Searches for third generation squarks with the ATLAS detector

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On Behalf of the ATLAS Collaboration

April 30, 2014

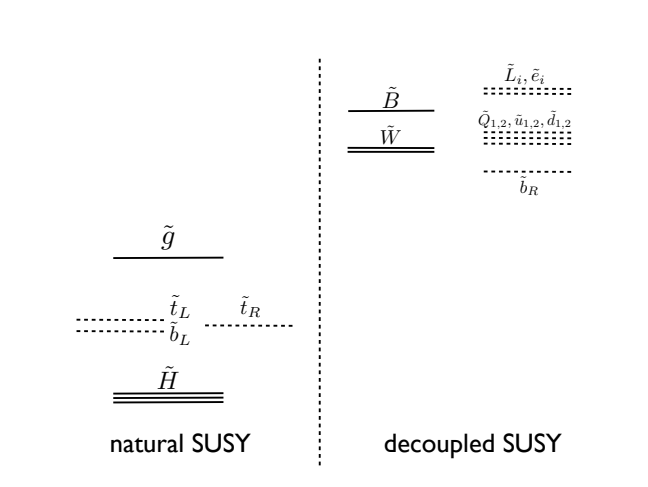
Introduction

SUSY predicts a partner with $\Delta S = 1/2$ for all SM particles

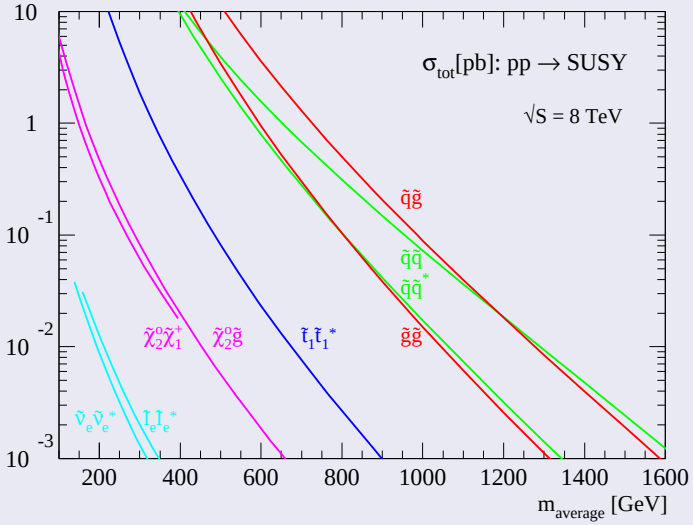
Spin	Interaction Eigenstates	Mass Eigenstates
0	$\begin{pmatrix}\tilde{e}^- \\ \tilde{\nu}_e\end{pmatrix}_L \begin{pmatrix}\tilde{\mu}^- \\ \tilde{\nu}_\mu\end{pmatrix}_L \begin{pmatrix}\tilde{\tau}^- \\ \tilde{\nu}_\tau\end{pmatrix}_L$ $\tilde{e}^*_R \quad \tilde{\mu}^*_R \quad \tilde{\tau}^*_R$ Sleptons	$\begin{pmatrix}\tilde{e}^- \\ \tilde{\nu}_e\end{pmatrix}_L \begin{pmatrix}\tilde{\mu}^- \\ \tilde{\nu}_\mu\end{pmatrix}_L \tilde{\tau}^-_1 \ \tilde{\tau}^-_2$ $\tilde{e}^*_R \quad \tilde{\mu}^*_R \quad \tilde{\nu}_{\tau_L}$ Sleptons
1/2		$\begin{pmatrix}\tilde{e}^- \\ \tilde{\nu}_e\end{pmatrix}_L \begin{pmatrix}\tilde{\mu}^- \\ \tilde{\nu}_\mu\end{pmatrix}_L \begin{pmatrix}\tilde{\tau}^- \\ \tilde{\nu}_\tau\end{pmatrix}_L$ $e^\dagger_R \quad \mu^\dagger_R \quad \tau^\dagger_R$ Leptons
0	$\begin{pmatrix}\tilde{u} \\ \tilde{d}\end{pmatrix}_L \begin{pmatrix}\tilde{c} \\ \tilde{s}\end{pmatrix}_L \begin{pmatrix}\tilde{t} \\ \tilde{b}\end{pmatrix}_L$ $\tilde{u}^*_R \ \tilde{d}^*_R \quad \tilde{c}^*_R \ \tilde{s}^*_R \quad \tilde{t}^*_R \ \tilde{b}^*_R$ Squarks	$\begin{pmatrix}\tilde{u} \\ \tilde{d}\end{pmatrix}_L \begin{pmatrix}\tilde{c} \\ \tilde{s}\end{pmatrix}_L \underline{\tilde{\mathbf{t}}_1} \ \underline{\tilde{\mathbf{t}}_2}$ $\tilde{u}^*_R \ \tilde{d}^*_R \quad \tilde{c}^*_R \ \tilde{s}^*_R \quad \underline{\tilde{\mathbf{b}}_1} \ \underline{\tilde{\mathbf{b}}_2}$ Squarks
1/2		$\begin{pmatrix}u \\ d\end{pmatrix}_L \begin{pmatrix}c \\ s\end{pmatrix}_L \begin{pmatrix}t \\ b\end{pmatrix}_L$ $u^\dagger_R \ d^\dagger_R \quad c^\dagger_R \ s^\dagger_R \quad t^\dagger_R \ b^\dagger_R$ Quarks
0	$\Phi_u = \begin{pmatrix}\phi^+_u \\ \phi^0_u\end{pmatrix} \ \Phi_d = \begin{pmatrix}\phi^0_d \\ \phi^-_d\end{pmatrix}$ Higgs Doublet Fields	$h^0 \ A^0 \ H^0 \ H^\pm$ Higgs Bosons
1/2	$\tilde{\Phi}_u = \begin{pmatrix}\tilde{\phi}^+_u \\ \tilde{\phi}^0_u\end{pmatrix} \ \tilde{\Phi}_d = \begin{pmatrix}\tilde{\phi}^0_d \\ \tilde{\phi}^-_d\end{pmatrix} \ \tilde{B}^0 \ \tilde{W}^0_3 \ \tilde{W}^\pm_{1,2} \ \tilde{g}$ Higgsinos Bino Winos Gluinos	$\tilde{\chi}^0_{1,2,3,4}$ Neutralinos $\tilde{\chi}^\pm_{1,2}$ Charginos $\underline{\tilde{\mathbf{g}}}$ Gluinos
1	$B^0 \quad W^0_3 \ W^\pm_{1,2} \quad g$ $\mathrm{U(1)_Y, SU(2)_L}$ Gauge Fields, Gluons	$\gamma \quad Z^0 \ W^\pm \quad g$ Photon, EW Gauge Bosons, Gluons
3/2		$\tilde{G}_{3/2}$ Gravitino
2		$G_{\mu\nu}$ Graviton

Natural SUSY

- It requires sparticles with dominant contributions to M_h radiative corrections to be relatively light



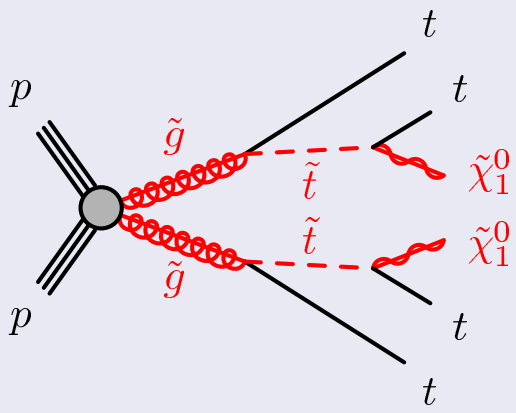
- In this context one expects
  - not too heavy gluinos
  - stop/sbottom as lightest squark

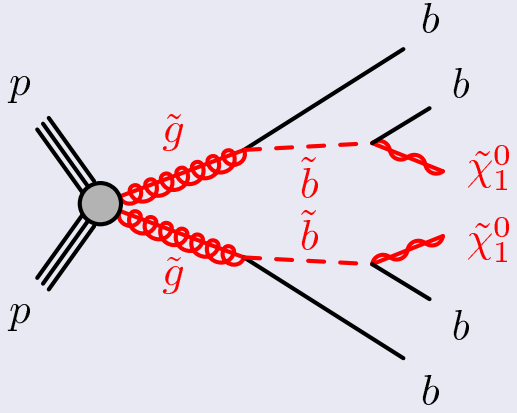


- Present talk reports on recent ATLAS analyses (or updates)
  - Dataset: $\int \mathcal{L}dt = (20.3 \pm 0.6)\mathrm{fb}^{-1}$ of p+p collisions at $\sqrt{s} = 8$ TeV in 2012
  - All limits at the 95% C.L.

