Using direct stop searches at ATLAS to constrain the parameter space of supersymmetric models

Walter Hopkins

University of Oregon

September 2 2015

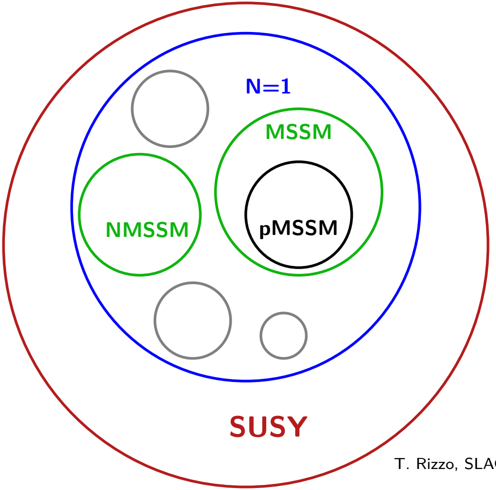
SLAC HEP Seminar

JHEP 09 (2014) 015
arXiv:1506.08616 (submitted to EPJC)
arXiv:1508.06608 (submitted to JHEP)

Outline

- Quick intro to SUSY
- The LHC and ATLAS
- ATLAS SUSY analysis primer: stop searches
- Stop searches results: simplified model interpretation
- pMSSM interpretation

SUSY parameter space



- SUSY is very broad and describes many models
- Masses and scales of SUSY are not specified!

T. Rizzo, SLAC Summer Institute 2012

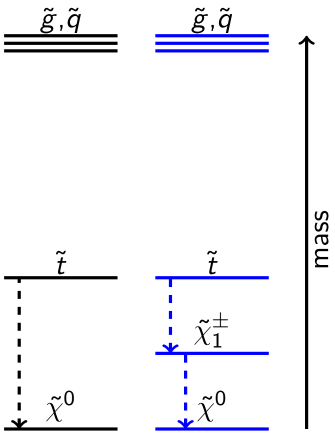
NMSSM = Next-to-Minimal Supersymmetric Standard Model
MSSM = Minimal Supersymmetric Standard Model
pMSSM = phenomenological Minimal Supersymmetric Standard Model

Simplified models

- SUSY has many tunable parameters ⇒ need to reduce
  - Even with experimental constraints (as in pMSSM with 19 free parameters)

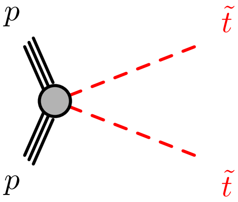
Solution: simplified models

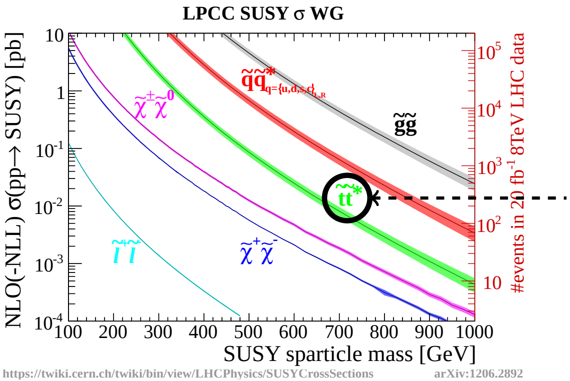
- Assume only select SUSY particle can be produced at LHC
  - Remainder is too massive (4-7 TeV)
  - Production cross section of light SUSY particle depends mainly on mass
- Make simplified assumption of decay chain
  - For example, only 1 or 2 decay modes possible for stops ($\tilde{t}$)



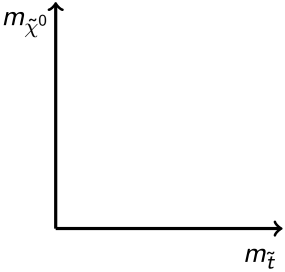
Stop quark production

- Top/stop quark are important for hierarchy problem solution
  - Preference for stop masses below ∼1 TeV
- Searching for **direct stop pair production**
  - QCD production ⇒ calculable
- Highest production cross section after gluinos and light squarks

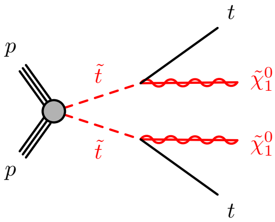


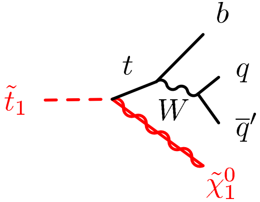


- $\tilde{t}_1 \rightarrow t + \tilde{\chi}^0$ where $\tilde{\chi}^0 =$ Lightest Supersymmetric Particle (LSP)
  - LSP doesn't interact with detector: missing energy
- Final states contains 2 tops and missing energy
  - Top pair decay with 0, 1, or 2 leptons
  - **Highlight 0-lepton (all hadronic) search as example**



Simplified model parameters: $m_{\tilde{t}}$, $m_{\tilde{\chi}^0}$

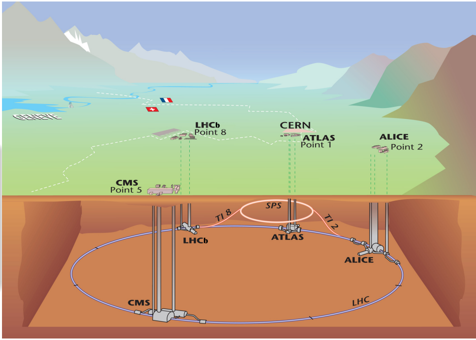




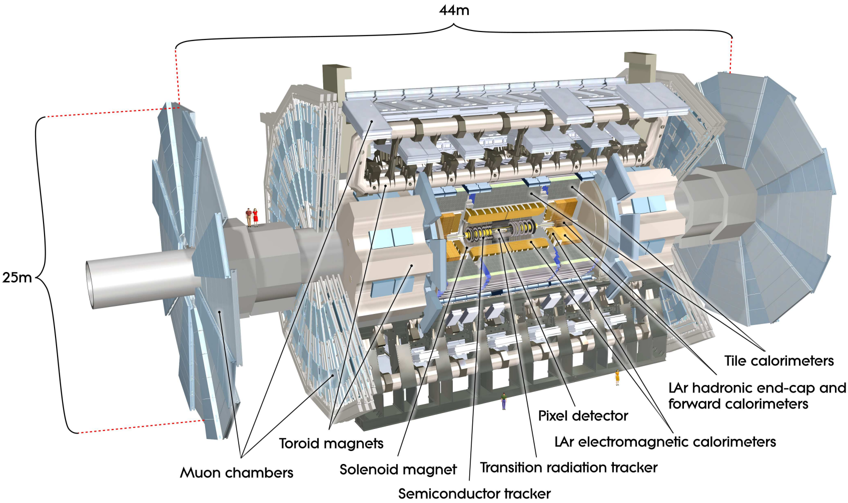
LHC

- 27 km circumference in Geneva-land
- 7 and 8 TeV proton-proton collisions ended in 2012
  - **13 TeV coming happening now!**

- **ATLAS: general purpose**
- CMS: general purpose
- LHCb: b-quark physics
- ALICE: Heavy-ion (lead-lead)



ATLAS Detector

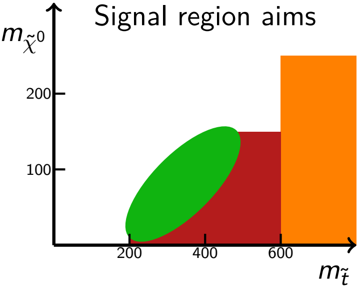


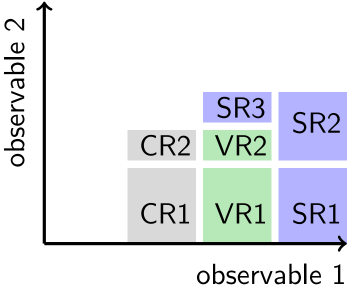
- Subdetectors highlight (for 0-lepton analysis):
  - Calorimeters: jets
  - Inner tracker: b quark identification

