

Searches for direct pair production of third generation squarks with the ATLAS detector

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On behalf of the ATLAS collaboration

SUSY15 - Lake Tahoe

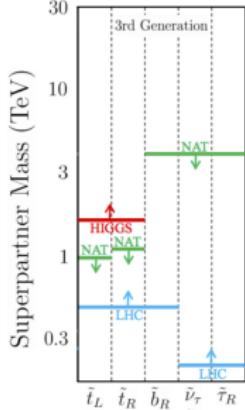
August 24, 2015



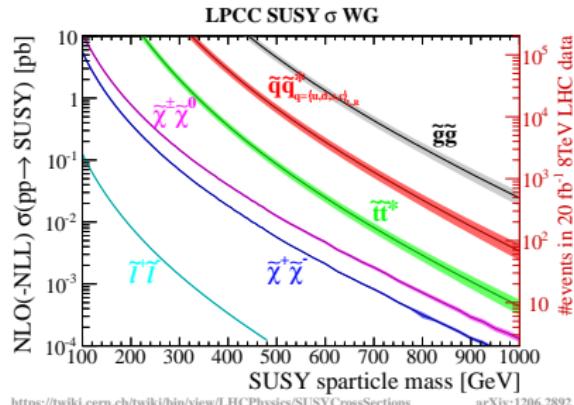
Introduction - Motivations

- SUSY offers a natural solution to the hierarchy problem and a dark matter candidate
- Due to large Yukawa coupling and $\tilde{q}_R - \tilde{q}_L$ mixing , the third generation squarks are expected to be lighter than other squarks.

arXiv:1302.6587

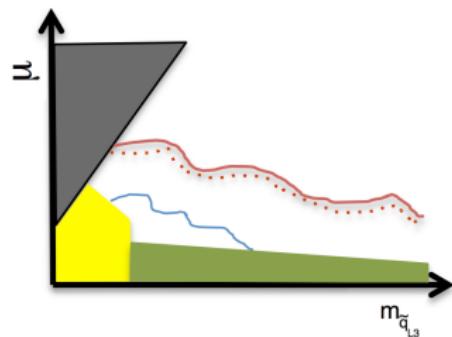
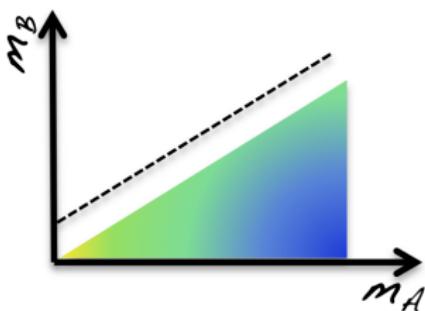


- Naturalness of the Higgs mass prefers stop/sbottom squarks at the TeV scale.
- They can be strongly produced and within the discovery reach of the LHC.



Approaches to 3rd generation searches

- Simplified Models:
 - Either a stop or a sbottom pair is produced
 - Decays into well defined final states
 - Focus on a process of interest with a small number of particles
- Limits interpreted on the masses of SUSY particles
- pMSSM Models:
 - Complicated final states
 - stop/sbottom have many allowed decay modes
- Limits interpreted on the phase space of the free parameters of the model

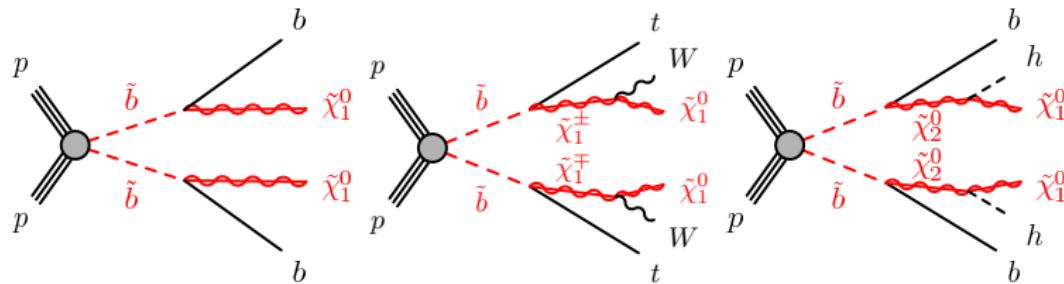


Outline

- Direct \tilde{b}_1 searches
 - Direct \tilde{t}_1 searches
 - Assuming no $\tilde{\chi}_1^\pm$ in the decay chain
 - Assuming presence of $\tilde{\chi}_1^\pm$ in the decay chain
 - Direct searches for \tilde{t}_2
 - pMSSM interpretations
 - New 3rd Generation searches results
-
- The results shown in this talk can be found in [arXiv:1506.08616](#), paper summarising the results on 3rd Generation searches with ATLAS if not otherwise stated
 - Talk will focus on main results and combinations.
Check the details of the analyses in the backup!

Direct sbottom searches results

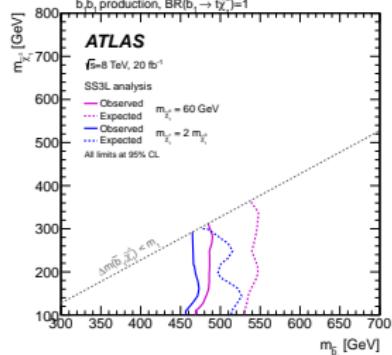
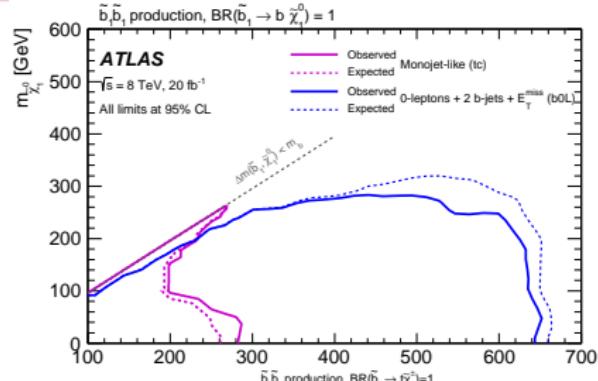
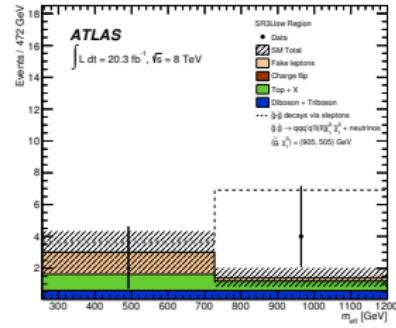
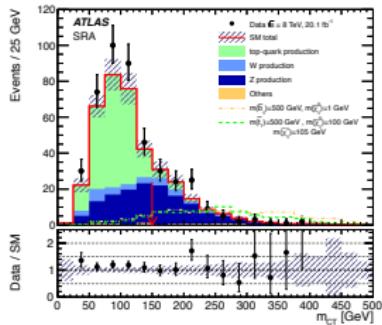
Direct sbottom searches results



- First two processes discussed in the talk. Check backup for $\tilde{b}_1 \rightarrow b\tilde{\chi}_2$

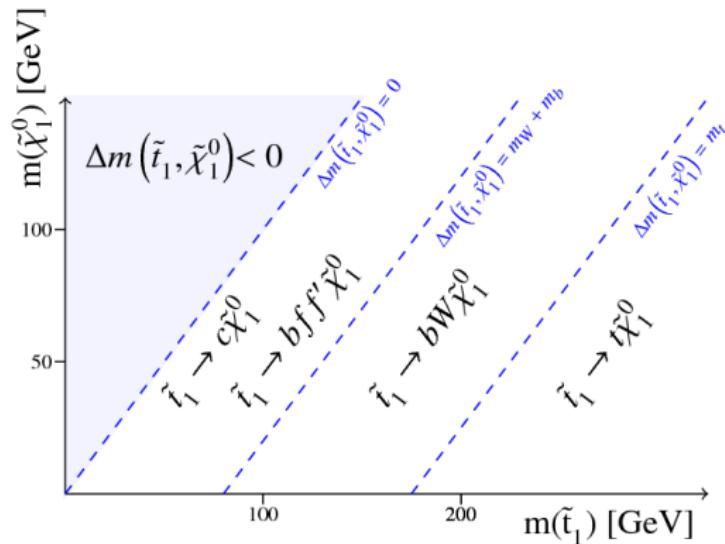
Direct sbottom searches

- In the $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$
 - Compressed scenario (**tc-M**): ISR mono-jet + E_T^{miss}
 - Bulk (**bOL**) : 0 leptons + b-jets + E_T^{miss} , use of boost-corrected contranverse mass m_{CT} arXiv:0910.0174
- In the $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^\pm (\tilde{\chi}_1^\pm \rightarrow W^{(*)}\tilde{\chi}_1^0)$
 - High jet multiplicity, 2 b-jets and up to 4 leptons
 - SR use either three leptons or same sign lepton pair

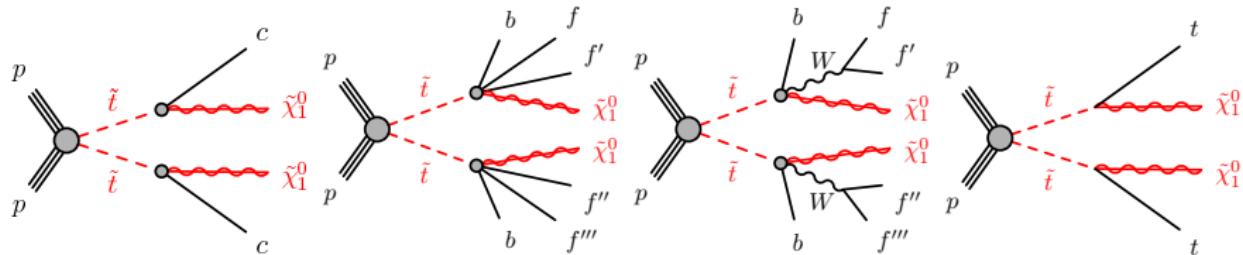


$m_{\tilde{b}_1}$ up to 640 GeV excluded at 95% CL for massless $\tilde{\chi}_1^0$ assuming $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$ with 100% BR