Gluino Mediated Production

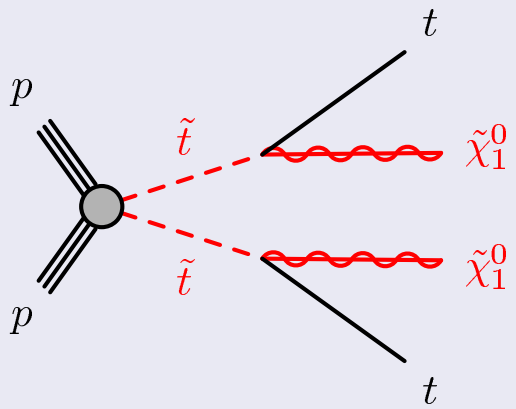
- Start with the highest cross section process
- Hypothesis: gluino lighter than $1^{st}/2^{nd}$ generation squarks
- Large b-jet multiplicity and large $\not{E}_T$ $\Rightarrow$ low SM background

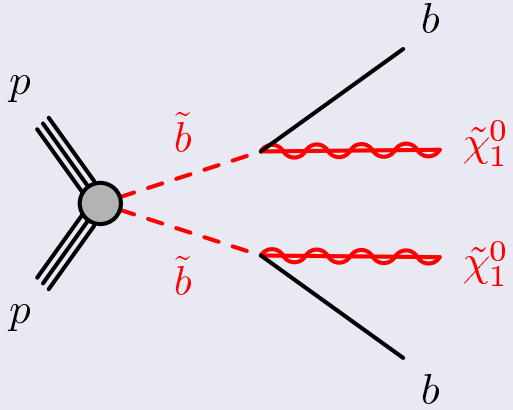




Direct Production

- Also look for direct production in case gluinos are out of reach
- Lower cross sections, still higher than those of EWK gauginos
- Lower b-jet multiplicity





Analysis

"Search for supersymmetry at $\sqrt{s}$ =8 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector"

- *Ref: arXiv:1404.2500 [hep-ex], subm. to JHEP*
- *See ATLAS talk by T. Gillam*

Inclusive Search Topology

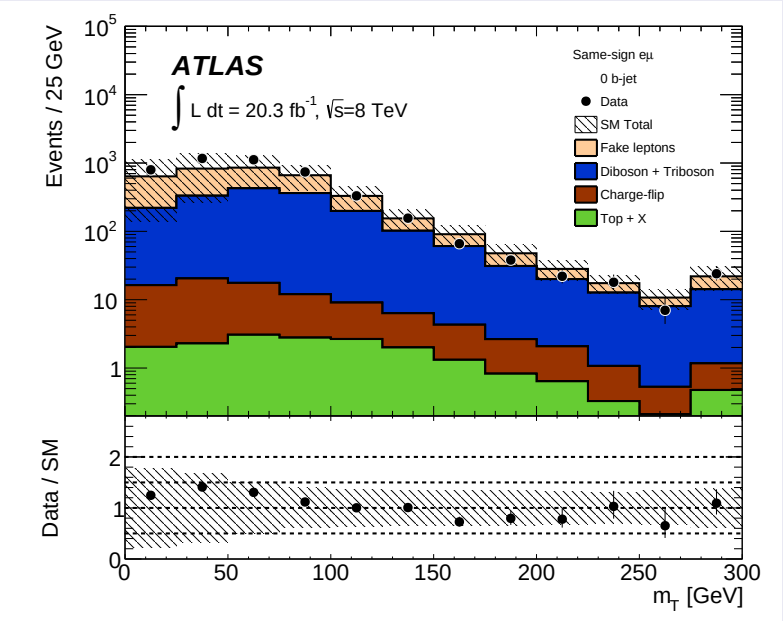
- $\ell^{\pm}\ell^{\pm} + [1-3]b - jets + \not{E}_T,\ (\ell^{\pm} = e^{\pm}/\mu^{\pm})$
- $\ell^{\pm}\ell^{\pm} + [0]b - jets + \not{E}_T$
- $3\ell^{\pm} + [1-3]b - jets + \not{E}_T$

Limits & Interpretations

- $M_T = \sqrt{2p_T(\ell^{\pm})\not{E}_T[1 - cos\Delta\phi(\ell^{\pm}, \not{E}_T)]}$
- Distr. in $e^{\pm}\mu^{\pm} + [0]b - jet + \not{E}_T$ inclusive topology

Limits & Interpretations

- $M_{eff} = \not{E}_T + \sum_{leptons} p_T + \sum_{jets} p_T$
- Distr. in $e^{\pm}e^{\pm} + [1-3]b - jet + \not{E}_T$ inclusive topology



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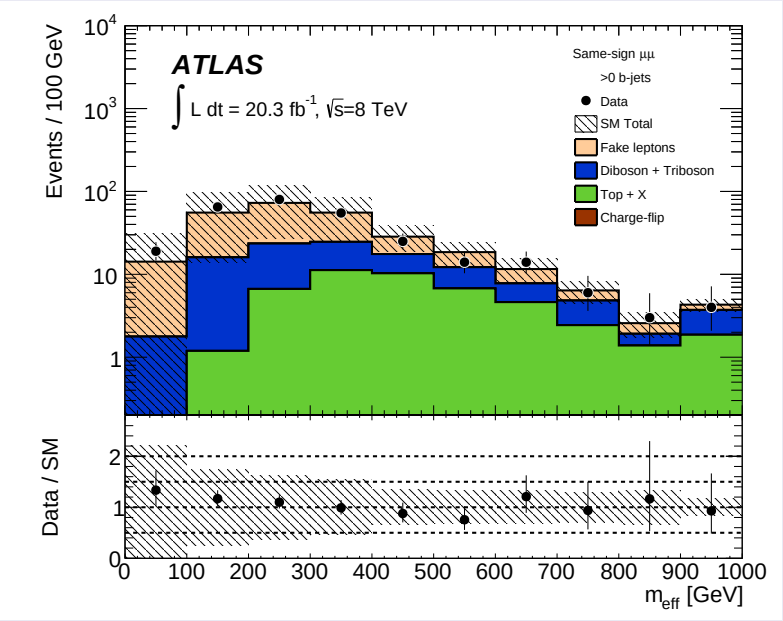


Background

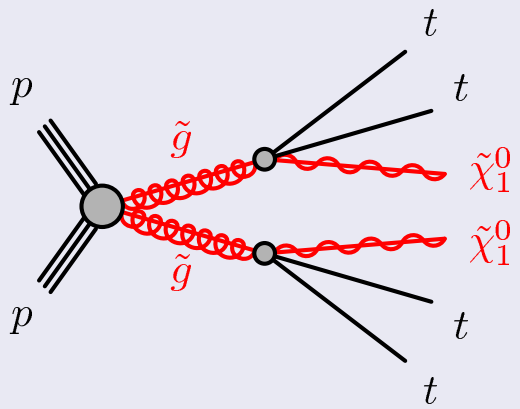
- MC estimate of physics background:
  - ttW, ttZ, WW, WZ
- Data-driven estimate of instrumental background:
  - hadron faking isolated $\ell^{\pm}$
  - non-isolated $\ell^{\pm}$ from heavy flavor hadron decay faking isolated $\ell^{\pm}$
  - $e^{\pm}$ from $\gamma-$conversion
  - $e^{\pm}$ with mis-measured charge

Limits Derivation

- Signal exclusion fit simultaneously all SRs (maximizes sensitivity to SUSY scenario)
- No excess observed in data wrt SM expectations in any analyses
- Limits are calculated using the CL_S prescription

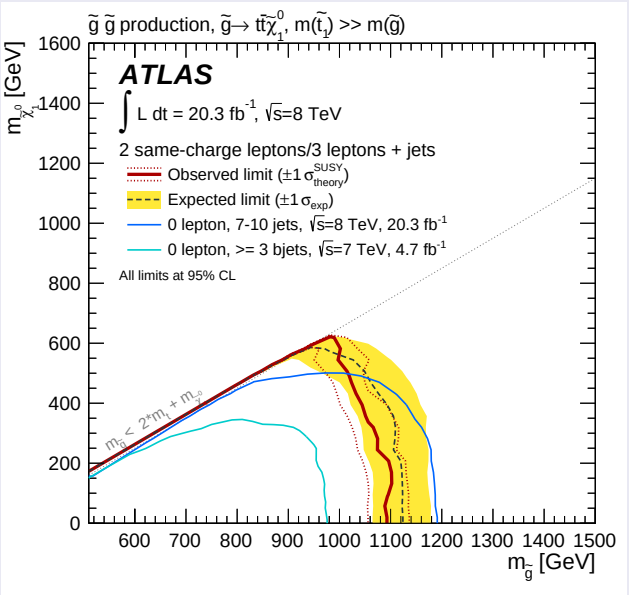
Gluino Mediated Production

- $M_{\tilde{g}} << M_{\tilde{t}_1}$



Gluino Mediated Production

- $M_{\tilde{g}} > M_{\tilde{t}_1}$
  $(M_{\tilde{\chi}_1^{\pm}}, M_{\tilde{\chi}_1^0}) = (118, 60)$ GeV



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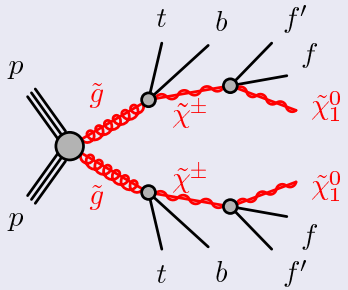

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- $\tilde{g} \rightarrow t + c + \tilde{\chi}_1^0$
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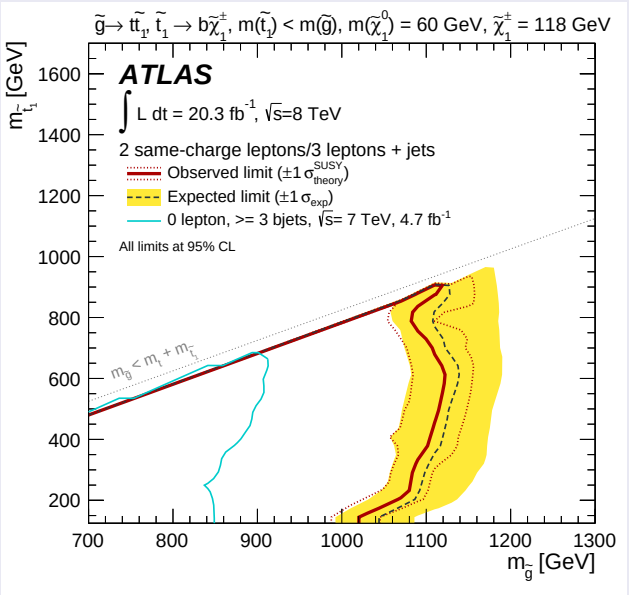