- Divide the signal "grid" into regions with similar final state kinematics
  - Identify backgrounds which can fake your signal signature
  - Find handles to reject background

- Estimate background from Monte Carlo (MC) simulations
  - Control regions (CR): Normalize the MC for specific background
  - Validation regions (VR): closer to SR and check normalization and shape

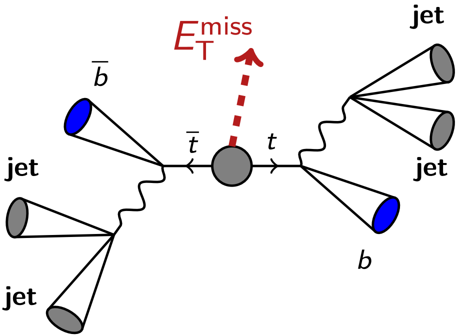
- Unblind and look for excesses
  - If nothing is found, set limits on models





Signal signature

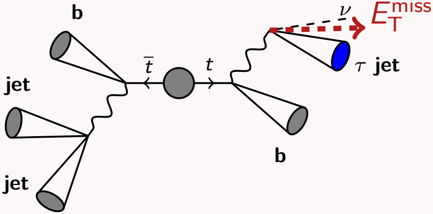
- Direct stop production with each $\tilde{t} \to t + \tilde{\chi}^0$
- Tops decay to W-boson + b-quark
- 2 LSP's results in large missing energy ($E_{\mathrm{T}}^{\mathrm{miss}}$)
- 2 b-jets from top decay
- More jets from W decay
- **Ideally: 6 jets (2 of which are b-jets) and missing energy**
  - 2 Top masses can be reconstructed



Possible backgrounds

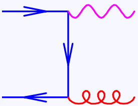
Semi-leptonic $t\bar{t}$

- Dominated by τ decays
- Only 1 reconstructed top mass
- τ's mimic jets but have less tracks associated with jet
- $E_{\mathrm{T}}^{\mathrm{miss}}$ near τ jet



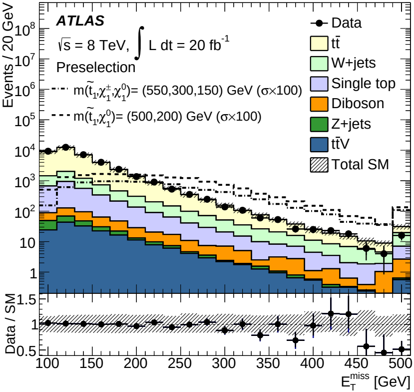
Other backgrounds

- Z/W + $b\bar{b}$, $c\bar{c}$ from gluon
  - $Z \to \nu\nu$
  - $W \to \ell\nu$
- Irreducible hadronic $t\bar{t} + Z \to \nu\nu$
  - Has 2 b-jets, 2 top masses, and $E_{\mathrm{T}}^{\mathrm{miss}}$



Discriminating signal from background

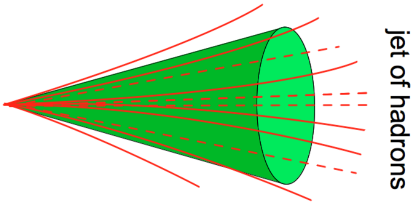
- Strongest discriminator is $E_{\mathrm{T}}^{\mathrm{miss}}$
- Amount of $E_{\mathrm{T}}^{\mathrm{miss}}$ in signal depends on $m_{\tilde{t}}$ and $m_{\tilde{\chi}^0}$
  - Compressed region: low $E_{\mathrm{T}}^{\mathrm{miss}}$
  - High $m_{\tilde{t}}$: high $E_{\mathrm{T}}^{\mathrm{miss}}$
- Baseline $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV
  - Highest $E_{\mathrm{T}}^{\mathrm{miss}} > 400$



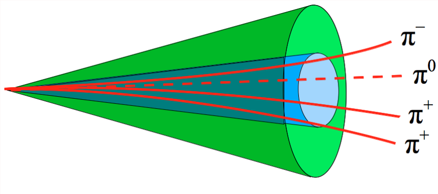
Semi-leptonic $t\bar{t}$ rejection: τ-veto

- Semi-leptonic $t\bar{t}$ background mainly from $t \to b + W(\to \tau + \nu)$
- Hadronic τ decay is dominant source of background
  - Most common decay into 1 and 3 pions
- Identified by:
  - Jet with $<=$ 4 tracks
  - $\Delta\phi$ between jet and $E_{\mathrm{T}}^{\mathrm{miss}}$ small ($\Delta\phi < \pi/5$)
- Events with such a τ jet are vetoed

Jets

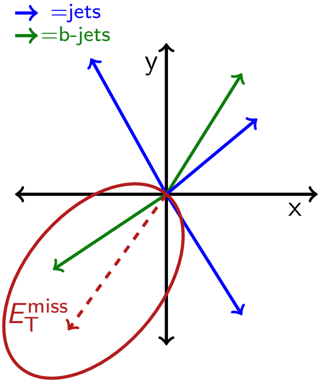


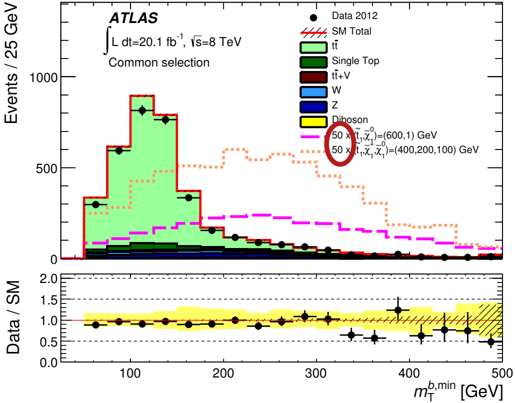
Hadronic τ-decay



More $t\bar{t}$ rejection: $m_T^{b,\min}$

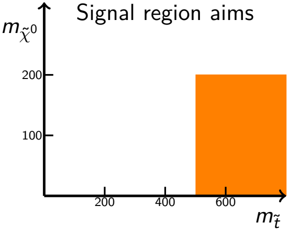
- $m_T = \sqrt{p_T^1 p_T^2 cos(\Delta\phi)}$
- $m_T^{b,\min} = m_T$ between b-jet closest to E_T^{miss} and E_T^{miss}
- $t\bar{t}$ background has cut off at $m_T^{b,\min} \sim 175$ GeV

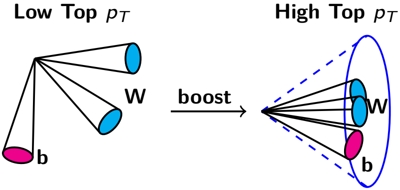




E_T^{miss}, τ-veto, and $m_T^{b,\min}$, effectively reduce $t\bar{t}$ contribution

