Searches for third generation squarks with ATLAS

Kerim Suruliz (University of Sussex)

on behalf of the ATLAS Collaboration

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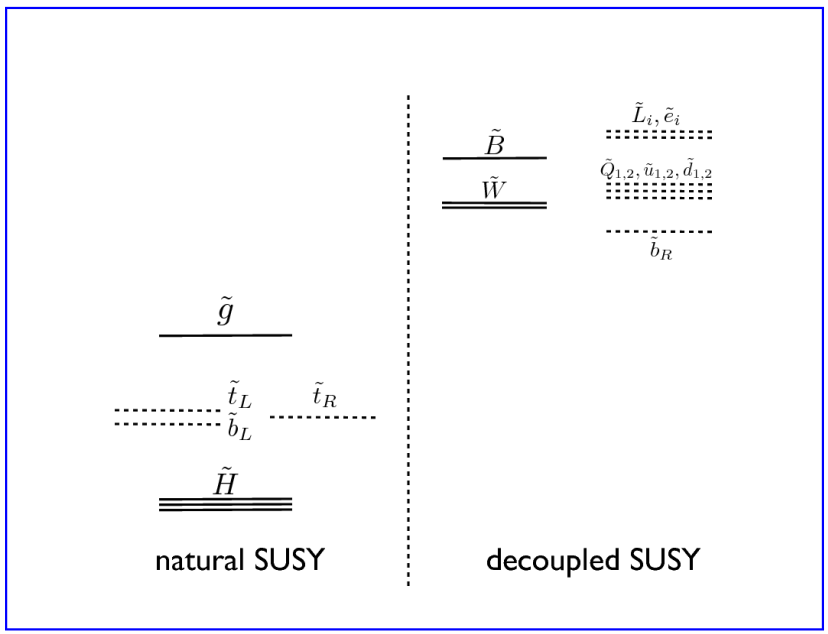
Introduction

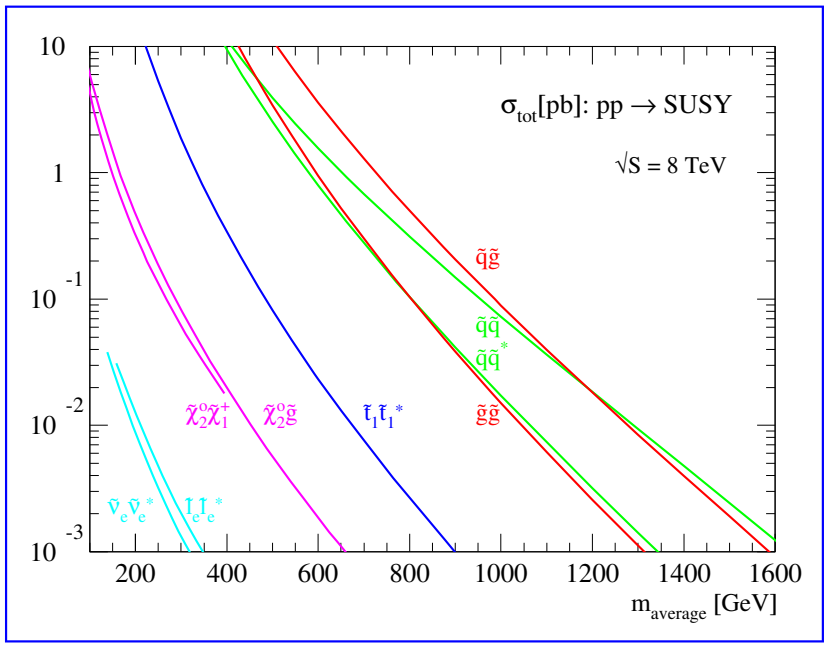
The Higgs mass receives radiative corrections from scalar partners of the top quark:

$$\delta m_h^2 \sim y_t^2 (m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2)$$

$\Longrightarrow$ the stops need to be light for SUSY to solve the hierarchy problem.

By $SU(2)$ symmetry, the left-handed sbottom also needs to be light.



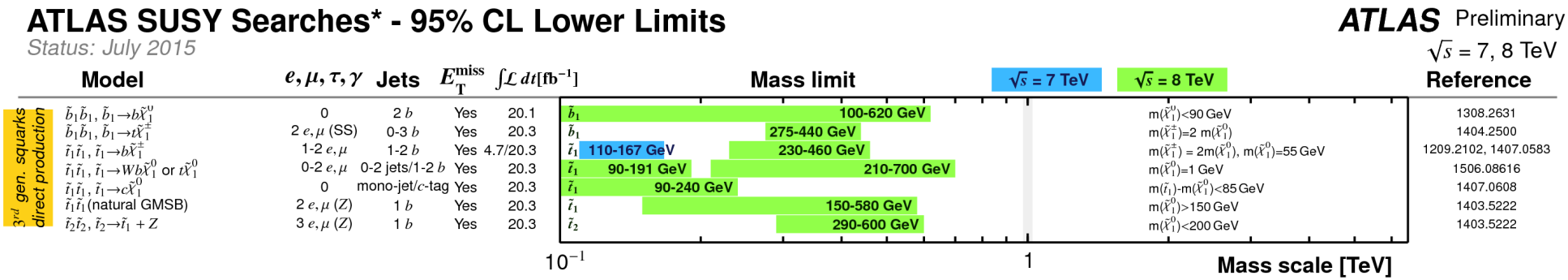


Strongly (pair)-produced $\tilde{t}/\tilde{b}$ with $\mathcal{O}(fb - pb)$ cross sections - **subject of dedicated ATLAS searches since early Run 1**.

Papucci et al, JHEP 1209 (2012) 035

State of the art

Summary of Run 1 searches reported in http://arxiv.org/abs/1506.08616, including three new analyses.



Limits up to ∼700 GeV, depending on the mass hierarchies and decay modes.

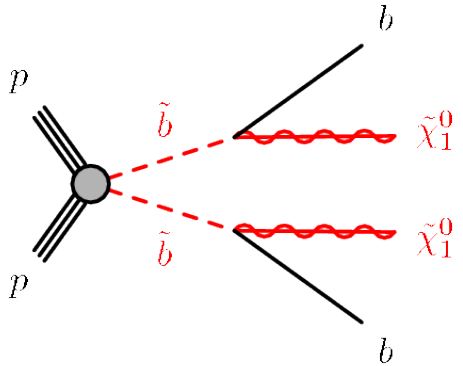
Recent focus on closing gaps in parameter space with dedicated searches and fully utilising Run 1 data by performing combinations of analyses.

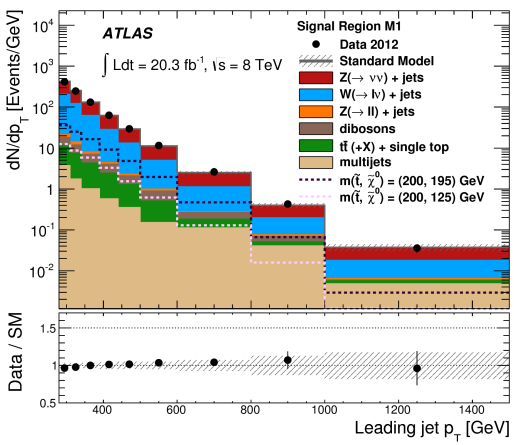
Overview

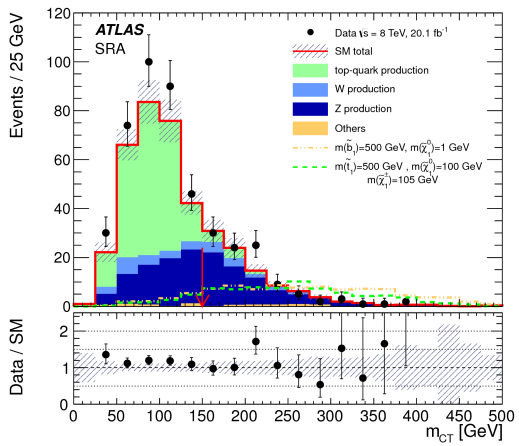
- searches for sbottoms
- searches for stops
  1. "bread and butter" decay modes: $\tilde{t}_1 \to t\tilde{\chi}_1^0, b\tilde{\chi}_1^{\pm}$
  2. compressed spectra
  3. the second stop, $\tilde{t}_2$
  4. light staus: $\tilde{t} \to \tilde{\tau}$
- complex decay chains: pMSSM models
- prospects for 13 TeV and conclusions

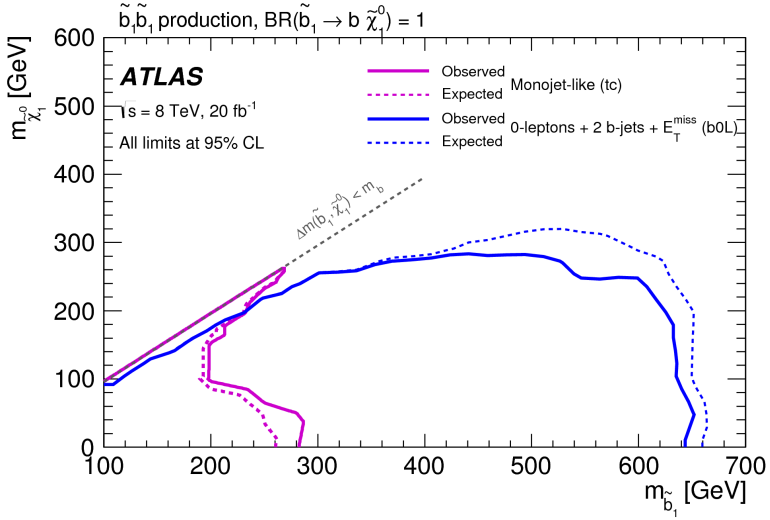
Searches for sbottoms $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$

- bb+MET-like in the bulk of parameter space - use m_{CT} variable for signal/background discrimination
- for compressed spectra, the monojet-like analysis (≤ 3 jets and large MET$> 220, > 340$ GeV) is more sensitive







