Model-Independent Exclusion of the Light Stop Scenario

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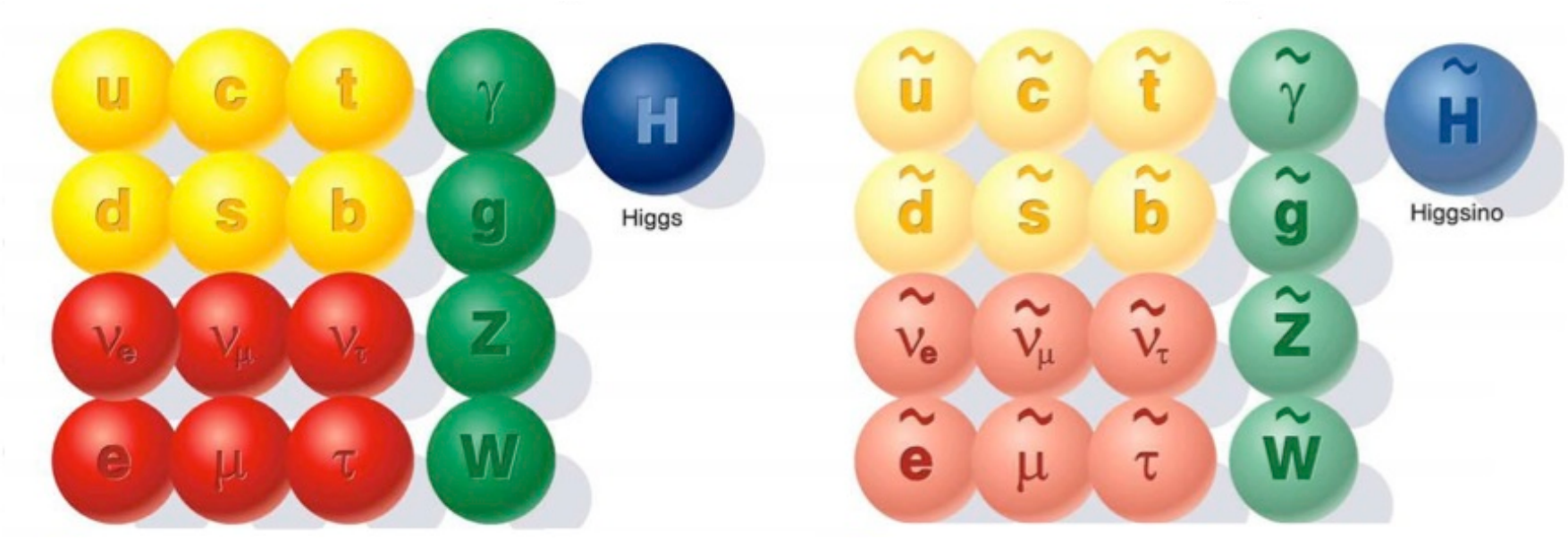
Collaboration with Alexander Belyaev and Veronica Sanz

Plan

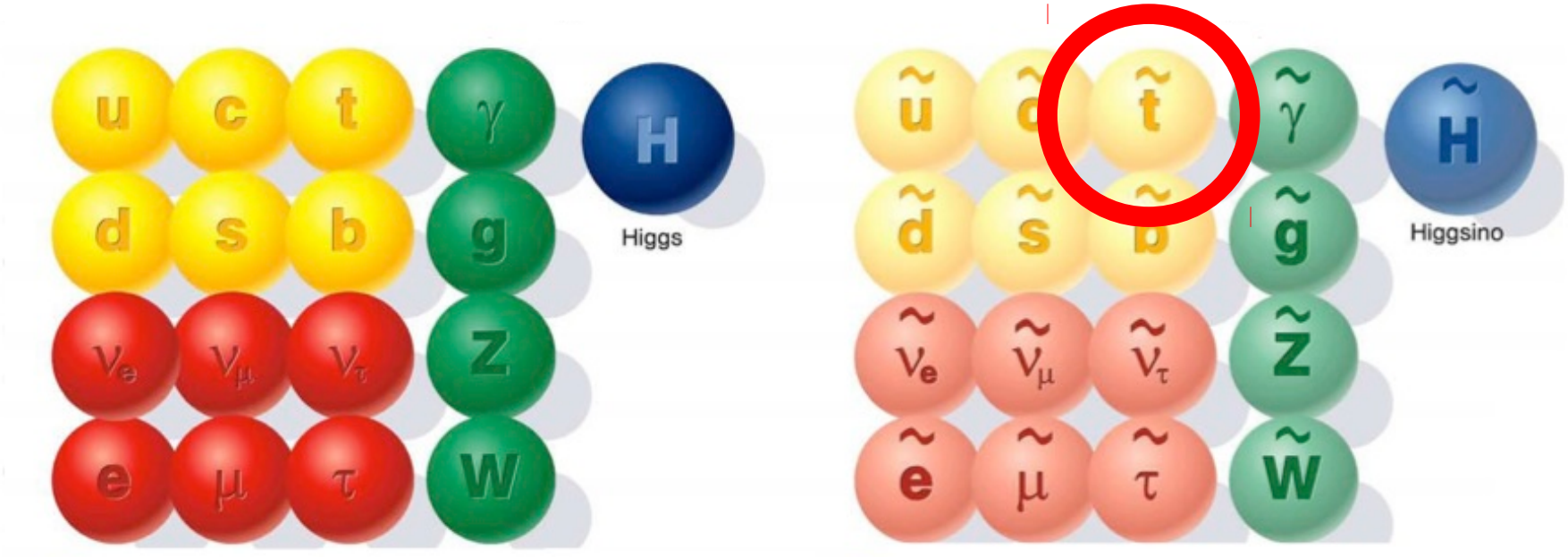
- Introduction
  - MSSM
  - Light stop scenario
    - Electroweak baryogenesis
  - Status of current stop searches
- Purpose - Extending ATLAS results
- Results
- Conclusion

The MSSM



- **Minimal** supersymmetric extension of standard model.
- Supersymmetric partner to each standard model particle (+ one additional Higgs doublet).

