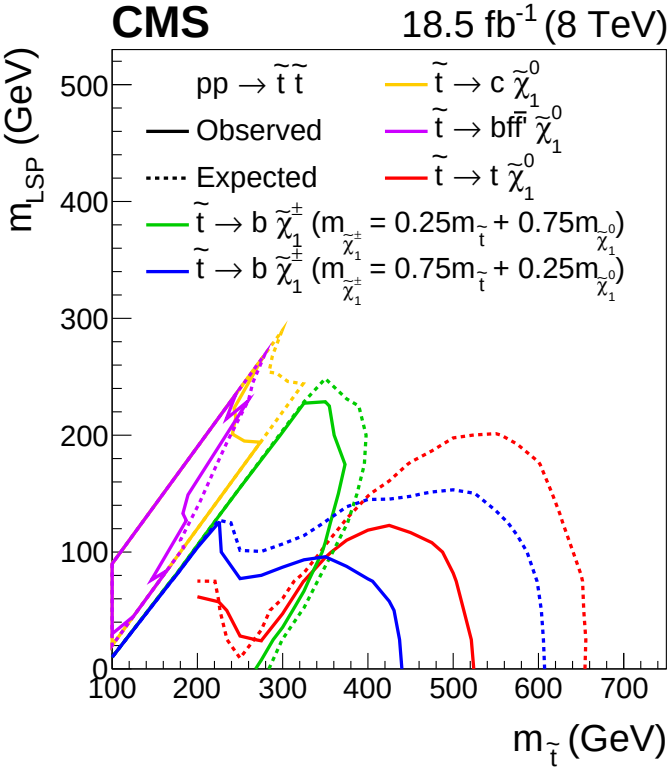
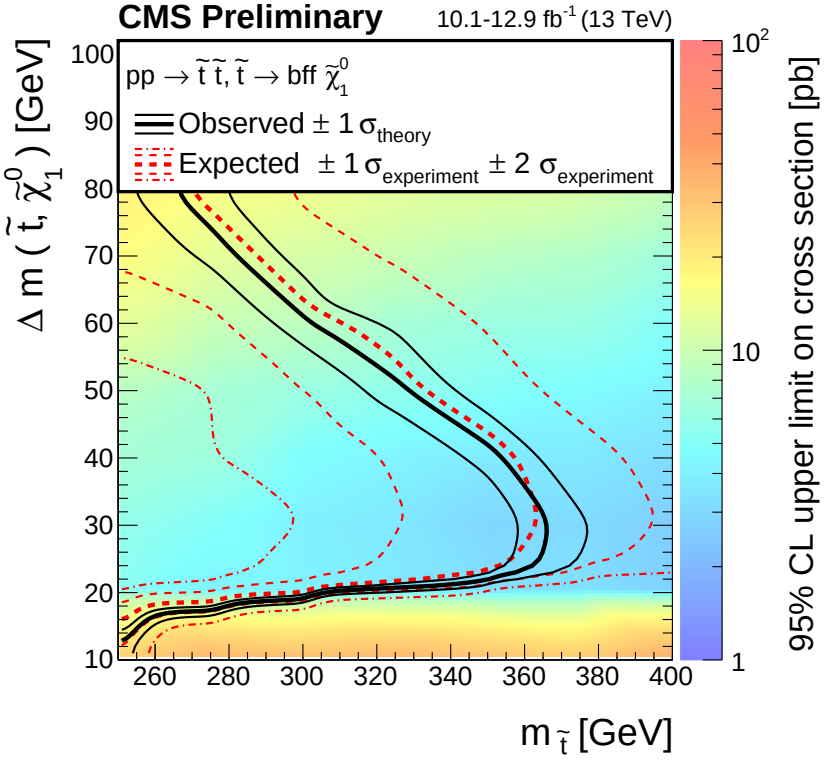
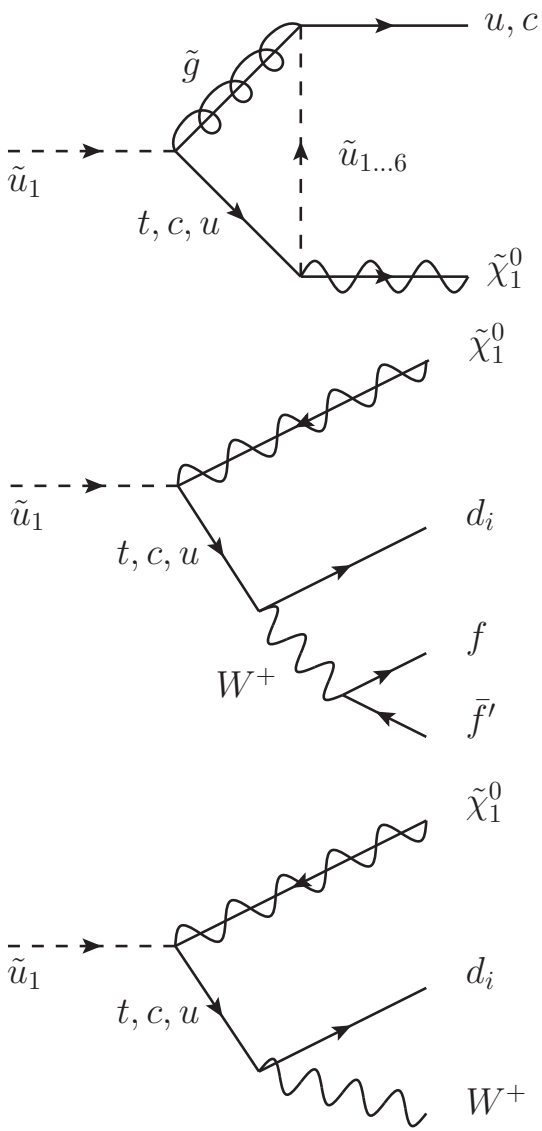