Direct Stop Searches - assuming no $\tilde{\chi}_1^\pm$ in the decay chain



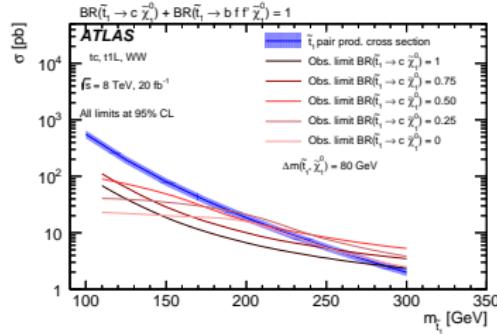
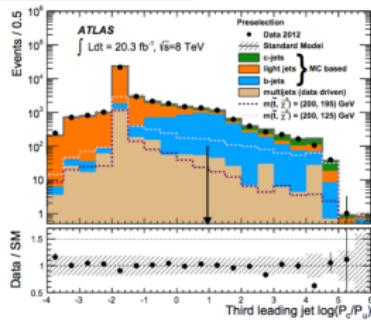
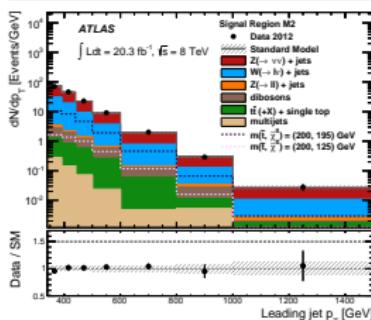
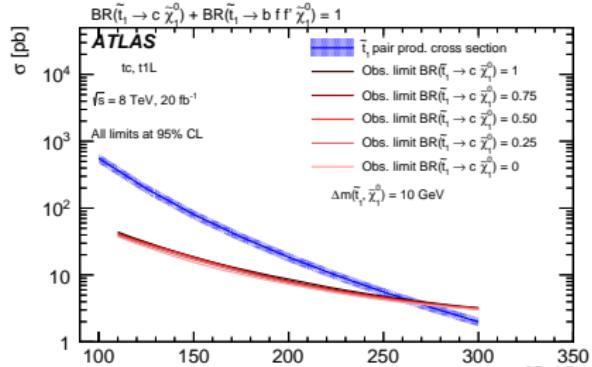
- Only \tilde{t}_1 and $\tilde{\chi}_1^0$ are considered
- Stop decay modes defined by mass separation $\Delta(\tilde{t}_1, \tilde{\chi}_1^0)$
- Exclusion limits in the $m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}$ plane



Direct Stop Searches - no $\tilde{\chi}_1^\pm$ in the decay chain

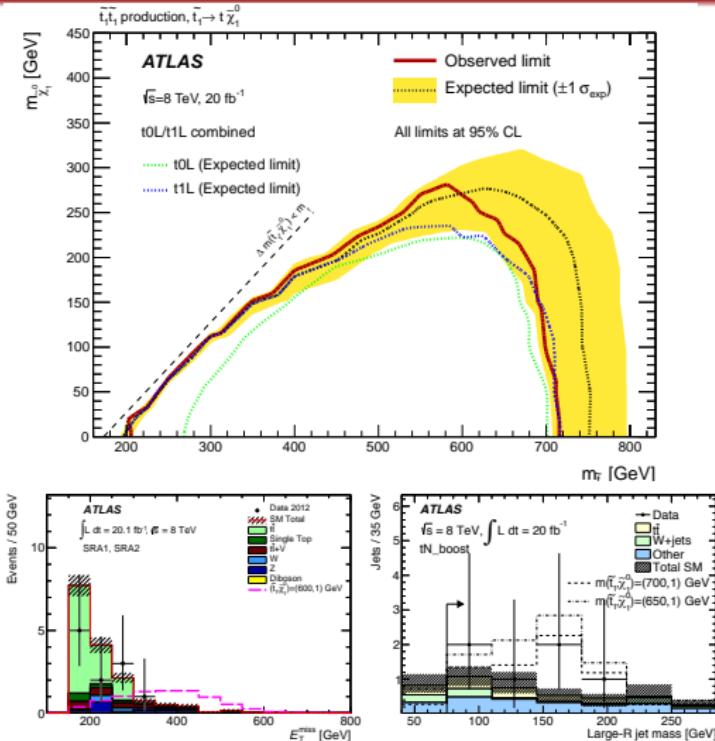
$$\Delta(\tilde{t}, \tilde{\chi}_1^0) < m_W + m_b$$

- $\tilde{t} \rightarrow c\tilde{\chi}_1^0$ and $\tilde{t} \rightarrow b f f' \tilde{\chi}_1^0$
- If $\Delta(\tilde{t}, \tilde{\chi}_1^0) \gtrsim m_b$
 - Monojet-like SR using p_T cut on ISR jet, \tilde{t}_1 pair undetected
 - c-tagging algorithms
 - Signature characterised by soft leptons
- Varying BRs at fixed values of $\Delta(m_{\tilde{t}}, m_{\tilde{\chi}_1^0}) = 10, 80$



- $m_{\tilde{t}_1} < 280$ GeV excluded at 95% CL in the compressed scenario
- Excluded $180 < m_{\tilde{t}_1} < 280$ GeV excluded under $\Delta(m_{\tilde{t}}, m_{\tilde{\chi}_1^0}) = 80$ GeV

Direct Stop Searches - no $\tilde{\chi}_1^\pm$ in the decay chain



$$\Delta(\tilde{t}, \tilde{\chi}_1^0) > m_t$$

- $\tilde{t} \rightarrow t\tilde{\chi}_1^0$: Combination of 0- and 1-lepton SRs
- **t0L** either targets:
 - Fully resolved top pairs (≥ 6 jets)
 - Boosted topologies and large- R jets
 - $t\bar{t}$, W+Jets, Z+Jets, multijets as main bkg.
- **t1L** targets large variety of possible final states
 - = 1/ I , ≥ 2 jets and large E_T^{miss}
 - 9 Total Signal regions optimised to target the full phase space - Both energetic and soft leptons signatures.
 - $t\bar{t}$ and W+jets
 - Asymmetric transverse mass (am_{T2})

Combination extends the exclusion limit of 50 GeV w.r.t. single analyses. Stop masses up to 720 GeV are excluded for massless neutralinos

Search with 2l in WW non resonant events - NEW

$$m_{\tilde{t}_1} \sim m_{\tilde{\chi}_1^\pm} \approx 200 \text{ GeV}$$

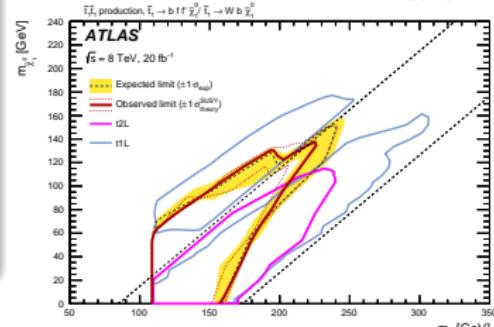
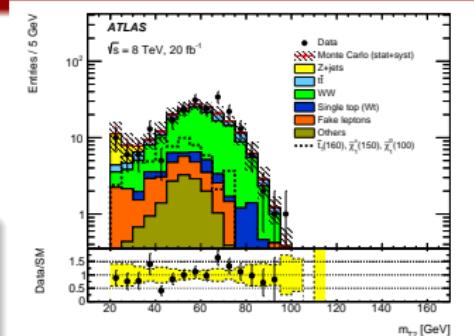
$$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \approx 10 \text{ GeV}$$

$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm, \quad \tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$$

$$m_W + m_b < \Delta(\tilde{t}, \tilde{\chi}_1^0) < m_t$$

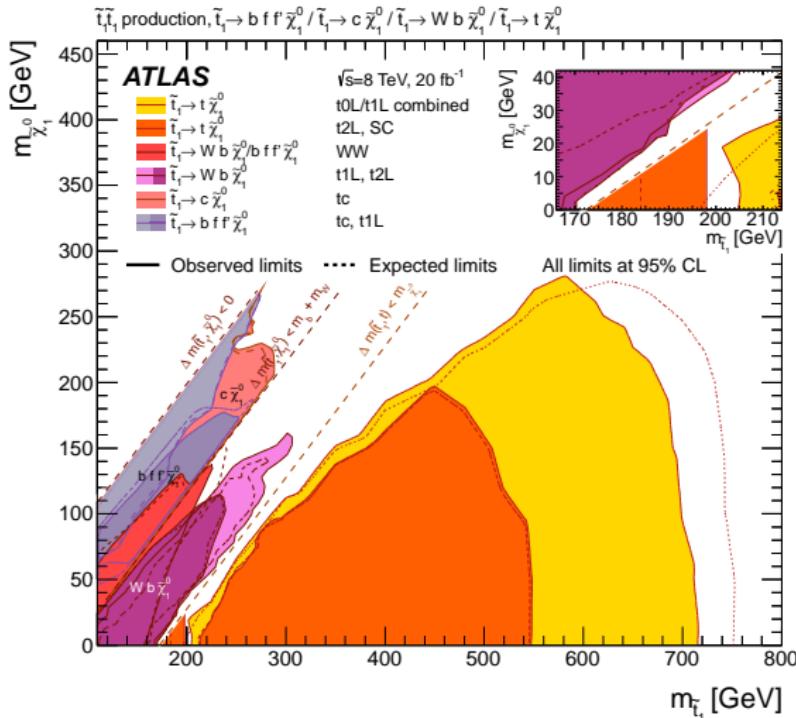
- Soft decay in $b\tilde{\chi}_1^\pm$ or 3-, 4-body decay
- SR with 2 OS leptons; bkg dominated by WW production: estimated in dedicated CRs
- Higher boost and more E_T^{miss}
- $\Delta X = \frac{p_T(l_1) + p_T(l_2)}{\sqrt{s}}$ $R_2 = \frac{E_T^{\text{miss}}}{E_T^{\text{miss}} + p_T(l_1) + p_T(l_2)}$
- SRs in terms of m_{T2} and θ_b .
- θ_b = angle between direction of motion of the 2l system and the beam axis in the com frame of the 2l