The MSSM

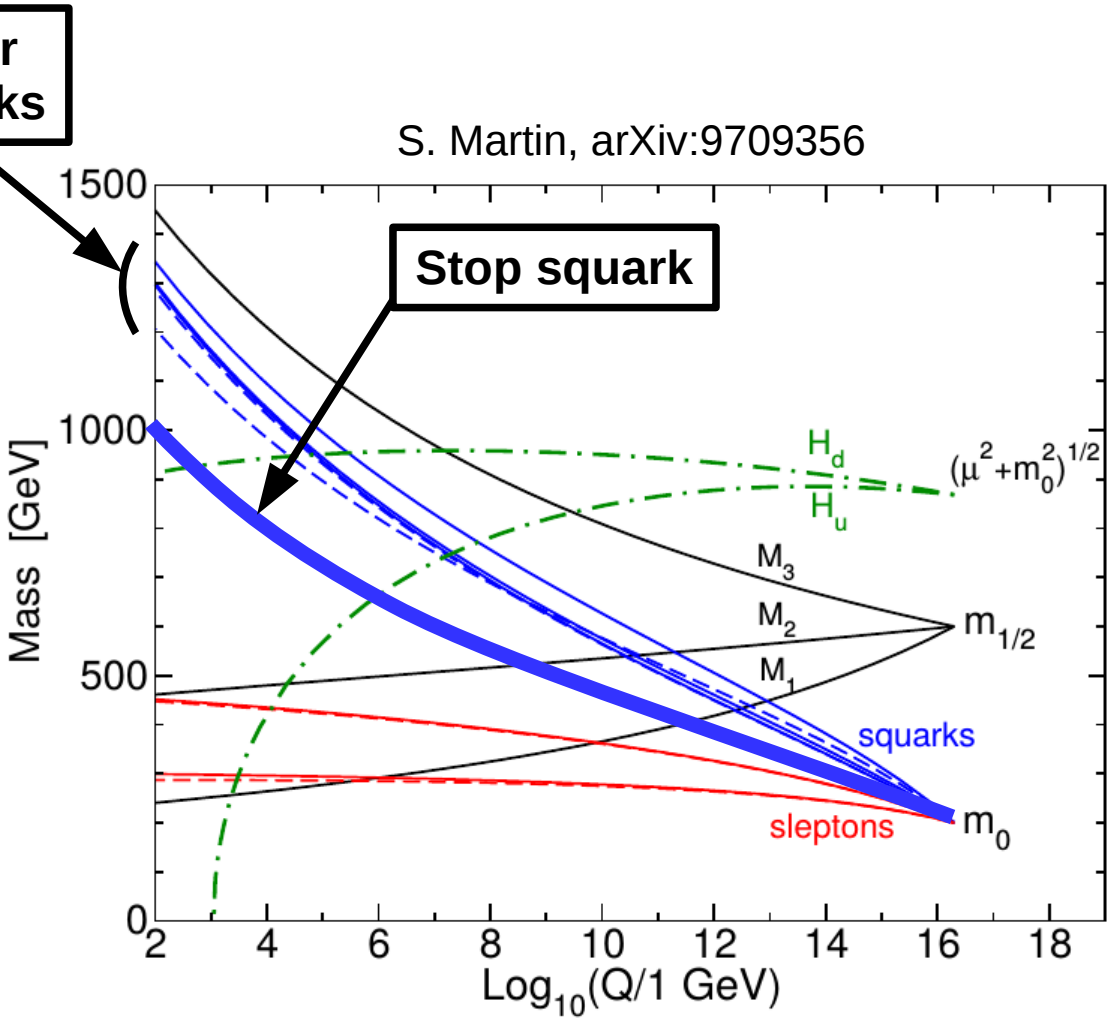


- **Minimal** supersymmetric extension of standard model.
- Supersymmetric partner to each standard model particle (+ one additional Higgs doublet).
- **Stop** is top quark partner.

Light stop scenario

- Stops are naturally light.
  - Large top Yukawa enters RGE.
  - Keeps the stop lighter than the other squarks.
- Light stops keep fine tuning low.

$$\Delta m_h^2 \sim m_t^2 \ln\left(\frac{m_{\tilde{t}}}{m_t}\right)$$



- Light stops allow electroweak baryogenesis.
- In typical scenario neutralino is the Lightest Supersymmetric Particle (LSP).

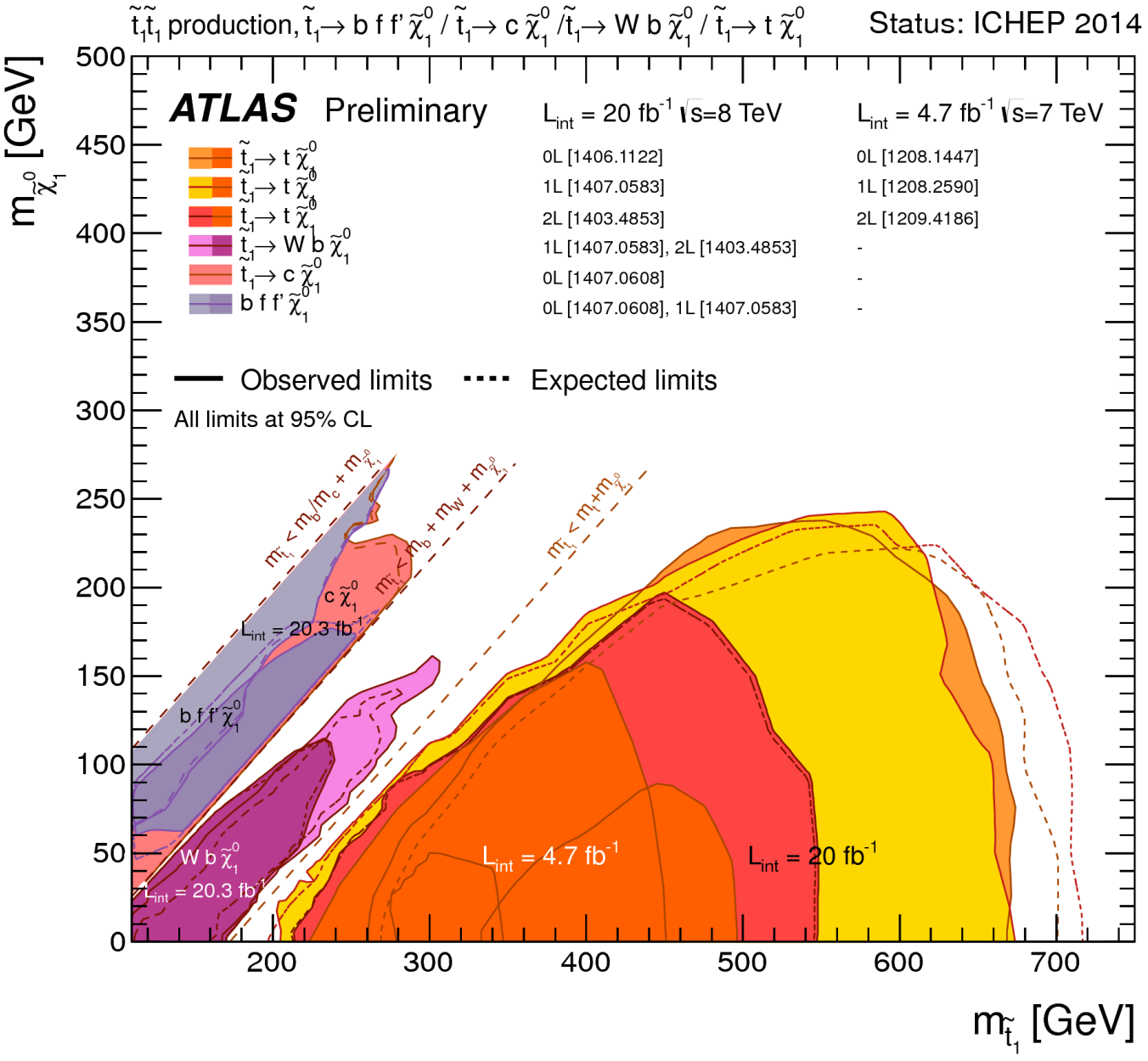
Electroweak Baryogenesis
The light stop scenario

- **Sakharov conditions**
  - 1) Departure from thermodynamic equilibrium.
  - 2) Baryon number violation (via sphaleron transitions).
  - 3) C and CP-violation.

- **All occur in the SM**
  - Unfortunately not enough to explain baryogenesis!