[CMS-SUS-14-006, arxiv:1605.08993]



[CMS-PAS-SUS-16-025]

Calculation: Only Selected Facts and Examples



- general flavor structure:

$$\begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \\ \tilde{u}_3 \\ \tilde{u}_4 \\ \tilde{u}_5 \\ \tilde{u}_6 \end{pmatrix} = \begin{pmatrix} U_{11} & \dots & \dots & \dots & U_{16} \\ \vdots & \ddots & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & \ddots & \vdots \\ U_{61} & \dots & \dots & \dots & U_{66} \end{pmatrix} \begin{pmatrix} \tilde{u}_L \\ \tilde{c}_L \\ \tilde{t}_L \\ \tilde{u}_R \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}$$

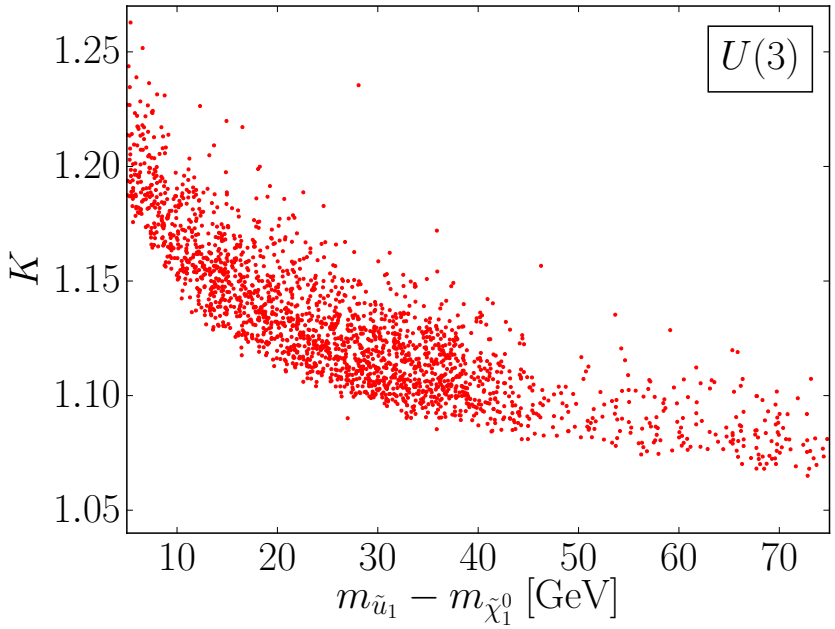
- overall-factor-scheme:

[Baur, Vermaseren, Zeppenfeld '92]

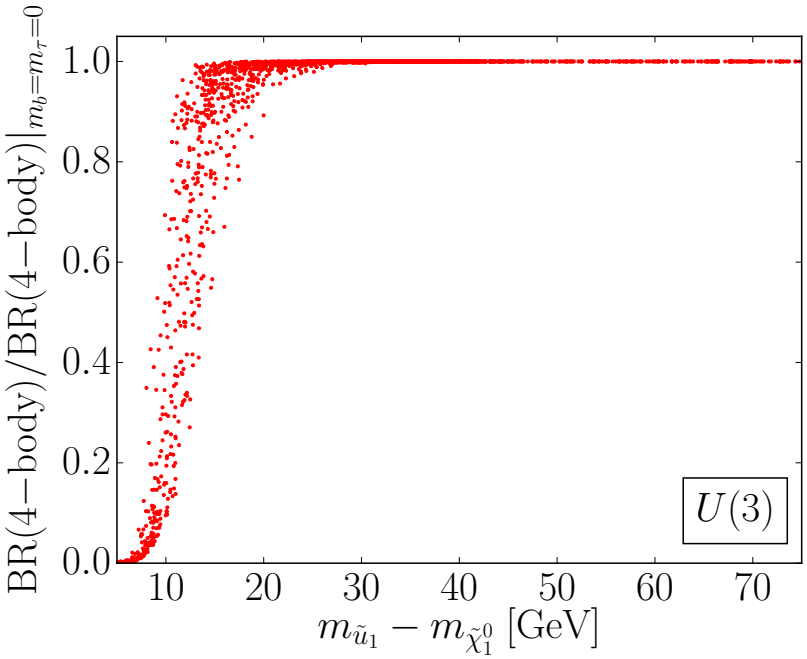
$$\prod_{\#W\text{propagators}} \frac{p_W^2 - m_W^2}{p_W^2 - m_W^2 + i m_W \Gamma_W}$$

Results: Two-body and Four-body Decays
$\Delta m < m_W$

[Gröber, Mühlleitner, Popenda, AW '14]



(a) K-factor for the two-body decay



(b) Bottom quark and Tau lepton mass effects

$$K = \Gamma_{NLO}/\Gamma_{LO}$$

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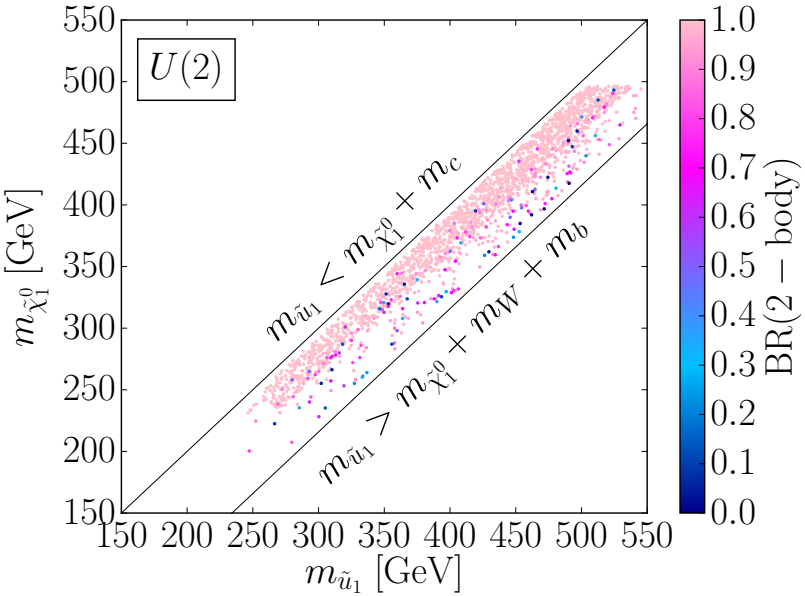
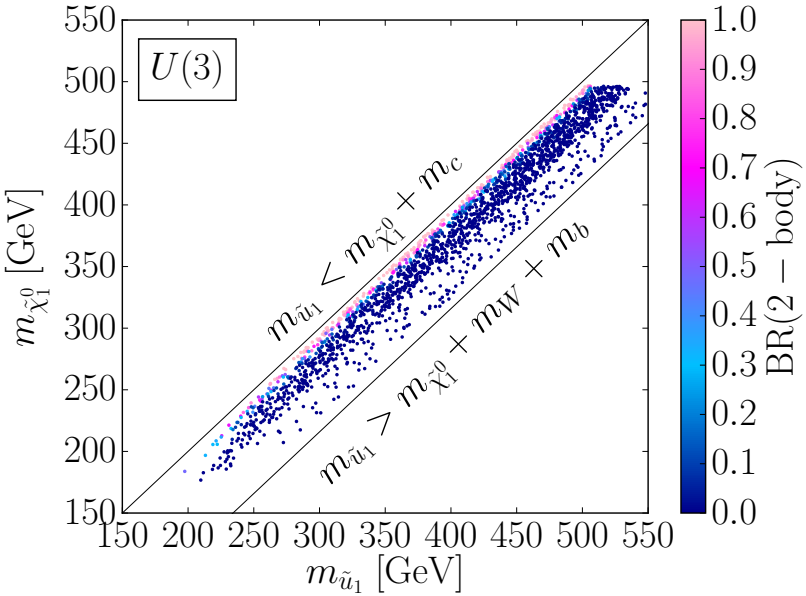