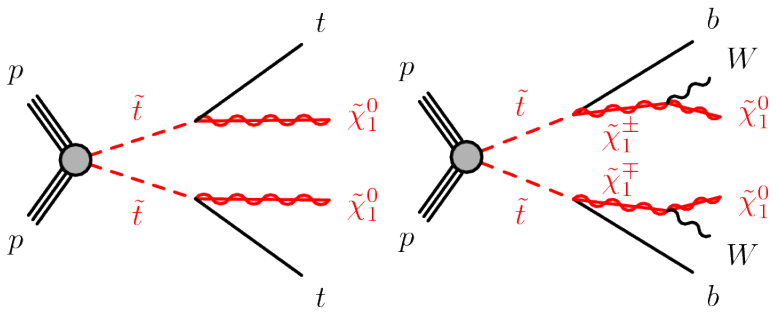


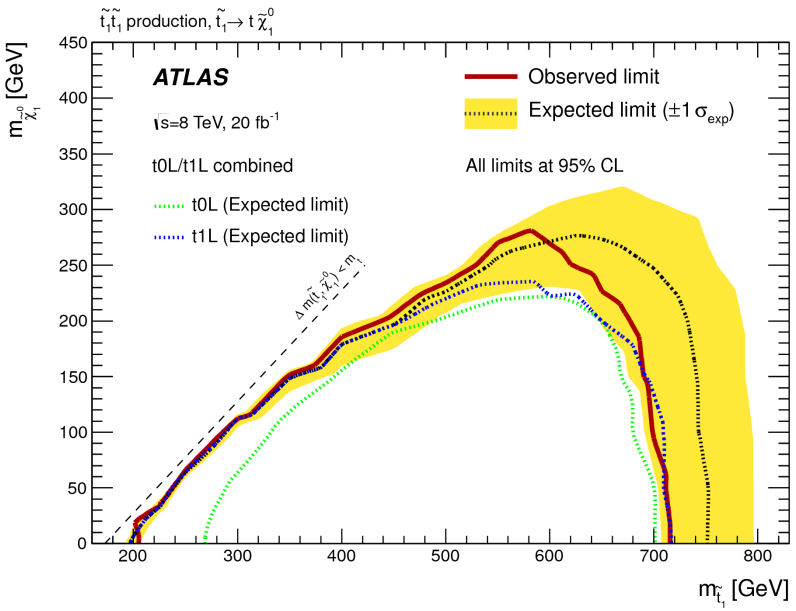
JHEP 10 (2013) 189; Phys. Rev. D. 90, 052008 (2014); arXiv:1506.08616

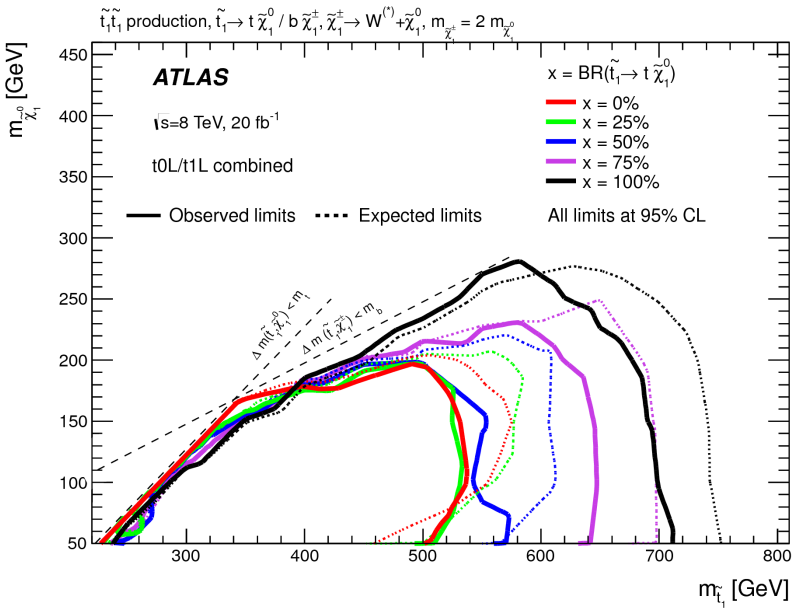
Stop with $\tilde{t}_1 \to t\tilde{\chi}_1^0, b\tilde{\chi}_1^\pm$

Statistical combination of the 0L and 1L analyses.

Many signal regions involved - resolved/boosted top decays, etc.







(Expected) gain about 50 GeV with respect to the individual 0L and 1L analyses for $\tilde{t}_1 \to t\tilde{\chi}_1^0$.

arXiv:1506.08616

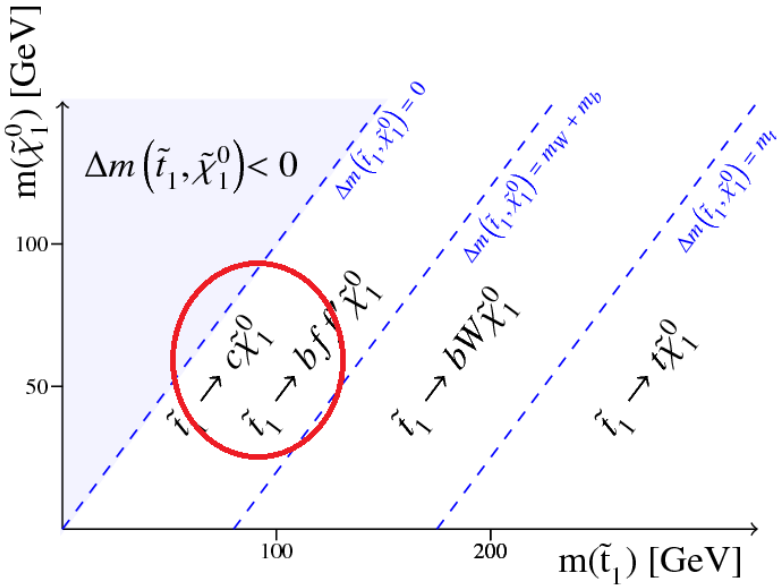
Compressed stop spectra

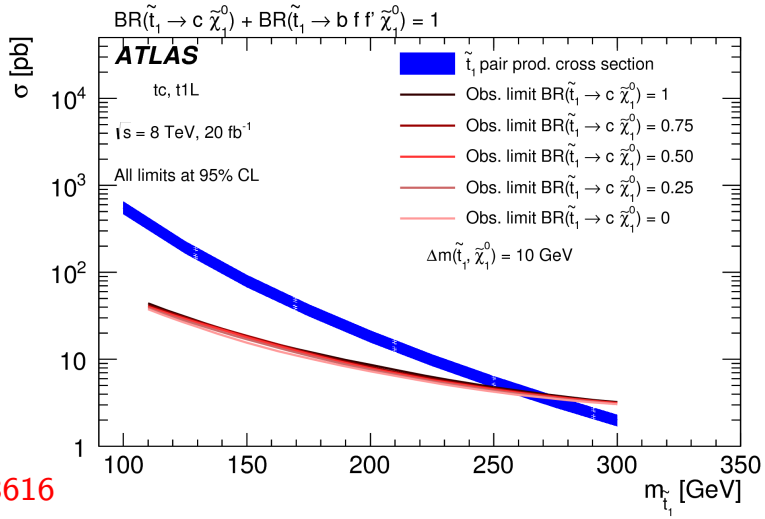
In the compressed region have competing 4-body ($\tilde{t}_1 \to bl\nu\tilde{\chi}_1^0$) and stop $\to$ charm ($\tilde{t}_1 \to c\tilde{\chi}_1^0$) decays; their relative contributions are model dependent.

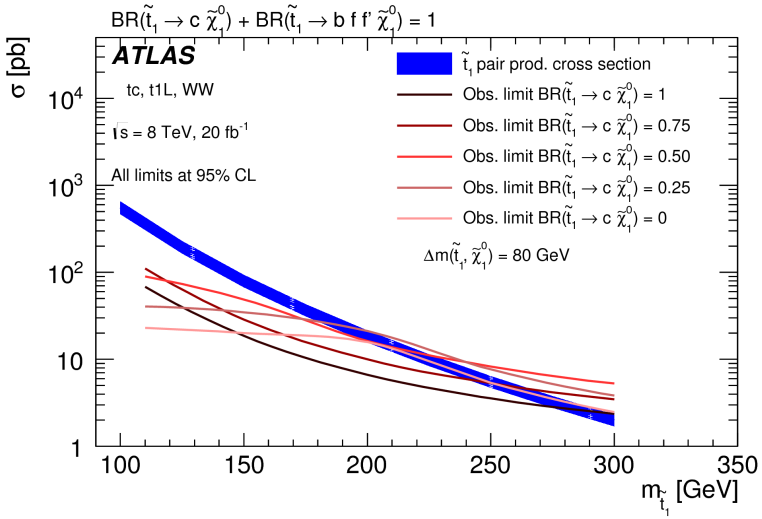
Four different analyses combined based on best expected sensitivity:

- monojet-like
- c-tagged jet
- one soft lepton
- WW-like (two leptons)

Results as a function of $BR(\tilde{t}_1 \to c\tilde{\chi}_1^0)$.