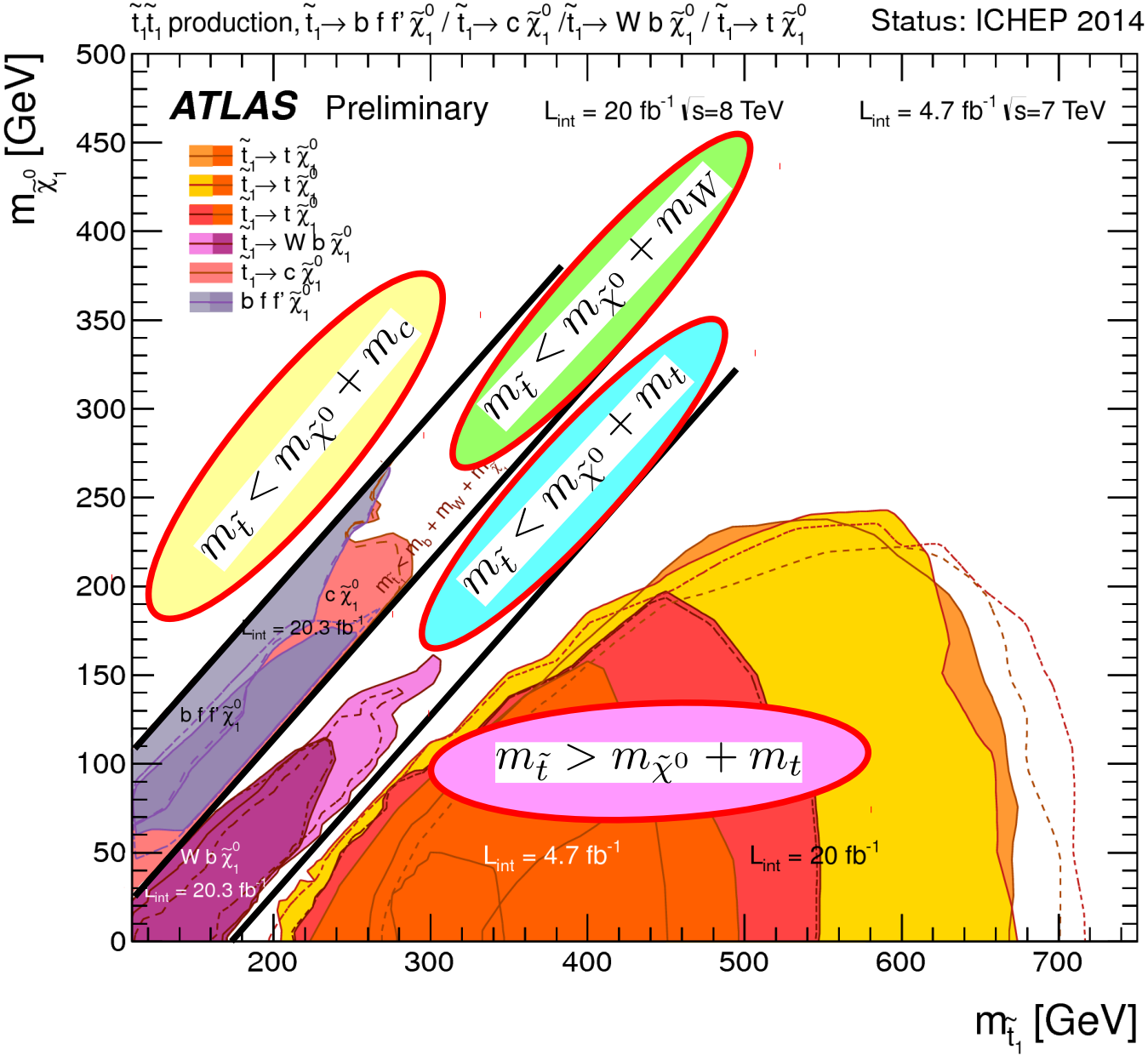
- **Light right handed stops enable a first-order phase transition**
  - large enough departure from thermodynamic equilibrium to explain baryogenesis.
  - Requires $m_{\tilde{t}} \lesssim m_t$

Current status of stop searches



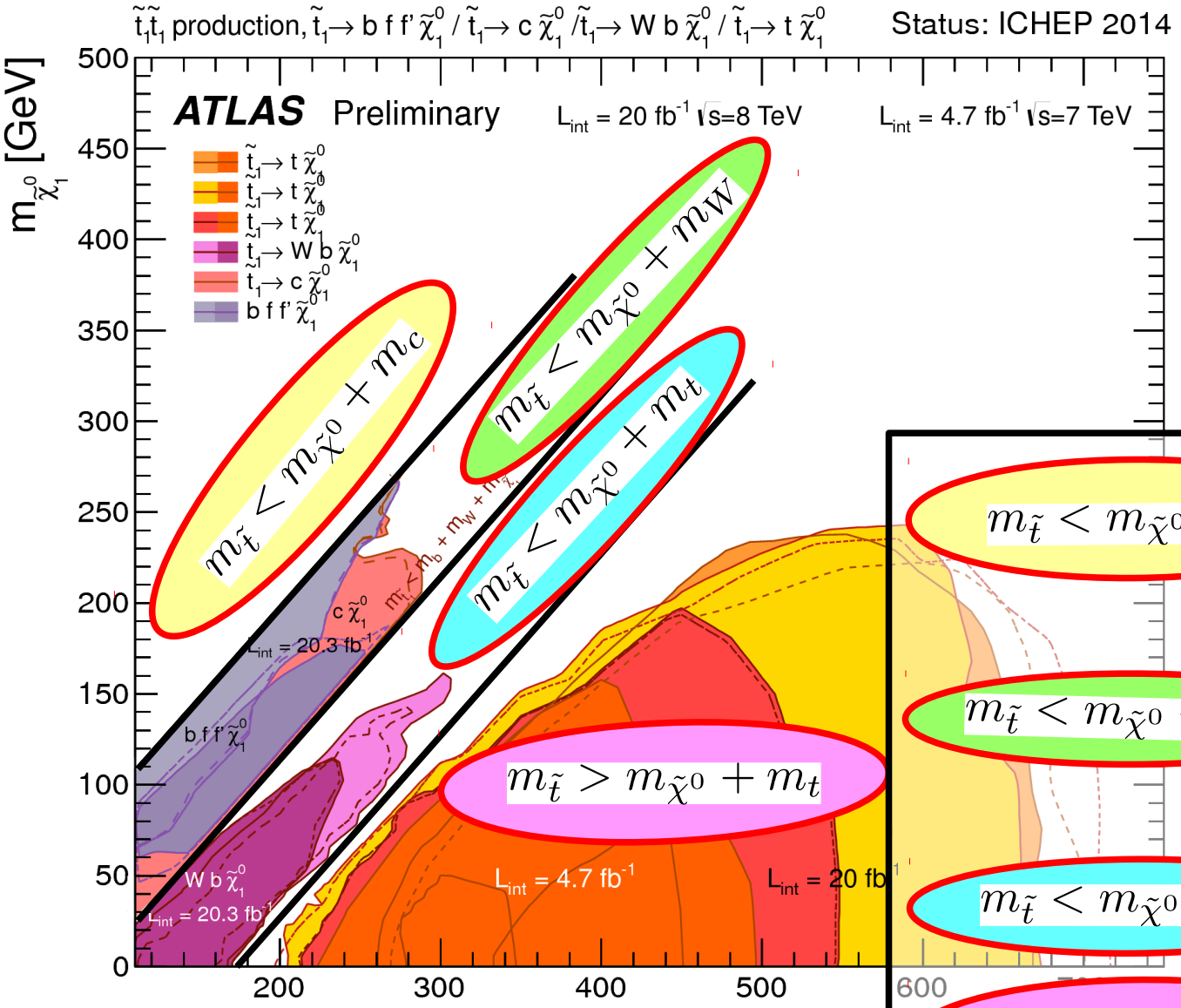
- Multiple search channels.
- Generally assume 100% branching ratios.
- Claim that stops ruled out up to 670 GeV only true for $M_{LSP} \sim 0$.
- If $M_{LSP} > 250$ GeV then only limit is $M_{stop} < M_{LSP}$

Current status of stop searches



- Separated into regions depending on relationship between stop mass and masses of decay products.

Current status of stop searches



- Separated into regions depending on relationship between stop mass and masses of decay products.

$m_{\tilde{t}} < m_{\tilde{\chi}^0} + m_c$ → **No Decay**

$m_{\tilde{t}} < m_{\tilde{\chi}^0} + m_W$ → $\tilde{t}_1 \to c\tilde{\chi}_1^0$, $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$

$m_{\tilde{t}} < m_{\tilde{\chi}^0} + m_t$ → $\tilde{t}_1 \to \tilde{b}W\chi_1^0$

$m_{\tilde{t}} > m_{\tilde{\chi}^0} + m_t$ → $\tilde{t}_1 \to \tilde{t}\chi_1^0$

Current status of stop searches

- Different search criteria depending on area of parameter space targeted.