Signal region example: high $m_{\tilde{t}}$

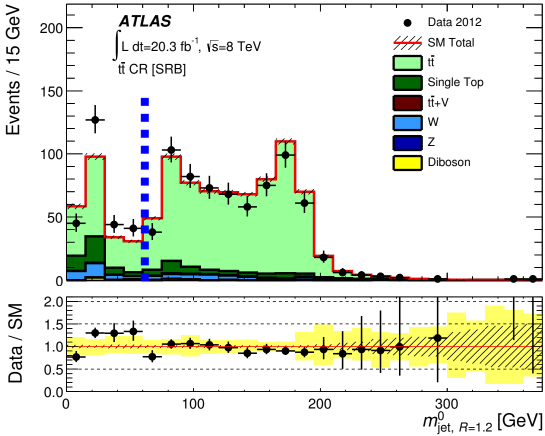




- At higher $m_{\tilde{t}}$, tops can have high p_{T} (boosted)
  - Jets from top become collimated
- Can reconstruct top mass from jets with a certain cone
  - Same algorithm (anti-k_t) used in jet recon is used to form "top jets" but with different parameters ($R = 1.2$)
- Top masses reject background: **2 top masses should be present in signal**
  - Semi-leptonic $t\bar{t}$ should only have 1 top
  - Z/W+jets should not have any tops

Control region example: $t\bar{t}$

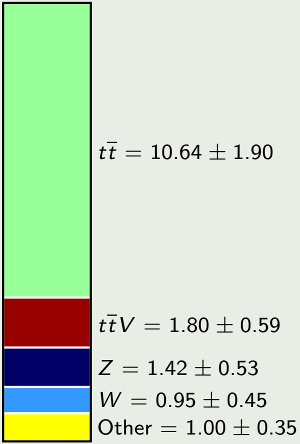
- Require 1 lepton ⇒ orthogonal to signal region
- Similar definition to signal region
  - 2 b-jets,
  - $E_T^{miss} > 150$ GeV
- Some modification to enhance $t\bar{t}$ purity



Good agreement between MC and data

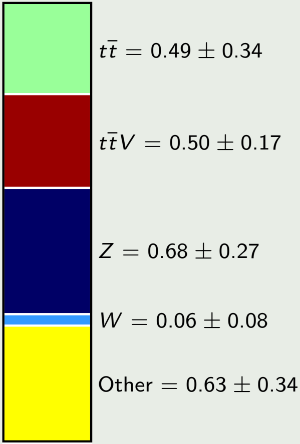
Final background composition (highlight)

Low E_T^{miss}, loose top reco



Total: 15.8 ± 1.9

High E_T^{miss}, tight top reco

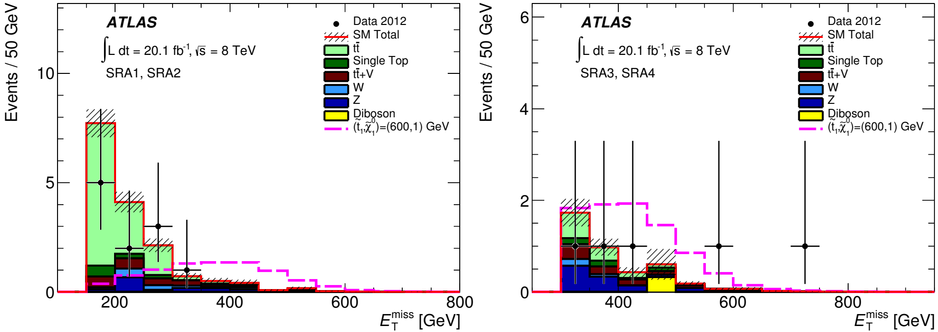


Total: 2.4 ± 0.7

Other contains: single top, dibosons, and multijet (negligible)

Background contribution changes drastically for different kinematic regions

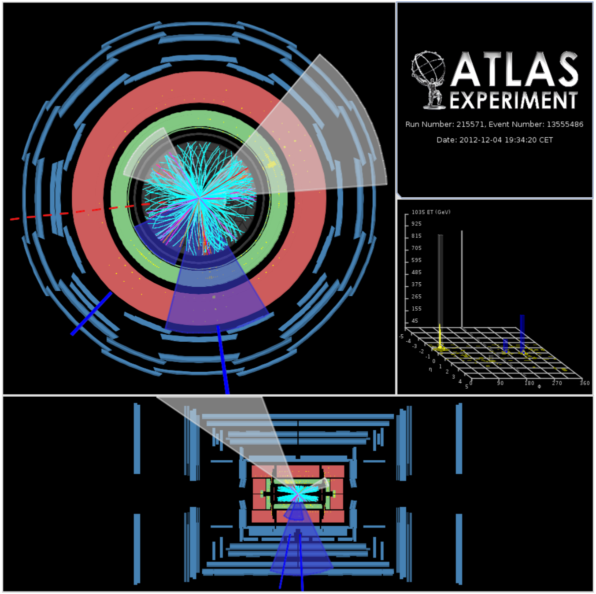
Unblinding example: E_T^{miss} after all other requirements



Number of events	SRA1	SRA2	SRA3	SRA4
Observed	11	4	5	4
Expected background	15.8 ± 1.9	4.1 ± 0.8	4.1 ± 0.9	2.4 ± 0.7

No significant excess over background:
In any of the stop searches (0, 1, 2-lepton, and more final states)

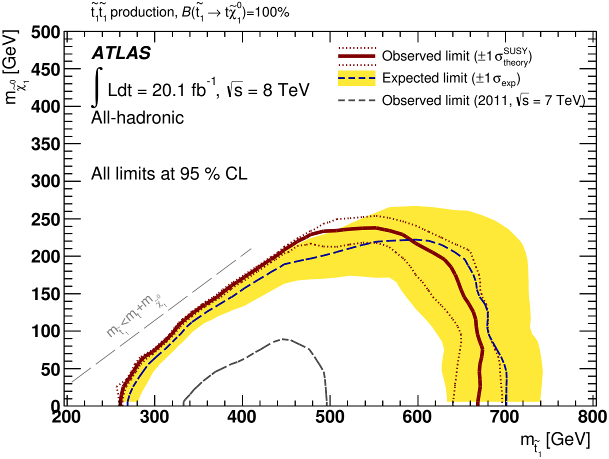
- Data event in with 5 jets
- $E_T^{miss} = 896$ GeV
- Top candidate masses: 167 GeV and 170 GeV



Interpretation of stop searches in terms of simplified models

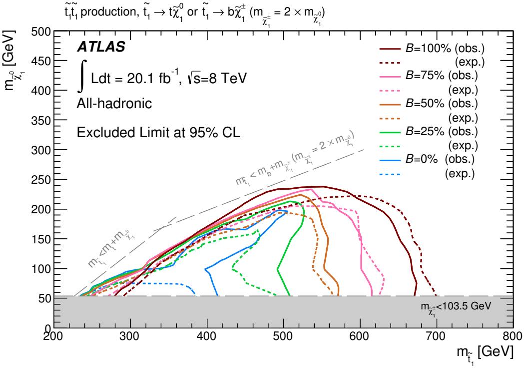
Stop 0-lepton limits: BF($\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$)=100%

- Limit considering only 0-lepton stop search
- Limits assume 100% decay to $t + \tilde{\chi}^0$
- At high $\tilde{t}_1$, low $\tilde{\chi}^0$ mass:
  - Expected limit of $275 < m_{\tilde{t}} < 700$ GeV
  - Observed limit of $270 < m_{\tilde{t}} < 645$ GeV



Stop 0-lepton limits: varying BFs

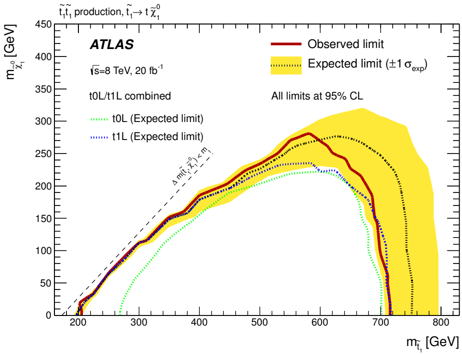
- Considered additional $\mathrm{BF}(t+\tilde{\chi}^0)$
  - 100%, 75%, 50%, 25%, 0%
- Only other decay: $\mathrm{b}+\tilde{\chi}_1^{\pm}$
  - Designed SR's for kinematics of this channel
- At $\mathrm{BF}(t+\tilde{\chi}^0)$=50% and $m_{\tilde{\chi}_1^0} < 60$ GeV: exclude $250 < m_{\tilde{t}} < 550$ GeV