SR	WW-SR1	WW-SR2	WW-SR3	WW-SR4	WW-SR5	WW-SR6	WW-SR7
$p_T(\ell_1)$				> 25 GeV			
$p_T(\ell_2)$				> 20 GeV			
R_1				> 0.3 + m_{eff} (TeV)			
m_{T2}				> 20 GeV			
ΔX				< 0.02			
R_2				> 0.5			
$ \cos \theta_b $	< 0.8	< 0.8	< 0.8	-	-	< 0.8	-
m_{T2}	< 45 GeV	> 25, < 55 GeV	-	> 70 GeV	> 90 GeV	> 25, < 70 GeV	> 80 GeV



Signal channel	Obs	Exp	S_{obs}^{95}	S_{exp}^{95}	$\langle \epsilon \sigma \rangle_{\text{obs}}^{95} [\text{fb}]$
SR1	40	47 ± 14	22.6	$25.2^{+9.4}_{-4.3}$	1.12
SR2	71	80 ± 13	25.3	$27.8^{+11.5}_{-4.1}$	1.24
SR3	215	203 ± 27	48.4	$46.6^{+4.9}_{-6.9}$	2.38
SR4	88	81 ± 11	35.1	$28.8^{+11.0}_{-5.4}$	1.73
SR5	4	3.4 ± 0.9	6.2	$5.7^{+2.1}_{-1.4}$	0.30
SR6	160	154 ± 19	45.6	$43.8^{+19.3}_{-14.4}$	2.25
SR7	21	23 ± 4	12.4	$13.4^{+4.8}_{-3.4}$	0.61

Summary of direct searches assuming no $\tilde{\chi}_1^\pm$



$$\Delta(\tilde{t}, \tilde{\chi}_1^0) \sim m_t$$

- Very similar kinematics to SM top pair production
- Top Spin correlation analysis:
 - Use of $\Delta\phi(II)$ from dileptonic $t\bar{t}$ decay
 - $2l, \geq 2$ jets (1b).
 - $Z+jets$ suppressed by $m(II)$
- $t\bar{t}$ production cross section
 - $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$
 - \tilde{t}_1 would have an impact on the measured $\sigma_{t\bar{t}}$
 - $e\mu$ events + 1-2 b-tag.

Exclusion limits up to $m_{\tilde{t}_1} \sim 720 \text{ GeV}$ for massless $\tilde{\chi}_1^0$
 $m_{\tilde{t}_1}$ down to 170 GeV are still not excluded.

Direct Stop Searches - with $\tilde{\chi}_1^\pm$ in the decay chain

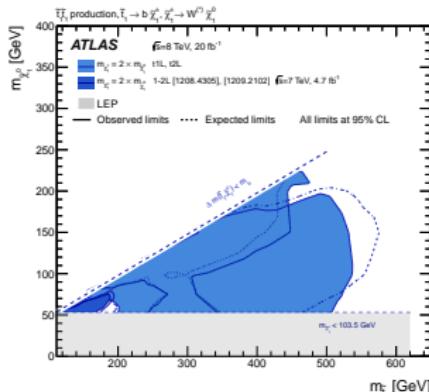
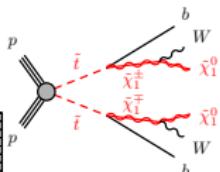
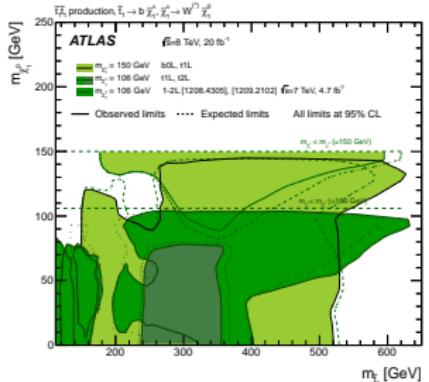
- A set of pMSSM configurations allows $m_{\tilde{t}_1} < m_{\tilde{\chi}_1^\pm} < m_{\tilde{t}_1}$
- Assumptions on $m_{\tilde{\chi}_1^\pm}$, stop mixing and $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0$ composition

$$m_{\tilde{\chi}_1^\pm} = 2m_{\tilde{\chi}_1^0}$$

- Large $\Delta(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0})$
- 1L SR. 2L only if $m_{\tilde{t}_1} \sim m_{\tilde{\chi}_1^\pm}$

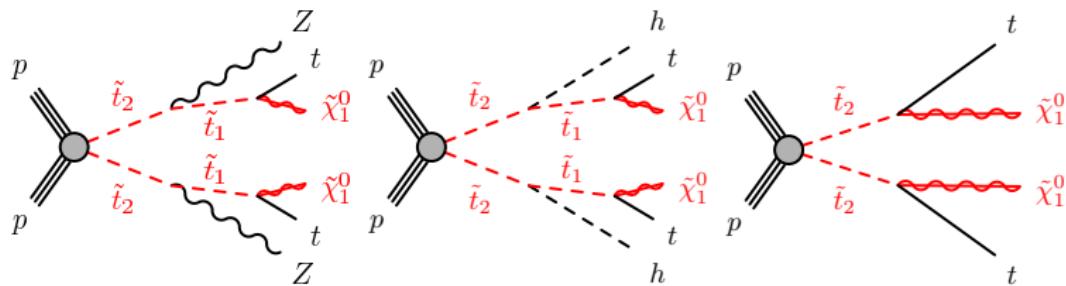
$\tilde{t}_1 \rightarrow bW^{(*)}\tilde{\chi}_1^0$ exclusion summary:

- $m_{\tilde{t}_1}$ up to 640 GeV are excluded
- $m_{\tilde{t}_1} < 260$ GeV, $100 < m_{\tilde{\chi}_1^0} < m_{\tilde{\chi}_1^\pm}$ not excluded (chargino mass fixed)
- $(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (180, 100, 50)$ GeV not excluded



Direct Searches for \tilde{t}_2

Direct Searches for \tilde{t}_2



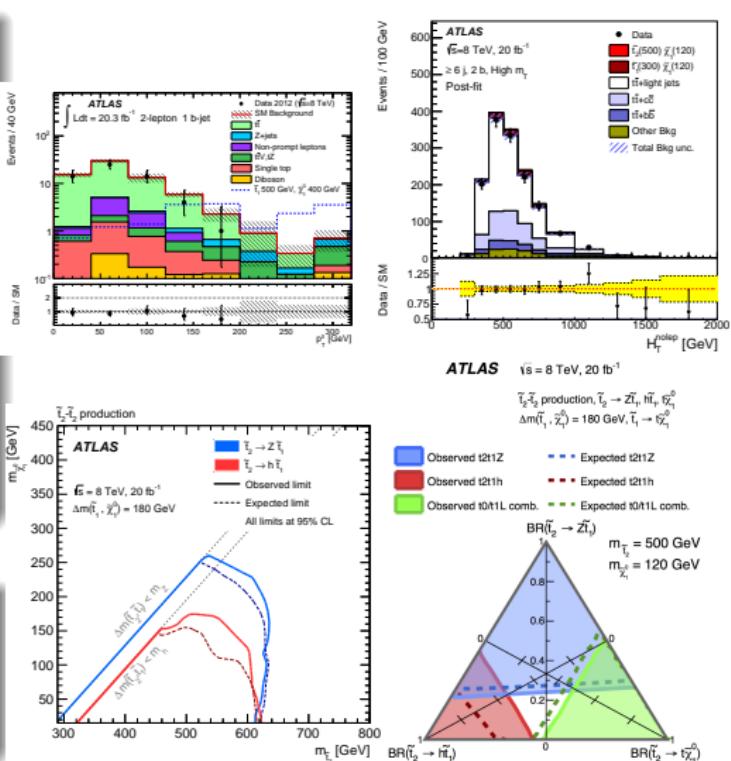
Limits on pair production of \tilde{t}_2

$$m_{\tilde{t}_1} \approx m_t + m_{\tilde{\chi}_1^0}$$

- $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ has no sensitivity (SM $t\bar{t}$ -like)
 - $\tilde{t}_2 \rightarrow \tilde{t}_1 Z$
 - High l multiplicity, cut on $p_T(l)$
 - $\tilde{t}_2 \rightarrow \tilde{t}_1 h$
 - Based on $t\bar{t}H$ analysis ref
 - High b-jet multiplicity, large E_T^{miss}
 - $H_T^{\text{nolep}} = \sum_i p_T^{\text{jet},i} + E_T^{\text{miss}}$
 - $t\bar{t}$ main background
 - Split in $t\bar{t} + \text{LF}$, $t\bar{t} + c\bar{c}$, $t\bar{t} + b\bar{b}$
 - $\tilde{t}_2 \rightarrow t\tilde{\chi}_1^0$
 - **t0L** and **t1L** Combined