Monojet search + charm tag search

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

Monojet search

$$\tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0$$

Monojet + 1 lepton

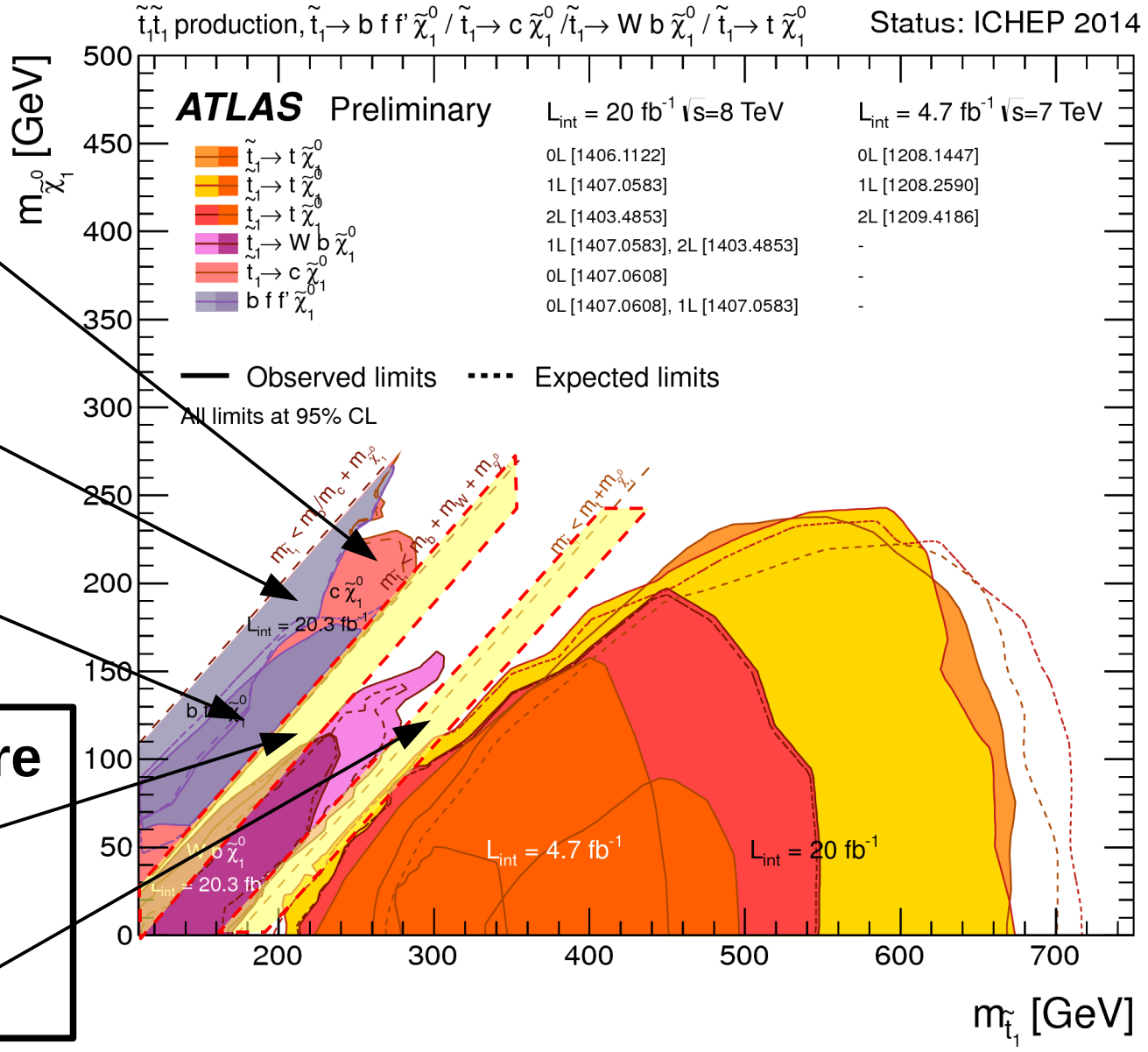
$$\tilde{t}_1 \rightarrow bff'\tilde{\chi}_1^0$$

Difficult regions where

$$m_{\tilde{t}} \sim m_{\tilde{\chi}^0} + M_W$$

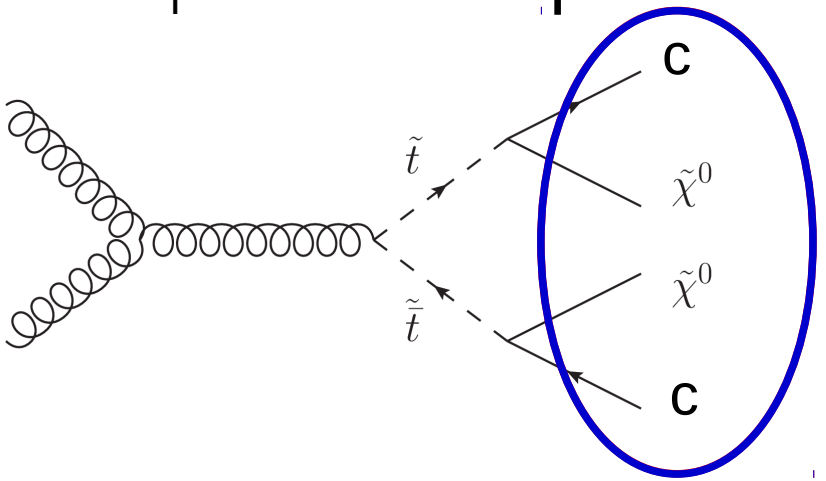
or

$$m_{\tilde{t}} \sim m_{\tilde{\chi}^0} + m_t$$



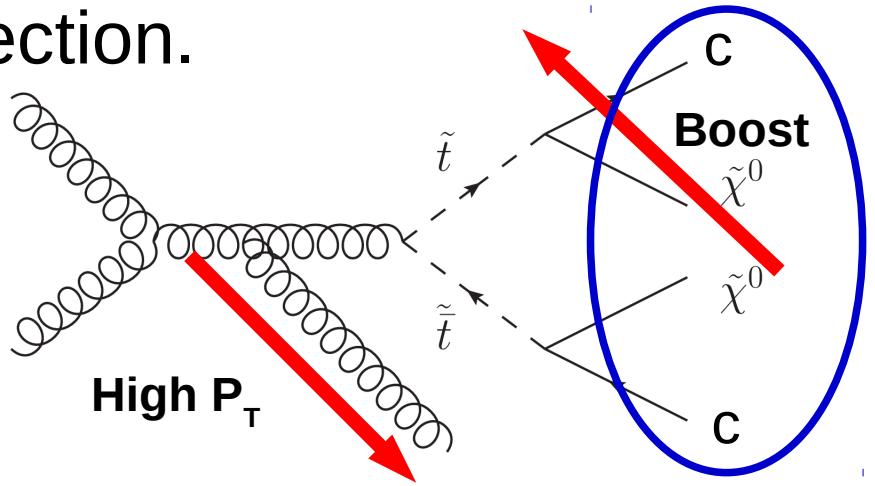
Monojet searches

- If $m_{\tilde{t}} \sim m_{\tilde{\chi}^0}$ then no missing transverse momentum (E_T^{miss}), and jets P_T too low to pass cuts.



$\tilde{\chi}^0$ and other decay products have very low momentum

- **With monojet** added, decaying particles boosted in opposite direction.



Boosted in opposite direction

- Can be recognised in detector.