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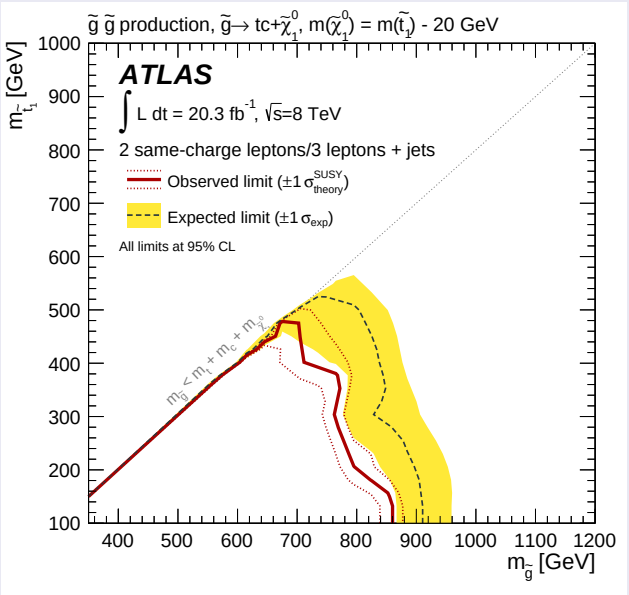

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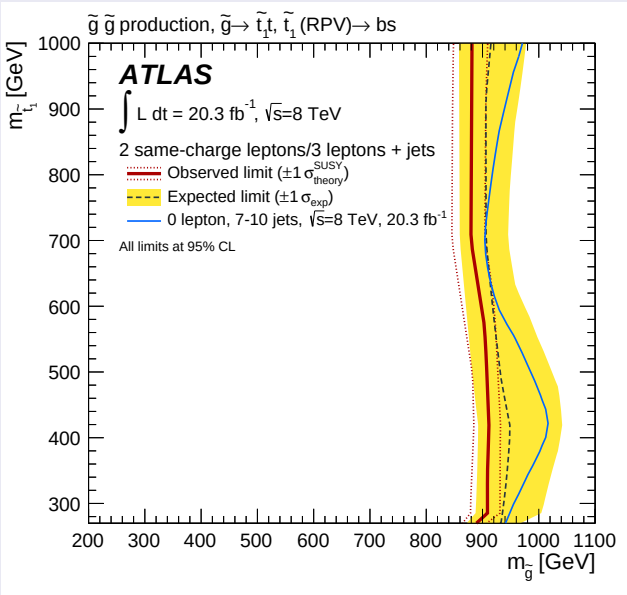
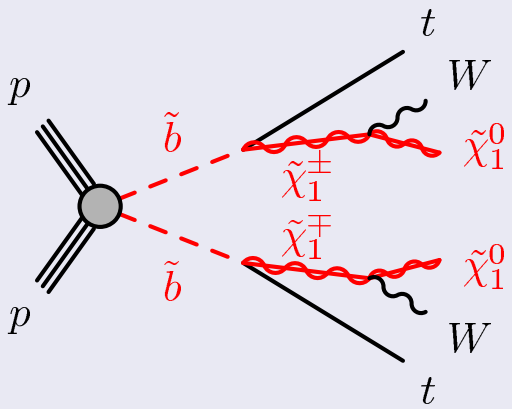


Direct Sbottom Pair Production

- $\tilde{b}_1 \rightarrow t + \tilde{\chi}_1^{\pm}$
  $M_{\tilde{\chi}_1^0} = 60$ GeV



Direct Sbottom Pair Production

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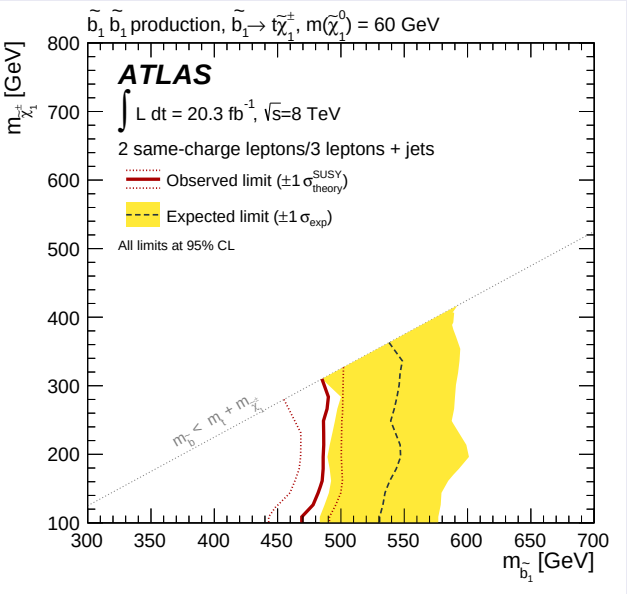

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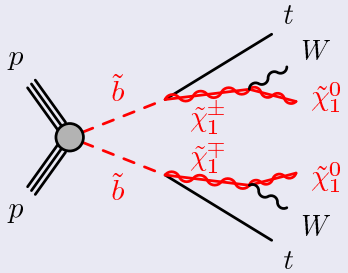

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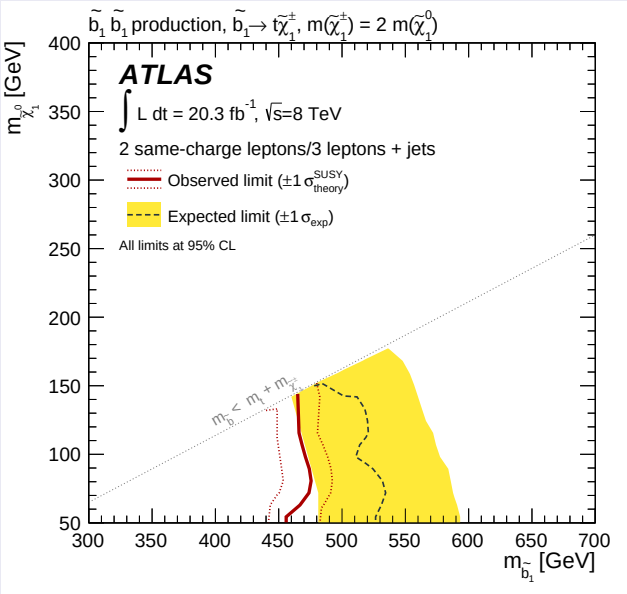

Minimal Supergravity

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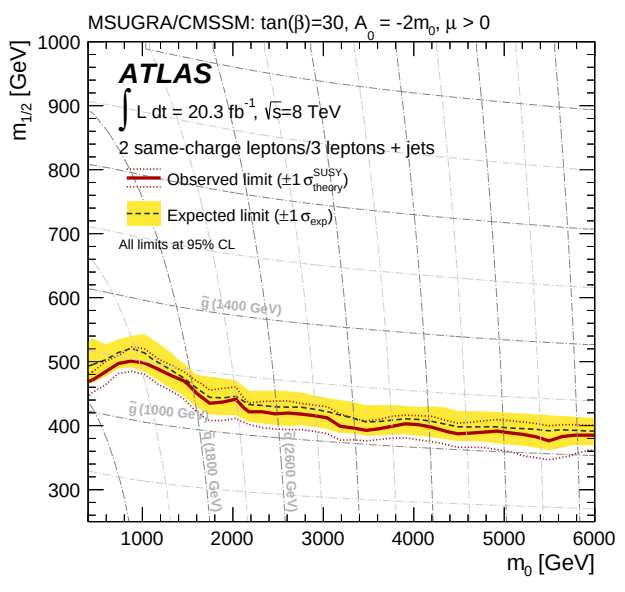

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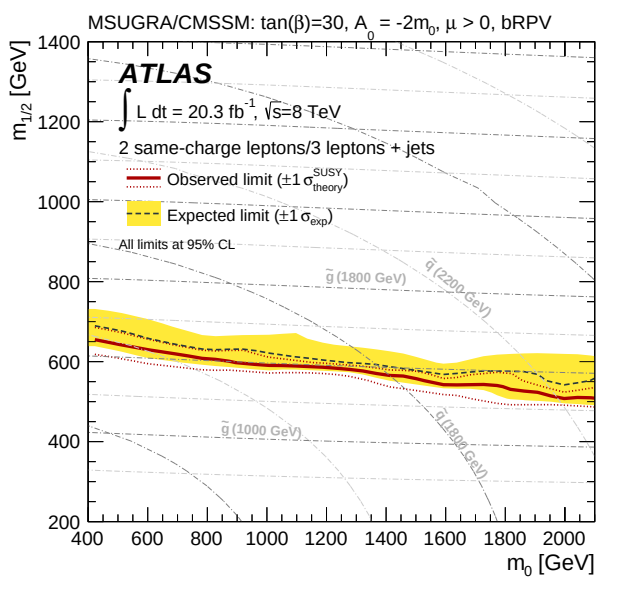
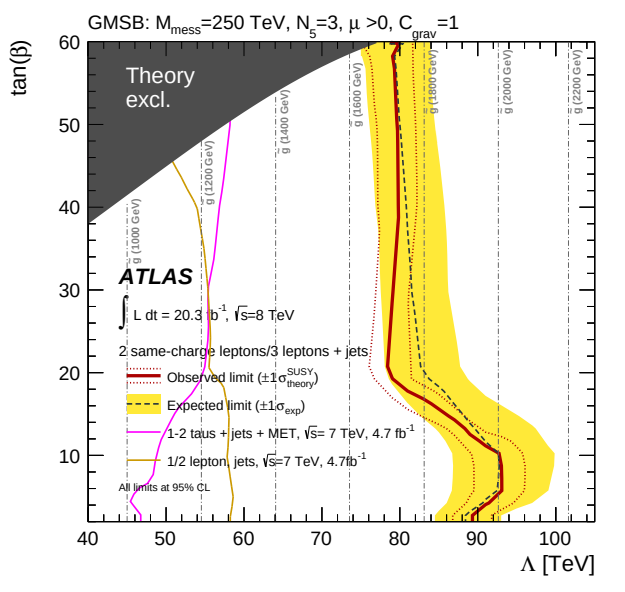