$m_{\tilde{t}_2} < 630$ GeV excluded at 95% CL for $m_{\tilde{\chi}^0} = 180$ GeV

Particular scenario still not excluded with $(m_{\tilde{t}_2}, m_{\tilde{\chi}^0_1}) = (500, 120)$ GeV



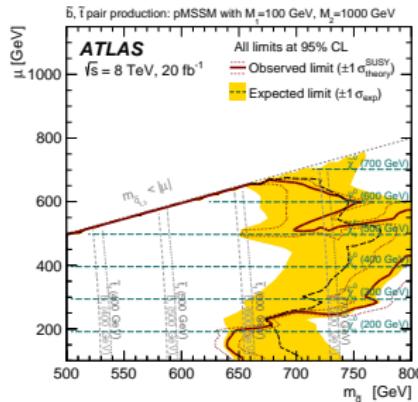
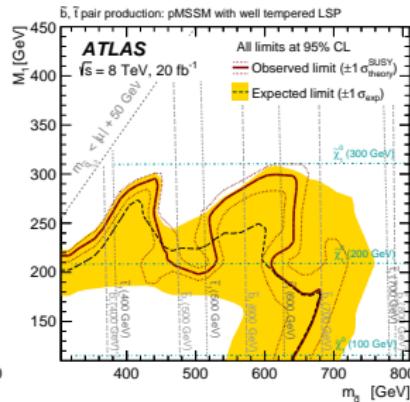
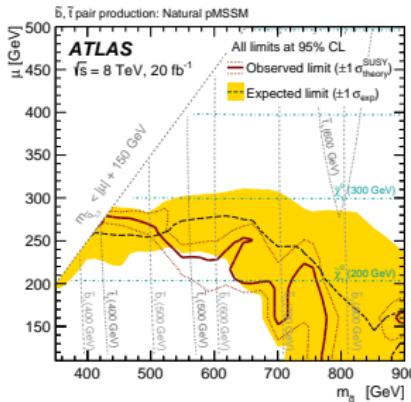
Interpretations in pMSSM models

Interpretations in pMSSM
models

Interpretations in pMSSM models

- Simplified models fail to encompass features on scenarios with complex \tilde{t} and \tilde{b} phenomenology
- Exclusion limits derived in the context of pMSSM models

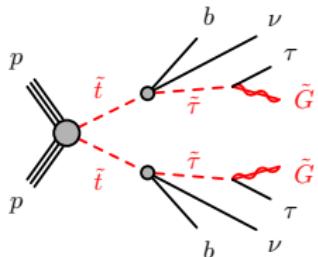
The combined exclusion contour is determined choosing the SR with the smallest expected CL_s



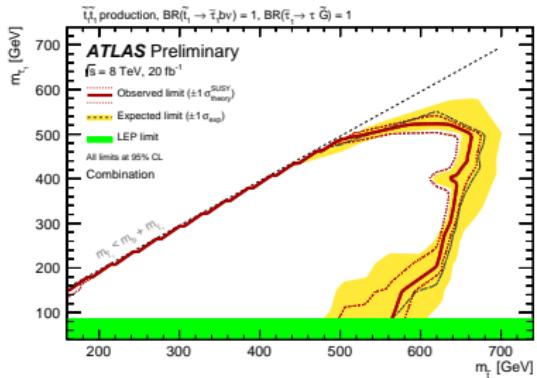
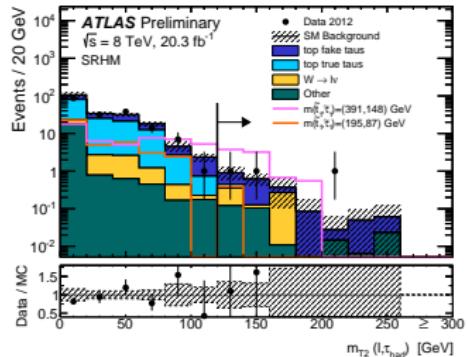
New 3rd Generation searches results

New 3rd Generation searches
results

Search for \tilde{t}_1 into $\tilde{\tau}_1$ - NEW

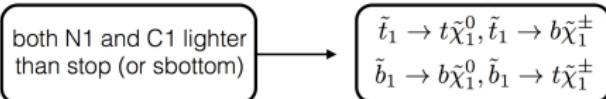


- Final state with $2\tau + b\text{-jets} + E_T^{\text{miss}}$
- Use of **transverse mass** as main discriminant
- Split by τ decay mode to maximise sensitivity
 - Had-had: $2\text{OS } \tau_{had} + \geq 2\text{jets} (\geq 1\text{b-jet}) + E_T^{\text{miss}}$
 - Lep-Had: $1\tau_{had} + \geq 2\text{jets} (1 - 2\text{b-jets})$
 - Lep-Lep: Reinterpretation of 2L SR:
JHEP06(2014)124

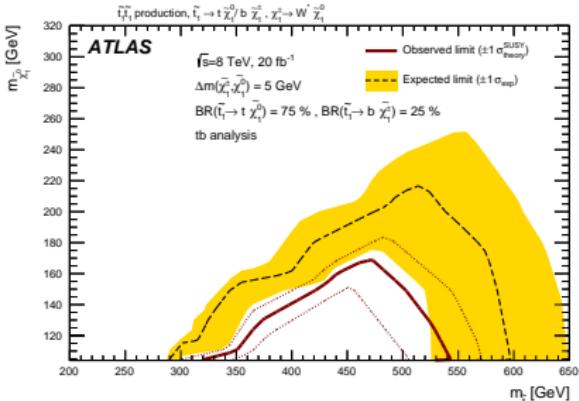
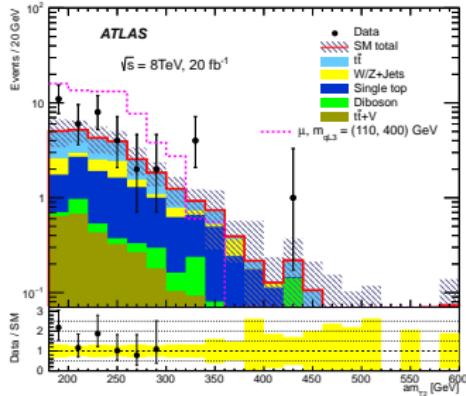


To be submitted to EPJC

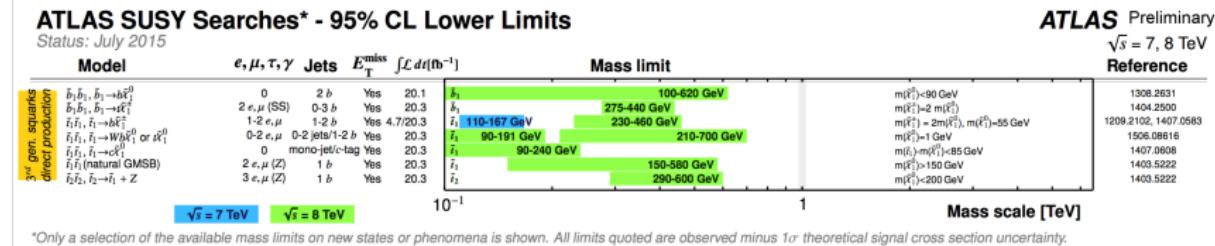
Search in 2b-jets, 1/ and E_T^{miss} (Top-Bottom) - NEW



- $\mu \ll M_1, M_2 \rightarrow \Delta(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_1^\pm})$ small
- $\tilde{t}_1\tilde{t}_1 \rightarrow tb\tilde{\chi}_1^0\tilde{\chi}_1^0 ff'$ with undetected soft fermions.
- Bkg dominated by $t\bar{t}$ and single- t : Likelihood fit on dedicated CRs
- am_{T2} constructed depending of the value of $m_{bl}(n)$, the invariant mass of the n^{th} b-jet and the lepton



Summary



- Despite our best efforts, no evidence for SUSY 3G in Run 1

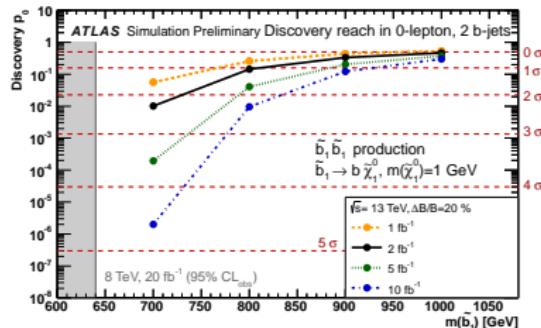
Summary:

- Latest results and exclusion limits combinations in the context of simplified models have been presented
- $m_{\tilde{t}_1}$ excluded up to 700 GeV under the assumption of $\tilde{\chi}_1^\pm$ not in the decay chain
- Still non excluded regions in the scenarios with $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \sim m_t$
- More complex phenomenology when $\tilde{\chi}_1^\pm$ is in the \tilde{t}_1 decay chain and in some scenarios, $m_{\tilde{t}_1}$ down to 200 GeV still not excluded
- Exclusion limits on three classes of pMSSM models have been set.