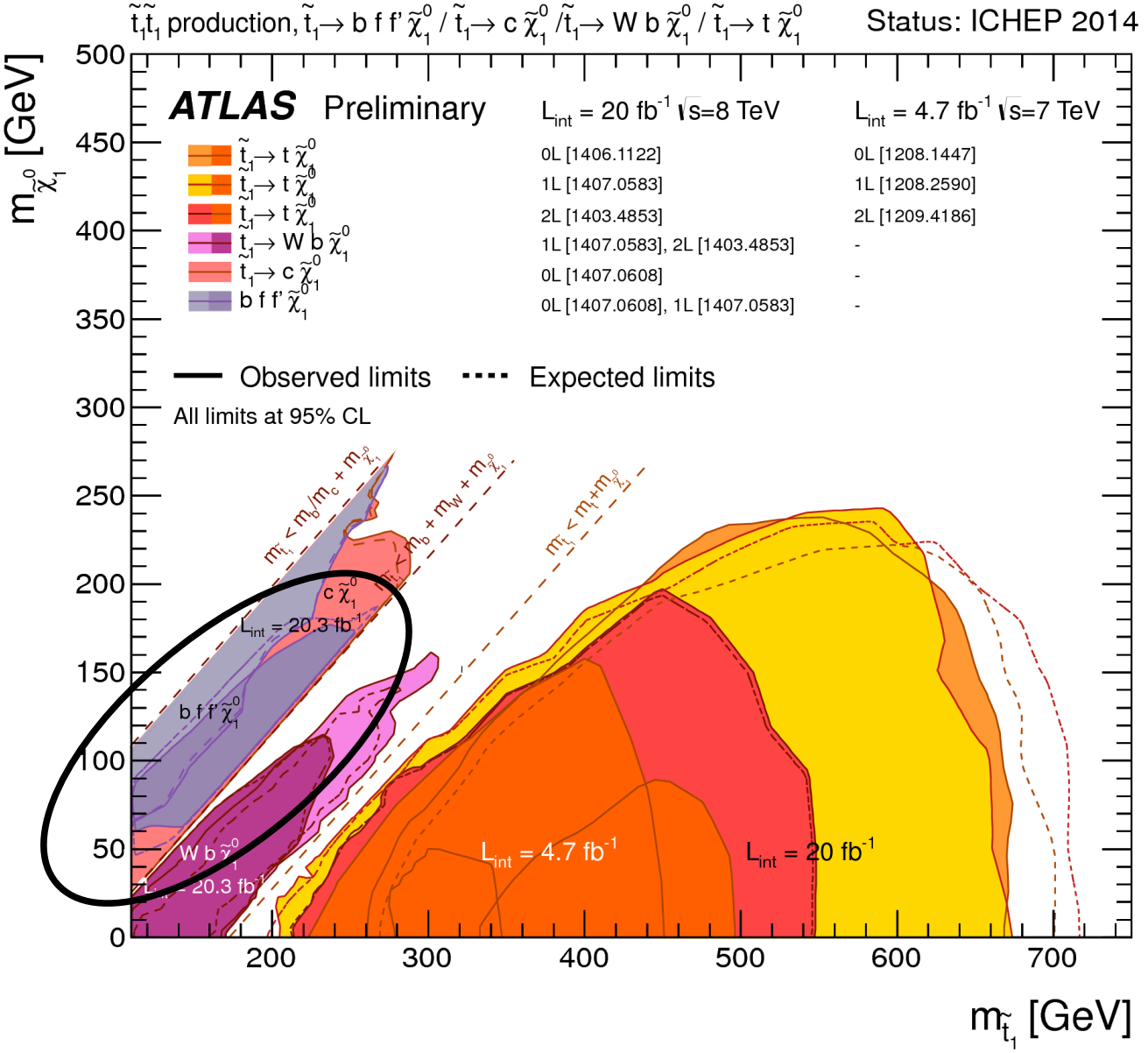
Our goal

Extend to cover area missed by ATLAS

- Due to difficulties in SUSY signal event generation and analysis, unable to cross the line where $m_{\tilde{t}} \sim m_{\tilde{\chi}^0} + m_W$

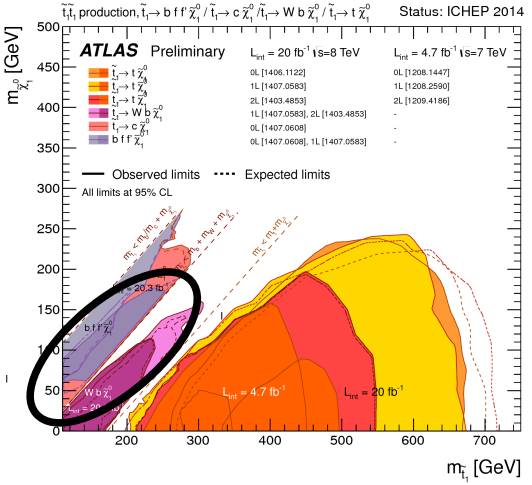
- Important region for **stop baryogenesis** and **naturalness**.

- Aim to overcome limitations and fill this gap as much as possible.



What we did

- Considered 3 different analysis regions near $m_{\tilde{t}} \sim m_{\tilde{\chi}^0} + m_W$ line.
  - Monojet
  - Monojet + charm-tag
  - Monojet + 1 lepton



- Produce full matrix element events using MadGraph5.
  - Computationally difficult.
  - **Overcomes limitation of ATLAS analysis,** which used Pythia (computationally easy but not valid in on-shell region).

- Use data to calculate which regions of parameter space are ruled out for each analysis.

Results $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

Monojet and Monojet + charm tag regions

Monojet Cuts

(3 subregions)

Leading Jet P_T > 280-450 GeV

Minimum E_T^{miss} > 220-450 GeV

+ other cuts

Monojet + charm tag

(2 subregions)