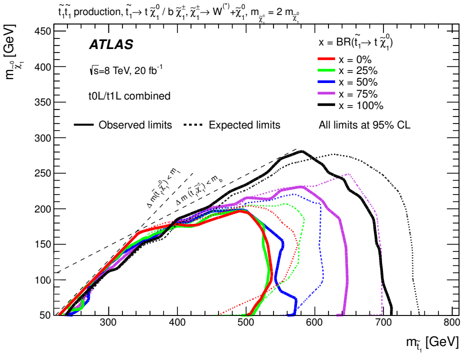


Set tight bounds, even at BF=50%

0 and 1 lepton combination

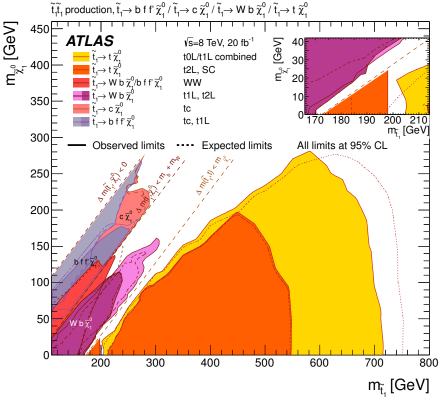
- Combination of 0 and 1-lepton stop results
  - For BF=0, 25, 50, 75, and 100%
- No excess over background
  - Sets stringent limits: $m_{\tilde{t}} < 700$ ($m_{\tilde{t}} < 570$) GeV at BF=100% (BF=50%)





Combining all Run 1 stop searches

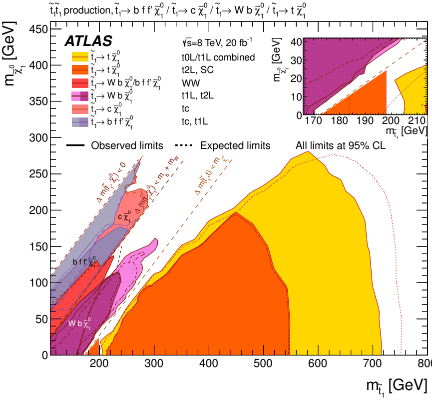
- Includes searches with different kinematics
  - Off-shell top and W
- Additional decay modes: $\tilde{t}_1 \rightarrow$charm+LSP
- Spin correlations measurement: enhanced sensitivity when $m_{\tilde{t}} \sim m_t + m_{\tilde{\chi}^0}$

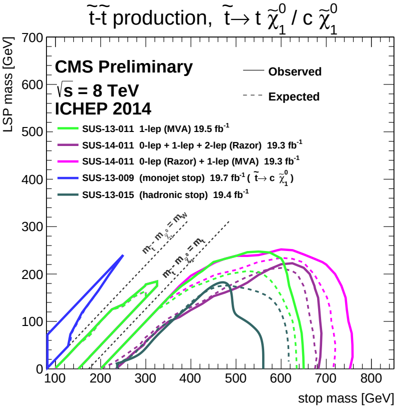


Many kinematic regions covered!

ATLAS is not alone!

- CMS performs similar searches
  - Similar results: $250 < m_{\tilde{t}} < 750$ GeV excluded (at 100% BF)



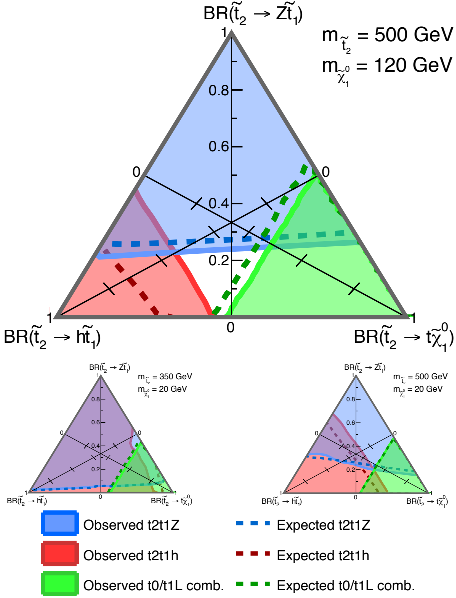


Superseded by SUS-13-023-PAS

Strong limits from both ATLAS and CMS

Sensitivity to other production modes

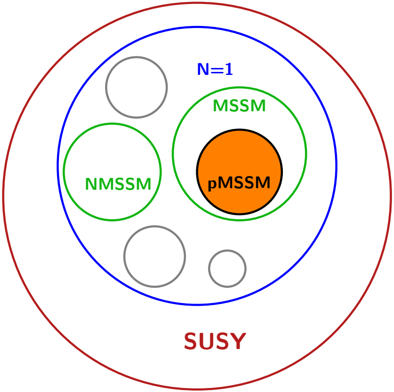
- There are 2 stops: light stop $= \tilde{t}_1$, heavy stop$=\tilde{t}_2$
  - Searches are aimed $\tilde{t}_1$ production
- If $m_{\tilde{t}_1} \sim m_t$: difficult direct $\tilde{t}_1$ detection
  - Similar to top production with low $E_{\mathrm{T}}^{\mathrm{miss}}$
- **Sensitivity to $\tilde{t}_2 \rightarrow t + \tilde{\chi}^0$ becomes dominant $\Rightarrow$ similar signature as $\tilde{t}_1$ search**
- 3 decays of $\tilde{t}_2$ considered
  - BF limits can be shown in triangle



Interpretation SUSY searches in terms of pMSSM models

pMSSM intro

- Minimal extension of the Standard Model
  - R-parity conserving and $\tilde{\chi}^0$ is LSP $\Rightarrow$ causes signatures with $E_{\mathrm{T}}^{\mathrm{miss}}$
- p = phenomenological $\Rightarrow$ constrained by experimental observations
- Results in 19 parameters
  - X^{19} possible model points, X = grid spacing. Need more reduction!



Use many analyses Run 1 searches + more to further constrain pMSSM

Scope of pMSSM scan

- Total of 22 analyses used, each with many signal regions
- Initial pMSSM models considered with random sampling of parameter space
  - **500 million** model points
- Apply more experimental constraints:
  - Pre-LHC direct searches, precision measurements, dark matter
- **300K** remaining model points
  - **30 billion** events generated
- **45K** models went through detector simulation
  - **600 million** events

Analysis
0-lepton + 2–6 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
0-lepton + 7–10 jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
1-lepton + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
$\tau(\tau/\ell)$ + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
SS/3-leptons + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
0/1-lepton + 3b-jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
Monojet
0-lepton stop
1-lepton stop
2-leptons stop
Monojet stop
Stop with Z boson
2b-jets + $E_{\mathrm{T}}^{\mathrm{miss}}$
tb+$E_{\mathrm{T}}^{\mathrm{miss}}$, stop
ℓh
2-leptons
2-τ
3-leptons
4-leptons
Disappearing Track
Long-lived particle
$H/A \to \tau^+\tau^-$