Gauge Mediated SUSY Breaking

- $M_{mess} = 250$ TeV, $N_5 = 3$
  $\mu > 0$, $C_{grav} = 1$

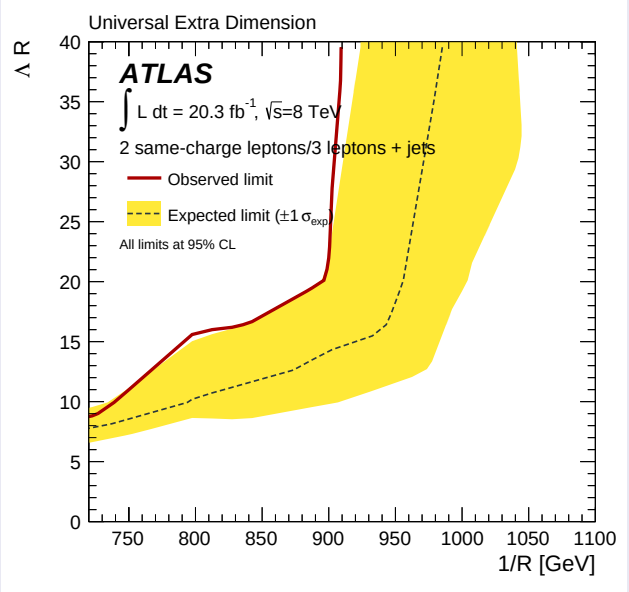
Gauge Mediated SUSY Breaking



Universal Extra Dimensions

- Non SUSY Model

Universal Extra Dimensions



Analysis

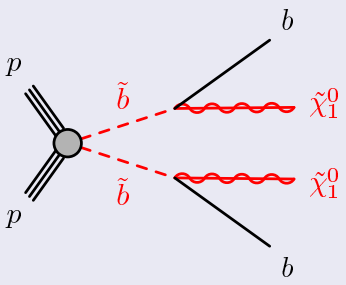
"Search for direct third-generation squark pair production in final states with missing transverse momentum and two b-jets in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector"

- *Ref: arXiv:1308.2631 [hep-ex], JHEP 10 (2013) 189*

Inclusive Search Topology

- $2b - jets + 0\ell^{\pm} + \not{E}_T$

Limits & Interpretations: Simplified Models



Limits & Interpretations: Simplified Models

- $\tilde{\chi}_1^{\pm} \rightarrow SoftTrack(s) + \not{E}_T$
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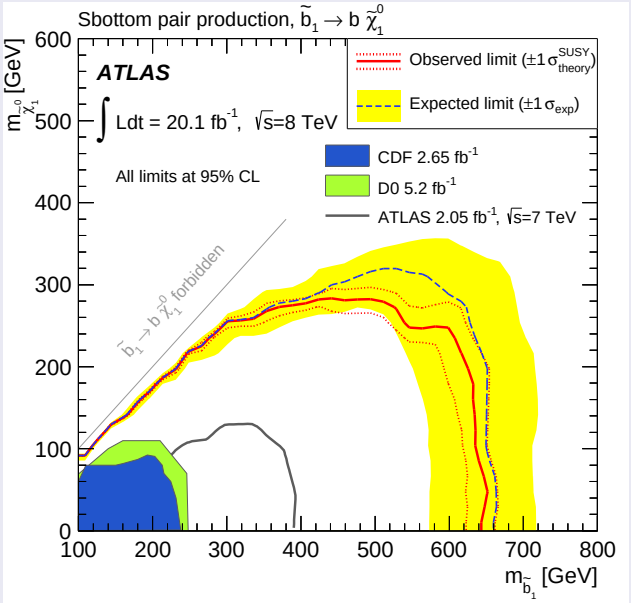

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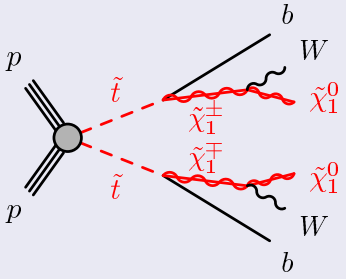

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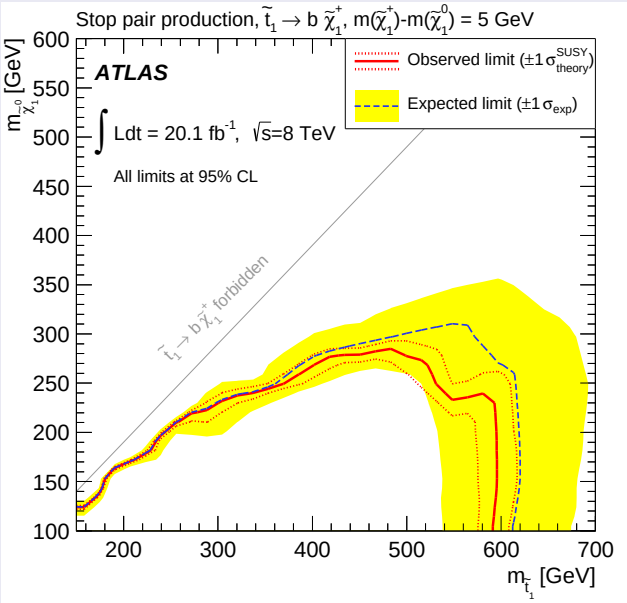

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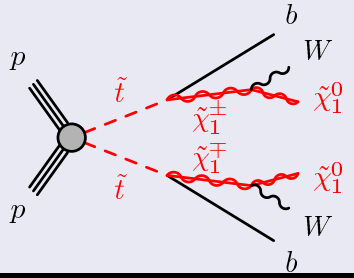

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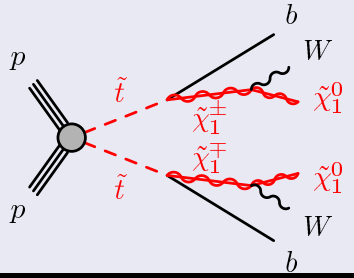
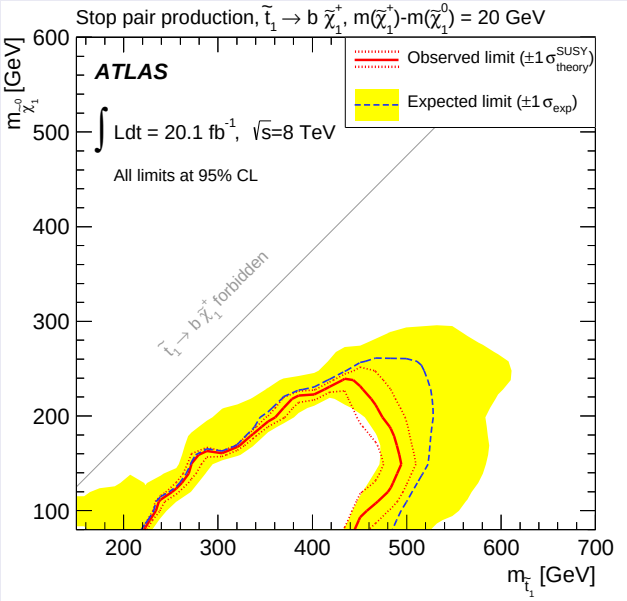




Analysis

"Search for direct production of the top squark in the all-hadronic $t\bar{t} + \not{E}_T$ final state in 21 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector"

- *Ref: ATLAS-CONF-2013-024*

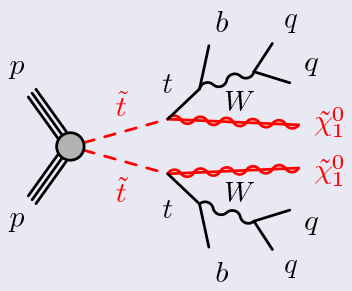
Inclusive Search Topology

- $t\bar{t} \rightarrow jets + 0\ell^{\pm} + \not{E}_T$

Event Selection

- Trigger: $\not{E}_T > 80$ GeV
- Offline:
  - Main Variables: M_T and $\not{E}_T$
  - Tau Veto