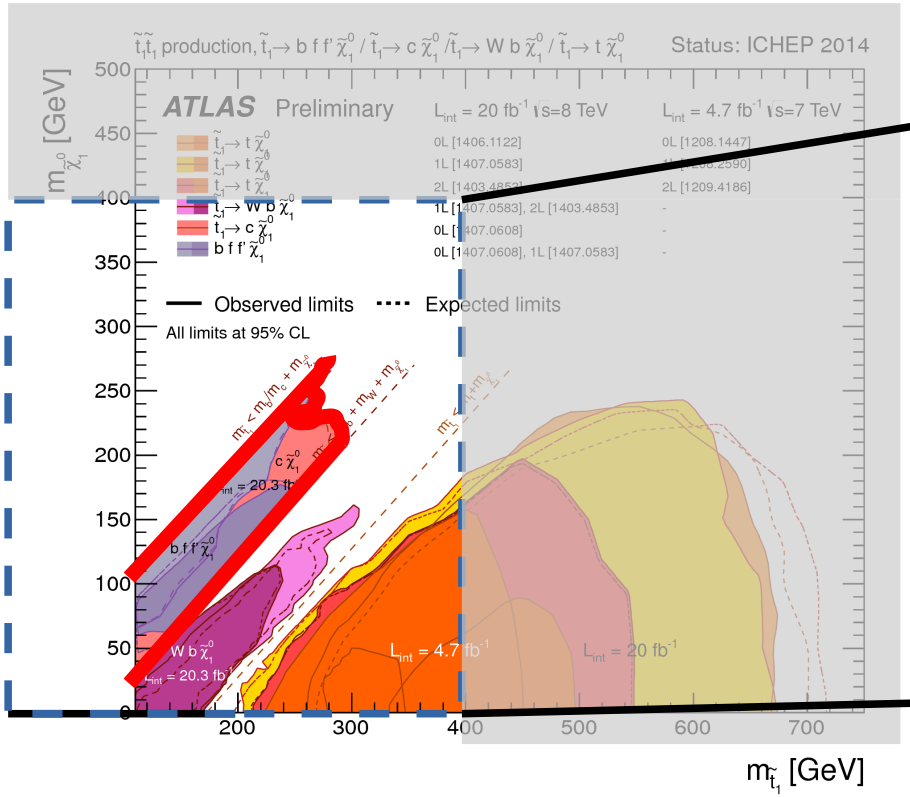
Charm tag on subleading jet

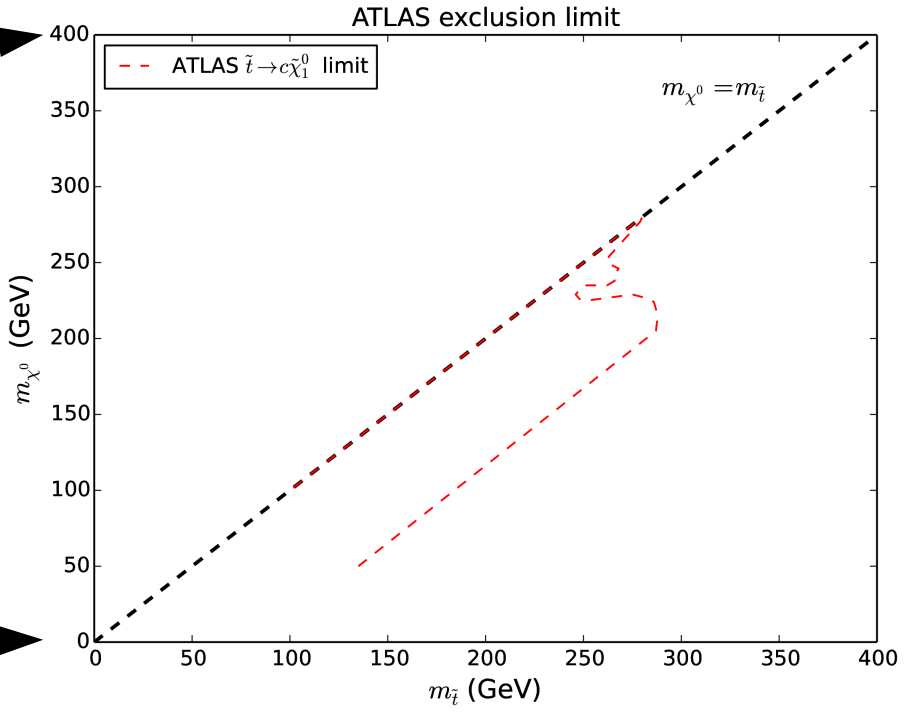
+

Leading Jet P_T > 290 GeV

Minimum E_T^{miss} > 250-350 GeV

+ other cuts





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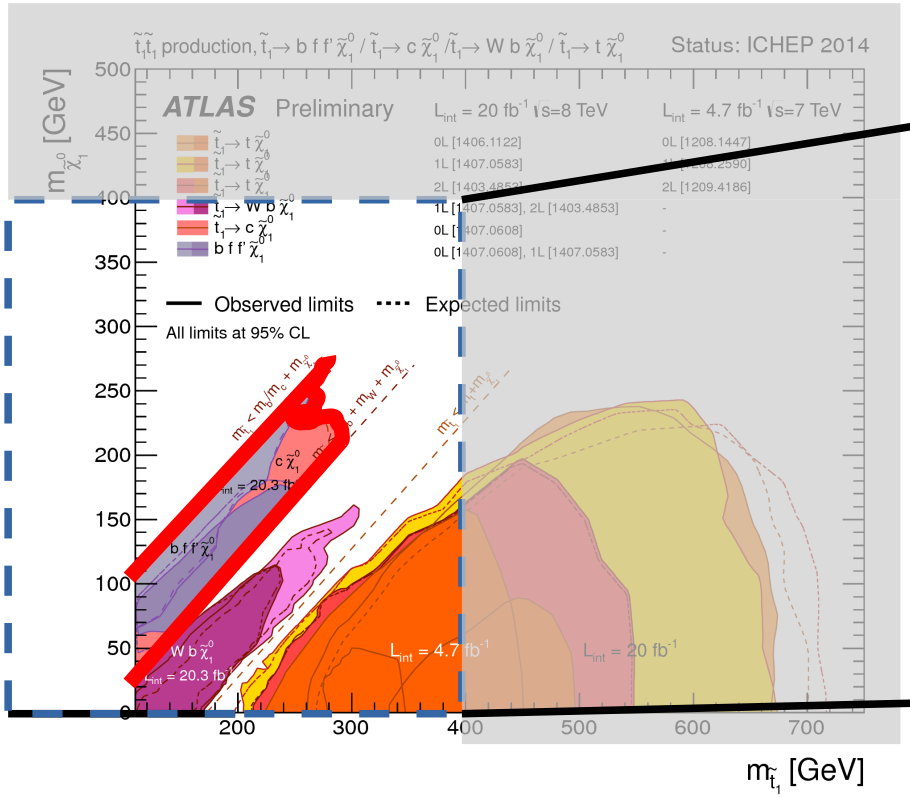