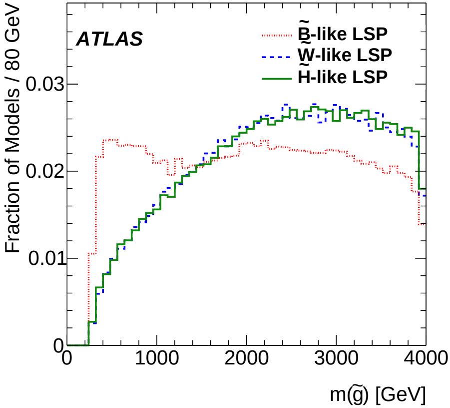
Massive effort to understand pMSSM parameter space constraints

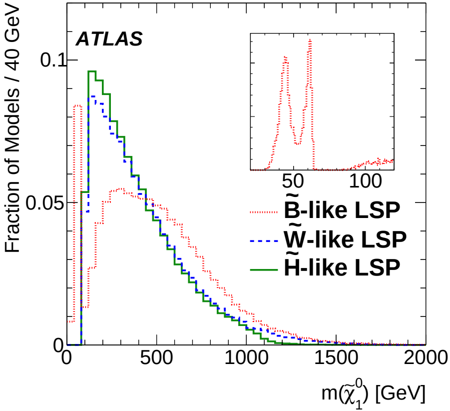
pMSSM experimental constraints

Parameter	Minimum value	Maximum value
$\Delta\rho$	-0.0005	0.0017
$\Delta(g-2)_\mu$	-17.7×10^{-10}	43.8×10^{-10}
$\mathrm{BR}(b \to s\gamma)$	2.69×10^{-4}	3.87×10^{-4}
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	1.6×10^{-9}	4.2×10^{-9}
$\mathrm{BR}(B^+ \to \tau^+\nu_\tau)$	66×10^{-6}	161×10^{-6}
$\Omega_{\tilde{\chi}_1^0} h^2$	—	0.1208
$\Gamma_{\mathrm{invisible(SUSY)}}(Z)$	—	2 MeV
Masses of charged sparticles	100 GeV	—
$m(\tilde{\chi}_1^\pm)$	103 GeV	—
$m(\tilde{u}_{1,2}, \tilde{d}_{1,2}, \tilde{c}_{1,2}, \tilde{s}_{1,2})$	200 GeV	—
$m(h)$	124 GeV	128 GeV

Effect of experimental constraints and nature of LSP

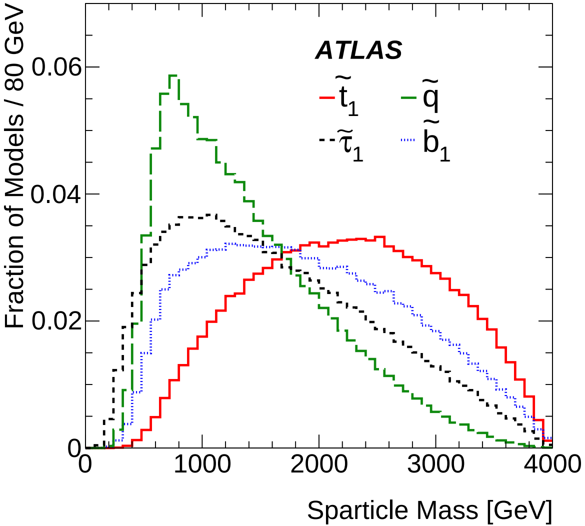
- Compared effect of constraints for various models:
  - $\tilde{\chi}^0$ is mostly Wino-like, Bino-like, Higgsino-like
- Bino-like models tend to overproduce dark matter
  - Spectra with additional annihilation channels preferred





Low Gluino mass preferred in bino-like models
Bino-like models clustered around Z and Higgs mass

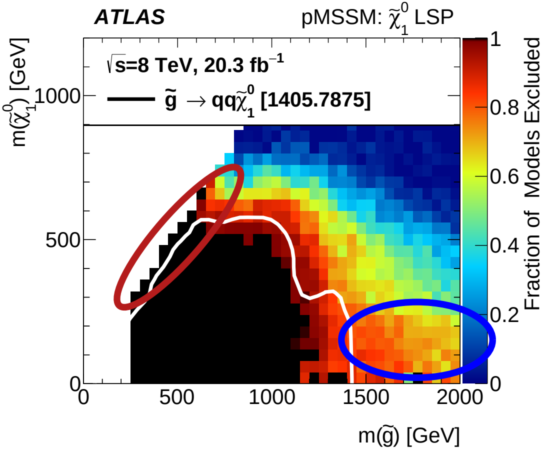
Effect of constraints on sparticle masses



Even before ATLAS results, few models have low stop (and sbottom) masses

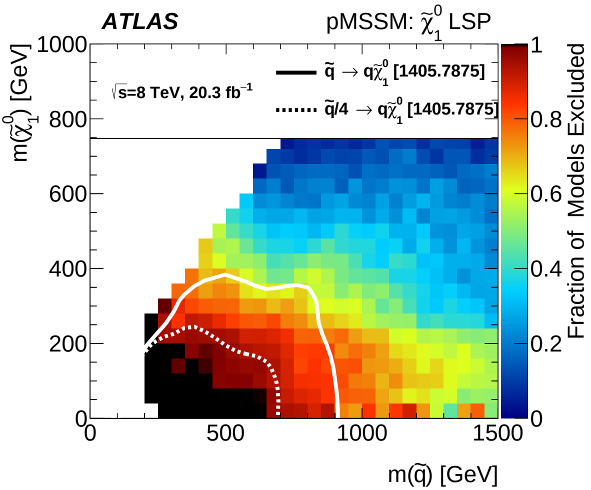
Constraints on gluinos after ATLAS SUSY results

- Gluinos (partner of gluon) have highest production cross section
- White line: searched aimed at finding gluinos
  - Dedicated search excludes nearly all pMSSM points within mass limit
- Additional searches extends reach
  - High gluino mass/low $\tilde{\chi}^0$ mass
  - Compressed region



Disappearing track and monojet searches extend sensitivity in $\tilde{g}/\tilde{\chi}^0$ plane

- Squark = 1st and 2nd generation quark partners
- Dedicated searches assume 8 fold mass degeneracy
  - Higher production cross section
- pMSSM doesn't make degeneracy assumptions
  - Simplified model (dashed white) with 4× reduction in agreement with pMSSM bounds

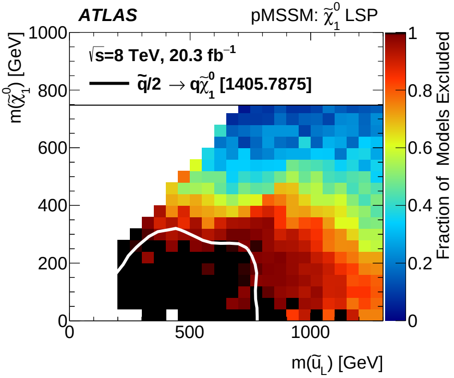


Absence of degeneracy assumptions gives more robust bounds

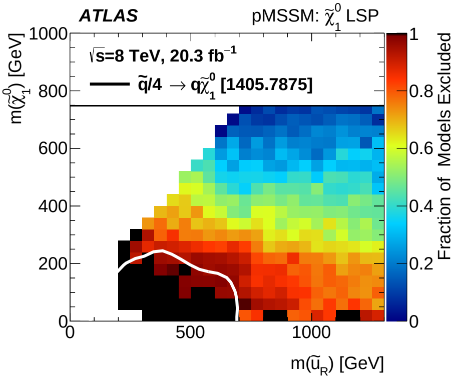
Dependence of constraints on squark type

- Simplified models assume chiral degeneracy
- Sensitivity to right-handed squarks is reduced
  - Lower production (no doublet)
  - Different decays