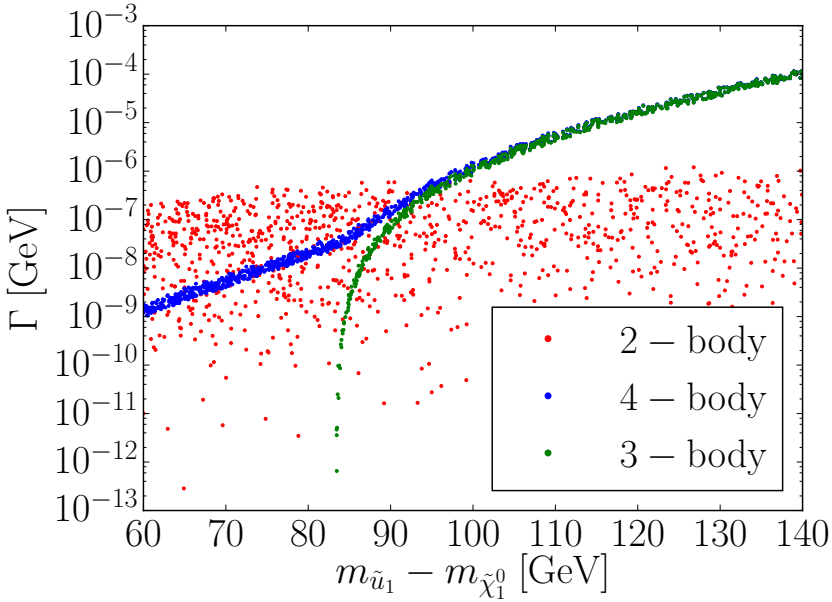
(c) $U(2)_{Q_L} \times U(2)_{u_R} \times U(3)_{d_R}$ symmetry



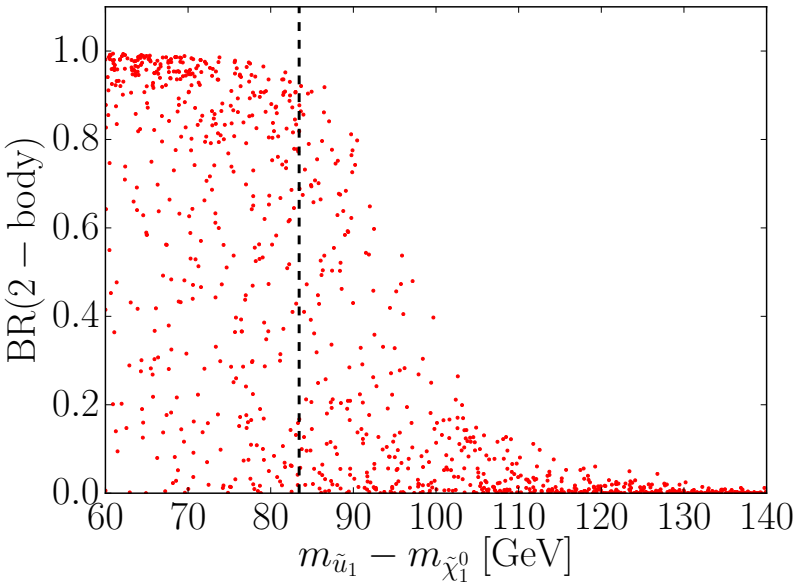
(d) $U(3)_{Q_L} \times U(2)_{u_R} \times U(3)_{d_R}$ symmetry