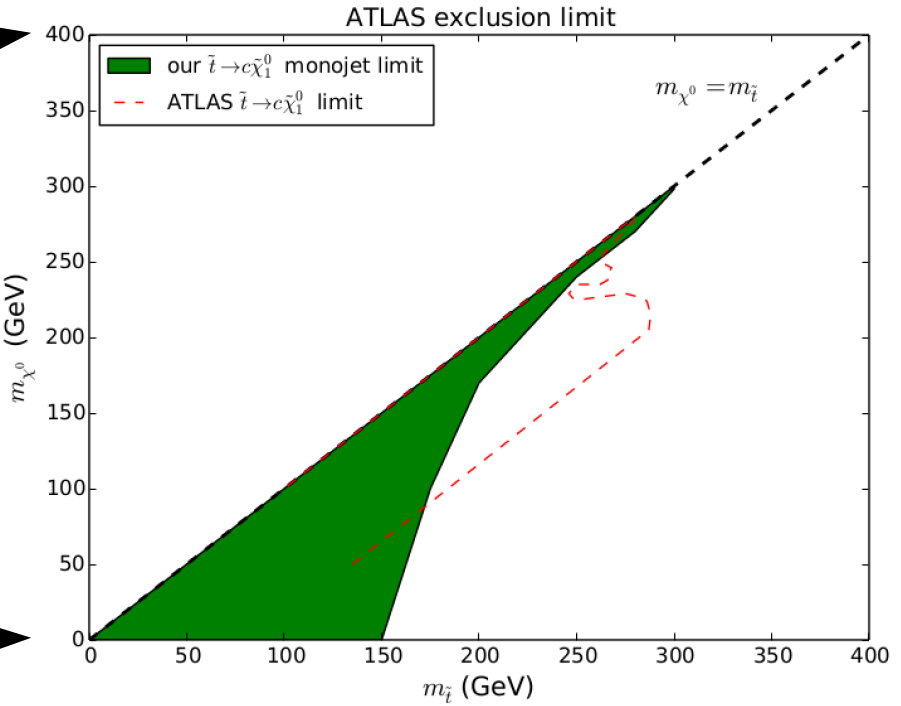

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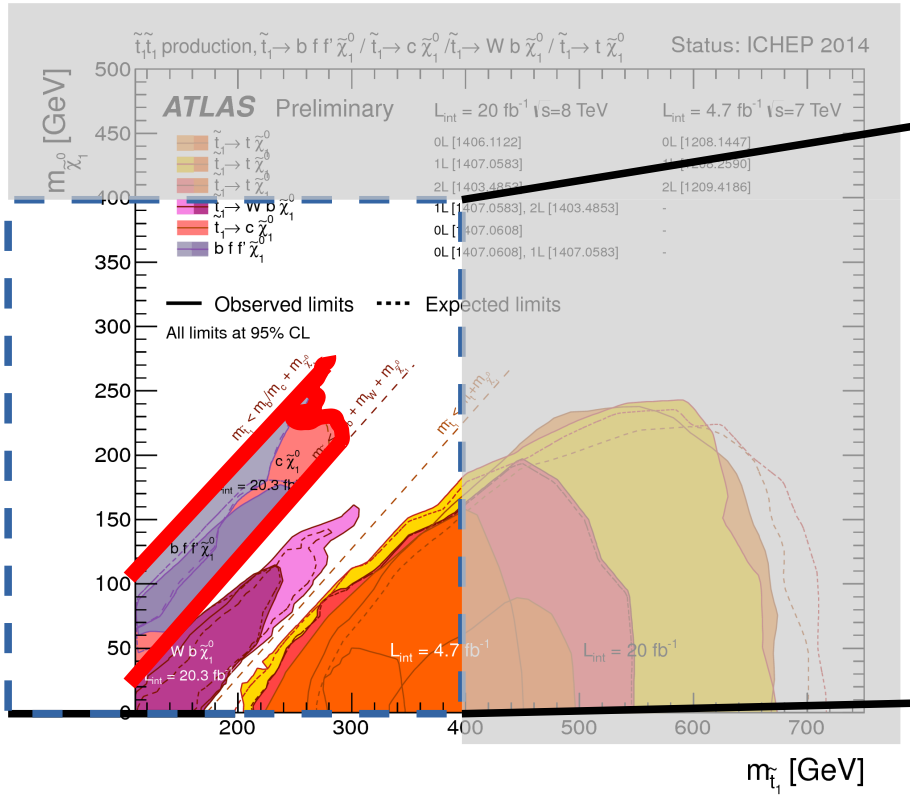
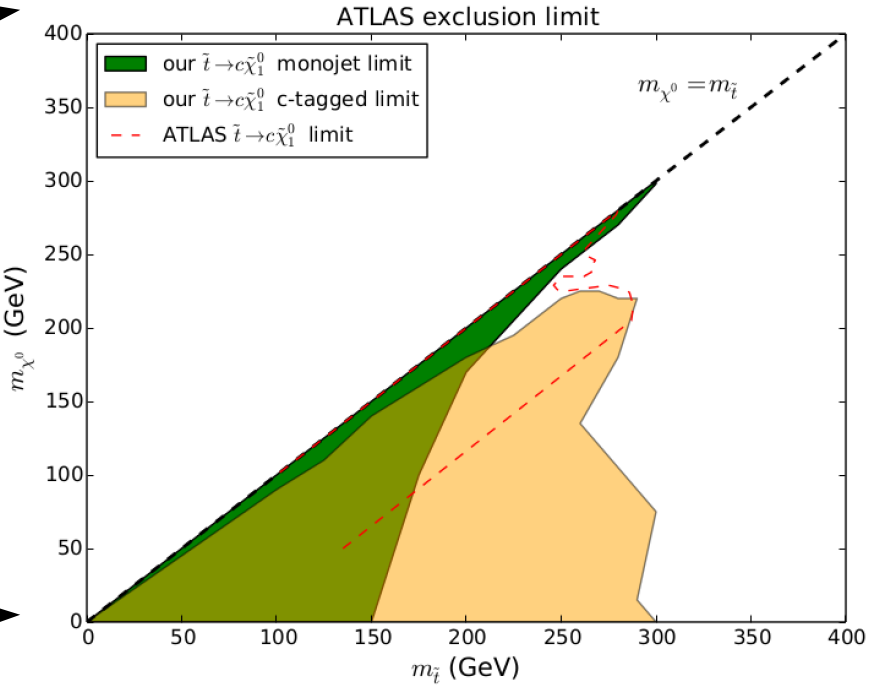


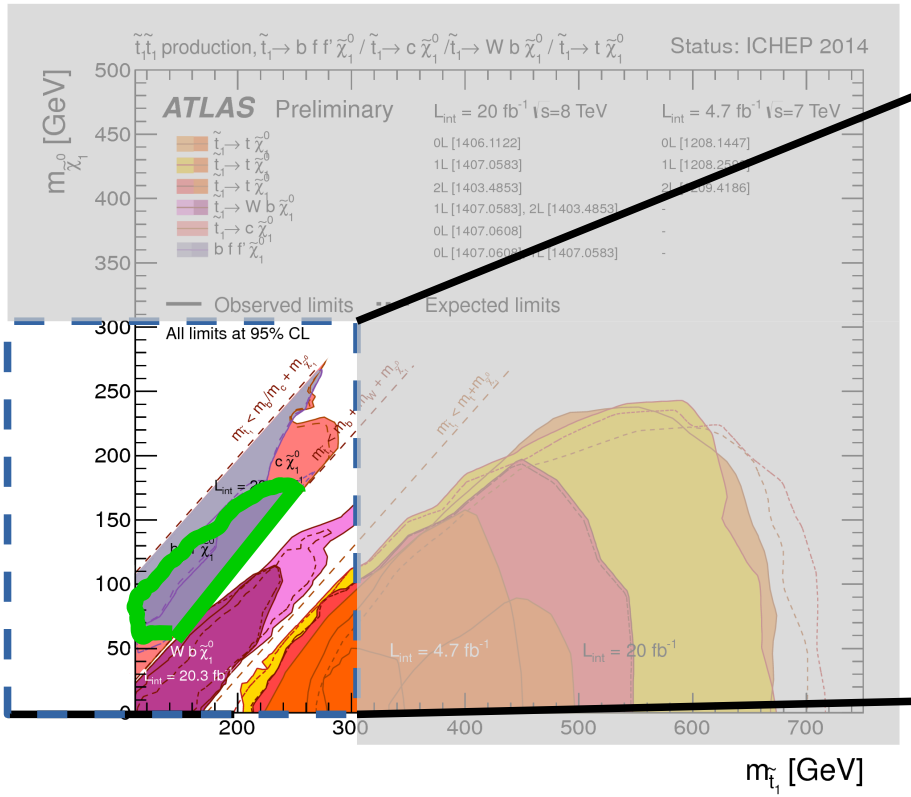


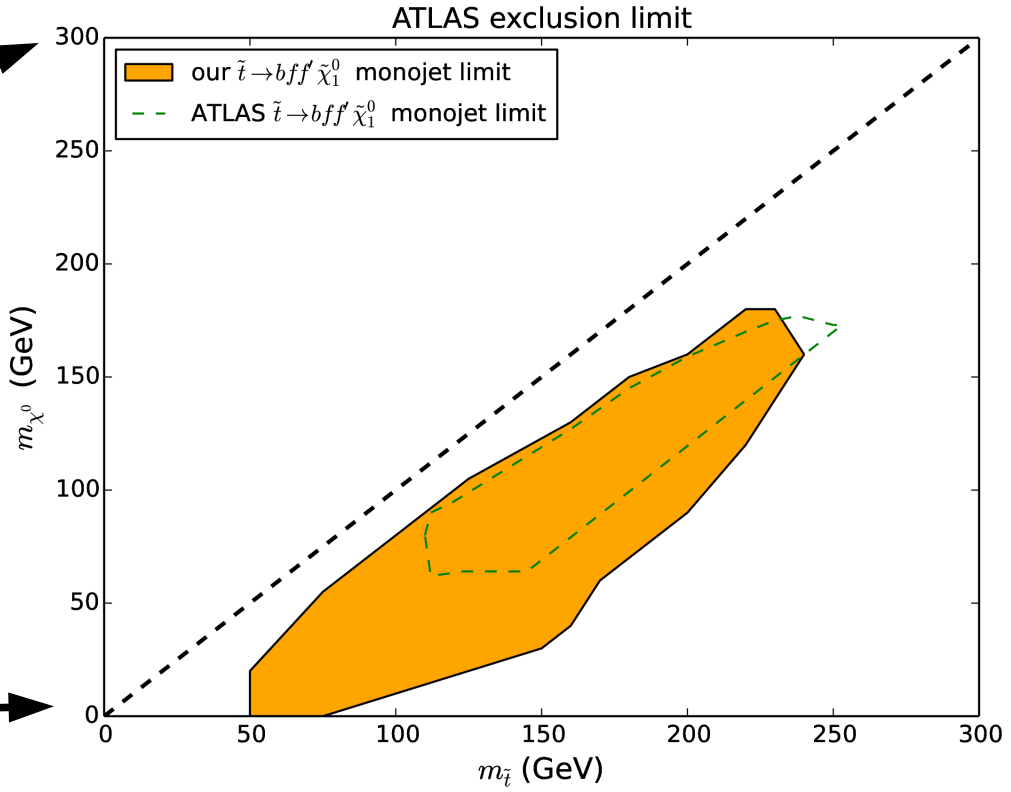
PRELIMINARY!