Left-handed

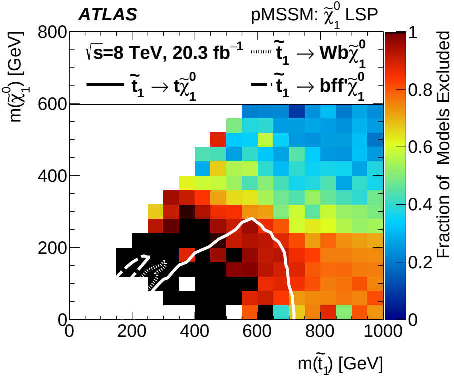


Right-handed

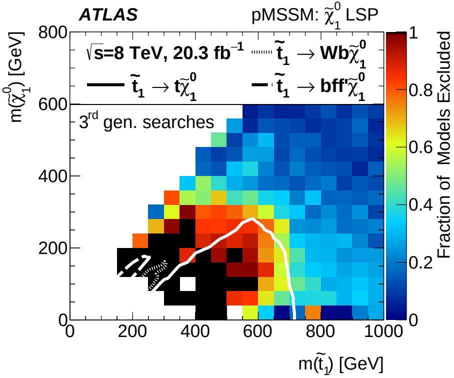


Bounds depend on chirality and type of squark

Limits from all analyses

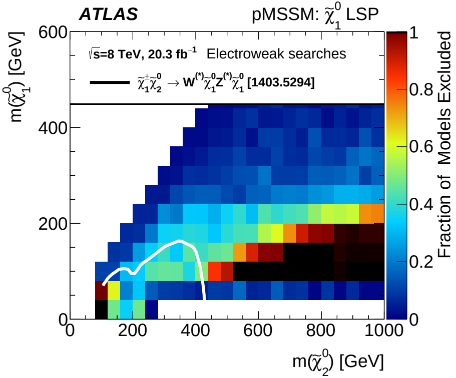


Limits from 3rd gen analyses



- Limits from 3rd generation (stop and sbottom) searches cover the $m_{\tilde{t}}$ region well
- Additional searches significantly help constrain high $m_{\tilde{t}}$ region

- Dedicated searches require multiple leptons
  - Assumes $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + Z$
- pMSSM allows many cases with low $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + Z$ BF
  - Reduction of sensitivity
- Greatest sensitivity at high $\tilde{\chi}_2^0$ mass due to disappearing track analysis

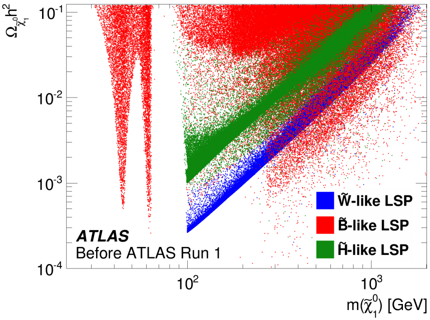


Strongest bounds are not from dedicated search!

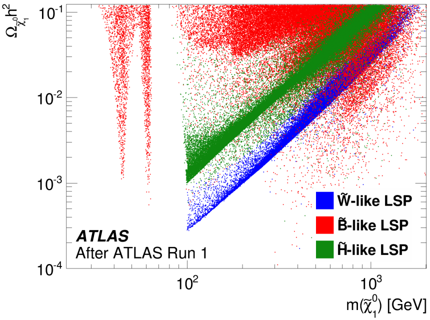
Dark matter relic density

- $\Omega_{\tilde{\chi}^0} h$ (Dark matter relic density) = current amount of dark matter
- Project pMSSM model points onto $m_{\tilde{\chi}^0} / \Omega_{\tilde{\chi}^0} h$ plane
- Compare pMSSM models on plane before and after new ATLAS limit
- $\tilde{\chi}^0$ is a mix of various SUSY fermions (gauginos)
  - Which fermion is dominant has strong effect on DM production

Before ATLAS

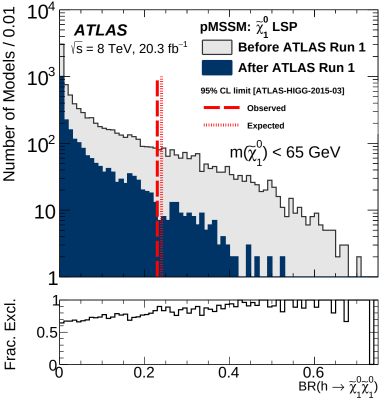


After ATLAS



Effect on Higgs coupling

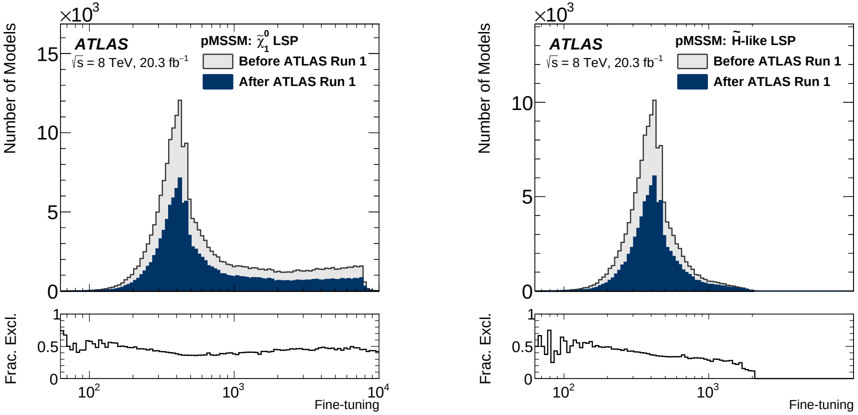
- Considered effect of SUSY searches on higgs to LSP coupling
- Only bino-line LSP's with $m < 65$ GeV
  - No wino or higgsino models meet relic density constraints
- Compared with observed bound from direct search result: $\text{BF}(h \to \tilde{\chi}^0 \tilde{\chi}^0) = 0.22$



Lower $\text{BF}(h \to \tilde{\chi}^0 \tilde{\chi}^0)$ are preferred by SUSY searches

Do ATLAS results prefer less fine tuning?

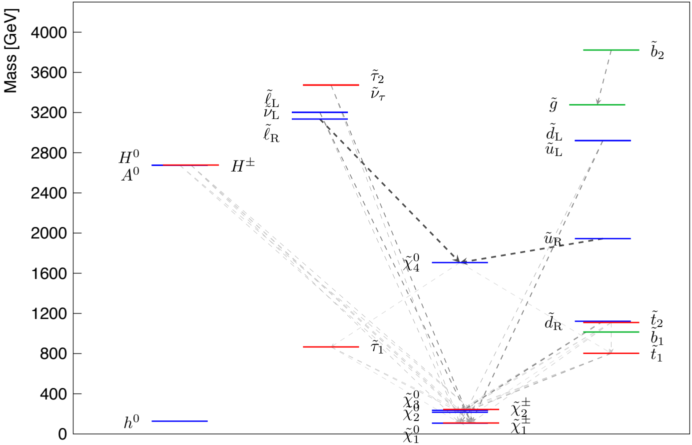
- Fine tuning defined by μ and A_t
- Tested for various LSP types separately



No shape difference: ATLAS has little to say about fine tuning
Except in Higgsino case

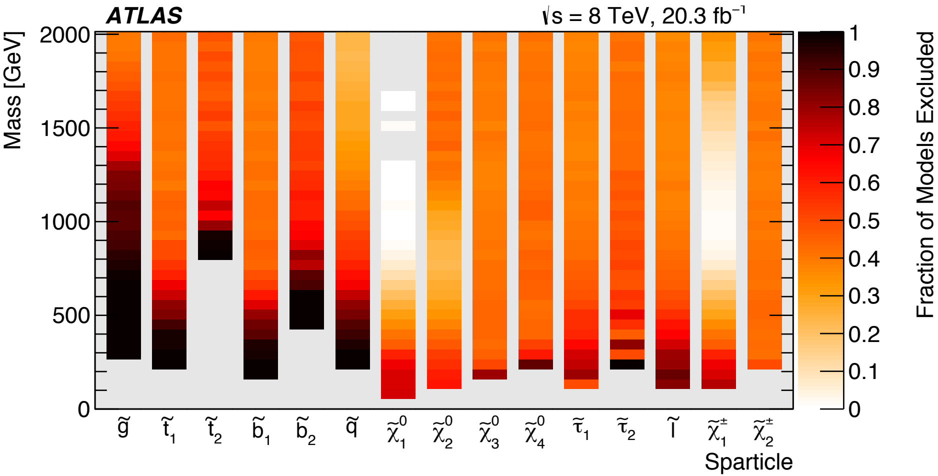
What's left?