Limits & Interpretations: Simplified Models



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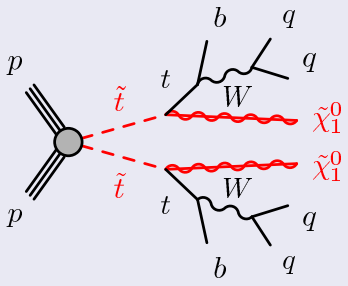
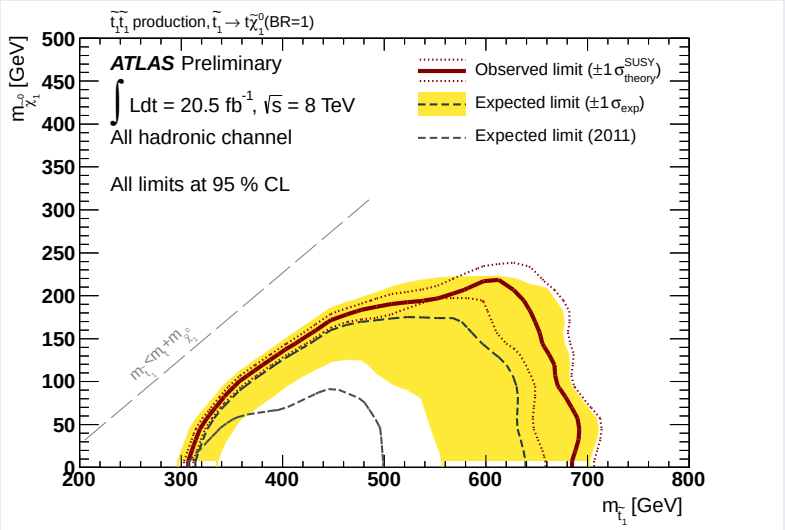




Analysis

"Search for strong production of supersymmetric particles in final states with missing transverse momentum and at least three b-jets using 20.1 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector"

- *Ref: ATLAS-CONF-2013-068*

Inclusive Search Topology

- $2c - jets + \not{E}_T$

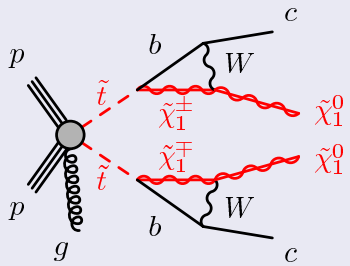
Event Selection

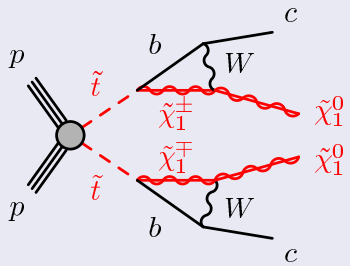
- Trigger: $\not{E}_T > 80$ GeV
- Offline:
  - Very Low ΔM: tag an ISR-jet $\rightarrow$ mono-jet selection
  - Low ΔM: tag a c-jet

c-tagging

- Trigger: $\not{E}_T > 80$ GeV
- Offline:
  - MVA: Tracks I.P. and properties of 2^{ndary} vertices
  - Performance: $\epsilon_c = 20\%$, $R_b \approx 5$, $R_{LF} \approx 140$

Limits & Interpretations: Simplified Models





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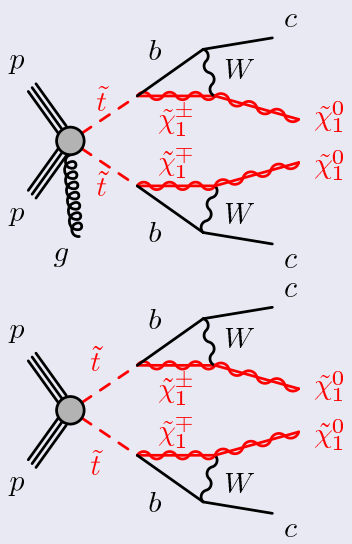
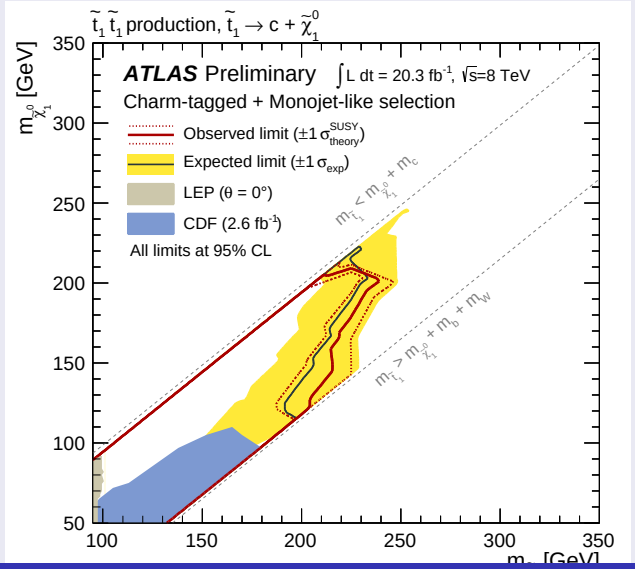




Analysis

"Search for strong production of supersymmetric particles in final states with missing transverse momentum and at least three b-jets using 20.1 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector"

- *Ref: ATLAS-CONF-2013-061*

Inclusive Search Topology

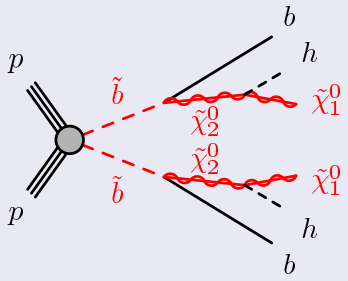
- $[0-1]\ell^{\pm} + jets + 3b - jets + \not{E}_T$

Event Selection

- Main Variables: M_{eff} and $\not{E}_T/\sqrt{H_T}$

Direct Sbottom Pair Production

- $BR(\tilde{b}_1 \rightarrow b + \tilde{\chi}_2^0) = 1$
  $BR(\tilde{\chi}_2^0 \rightarrow h + \tilde{\chi}_1^0) = 1$



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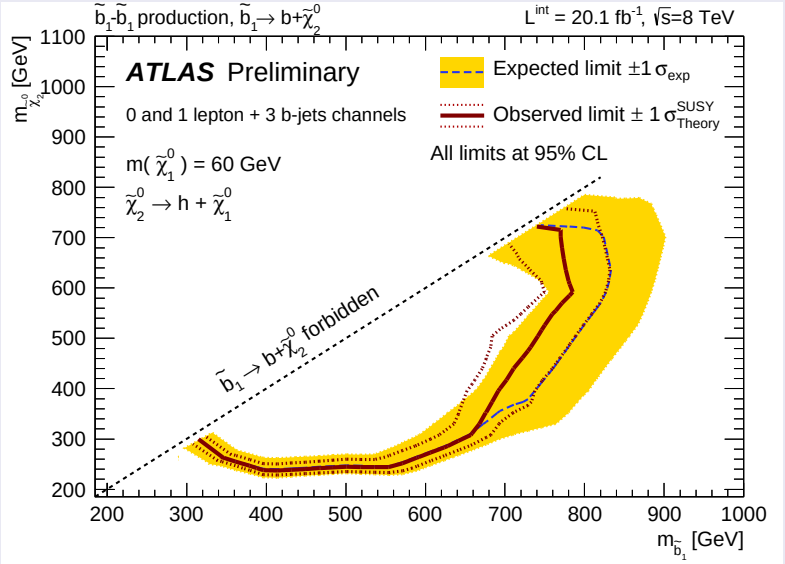
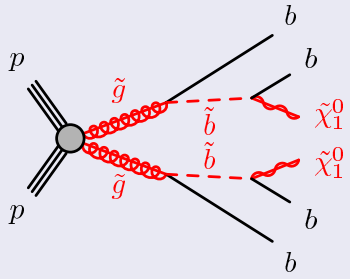


Gluino Mediated Sbottom Pair Production

- $BR(\tilde{g} \to \tilde{b}_1 + \bar{b}) = 1$
  on-shell $\tilde{b}_1$
  $BR(\tilde{b}_1 \to b + \tilde{\chi}_1^0) = 1$



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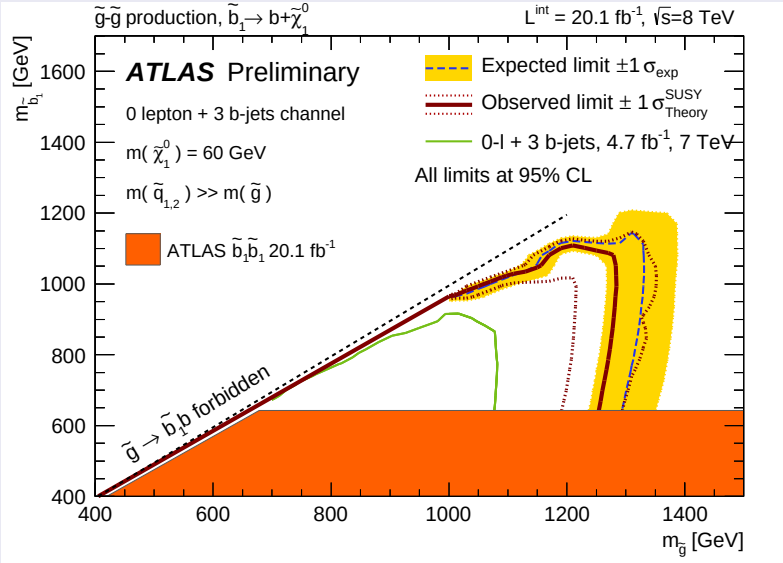

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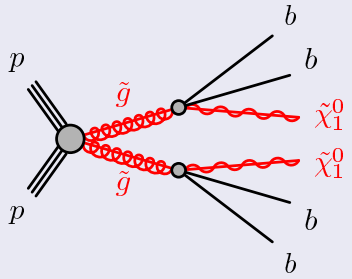