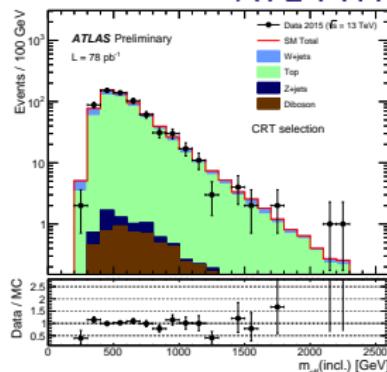
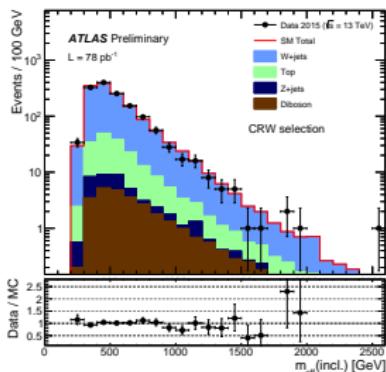
First Look at Run 2

Intensive preparation for Run 2

- Expect considerable improvement in sensitivity
- 5 fb^{-1} will be sufficient to reach 3σ evidence for \tilde{b}_1 at 730 GeV, or set exclusion limits up to 790 GeV



ATL-PHYS-PUB-2015-005



First look to the 13 TeV data shows a good agreement in the 0/1L $t\bar{t}$ and W CRs

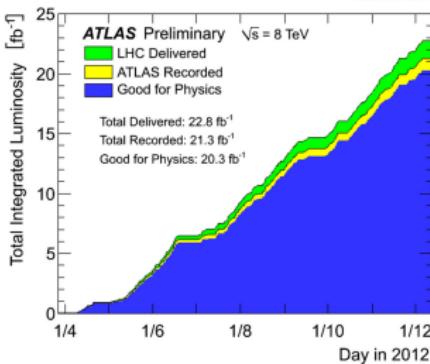
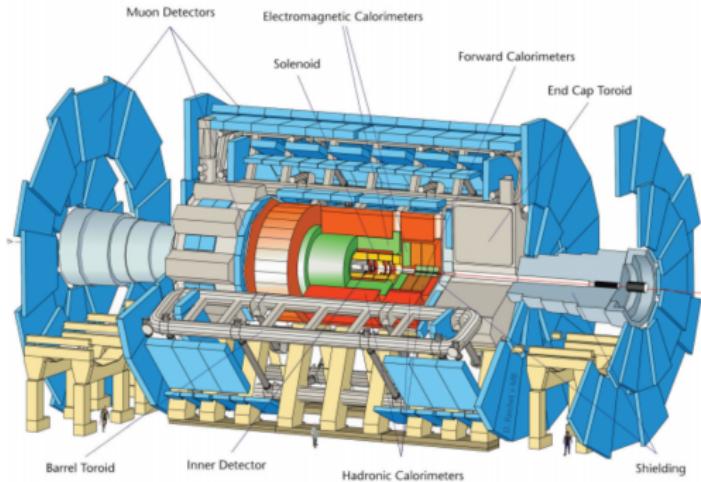
Conclusion

Thanks for the attention

BACKUP

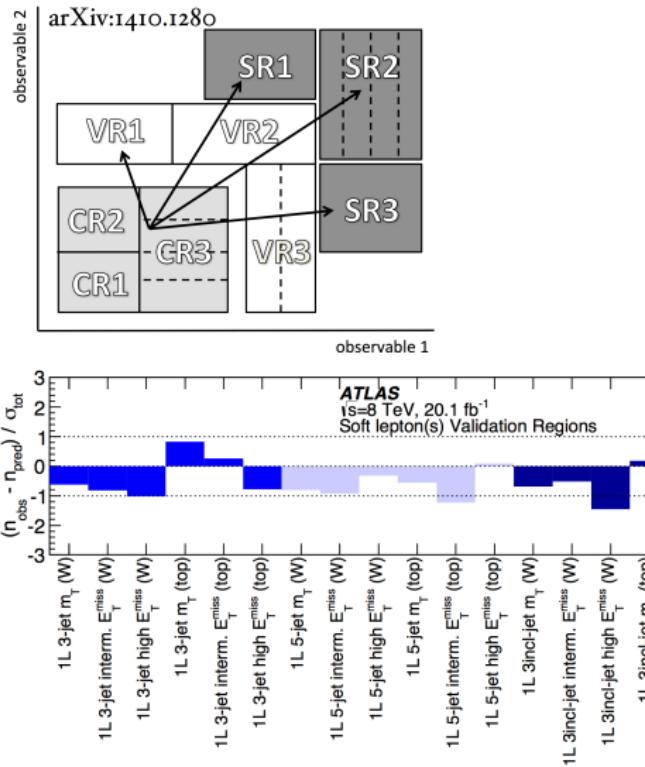
Introduction - Atlas Detector

- Inner Detector in 2T solenoid magnet: tracking and p measurement in $|\eta| < 2.5$
- LAr high-granularity electromagnetic calorimeter: $|\eta| < 3.2$
- Scintillator-tile hadron calorimeter $|\eta| < 1.7$
- LAr hadron and em calorimeters for endcaps and forward regions: $1.5 < |\eta| < 4.9$
- Muon spectrometers providing trigger coverage ($|\eta| < 2.4$) and muon ID and p measurement ($|\eta| < 2.7$)
- March-December 2012 dataset with $\sqrt{s} = 8 \text{ TeV}$, 20.3 fb^{-1} , with 2.8% of associated uncertainty



General Analysis Strategy

- **Signal Selection (signal region SR):** Optimisation on a set of variables to discriminate between a specific SUSY model and SM background
- **Background estimate:**
 - **Irreducible background:** use of MC simulation for modelling and use of data in CRs (control regions) to constrain the normalisation
 - **Reducible background:** use of data driven method
- **Validation Regions (VRs):** regions statistically independent but kinematically close to the SRs used to check the validity of the background estimates in CRs in the SRs



arXiv:1501.035555

Systematics Uncertainties

- The systematic sources are analysis specific, but they follow similar structure
 - Detector response systematics: JES, JER, MET resolution...
 - Analysis specific systematics: normalisation on the data driven background estimate,..
 - Theoretical uncertainties: ISR/FSR, cross sections,...
 - Background normalisation (Control Region statistics dependent)
 - MC statistics
- Many systematics cancel during the CR → SR extrapolation

SUSY Fine Tuning Formulas - Slide from T. Lari

- ❖ The derivation of upper bounds on the different SUSY particles from naturalness was first discussed in a paper of Barbieri and Giudice in 1987 (Nucl. Phys. B306, 63)
- ❖ After the 2011 LHC results pushed limits on squark and gluinos around 1 TeV, lots of discussion on naturalness-based susy spectra. In slide X I used the formulas in Papucci, Rudermann and Weiler, arXiv:1110.6926v1

$$\mu \lesssim 200 \text{ GeV} \left(\frac{m_h}{120 \text{ GeV}} \right) \left(\frac{\Delta^{-1}}{20\%} \right)^{-1/2} \quad \text{Tree-level Higgs mass relation to Higgsinos. Very simple, just solve for delta.}$$

$$\delta m_{H_u}^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2 \right) \log \left(\frac{\Lambda}{\text{TeV}} \right)$$



$$\sqrt{m_{t_1}^2 + m_{t_2}^2} \lesssim 600 \text{ GeV} \frac{\sin \beta}{(1 + x_t^2)^{1/2}} \left(\frac{\log(\Lambda/\text{TeV})}{3} \right)^{-1/2} \left(\frac{m_h}{120 \text{ GeV}} \right) \left(\frac{\Delta^{-1}}{20\%} \right)^{-1/2}$$

One loop Higgs mass relation to stops. The **minimum** fine tuning for a given lightest stop mass occurs for $\sin b = 1$, no mixing, and $m_{t1} = m_{t2}$. I put these conditions and solved for delta.

$$\delta m_{H_u}^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2 \left(\frac{\Lambda}{\text{TeV}} \right)$$
$$M_3 \lesssim 900 \text{ GeV} \sin \beta \left(\frac{\log(\Lambda/\text{TeV})}{3} \right)^{-1} \left(\frac{m_h}{120 \text{ GeV}} \right) \left(\frac{\Delta^{-1}}{20\%} \right)^{-1/2}$$

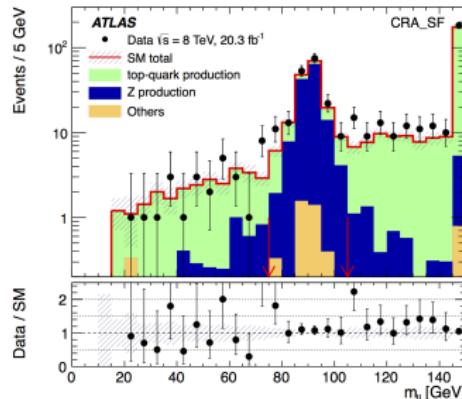
Two loop contribution from gluinos. The **minimum** fine tuning for a given gluino mass occurs for $\sin b = 1$. I put these conditions and solved for delta.