- How does a pMSSM model that isn't excluded look?
- Consider the most "natural":
  - "natural" = lowest stop mass so that top/stop loop cancels maximally
- Most "natural" that evades all bounds: $\mathbf{m_{\tilde{t}} \sim 800}$ **GeV**
  - Stop exclusion reminder: $\mathbf{m_{\tilde{t}} < 750}$ **GeV**



This model seems to have just escaped our reach!

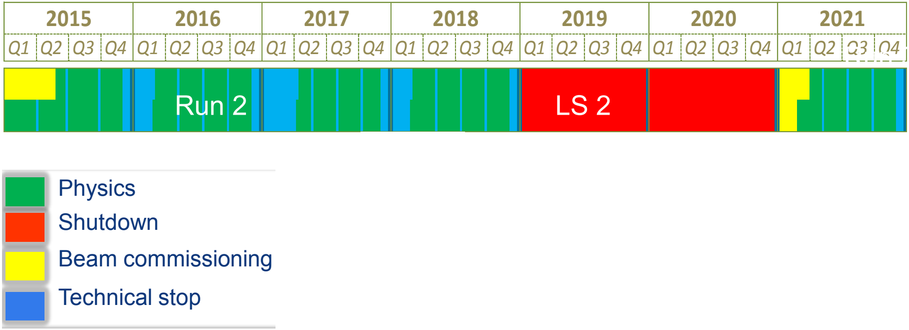
Summary of sparticle mass bounds



Black areas are robustly excluded

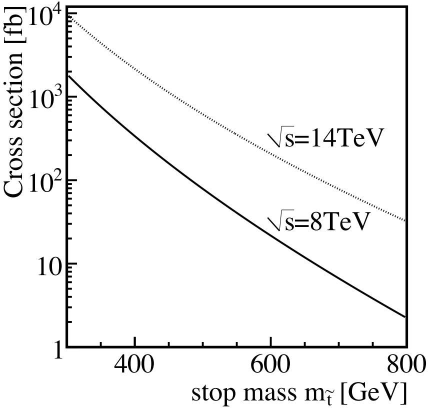
For Run 2

- $\sqrt{s} = 13$ TeV
- $\sim$100 pb^{-1} of 13 TeV 50 ns data collected
- $\sim 2 - 4$ fb^{-1} by the end of 2015
- $\sim$ 100 fb^{-1} by end of Run 2



Run 2 considerations

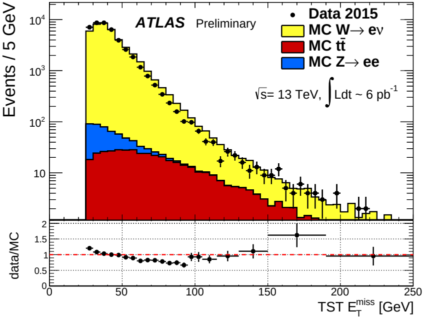
- Increase in $\sqrt{s}$
  - **Factor of ∼10 increase of cross section for $m_{\tilde{t}} = 800$ GeV**
  - **More boosted topologies**
- Background cross section increases:
  - $t\bar{t} \sim 3\times$
  - W/Z+jets $\sim 2\times$
  - $t\bar{t}+Z \sim 4\times$
- Run 2 comes with challenges
  - Higher trigger thresholds
    - Run 1: $E_{\mathrm{T}}^{\mathrm{miss}}$>150 GeV
    - Run 2: $E_{\mathrm{T}}^{\mathrm{miss}}$>250 GeV
  - Different background makeup



arXiv:1205.2696 [hep-ph]

Run 2 has started!

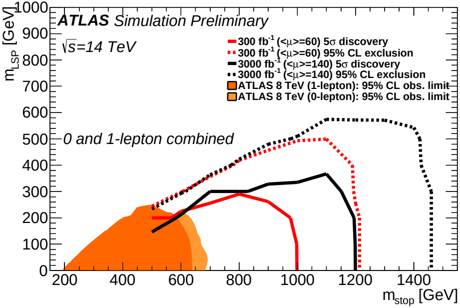
- 13 TeV data taking started in May/June
  - With 50 ns proton bunch spacing
- With 6 pb^{-1}: first $E_{\mathrm{T}}^{\mathrm{miss}}$ studies
  - Data/MC comparisons in $W \to e\nu$ events



Good MC/data agreement!

Run 2 and beyond

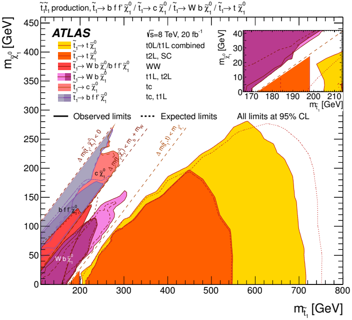
- Run 2 should yield $\sim 100\ \text{fb}^{-1}$ by 2018
- High Luminosity LHC planned: total data $\sim 3000\ \text{fb}^{-1}$
  - What if early data shows no signs of SUSY?
  - Will more data yield insight?

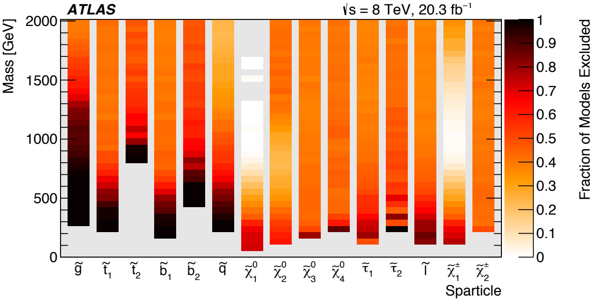


Due to small cross sections at high stop mass more luminosity is important for search

Summary

- Searched for direct stop production
- **Found nothing!**
- Set limits on $m_{\tilde{t}}$, $m_{\tilde{\chi}^0}$
  - $m_{\tilde{t}} > 750$ GeV for low $m_{\tilde{\chi}^0}$
- Constrained pMSSM parameters space
- **Run 2 is happening!**





Is SUSY just around the corner? Run 2 will tell us!