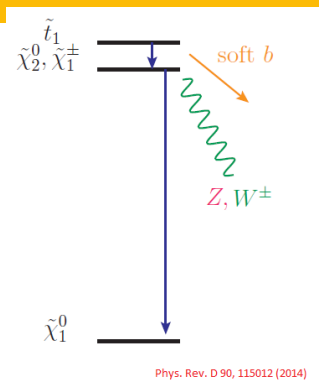






arXiv:1506.08616

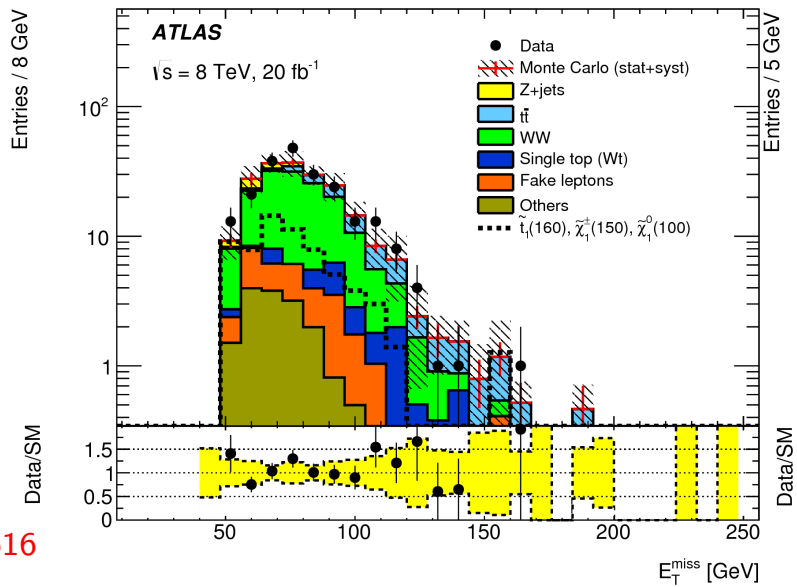
WW-like stop search

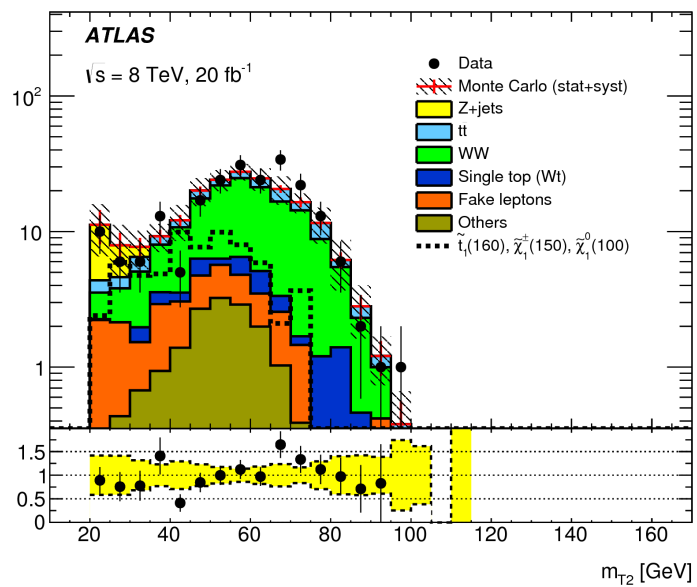


Past discrepancies (now mostly resolved) between measured WW x-sec and prediction motivated a search for a light stop model with WW-like final state (soft jets).

Use events with two leptons - no requirements on jets. A number of discriminating variables:

- the stransverse mass, m_{T2}
- $\Delta X = (p_z(l_1) + p_z(l_2))/\sqrt{s}$ to reject WW
- $R_2 = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}(l_1) + p_{\mathrm{T}}(l_2)}$

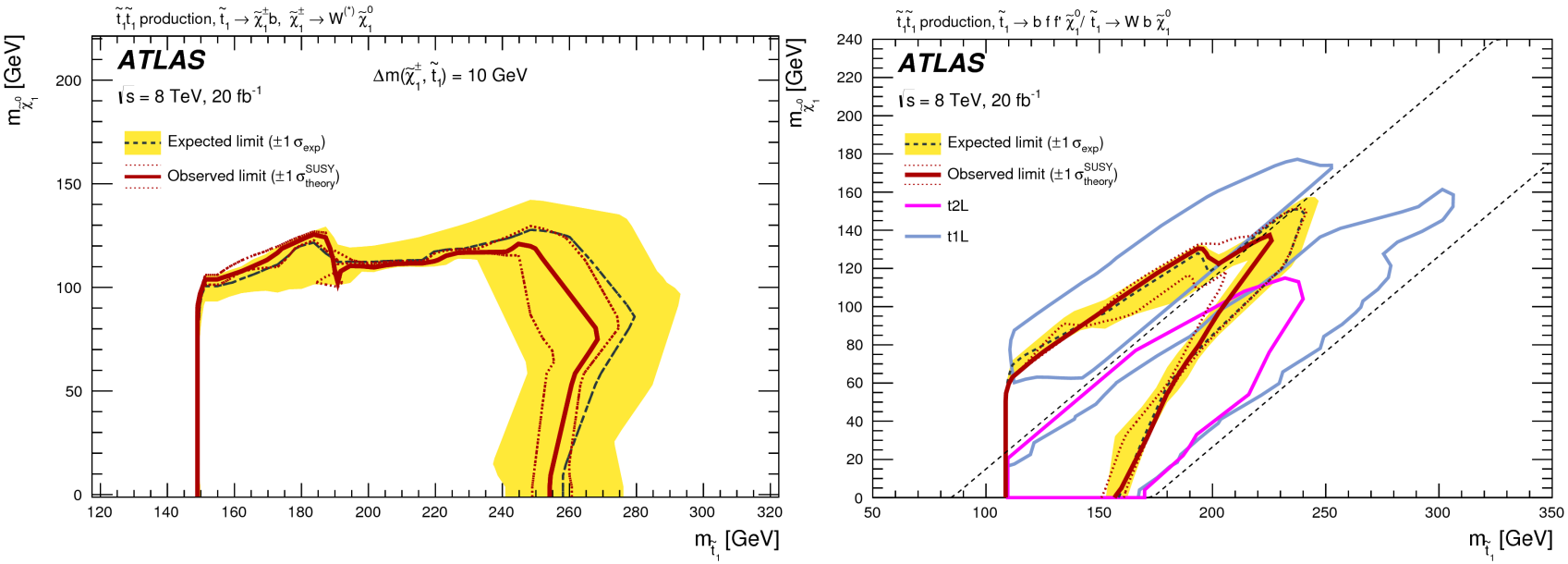




arXiv:1506.08616

WW-like analysis: results

Also sensitive to scenarios with 3-body ($\tilde{t}_1 \to bW\tilde{\chi}_1^0$) and 4-body ($\tilde{t}_1 \to bl\nu\tilde{\chi}_1^0$) decays of the stop.



Nicely covers the interface region between 3-body and 4-body stop decays.

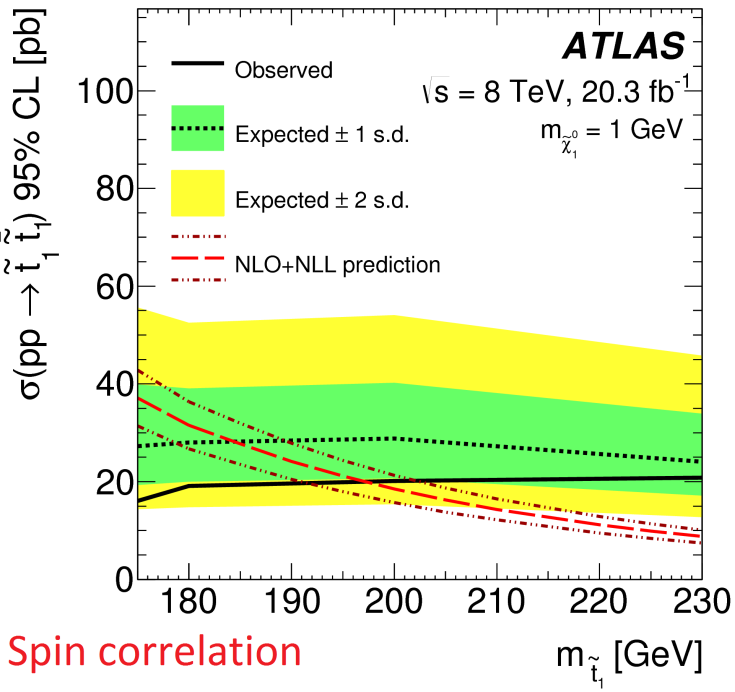
arXiv:1506.08616

Stealth stop

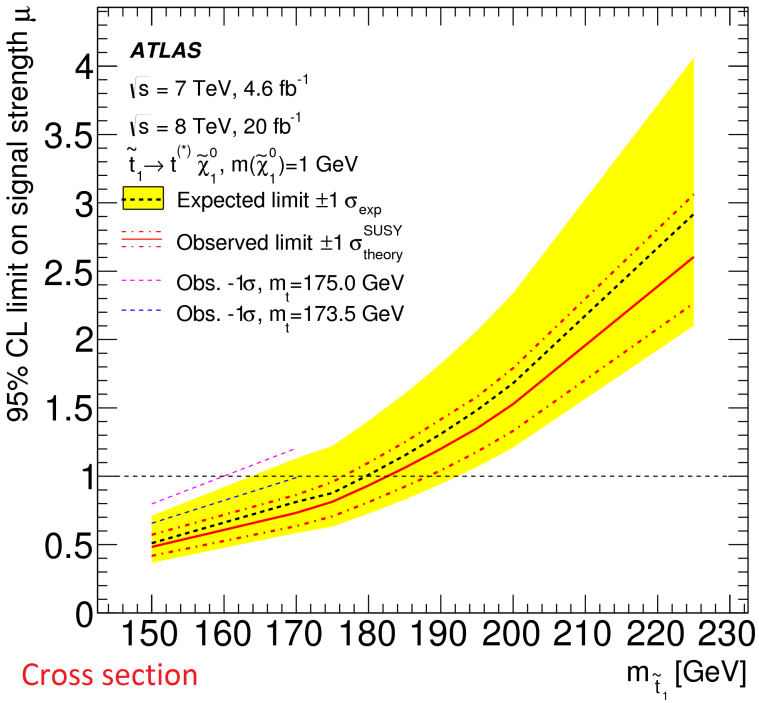
Tricky $m_{\tilde{t}_1} \sim m_t$, low LSP mass region targeted by two SM measurement reinterpretations:

- top spin correlation
- top cross section

Eur. Phys. J. C74 (2014) 3109, Phys. Rev. Lett. 114, 142001 (2015), arXiv:1506.08616



Spin correlation

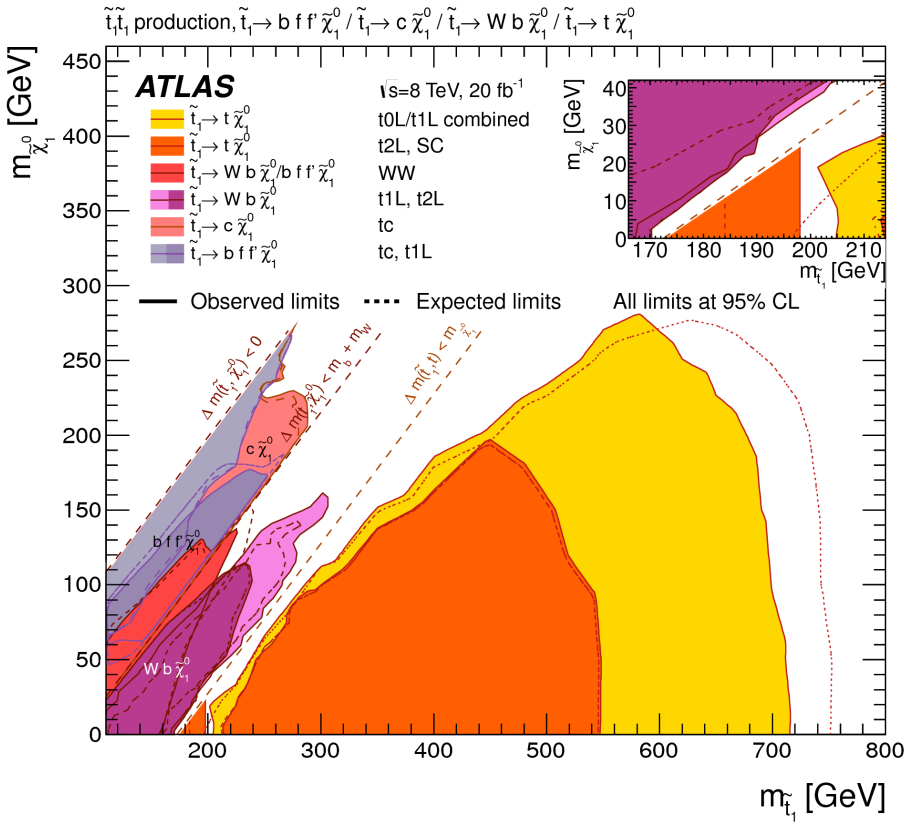


Cross section

NEW: the top x-sec analysis now extended to 3-body scenarios.