Direct Sbottom Searches: 0L (JHEP 1310 (2013) 189)

- b0L Signal Regions
- Z+HF, W+HF, ttbar main bkgd
- $m_{CT}(\nu_1, \nu_2) = [E_T(\nu_1) - E_T(\nu_2)]^2 - [\vec{p}_T(\nu_1) - \vec{p}_T(\nu_2)]^2$

Description	Signal Regions	
	SRA	SRB
Event cleaning	Common to all SR	
Lepton veto	No e/μ after overlap removal with $p_T > 7(6)$ GeV for $e(\mu)$	
E_T^{miss}	> 150 GeV	> 250 GeV
Leading jet $p_T(j_1)$	> 130 GeV	> 150 GeV
Second jet $p_T(j_2)$	> 50 GeV,	> 30 GeV
Third jet $p_T(j_3)$	veto if > 50 GeV	> 30 GeV
$\Delta\phi(p_T^{\text{miss}}, j_1)$	-	> 2.5
b -tagging	leading 2 jets	2nd- and 3rd-leading jets
	$(p_T > 50$ GeV, $ \eta < 2.5)$	$(p_T > 30$ GeV, $ \eta < 2.5)$
	$n_{b\text{-jets}} = 2$	
$\Delta\phi_{\min}$	> 0.4	> 0.4
$E_T^{\text{miss}}/m_{\text{eff}}(k)$	$E_T^{\text{miss}}/m_{\text{eff}}(2) > 0.25$	$E_T^{\text{miss}}/m_{\text{eff}}(3) > 0.25$
m_{CT}	$> 150, 200, 250, 300, 350$ GeV	-
$H_{T,3}$	-	< 50 GeV
m_{bb}	> 200 GeV	-

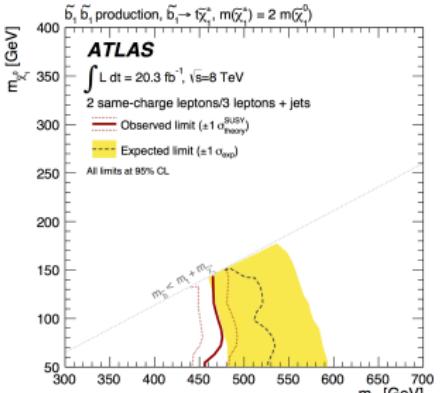
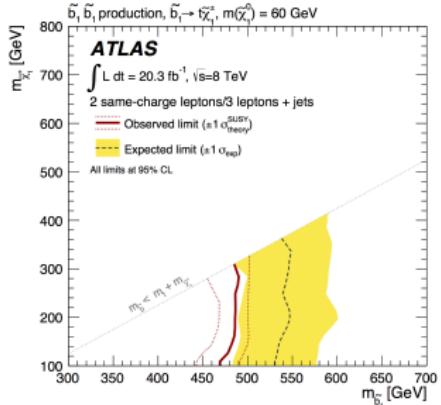
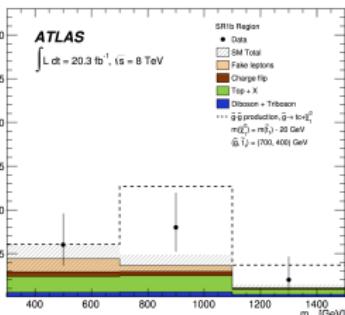
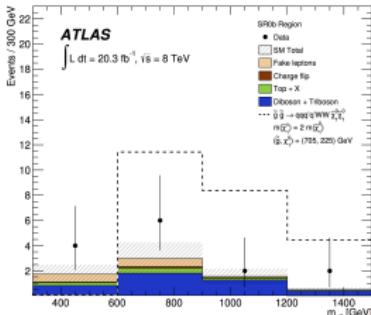
- Bkg normalisations obtained from simultaneous fit in CRs
- di-lepton side-bandes used to control Z+HF contribution
- Normalisation fits in agreement with MC predictions



Direct Sbottom Searches: SS and 3L (arXiv:1404.2500)

- 5 signal region with either SS or 3 leptons in the final state
- prompt (W or Z decays), "fake" leptons and charge mis-measured electrons (high-pT of the brem γ)

SR	Leptons	$N_{b\text{-jets}}$	Other variables	Additional requirement on m_{eff}	
SR3b	SS or 3L	≥ 3	$N_{\text{jets}} \geq 5$	$m_{\text{eff}} > 350$ GeV	
SR0b	SS	= 0	$N_{\text{jets}} \geq 3$, $E_T^{\text{miss}} > 150$ GeV, $m_{\text{T}} > 100$ GeV	$m_{\text{eff}} > 400$ GeV	
SR1b	SS	≥ 1	$N_{\text{jets}} \geq 3$, $E_T^{\text{miss}} > 150$ GeV, $m_{\text{T}} > 100$ GeV, SR3b veto	$m_{\text{eff}} > 700$ GeV	
SR3Llow	3L	-	$N_{\text{jets}} \geq 4$, $50 < E_T^{\text{miss}} < 150$ GeV, Z boson veto, SR3b veto	$m_{\text{eff}} > 400$ GeV	
SR3Lhigh	3L	-	$N_{\text{jets}} \geq 4$, $E_T^{\text{miss}} > 150$ GeV, SR3b veto	$m_{\text{eff}} > 400$ GeV	



Direct Sbottom Searches: $\tilde{b}_1 \rightarrow b\tilde{\chi}_2$

- $\tilde{b}_1 \rightarrow b\tilde{\chi}_2 (\tilde{\chi}_2 \rightarrow h\tilde{\chi}_1)$

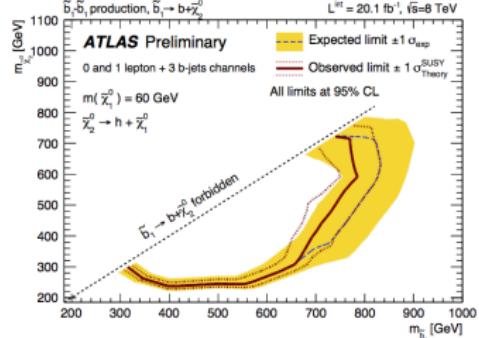
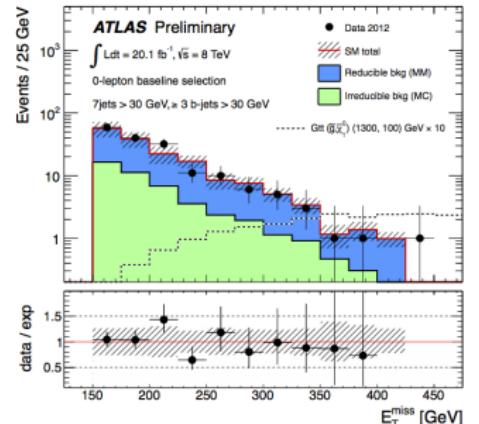
- Up to 6 jets in the final state
- 4 jets with $p_T > 30$ GeV (3 b-tagged)
- Large E_T^{miss} - Large

$$m_{\text{eff}} = \sum_i^{\text{jets}} p_T^i + E_T^{\text{miss}}$$

baseline 0- ℓ selection: lepton veto, $p_T^h > 90$ GeV, $E_T^{\text{miss}} > 150$ GeV,
 ≥ 4 jets with $p_T > 30$ GeV, $\Delta\phi_{\min}^{4j} > 0.5$, $E_T^{\text{miss}} / m_{\text{eff}}^{4j} > 0.2$, ≥ 3 b-jets with $p_T > 30$ G

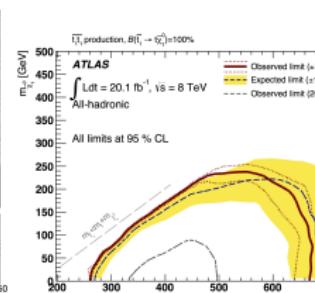
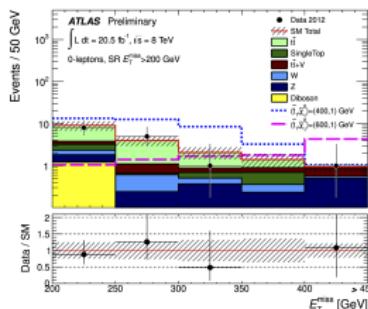
	N jets (p_T [GeV])	E_T^{miss} [GeV]	m_{eff} [GeV]	$E_T^{\text{miss}} / \sqrt{H_T^{4j}}$ [$\sqrt{\text{GeV}}$]
SR-0 ℓ -4j-A	≥ 4 (50)	> 250	$m_{\text{eff}}^{4j} > 1300$	—
SR-0 ℓ -4j-B	≥ 4 (50)	> 350	$m_{\text{eff}}^{4j} > 1100$	—
SR-0 ℓ -4j-C*	≥ 4 (30)	> 400	$m_{\text{eff}}^{4j} > 1000$	> 16
SR-0 ℓ -7j-A	≥ 7 (30)	> 200	$m_{\text{eff}}^{\text{incl}} > 1000$	—
SR-0 ℓ -7j-B	≥ 7 (30)	> 350	$m_{\text{eff}}^{\text{incl}} > 1000$	—
SR-0 ℓ -7j-C	≥ 7 (30)	> 250	$m_{\text{eff}}^{\text{incl}} > 1500$	—

- No statistical evidence of any excess
- 95% CL limits assuming 100% BR of
 $\tilde{b}_1 \rightarrow \tilde{\chi}_2^\pm$



Direct Stop Searches in 0L channel (JHEP 09 (2014) 015)

- Final state with 0L + 6 jets (2b) + E_T^{miss}
- Bkg: ttbar, W+Jets (missed lepton), Z+jets, ttZ
- bjet closest to $\vec{p}_T^{\text{miss}} \rightarrow m_T^b > 175$ GeV
- SRs exploit R=1.2 reclustered jets
- Multijet from Jet Smearing