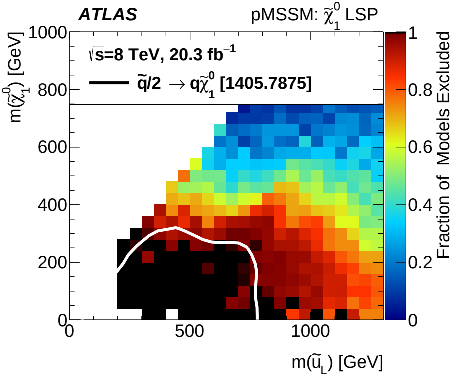
Backup

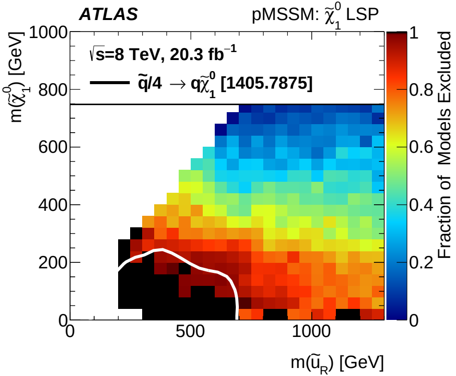
Expected background: details

Parameter	Min value	Max value	Note
$m_{\tilde{L}_1} (= m_{\tilde{L}_2})$	90 GeV	4 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1} (= m_{\tilde{e}_2})$	90 GeV	4 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	90 GeV	4 TeV	Left-handed stau doublet mass
$m_{\tilde{e}_3}$	90 GeV	4 TeV	Right-handed stau mass
$m_{\tilde{Q}_1} (= m_{\tilde{Q}_2})$	200 GeV	4 TeV	Left-handed squark (first two gens.) mass
$m_{\tilde{u}_1} (= m_{\tilde{u}_2})$	200 GeV	4 TeV	Right-handed up-type squark (first two gens.) mass
$m_{\tilde{d}_1} (= m_{\tilde{d}_2})$	200 GeV	4 TeV	Right-handed down-type squark (first two gens.) mass
$m_{\tilde{Q}_3}$	100 GeV	4 TeV	Left-handed squark (third gen.) mass
$m_{\tilde{u}_3}$	100 GeV	4 TeV	Right-handed top squark mass
$m_{\tilde{d}_3}$	100 GeV	4 TeV	Right-handed bottom squark mass
$\|M_1\|$	0 GeV	4 TeV	Bino mass parameter
$\|M_2\|$	70 GeV	4 TeV	Wino mass parameter
$\|\mu\|$	80 GeV	4 TeV	Bilinear Higgs mass parameter
M_3	200 GeV	4 TeV	Gluino mass parameter
$\|A_t\|$	0 GeV	8 TeV	Trilinear top coupling
$\|A_b\|$	0 GeV	4 TeV	Trilinear bottom coupling
$\|A_\tau\|$	0 GeV	4 TeV	Trilinear τ lepton coupling
M_A	100 GeV	4 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

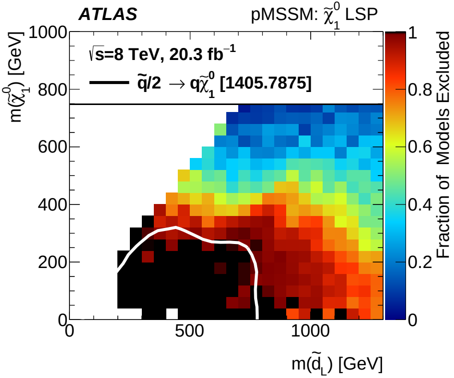
Left vs right handed squark/sleptons sensitivity

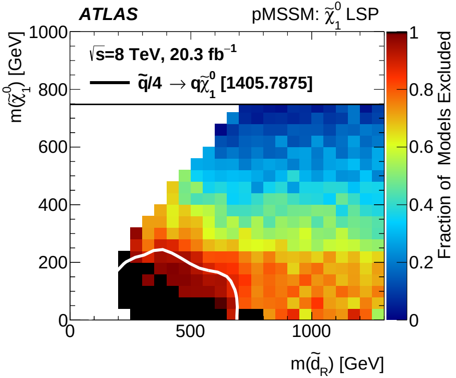
- Check sensitivity if squarks or sleptons are dominantly right or left handed
- Sensitivity tends to be better if mostly left-handed
  - Left-handed doublet requires mass degeneracy between up and down type
- For sleptons sensitivity is lower for right-handed sleptons
  - Due to lack of left handed weak decay modes in right handed squarks


ATLAS
pMSSM: $\tilde{\chi}_1^0$ LSP
$\sqrt{s}$=8 TeV, 20.3 fb^{-1}
$\tilde{q}/2 \rightarrow q\tilde{\chi}_1^0$ [1405.7875]
$m(\tilde{\chi}_1^0)$ [GeV]
$m(\tilde{u}_L)$ [GeV]
Fraction of Models Excluded
0
200
400
600
800
1000
500
0.2
0.4
0.6
0.8
1

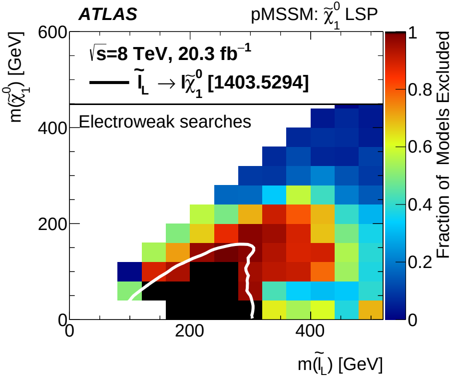

ATLAS
pMSSM: $\tilde{\chi}_1^0$ LSP
$\sqrt{s}$=8 TeV, 20.3 fb^{-1}
$\tilde{q}/4 \rightarrow q\tilde{\chi}_1^0$ [1405.7875]
$m(\tilde{\chi}_1^0)$ [GeV]
$m(\tilde{u}_R)$ [GeV]
Fraction of Models Excluded
0
200
400
600
800
1000
500
0.2
0.4
0.6
0.8
1

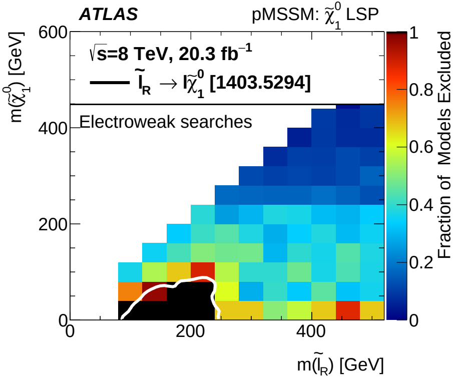
Left and right handed down squark limits





Left and right handed slepton limits





Expected background: details

Analysis	All LSPs	Bino-like	Wino-like	Higgsino-like
0-lepton + 2-6 jets + E_T^{miss}	32.1%	35.8%	29.7%	33.5%
0-lepton + 7-10 jets + E_T^{miss}	7.8%	5.5%	7.6%	8.0%
0/1-lepton + 3 b-jets + E_T^{miss}	8.8%	5.4%	7.1%	10.1%
1-lepton + jets + E_T^{miss}	8.0%	5.4%	7.5%	8.4%
Monojet	9.9%	16.7%	9.1%	10.1%
SS/3-leptons + jets + E_T^{miss}	2.4%	1.6%	2.4%	2.5%
$\tau(\tau/\ell)$ + jets + E_T^{miss}	3.0%	1.3%	2.9%	3.1%
0-lepton, stop	9.4%	7.8%	8.2%	10.2%
1-lepton, stop	6.2%	2.9%	5.4%	6.8%
2b-jets + E_T^{miss}	3.2%	3.4%	2.4%	3.8%
2-leptons, stop	0.8%	1.1%	0.8%	0.7%
Monojet, stop	3.5%	11.3%	2.8%	3.6%
Stop with Z boson	0.4%	1.0%	0.4%	0.5%
tb+E_T^{miss},stop	4.2%	1.9%	3.1%	5.0%
ℓh, electroweak	0.0%	0.0%	0.0%	0.0%
2-leptons, electroweak	1.3%	2.2%	0.7%	1.6%
2-taus, electroweak	0.2%	0.3%	0.2%	0.2%