- Excludes stop masses below 175 GeV for $m_{\tilde{\chi}_1^0} = 1$ GeV.
- Less sensitive at higher $m_{\tilde{\chi}_1^0}$ due to softer b-jets in signal.

Summary of stop searches with only $\tilde{t}_1$ and $\tilde{\chi}_1^0$ present



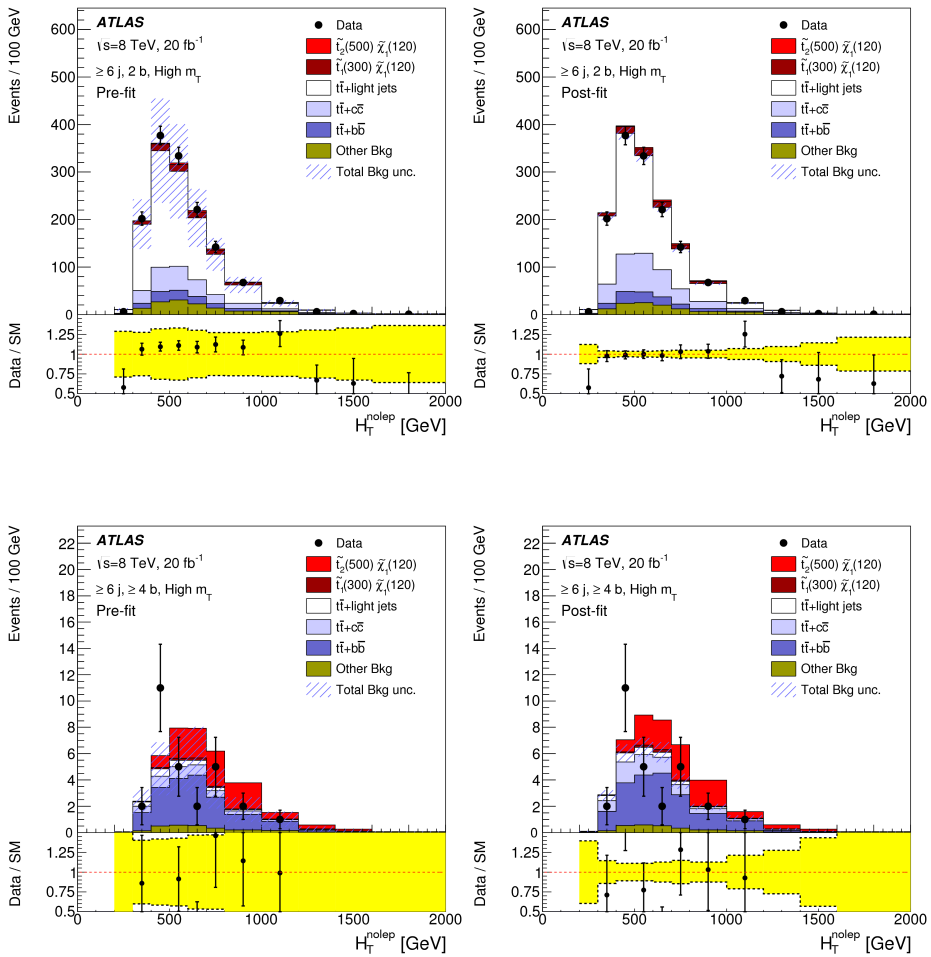
- Parameter space well-covered by the various searches

arXiv:1506.08616

Searching for $\tilde{t}_2$

- Scenarios with $m_{\tilde{t}_1} \sim m_t$ are hard: $\tilde{t}_1\tilde{t}_1$ production looks like $t\bar{t}$.
- Naturalness $\implies$ $\tilde{t}_2$ should also be light, so consider $\tilde{t}_2 \to \tilde{t}_1$ decays.
- Previously considered $\tilde{t}_2 \to \tilde{t}_1 Z$; now also $\tilde{t}_2 \to \tilde{t}_1 h$

- Similar to a $t\bar{t}h$ search; $h \to bb$ dominant decay mode
- SRs with 6 jets and 2,3 or 4 b-jets
- $t\bar{t}$+HF an important background, constrained by data



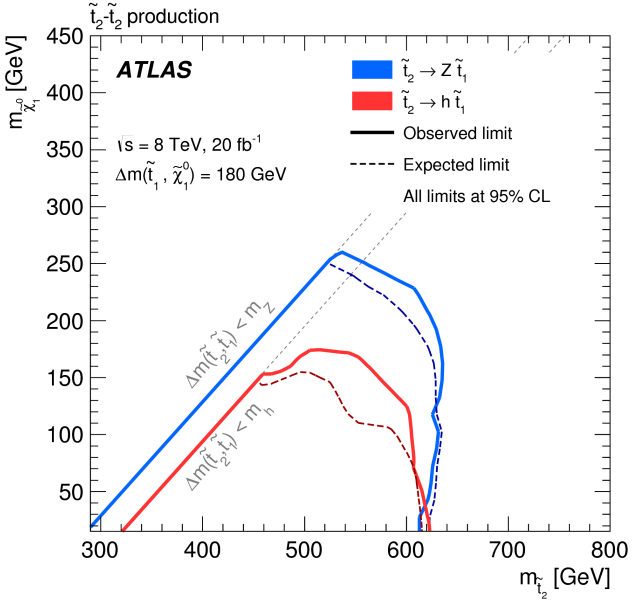
arXiv:1506.08616

Searching for $\tilde{t}_2$: results

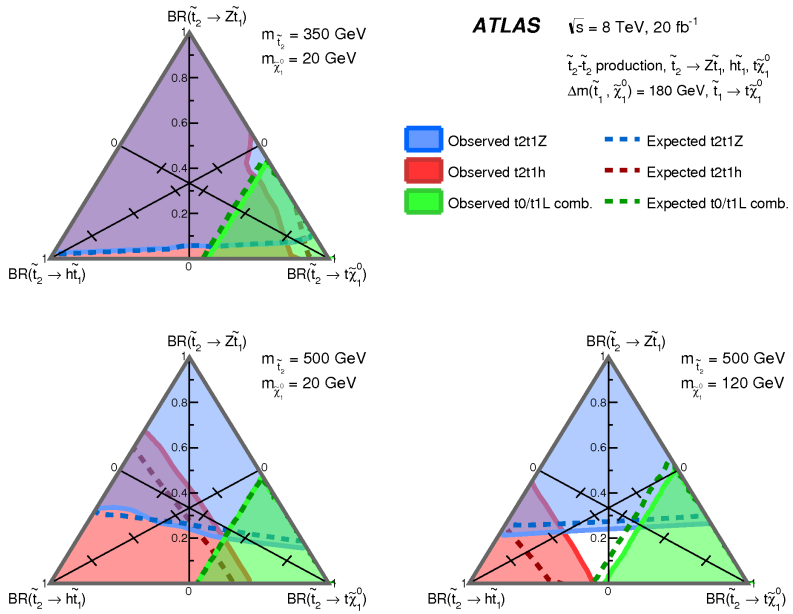
Signal with $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) = 180$ GeV considered.

Interpreted in the $m_{\tilde{t}_2}$–$m_{\tilde{\chi}_1^0}$ plane.

Exclude $m_{\tilde{t}_2} < 600$ GeV for a massless LSP.



Can also interpret for various BRs of $\tilde{t}_2 \to \tilde{t}_1 Z$, $\tilde{t}_2 \to \tilde{t}_1 h$, $\tilde{t}_2 \to t\tilde{\chi}_1^0$ by combining with the 3l and stop 0l/1l channels.