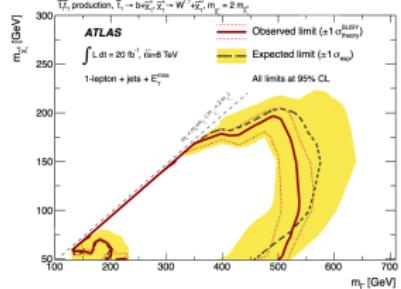
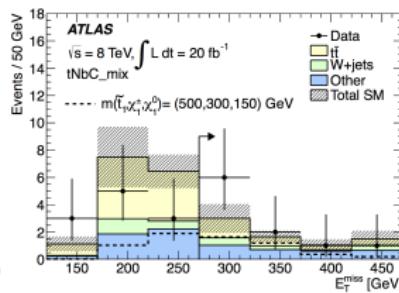
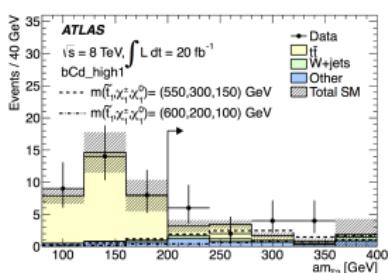
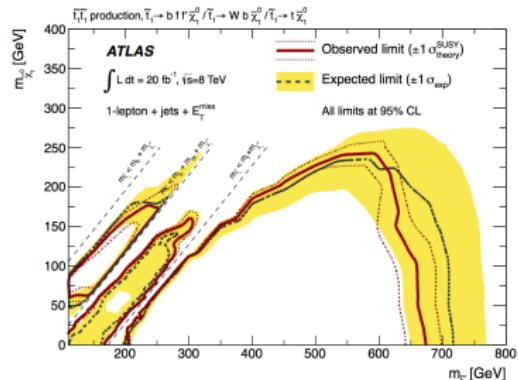
	SRA1	SRA2	SRA3	SRA4
anti- k_T $R = 0.4$ jets	$\geq 6, p_T > 80, 80, 35, 35, 35, 35$ GeV			
$m_{b,jj}^0$	< 225 GeV	[50,250] GeV		
$m_{b,jj}^1$	< 250 GeV	[50,400] GeV		
$\min[m_T(\text{jet}^l, \text{p}_T^{\text{miss}})]$	–		> 50 GeV	
τ veto		yes		
E_T^{miss}	> 150 GeV	> 250 GeV	> 300 GeV	> 350 GeV

	SRB1	SRB2
anti- k_T $R = 0.4$ jets	4 or 5, $p_T > 80, 80, 35, 35, (35)$ GeV	$5, p_T > 100, 100, 35, 35, 35$ GeV
$\Delta\phi_{m_T}$	< 0.5	> 0.5
$p_T^0, \text{jet}, R=1.2$	–	> 350 GeV
$m_{\text{jet}, R=1.2}^0$	> 80 GeV	[140, 500] GeV
$m_{\text{jet}, R=1.2}^1$	[60, 200] GeV	–
$m_{\text{jet}, R=0.8}^0$	> 50 GeV	[70, 300] GeV
$m_{\text{jet}, R=0.8}^1$	> 175 GeV	> 125 GeV
$m_T(\text{jet}^l, \text{p}_T^{\text{miss}})$	> 280 GeV for 4-jet case	–
$E_T^{\text{miss}}/\sqrt{H_T}$	–	$> 17/\sqrt{\text{GeV}}$
E_T^{miss}	> 325 GeV	> 400 GeV

	SRC1	SRC2	SRC3
anti- k_T $R = 0.4$ jets	$5, p_T > 80, 80, 35, 35, 35$ GeV		
$ \Delta\phi(b, b) $		$> 0.2\pi$	
m_T^b, min	> 185 GeV	> 200 GeV	> 200 GeV
m_T^b, max	> 205 GeV	> 290 GeV	> 325 GeV
τ veto		yes	
E_T^{miss}	> 160 GeV	> 160 GeV	> 215 GeV

Direct Stop Searches in 1L channel (JHEP 1411 (2014) 118)

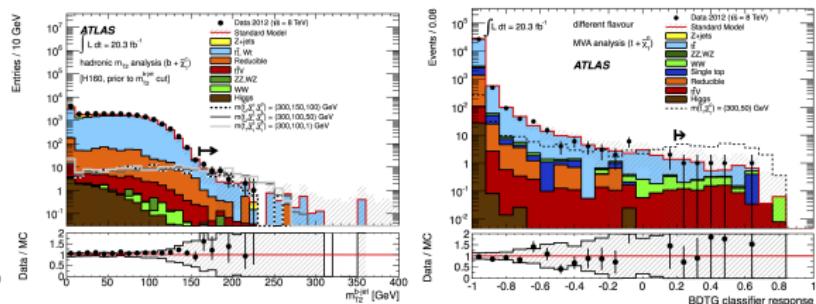
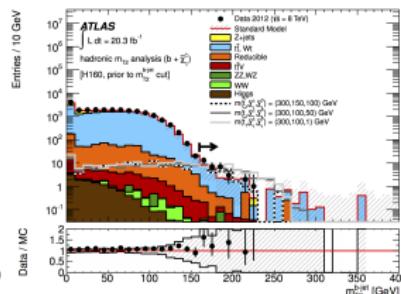
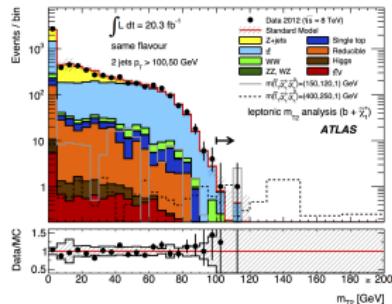
- Search targets the processes $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ or $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, with $\tilde{\chi}_1^\pm \rightarrow W + LSP$
- 9 total Signal regions with 1 ℓ , large E_T^{miss} , 2nd ℓ veto. Target the full phase space
- $t\bar{t}$ and W main bkgs, constrained by normalisation fits to CRs.
- Use of transverse and stransverse mass, τ_{had} veto and topness



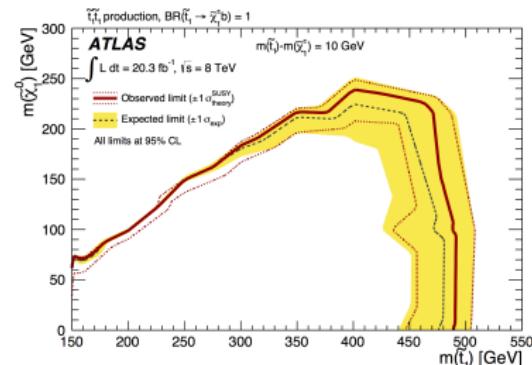
- CL set on direct production of \tilde{t}_1 pairs under various BR and $m_{\tilde{\chi}_1^\pm}$ assumptions

Direct Stop Searches in 2L channel (JHEP 1406 (2014) 124)

- Search targets decays $\tilde{t}_1 \rightarrow b\tilde{\chi}_0^\pm$ or 3-body decay $\tilde{t}_1 \rightarrow bl\nu$ or $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
- Signal regions based either on transverse mass (leptonic or hadronic) or on MVA techniques
- Prompt bkgd from SM processes ($t\bar{t}$, VV , Wt , ...) from MC. Fakes and non prompt leptons estimated by data driven techniques

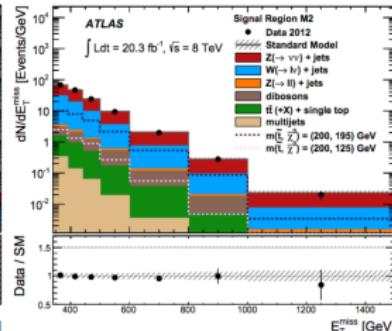
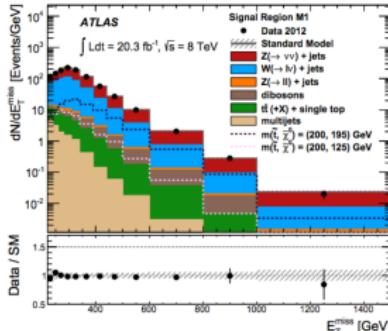


- CL set on direct production of \tilde{t}_1 pairs under various BR and $m_{\tilde{\chi}_1^\pm}$ assumptions

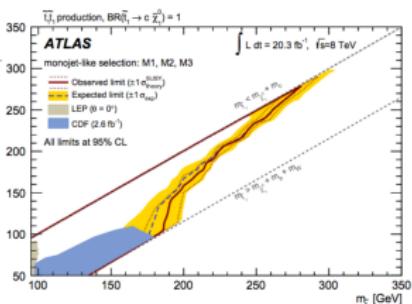


Monojet Searches (arXiv:1407.0608v2)

- Search targets compressed spectra of $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$ and $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ and four body decay
- SM bkg $Z(\rightarrow \nu\nu) + \text{jets}$, $t\bar{t}$ and $W(\rightarrow l\nu) + \text{jets}$. Fit to data in CRs
- Multijet events estimated by JetSmearing