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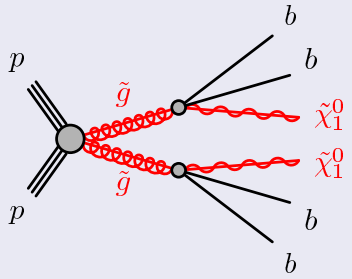
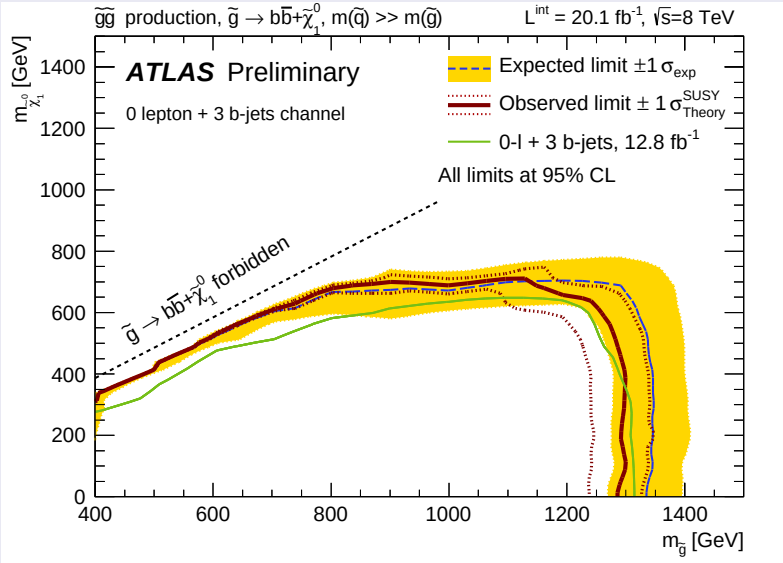
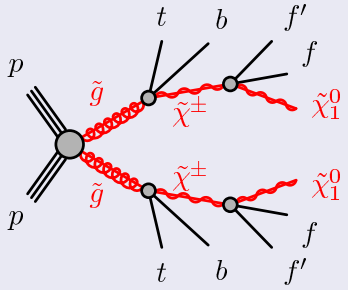




Gluino Mediated Stop Pair Production

- $BR(\tilde{g} \rightarrow t + \tilde{\chi}_1^0) = 1$,
  $BR(\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^{\pm}) = 1$
  $BR(\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} + \tilde{\chi}_1^0) = 1$
  $(M_{\tilde{\chi}_1^{\pm}}, M_{\tilde{\chi}_1^0}) = (120, 60)$ GeV



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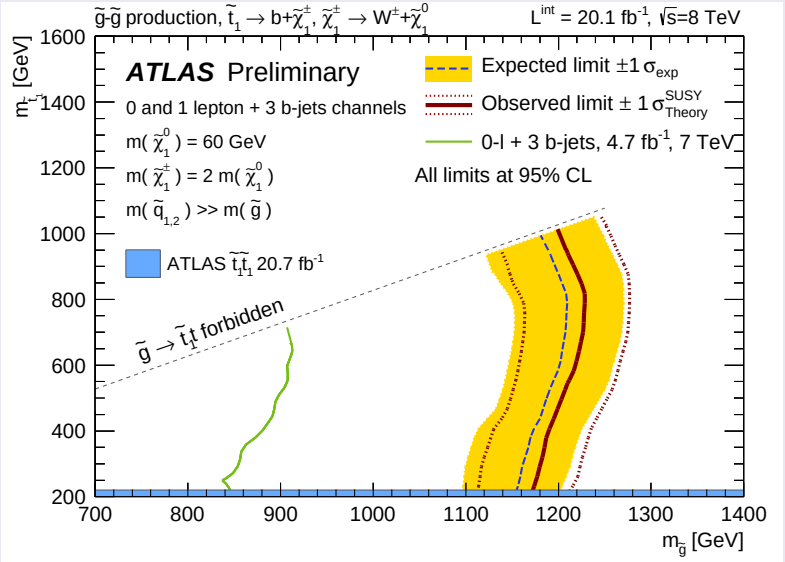

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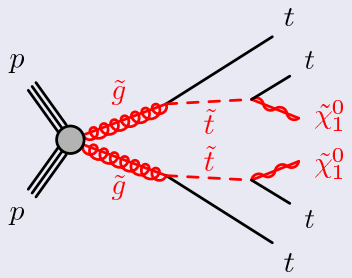

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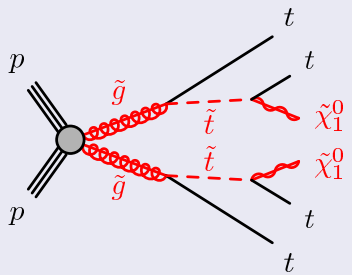
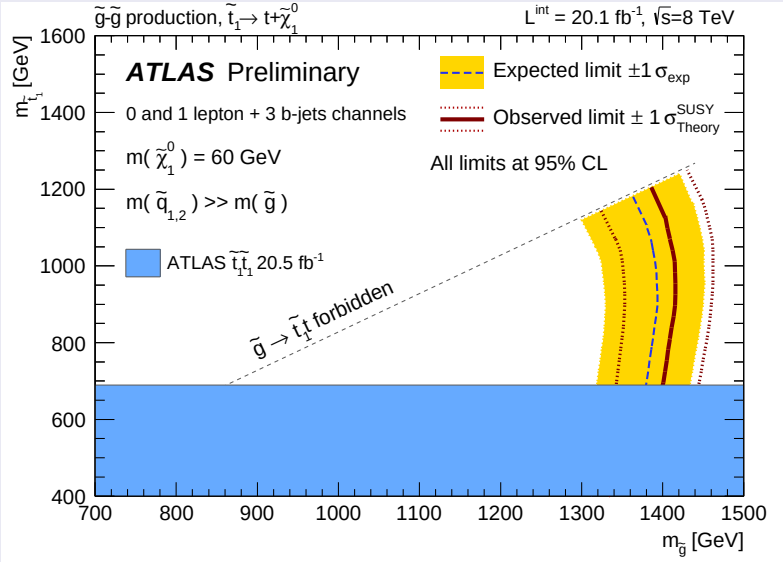
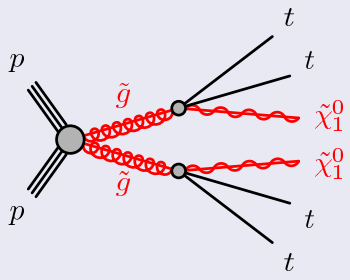




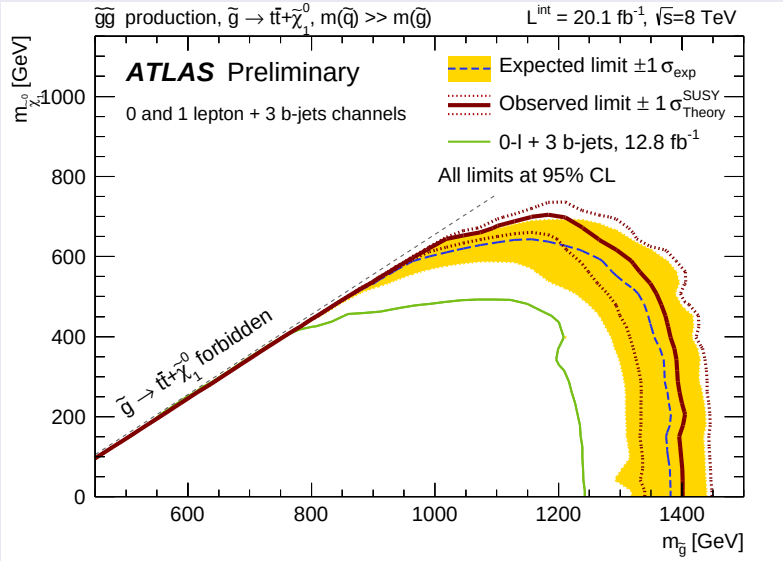
Gluino Mediated Stop Pair Production (cont'd)

- $BR(\tilde{g} \rightarrow t + \bar{t} + \tilde{\chi}_1^0) = 1$
  off-shell $\tilde{t}_1$



Gluino Mediated Stop Pair Production (cont'd)

- $BR(\tilde{g} \rightarrow b + \bar{t} + \tilde{\chi}_1^{\pm}) = 1$
  $M_{\tilde{\chi}_1^{\pm}} - M_{\tilde{\chi}_1^0} = 2$ GeV



Gluino Mediated Stop Pair Production (cont'd)

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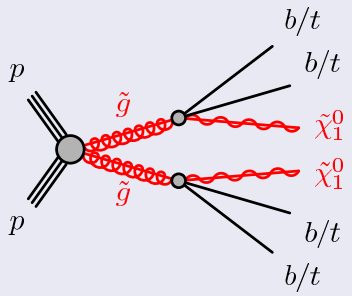