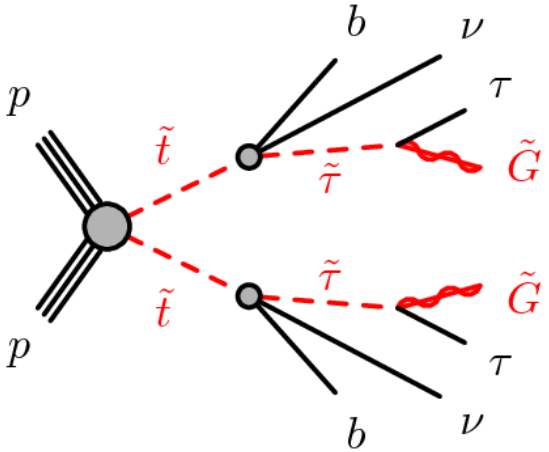


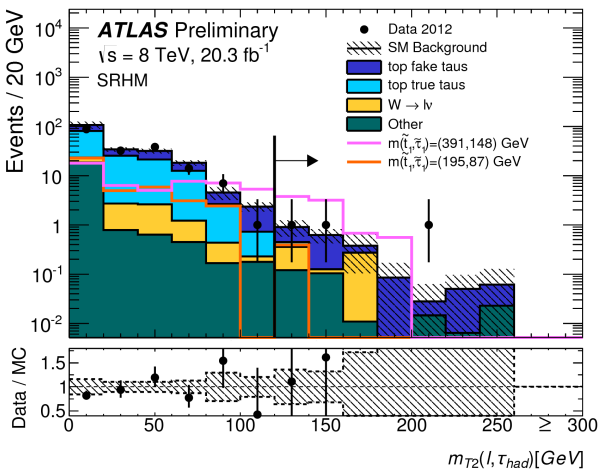
arXiv:1506.08616

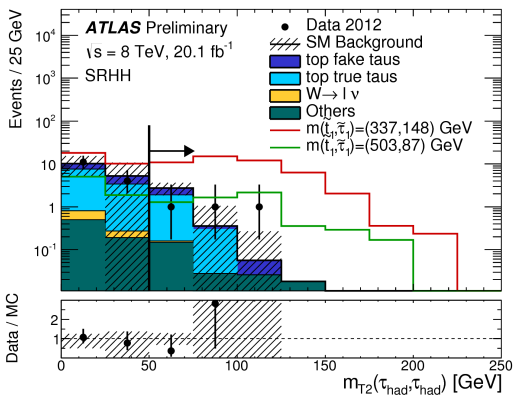
Stop decays via staus

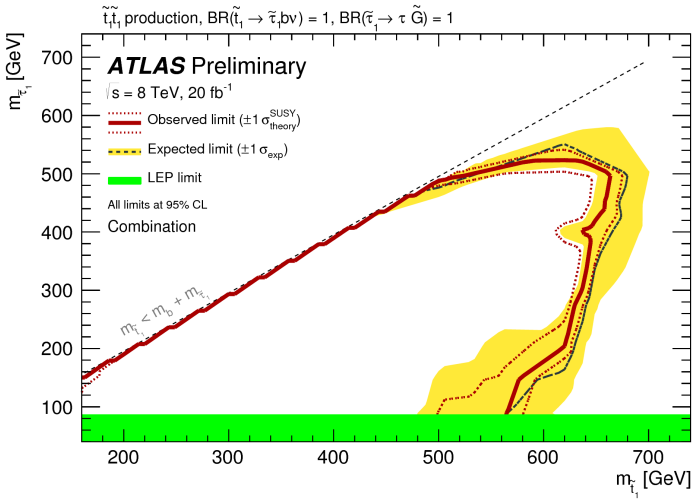
GMSB models with light stops and staus.

- 3-body decay $\tilde{t}_1 \rightarrow b\nu_\tau\tilde{\tau}_1$ possible
- followed by $\tilde{\tau}_1 \rightarrow \tau\tilde{G}$
- $\longrightarrow$ 2τ+2b+MET signature
- uses $\tau_{\mathrm{had}}\tau_{\mathrm{had}}$, $\tau_{\mathrm{had}}l$ and ll channels









Stop masses up to 650 GeV excluded for very light $\tilde{G}$, depending on stau mass.

pMSSM models

Consider well-motivated models with complex phenomenology involving stops/sbottoms.

Natural pMSSM

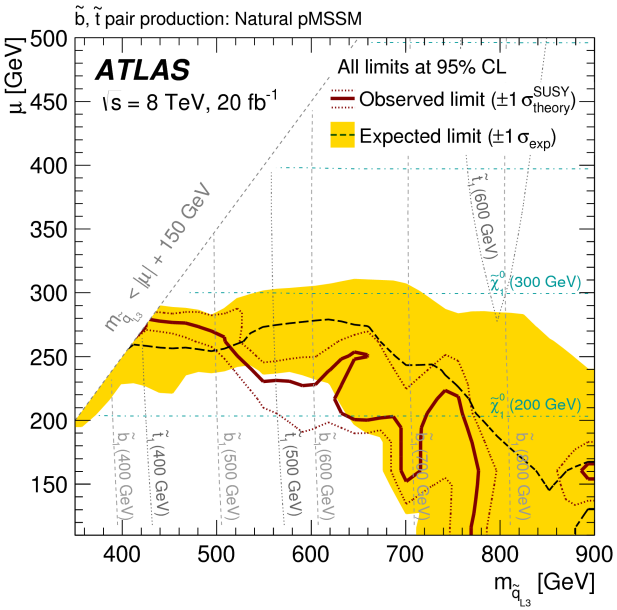
- Higgsino-like LSP, $m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^0} \approx m_{\tilde{\chi}_1^0}$
- scan over μ and $m_{\tilde{q}_{L3}}$

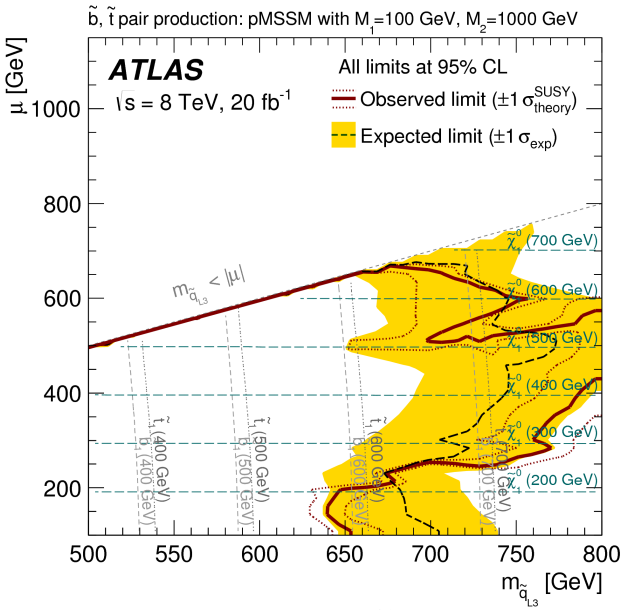
h/Z-enriched pMSSM

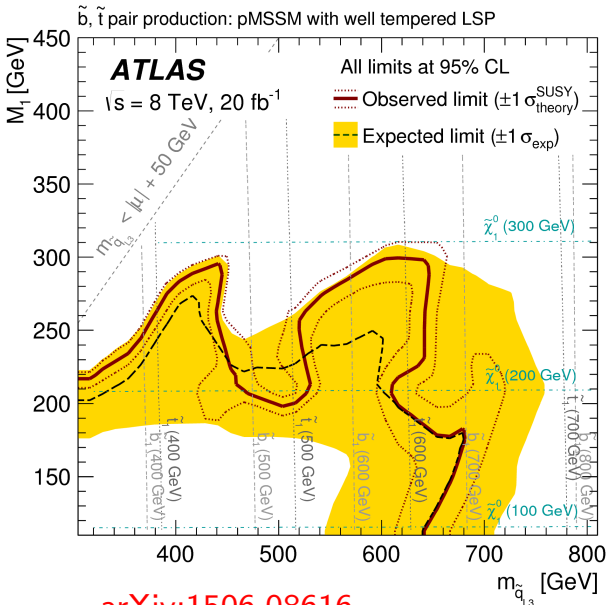
- $M_1 = 100$ GeV
- vary μ and $m_{\tilde{q}_{\mathrm{L3}}}$ or μ and $m_{\tilde{b}_{\mathrm{R}}}$
- often have $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$

Well-tempered neutralino pMSSM

- satisfy DM constraint and low fine tuning
- $\mu \sim -M_1$







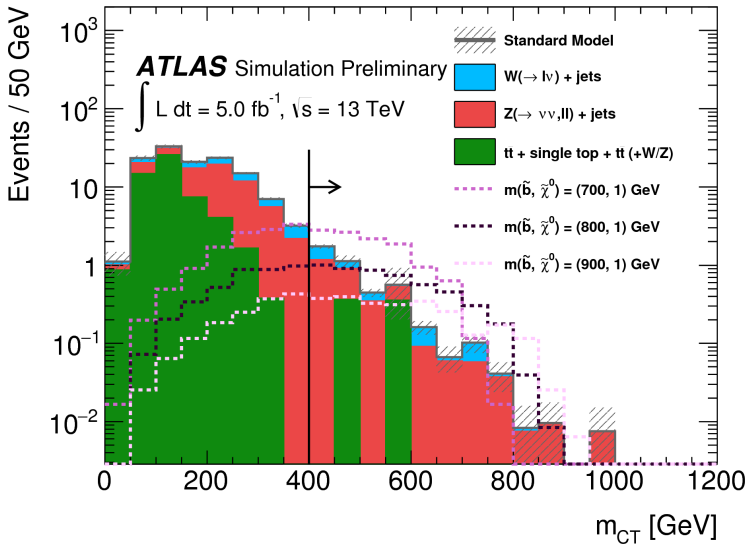
arXiv:1506.08616

Limits of $\sim 600 - 700$ GeV on the physical $\tilde{t}_1, \tilde{b}_1$ masses.

13 TeV expectations: sbottom pair production

Conservative estimate of sensitivity with early 13 TeV data for $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$ and a light LSP.

- Retain the approach of the 8 TeV search
- consider higher m_{CT} threshold (>400 GeV)
- also consider two scenarios for background systematic uncertainties: 20% and 40%



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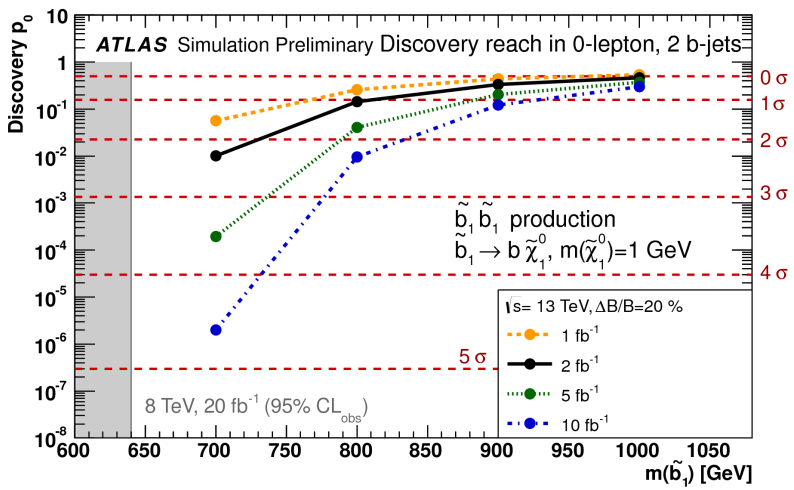
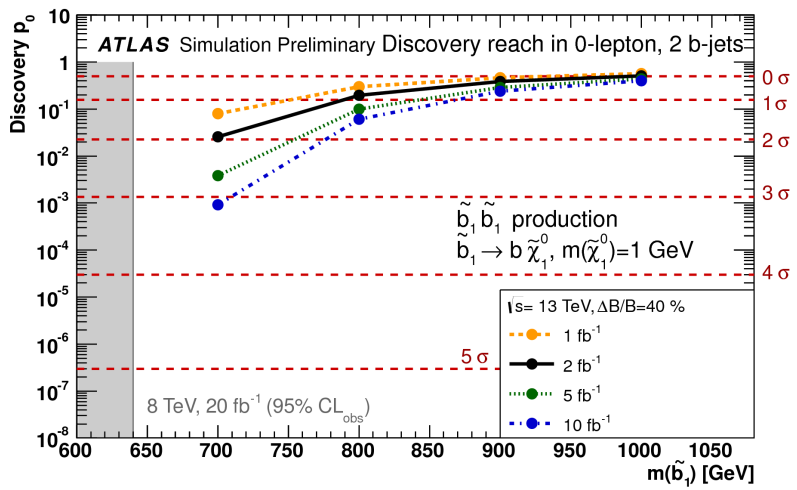