Results $\tilde{t}_1 \to bff'\tilde{\chi}_1^0$

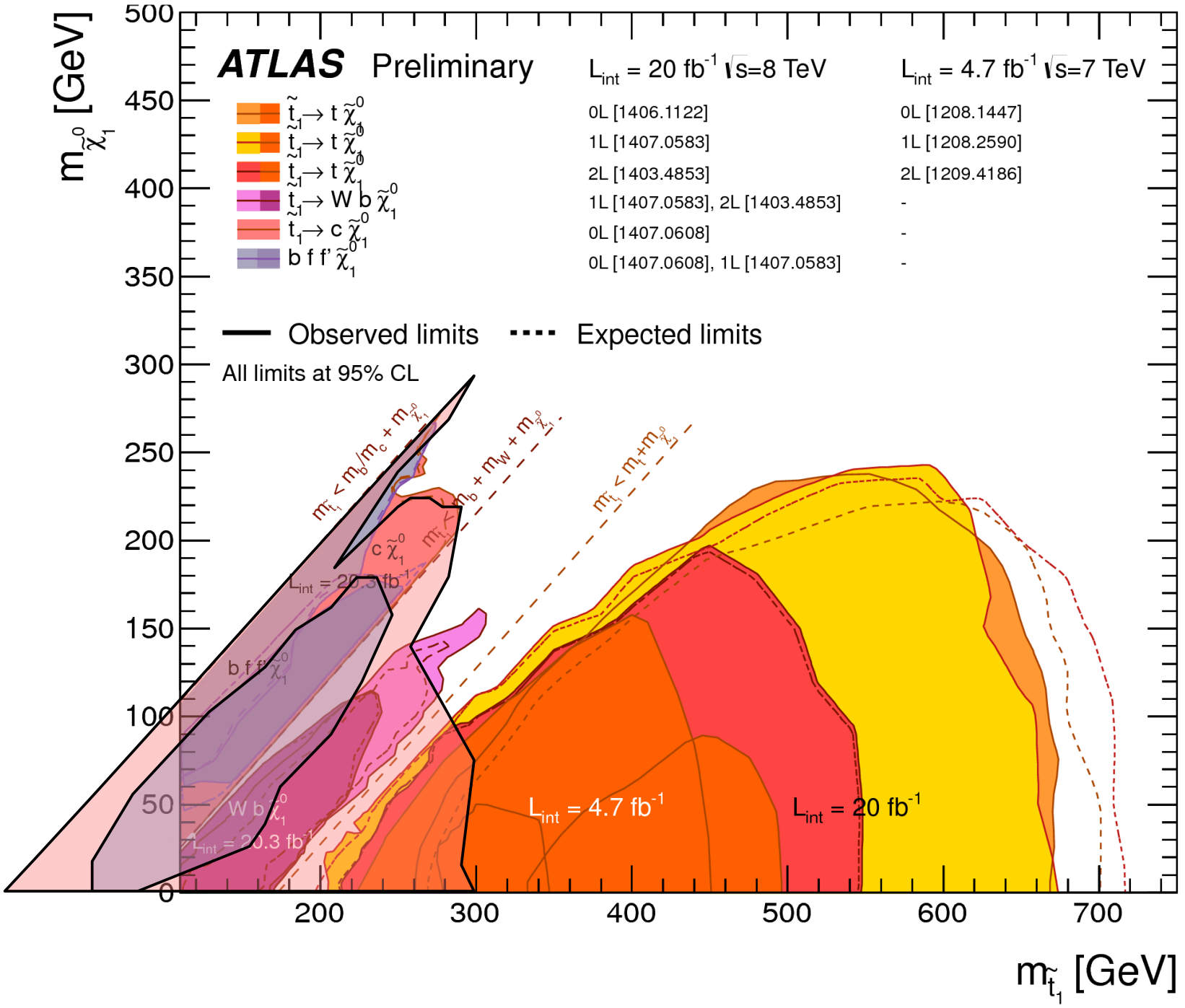
Monojet + 1 lepton

- Currently normalised to a cross section such that exclusion matches ATLAS in region where ATLAS results are valid.





Superimposed results on ATLAS plot



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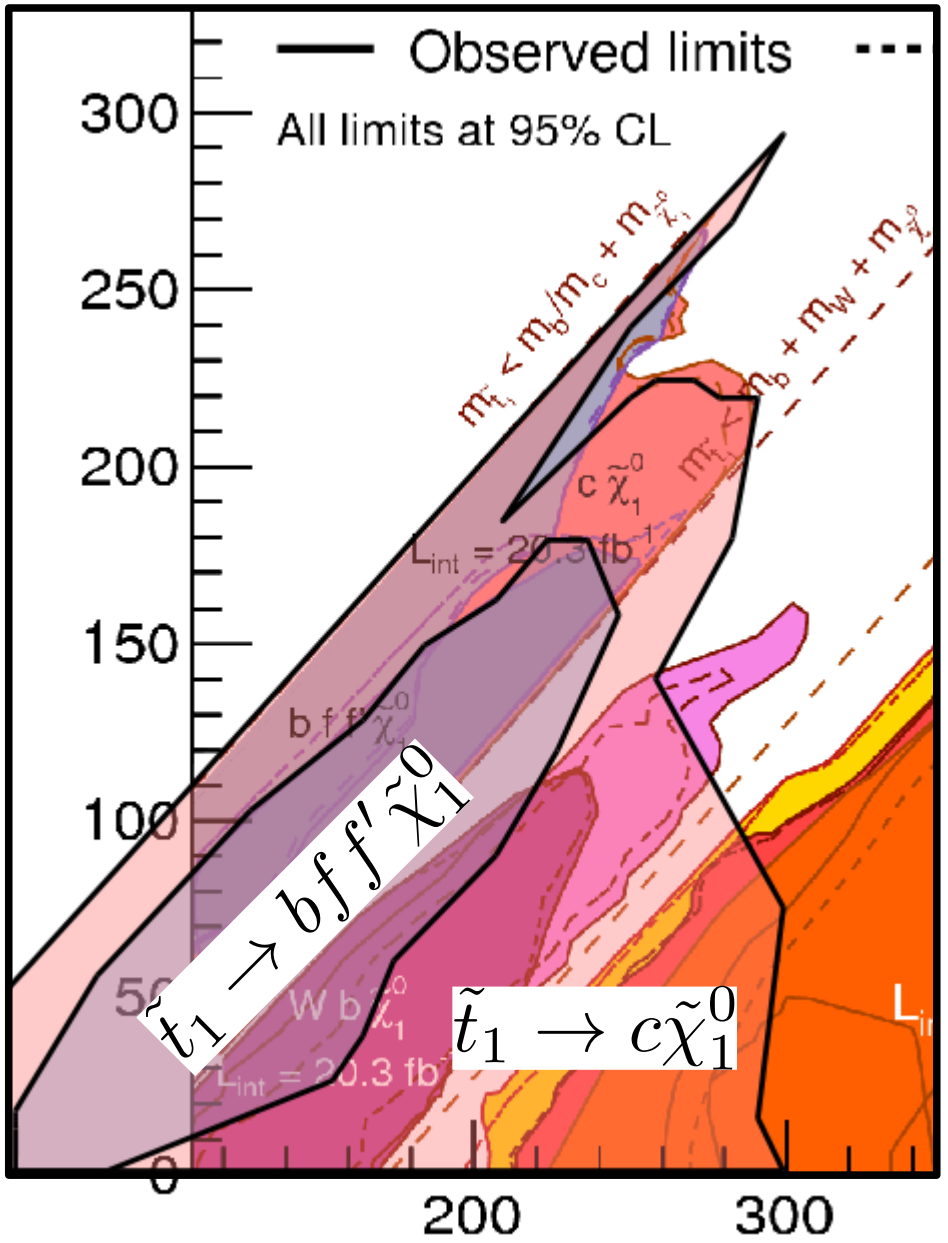

- Good agreement with ATLAS in region where both overlap.
- Successfully extended analysis beyond $m_{\tilde{t}} \sim m_{\tilde{\chi}^0} + m_W$ line.
- "Ruled out" $m_{\tilde{t}} < m_t$ (assuming 100% branching ratios).

Further work

- Aim to fully rule out $m_{\tilde{t}} < m_t$ regardless of branching ratios.
  - Would rule out stop baryogenesis.
  - Will consider combinations of branching ratios < 100% for this purpose.
  - Need to also consider light charginos in decay chain.

Conclusion

- Successfully extended analysis into regions missed by original ATLAS analysis.
- Further reduces parameter space for light stop baryogenesis.
- Preliminary results show we should be able to rule out light stops regardless of decay branching ratios.