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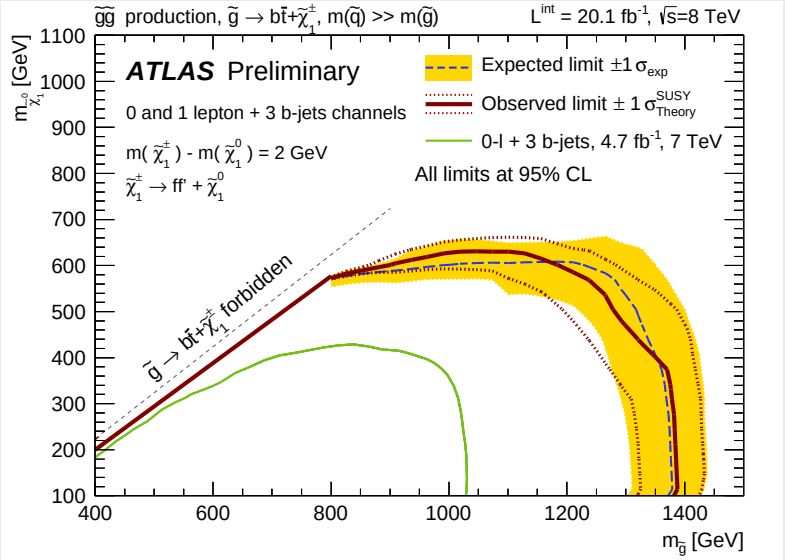
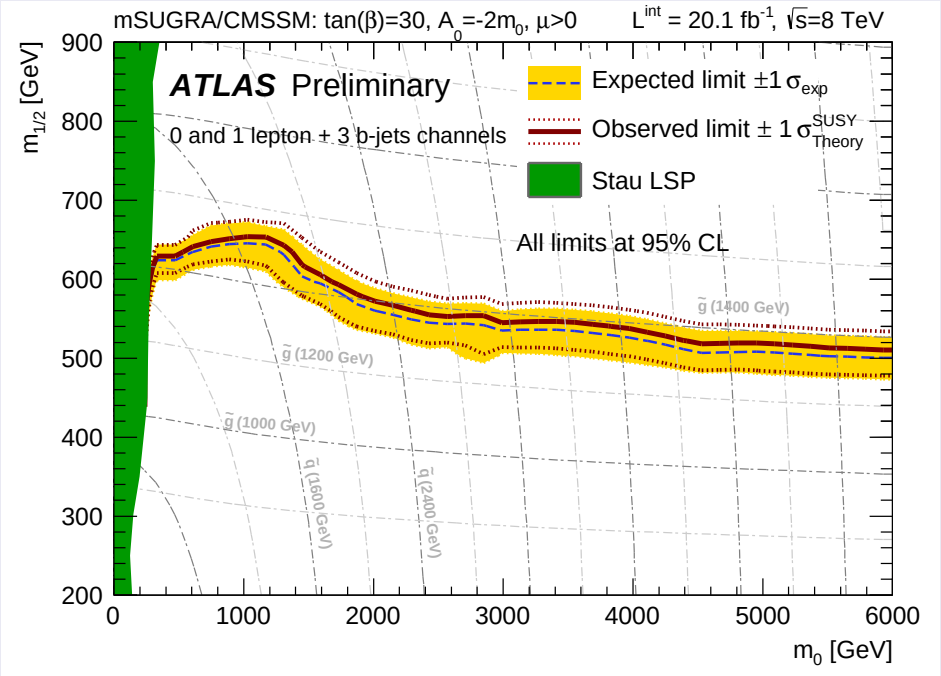


Minimal Supergravity



Analysis

"Search for the direct pair production of top squarks decaying to a b quark, a tau lepton, and weakly interacting particles, in $\sqrt{s} = 8$ TeV pp collisions using 20 fb^{-1} of ATLAS data"

- *Ref: ATLAS-CONF-2014-014*

Inclusive Search Topology

- $\ell^{\pm}\ell^{\mp} + \not{E}_T$

Event Selection

- Main variable: M_{T2}
- $M_{T2}(\mathbf{p}_T^{vis_1}, \mathbf{p}_T^{vis_2}, \not{\mathbf{p}}_T) = \min_{\mathbf{p}_T^{invis_1} + \mathbf{p}_T^{invis_2} = \not{\mathbf{p}}_T} max[M_T(\mathbf{p}_T^{vis_1}, \mathbf{p}_T^{invis_1}), M_T(\mathbf{p}_T^{vis_2}, \mathbf{p}_T^{invis_2})]$

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- New selection for small $\tilde{t}_1$ and $\tilde{\tau}_1^{\pm}$ masses

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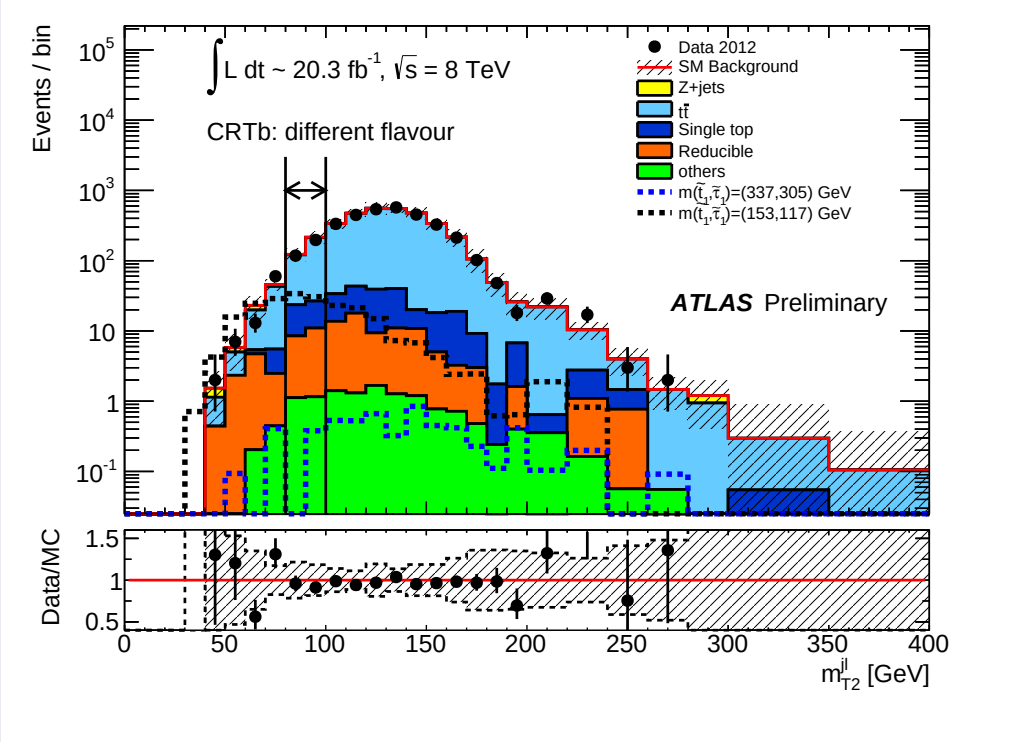
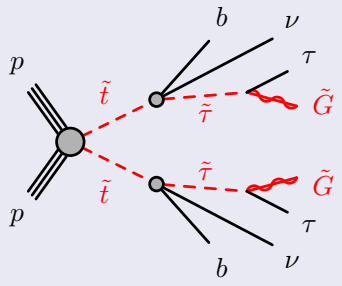
Event Selection (cont'd)



Gauge Mediated SUSY Breaking

- $BR(\tilde{t}_1 \rightarrow b + \nu + \tilde{\tau}_1^{\pm}) = 1$
  $BR(\tilde{\tau}_1^{\pm} \rightarrow \tau^{\pm} + \tilde{G}_{3/2}) = 1$



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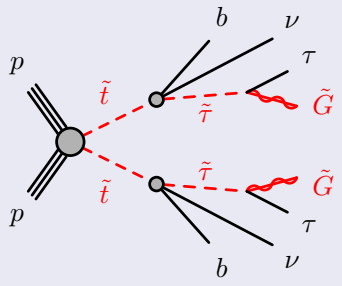
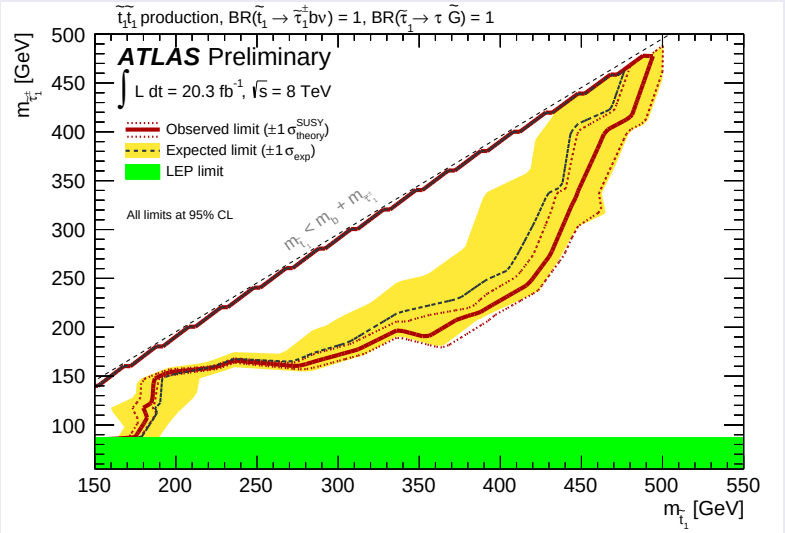




Limits & Interpretations: Simplified Model

Analysis

"Search for direct top squark pair production in events with a Z boson, b-jets and missing transverse momentum in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector"

- *Ref: arXiv:1403.5222 [hep-ex], subm. to EJPC*
- Motivation: In case direct $\tilde{t}_1\bar{\tilde{t}}_1$ searches have limited sensitivities due to compressed scenarios, consider production of $\tilde{t}_2\bar{\tilde{t}}_2$