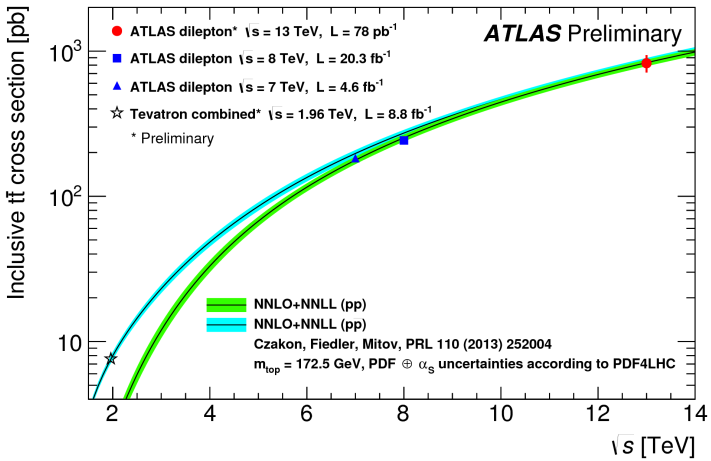
Conclusions

Extensive searches for stops/sbottoms carried out with Run 1 LHC data.

Large chunks of parameter space have been excluded and natural SUSY is under pressure.

- Sensitivity up to $m_{\tilde{t},\tilde{b}} \sim 700$ GeV, depending on decay modes and mass hierarchies
- Limits are weaker for compressed spectra - dedicated analyses target those regions

ATLAS-CONF-2015-033



Analysis of 13 TeV data is in progress - $t\bar{t}$ x-sec already measured.

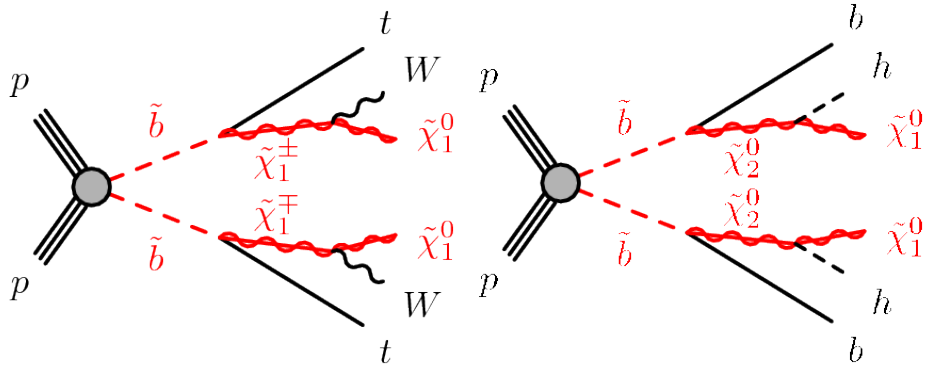
Exciting new results are coming up soon!

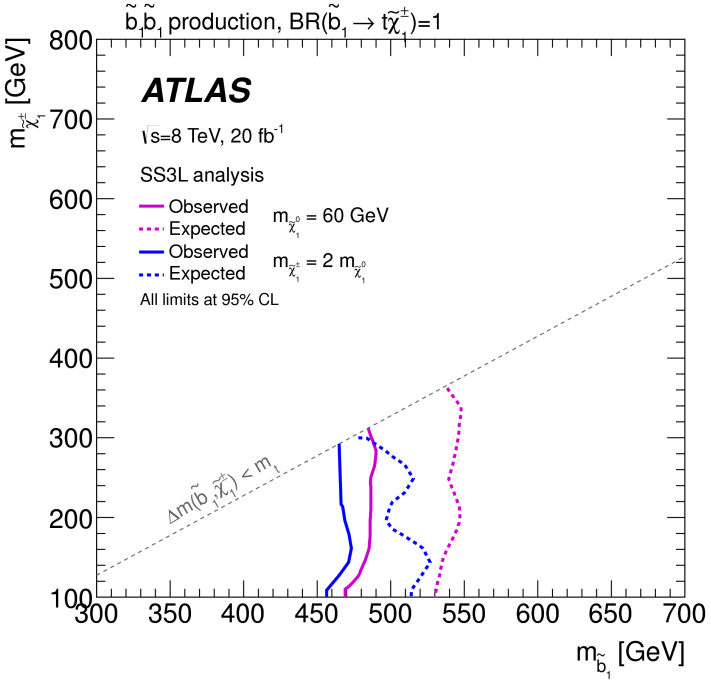
Backup

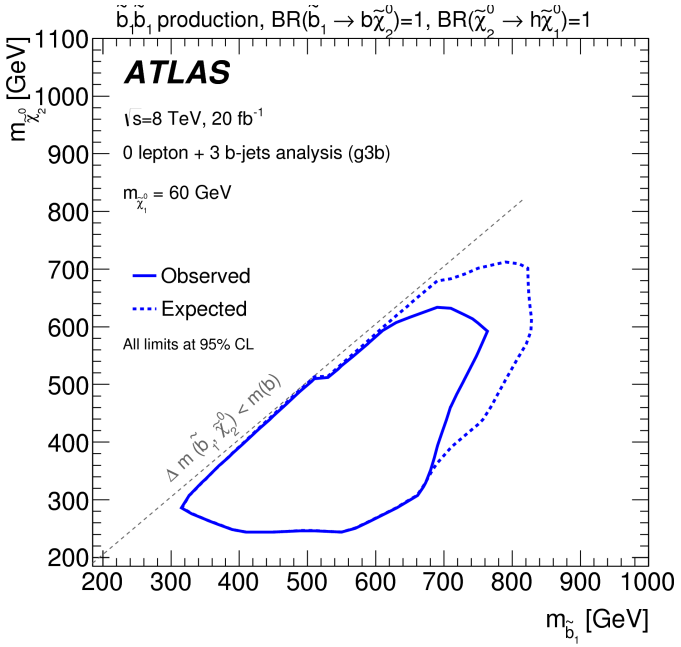
Other searches for sbottoms

Other $\tilde{b}_1$ decays considered:

- $\tilde{b}_1 \to b\tilde{\chi}_1^{\pm}$ - targeted by the same-sign 2l/3l analysis
- $\tilde{b}_1 \to b\tilde{\chi}_2^0, \tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$ - many b's in final state; targeted by 3b analysis





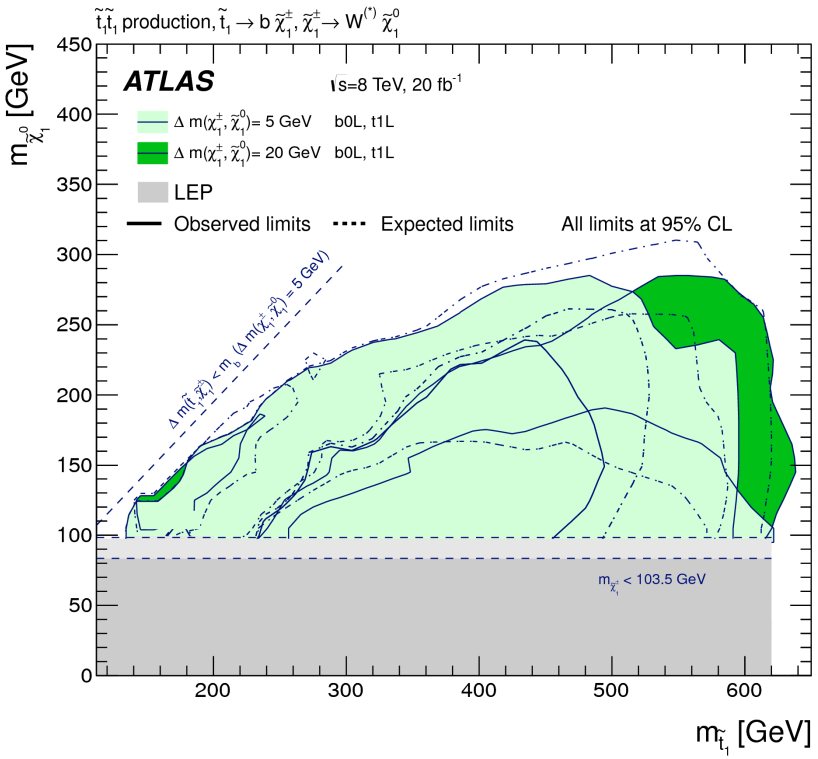


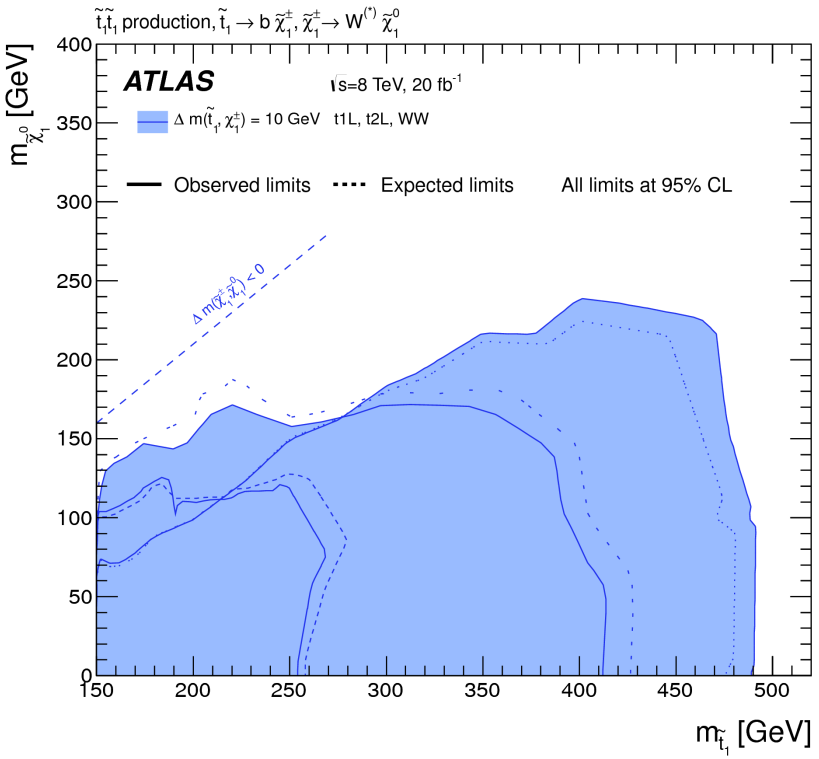
arXiv:1506.08616

Summary exclusion plots for $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$

Different assumptions for mass hierarchies considered.