Results: Three- and Four-body Decay Threshold
$\Delta m \in [60, 140]$**GeV**

[Gröber, Mühlleitner, Popenda, AW '15]



(e) Partial decay widths for the three decay modes



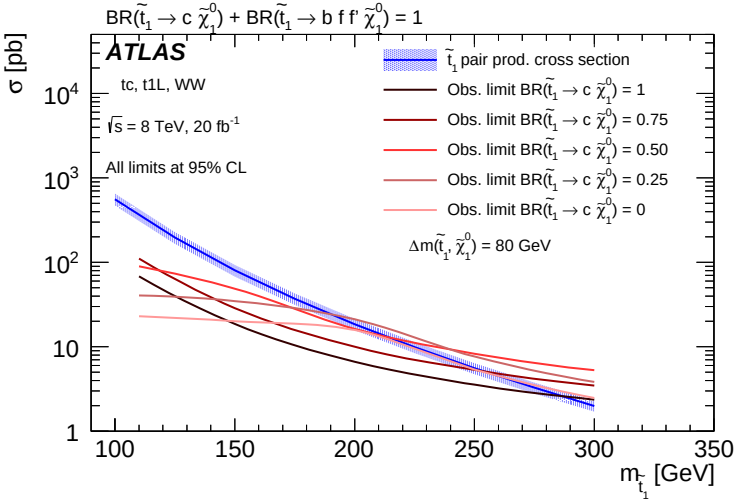
(f) BR of the two-body decay at the threshold

Former $U(2)$-symmetry case is used here.

Conclusion

Conclusion

- calculated the two-, three- and four-body decays with FV in the MSSM
  $\longrightarrow$ SUSYHIT [Djouadi, Mühlleitner, Spira '06][Gröber, Mühlleitner, Popenda, AW '15]
- masses of bottom quark and tau lepton taken into account
- threshold effects at the *W*-boson threshold considered
- NLO contributions for the two-body decay amount up to 25%
- two-body decay can cover the *W*-threshold in the case of large FV effects
- BRs can deviate significantly from one in all channels
- complementary searches in all channels needed



[ATLAS Collaboration '15]

Backup: Scan Range

$$
\begin{aligned}
A_t &\in [1000, 2000]\ \text{GeV} \\
m_{\tilde{U}_3} &\in [300, 600]\ \text{GeV} \\
m_{\tilde{Q}_{L3/(L1,L2,L3)}} &\in [1000, 1500]\ \text{GeV} \\
\tan\beta &\in [1, 15] \\
M_1 &\in [75, 500]\ \text{GeV} \\
m_A &\in [150, 1000]\ \text{GeV}
\end{aligned}
$$

All other parameters fixed:

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

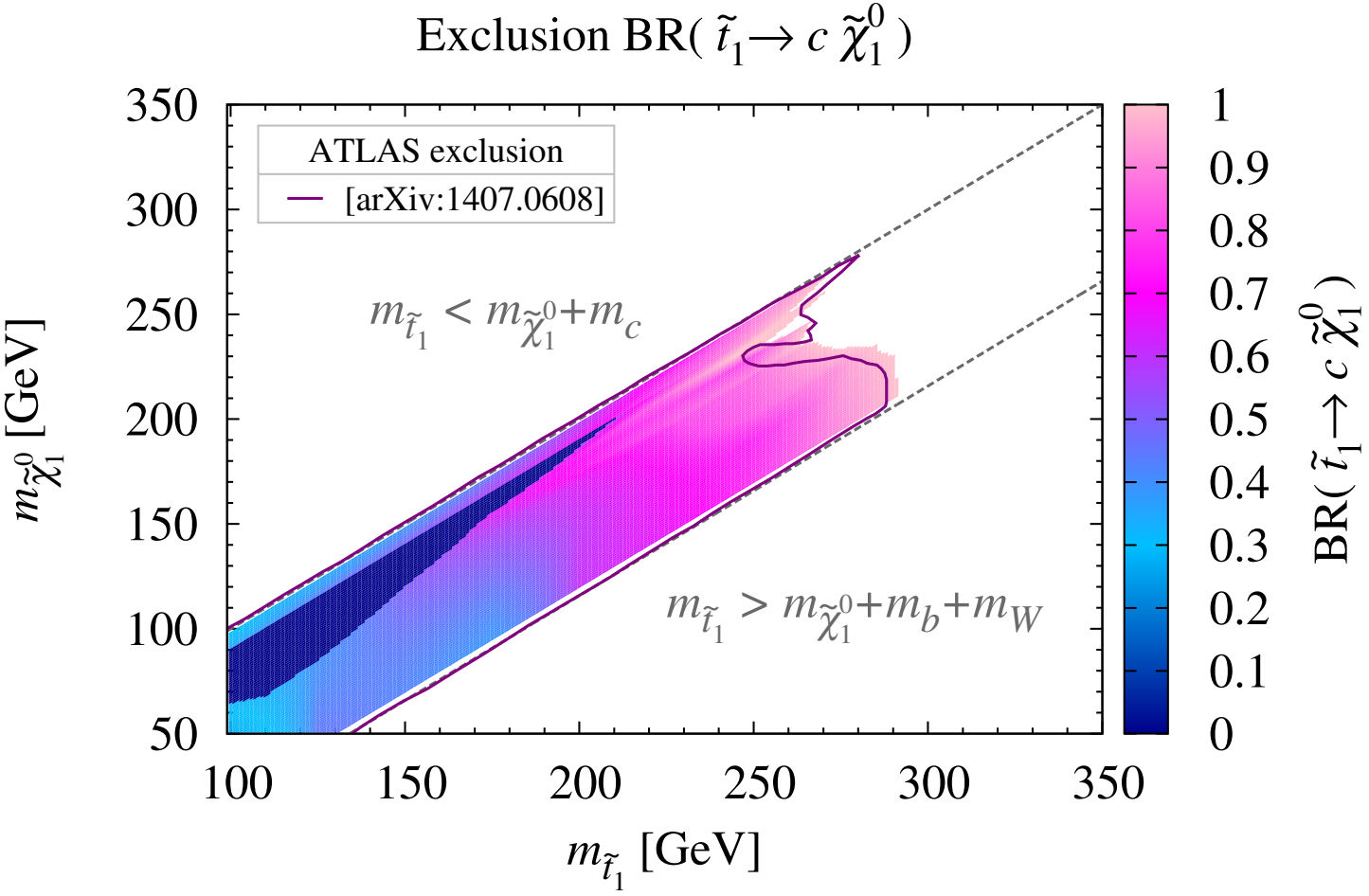
Backup: Implementation and Constraints

- implementation of the decays: `SUSYHIT` [Djouadi, Mühlleitner, Spira '06]
- 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]
  $BR(b \to X_s\gamma)$, $BR(B \to \tau\nu)$, $BR(B^0_{(s)} \to \mu^+\mu^-)$
- ρ-parameter: `SPheno` [Porod '12]
- constraint on the gluino mass
  $m_{\tilde{g}} > 1.45$ TeV [CMS-SUS-13-007, ATL-PHYS-PROC-2013-179]
- limits on $m_{\tilde{u}_1}$:
  - $m_{\tilde{u}_1} - m_{\tilde{\chi}^0_1} < 80$ GeV: own method [Gröber, Mühlleitner, Popenda, AW '15]
  - $m_{\tilde{u}_1} - m_{\tilde{\chi}^0_1} \geq 80$ GeV: `SModelS` [Kraml et al. '14]