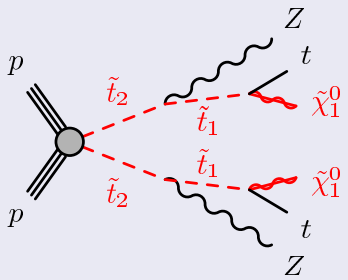
Inclusive Search Topology

- $Z(\rightarrow \ell^{\pm}\ell^{\mp}) + 2b - jets + \not{E}_T$

Limits & Interpretations: Simplified Model

Gauge Mediated SUSY Breaking

- $BR(\tilde{t}_2 \rightarrow Z + \tilde{t}_1) = 1$



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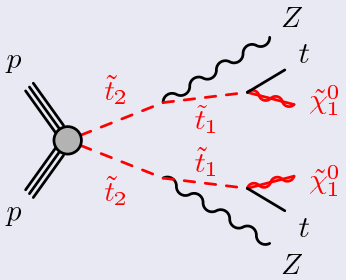

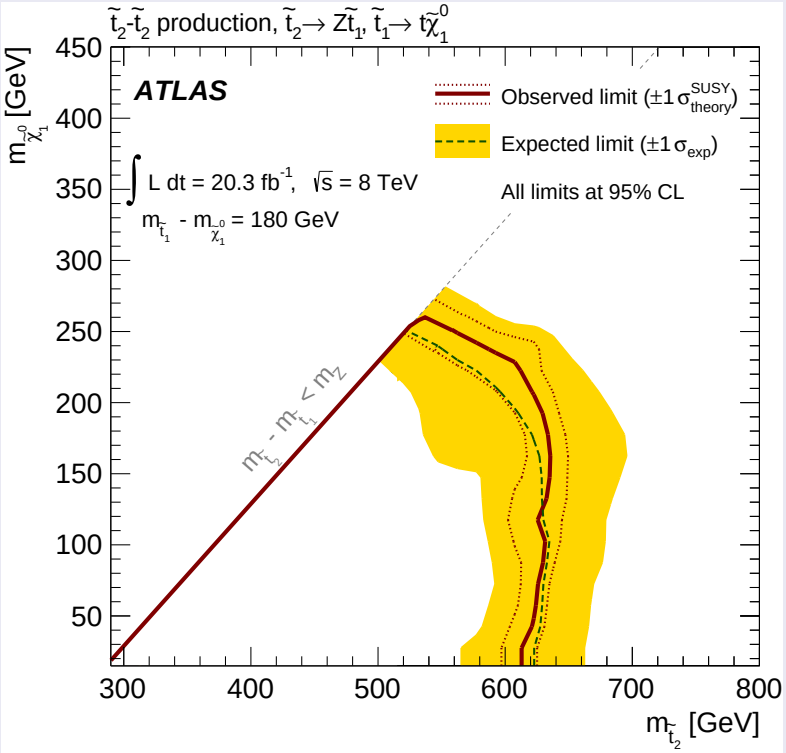

Natural Gauge Mediated SUSY Breaking

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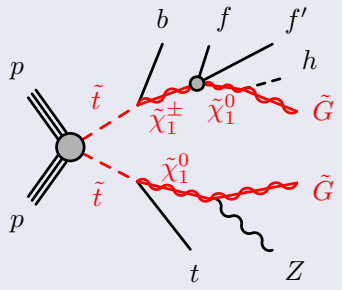

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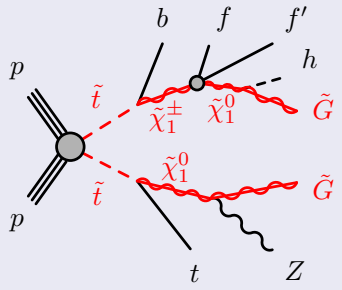

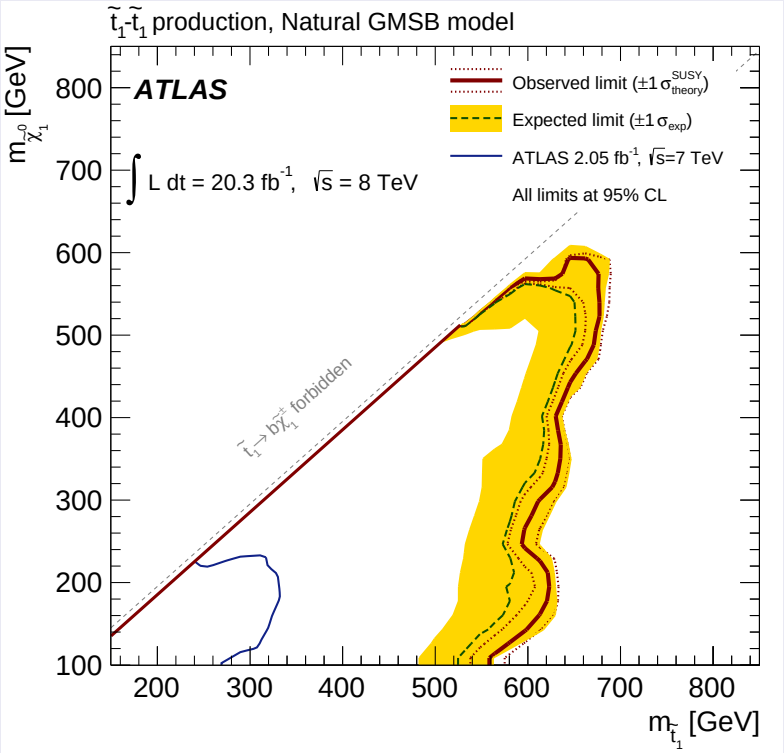

Conclusion

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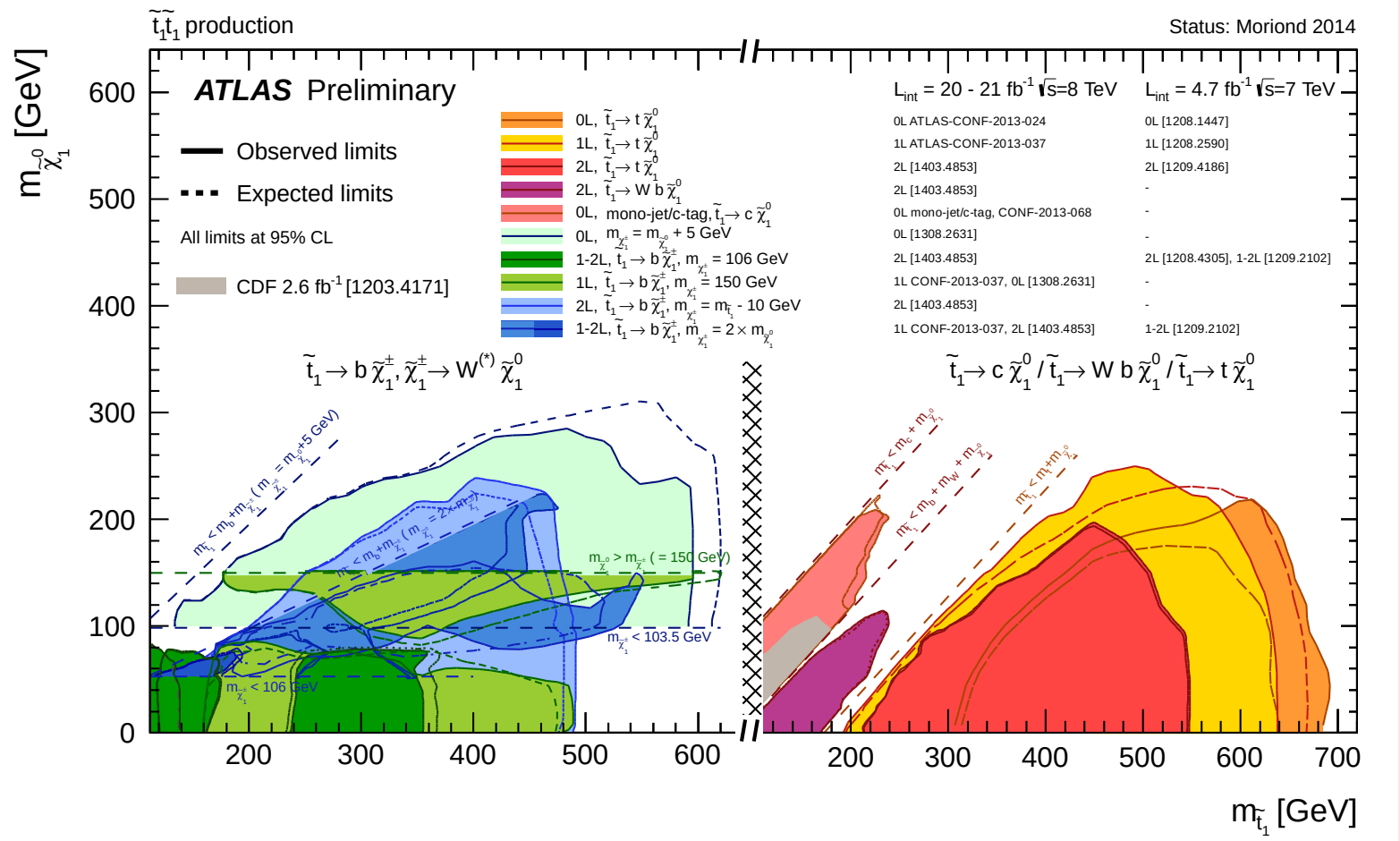
Conclusion (cont'd)



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- BACK-UP

ATLAS SUSY Limits