- Small $m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$ (bb+MET like)
- Small $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^{\pm}}$



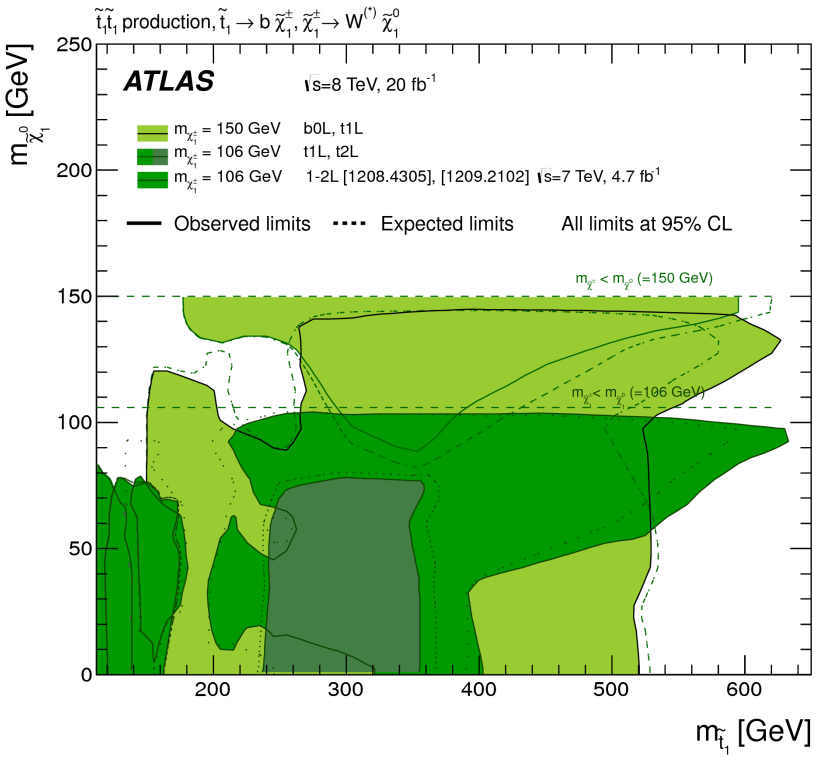


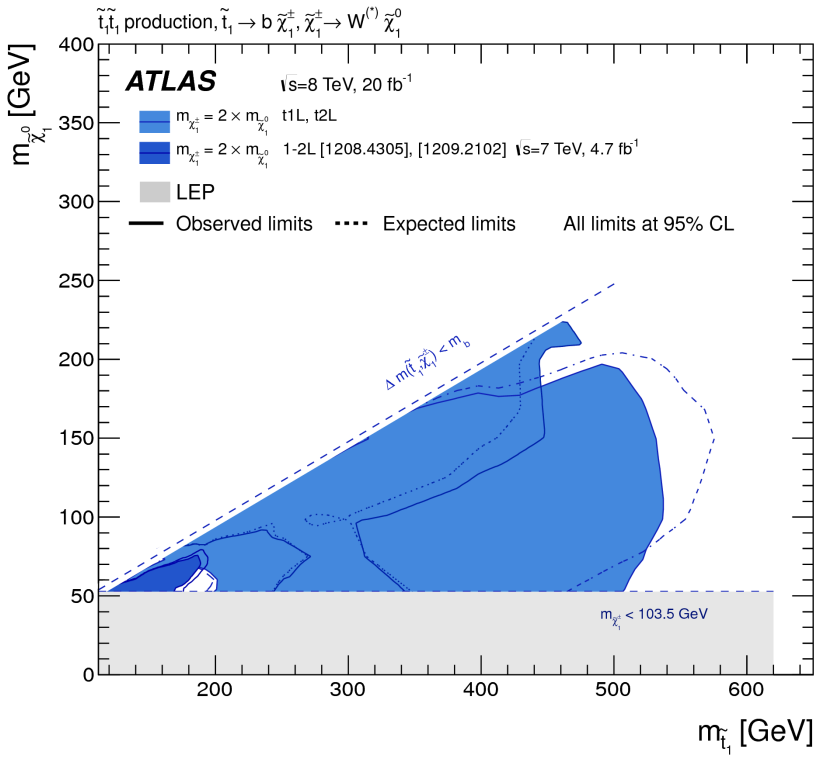
arXiv:1506.08616

Summary exclusion plots for $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm}$

Different assumptions for mass hierarchies considered.

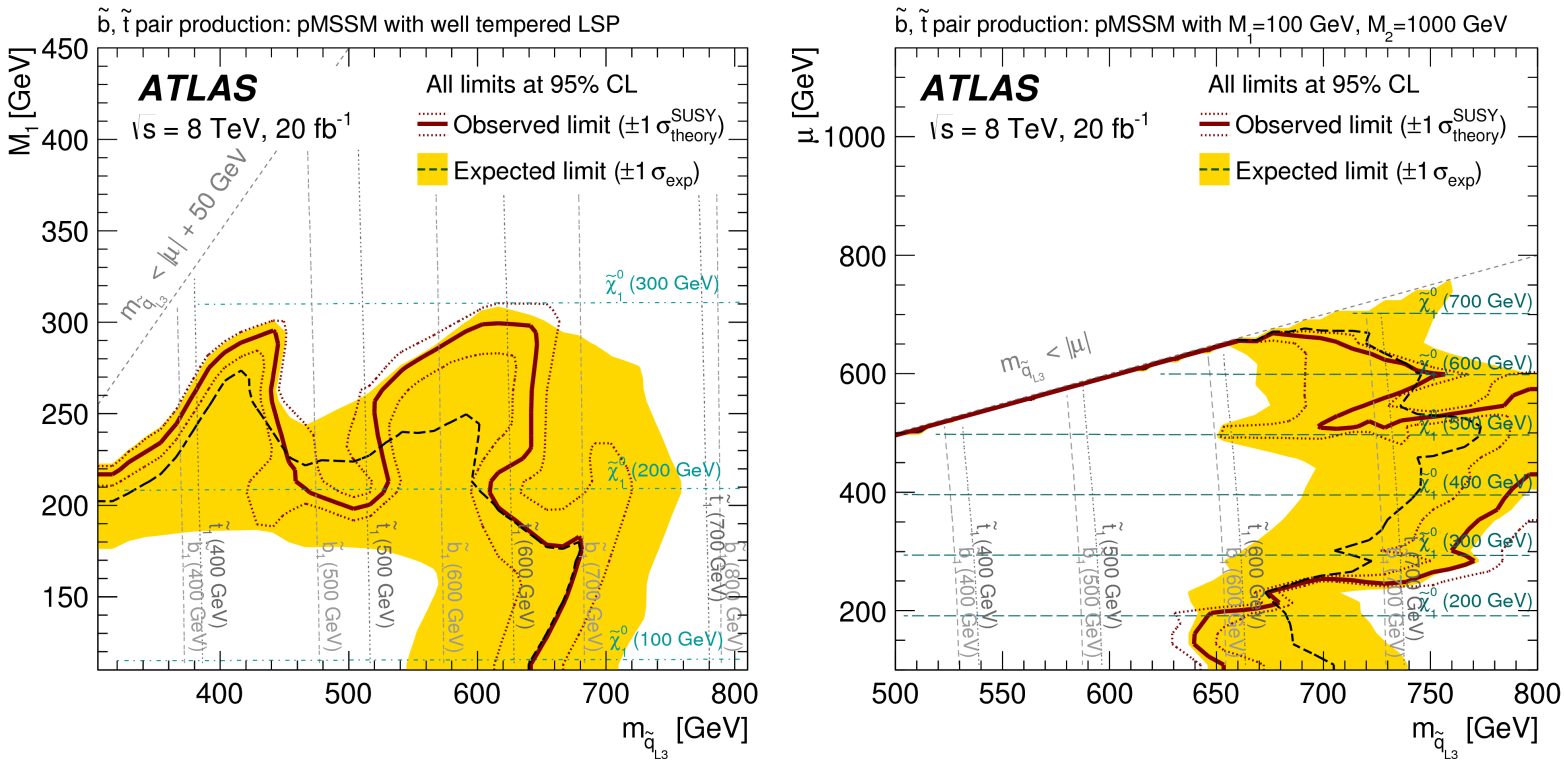
- $m_{\tilde{\chi}_1^{\pm}} = 2m_{\tilde{\chi}_1^0}$ (gaugino mass unification)
- fixed chargino mass, scan over $m_{\tilde{\chi}_1^0}$





arXiv:1506.08616

pMSSM: exclusions for RH stop/sbottom

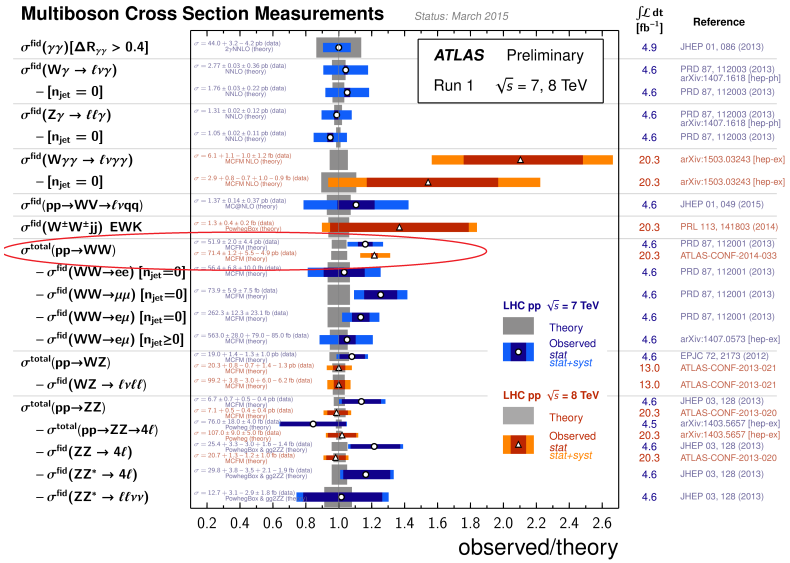


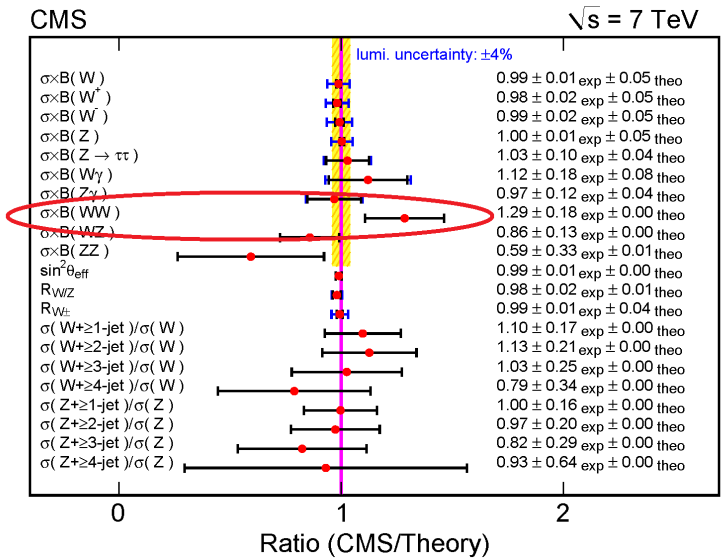
The limits are somewhat weaker compared to the left-handed case.