Backup: Two-body and Four-body Decays

$\Delta m < m_W$

[Gröber, Mühlleitner, Popenda, AW '14]



Reinterpreted exclusion limits for the two-body decay

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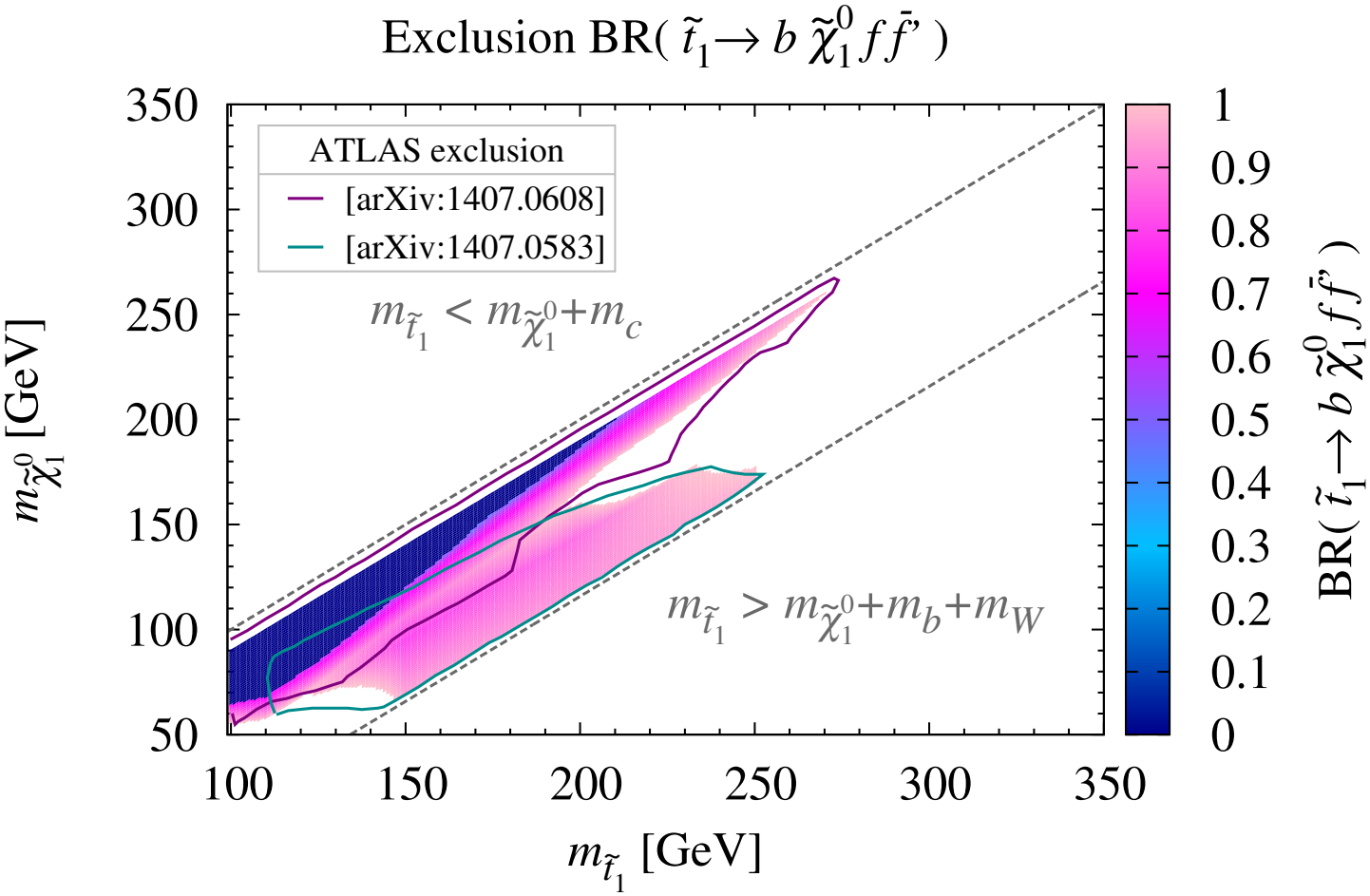

Reinterpreted exclusion limits for the four-body decay