arXiv:1506.08616

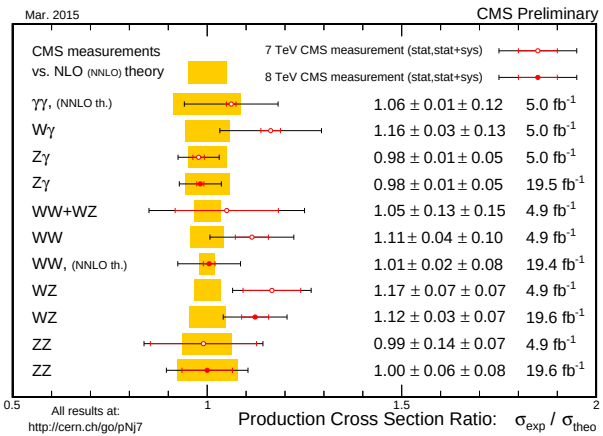
WW-like stop pair production?

In the past measured WW cross section higher than theoretical predictions.





However, most recent theory computations (NNLO) and measurements compatible with each other.

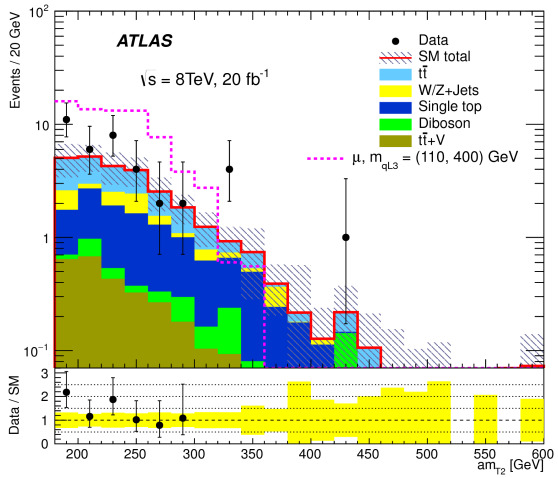


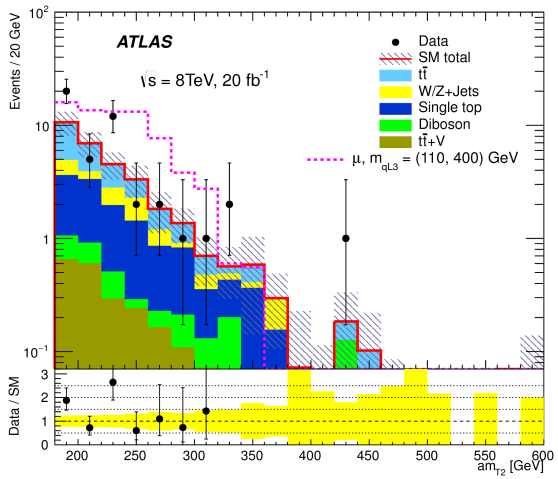
tb+MET search

A dedicated analysis targeting naturalness-inspired scenarios with $\tilde{t}_1 \to t\tilde{\chi}_1^0, \tilde{t}_1 \to b\tilde{\chi}_1^\pm$ and $\tilde{b}_1 \to b\tilde{\chi}_1^0, \tilde{b}_1 \to t\tilde{\chi}_1^\pm$ all open with comparable BRs.

Strategy

- Also assumes $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0} \implies m_{\tilde{\chi}_1^\pm} \to \tilde{\chi}_1^0 f f'$ with soft $f, f' \implies tb$+MET-like final state
- Signal regions "in-between" the tt+MET and bb+MET SRs
- One lepton required
- Uses m_{eff}, $E_{\text{T}}^{\text{miss}}$ and $E_{\text{T}}^{\text{miss}}$ significance, m_T, m_{bl} and am_{T2} (asymmetric variant of m_{T2}) as discriminants
- $t\bar{t}$ and W+jets backgrounds determined from control regions

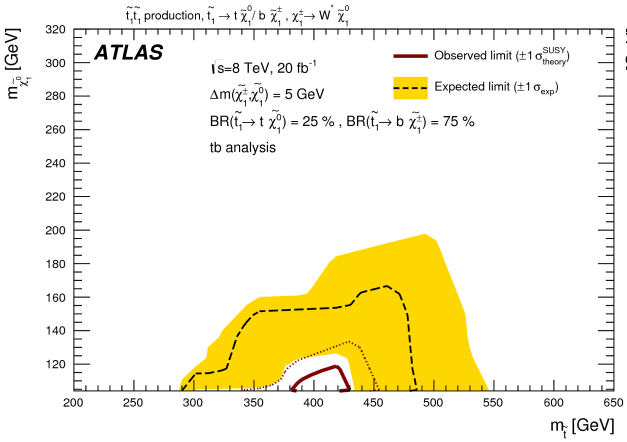


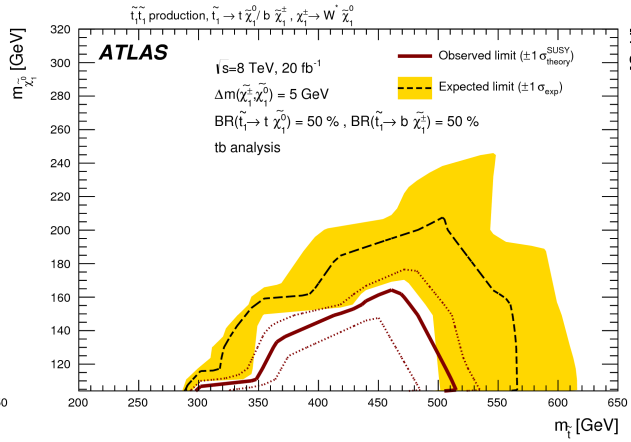


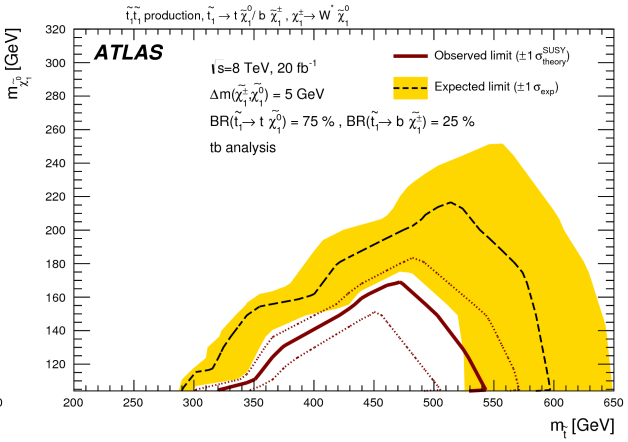
arXiv:1506.08616

tb+MET search: results

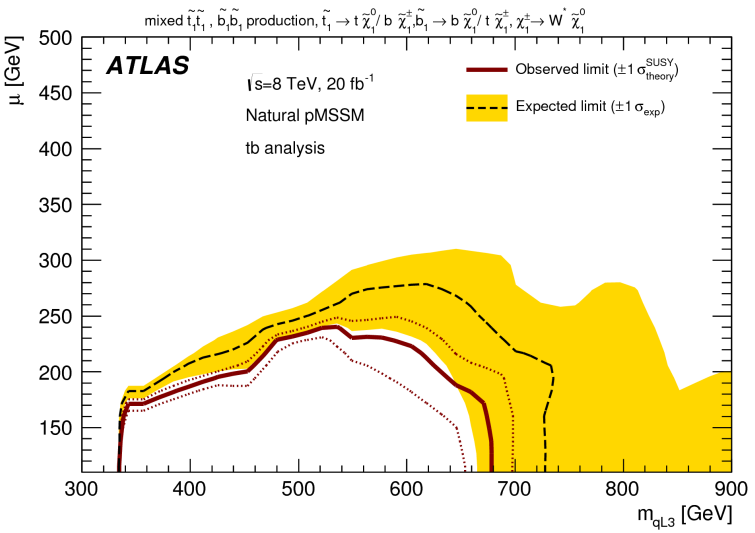
Interpreted for $\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to t\tilde{\chi}_1^0, b\tilde{\chi}_1^\pm$ with varying BRs.







Has good sensitivity in the "natural pMSSM" model (Higgsino-like LSP, light stops and $\tilde{b}_1$).



arXiv:1506.08616

Stop to stau: analysis channels

leptonic-hadronic channel

- require 1 hadronic τ+1e/μ
- ≥ 1 or 2 b-jets
- uses $m_{\mathrm{T2}}(l, \tau_{\mathrm{had}})$, $m_{\mathrm{T2}}(bl, b\tau_{\mathrm{had}})$, $m_{\mathrm{T2}}(bl, b)$, m_{eff}, H_T/m_{eff}

hadronic-hadronic channel

- require 2 hadronic τs
- ≥ 1 b-jet
- uses $m_{\mathrm{T2}}(\tau^1_{\mathrm{had}}, \tau^2_{\mathrm{had}}), m^{\mathrm{sum}}_{\mathrm{T}}(\tau^1_{\mathrm{had}}, \tau^2_{\mathrm{had}})$ and $E^{\mathrm{miss}}_{\mathrm{T}}$