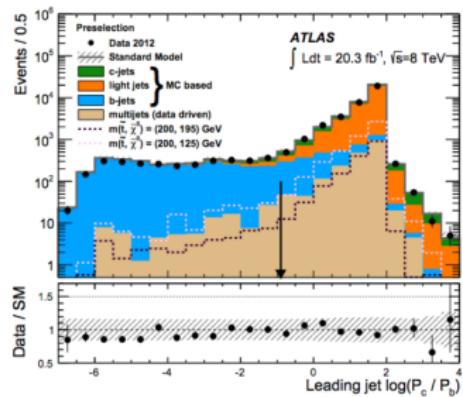
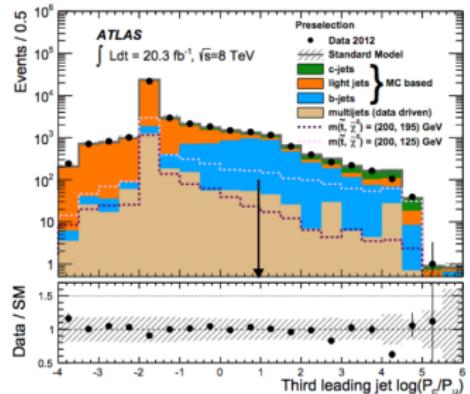
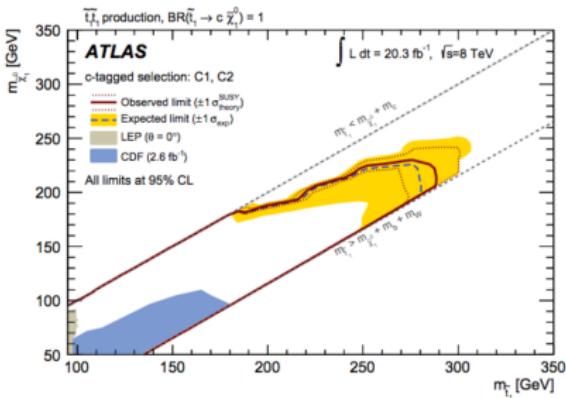
Selection criteria			
Preselection			
Primary vertex			
$E_T^{\text{miss}} > 150 \text{ GeV}$			
At least one jet with $p_T > 150 \text{ GeV}$ and $ \eta < 2.8$			
Jet quality requirements			
Lepton vetoes			
Monojet-like selection			
At most three jets with $p_T > 30 \text{ GeV}$ and $ \eta < 2.8$			
$\Delta\phi(\text{jet}, p_T^{\text{miss}}) > 0.4$			
Signal region	M1	M2	M3
Minimum leading jet p_T (GeV)	280	340	450
Minimum E_T^{miss} (GeV)	220	340	450



Stop into charm (arXiv:1407.0608v2)

- Similar to the mono jet searches, left compress scenarios.
- Multivariate c-tagger trained against b jets and LF jets separately.
- c-tagging uncertainty below 3% in the SRs

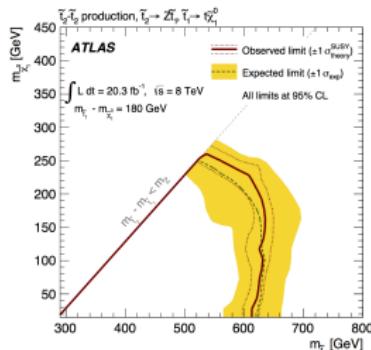
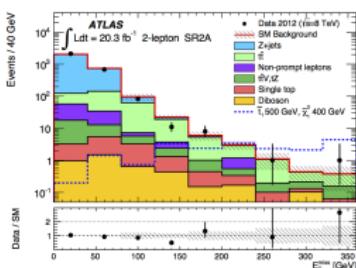
c-tagged selection		
At least four jets with $p_T > 30 \text{ GeV}$ and $ \eta < 2.5$		
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.4$	C1	C2
All four jets must pass loose tag requirements (b -jet vetoes)	290	290
At least one medium charm tag in the three subleading jets	250	350
Signal region		
Minimum leading jet p_T (GeV)	290	290
Minimum E_T^{miss} (GeV)	250	350



Direct $\tilde{t}_2 \rightarrow \tilde{t}_1 Z$ search (EPJC74 (2014) 2883)

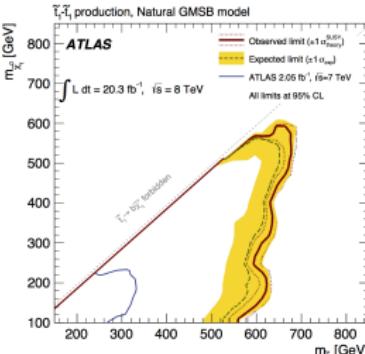
	SR2A	SR2B	SR2C	CR2A	CR2C	SR3A	SR3B
N^{leptons}	2	2	2	2	2	3	3
$p_T(t_1)$ [GeV]	> 25	> 25	> 25	> 25	> 25	> 40	> 60
dilepton flavour	SF	SF	SF,DF	SF,DF	SF	SF	SF
$ m_{\ell\ell} - m_Z $ [GeV]	< 5	< 10	< 5	< 50	< 50	< 10	< 10
				> 10 (SF)	> 10 (SF)		
$N^{\text{b-jets}}$	≥ 1	≥ 1	≥ 1	≥ 1	≥ 1	≥ 1	≥ 1
N^{jets}	3, 4	3, 4	≥ 5	3, 4	≥ 5	≥ 5	≥ 5
$p_T(\text{jet}_1)$ [GeV]	> 30	> 30	> 30	> 30	> 30	> 50	> 40
$p_T(\text{jet}_N)$ [GeV]	> 30	> 30	> 30	> 30	> 30	> 30	> 40
E_T^{miss} [GeV]	> 160	> 200	> 160	> 160	> 120	> 60	> 60
$p_T(t\ell)$ [GeV]	> 80	> 160	> 80	> 80	> 80	-	-
$\Delta\phi(\ell\ell)$ [rad]	< 1.5	< 1.5	< 1.5	< 1.5	< 1.5	-	-

- Bkgs from fake/non-prompt leptons: use of Matrix Method
- tbar and ttbar+V: CR constrain
- Z+jets: Jet Smearing method
- Final state with several leptons: $p_T(\ell\ell)$ and SFOS $\Delta\phi(\ell\ell)$ cut



	SR2A	SR2B	SR2C
Data	10	1	2
Fitted total SM	10.8 ± 1.7	2.4 ± 0.9	3.5 ± 0.5
p_0	0.50	0.50	0.50
Fitted $t\bar{t}$	7.3 ± 1.4	1.4 ± 0.7	2.4 ± 0.4
Fitted single top	0.61 ± 0.15	0.23 ± 0.17	$0.10^{+0.11}_{-0.10}$
Fitted $Z + \text{jets}$	0.91 ± 0.22	0.14 ± 0.06	0.16 ± 0.06
Fitted diboson	0.46 ± 0.34	0.27 ± 0.21	0.15 ± 0.12
Fitted $t\bar{V}, tZ$	1.0 ± 0.4	0.38 ± 0.18	0.65 ± 0.23
Fitted non-prompt	0.52 ± 0.11	< 0.05	< 0.01
MC exp. total SM	11.6	3.0	4.8
MC exp. $t\bar{t}$	8.1	2.0	3.7
MC exp. single top	0.61	0.24	0.14
Data-driven $Z + \text{jets}$	0.88	0.13	0.18
MC exp. diboson	0.48	0.28	0.15
MC exp. $t\bar{V}, tZ$	1.0	0.38	0.66
Data-driven non-prompt	0.52	< 0.05	< 0.01

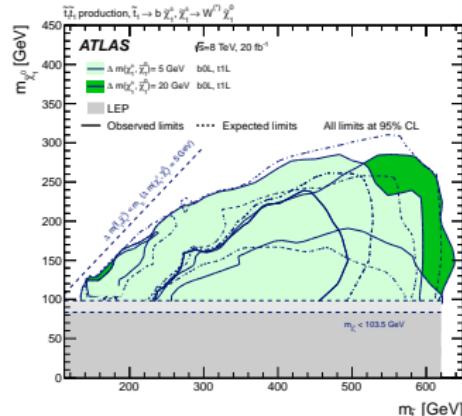
	SR3A	SR3B
Data	4	2
Total SM	4.5 ± 1.4	1.3 ± 0.4
p_0	0.50	0.30
MC exp. $t\bar{V}, tZ$	3.5 ± 1.2	1.1 ± 0.4
MC exp. diboson, triboson	0.1 ± 0.1	0.1 ± 0.1
MC exp. $Wh, Zh, t\bar{th}$	0.1 ± 0.1	0.04 ± 0.04
Data-driven non-prompt	0.8 ± 0.7	< 0.2



Summary of Stop Searches with $\tilde{\chi}_1^\pm$ in the decay chain

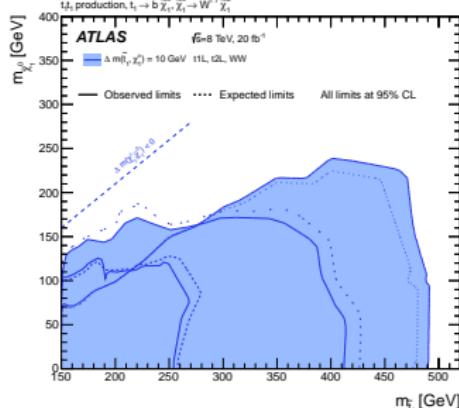
$$\Delta(m_{\tilde{t}_1^\pm}, m_{\tilde{\chi}_1^0}) = 5, 20 \text{ GeV}$$

- $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm \rightarrow bff'\tilde{\chi}_1^0$
- Either use of lepton veto or single soft lepton requirement
- Stop masses up to 620 GeV with $m_{\tilde{\chi}_1^0} = 150$ GeV are excluded



$$\Delta(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^\pm}) = 10 \text{ GeV}$$

- At low $m_{\tilde{t}_1}$ compressed scenario: covered by SRs targeting soft leptons (i.e. WW)
- At high $m_{\tilde{t}_1}$ high- p_T leptons: use of 2L final state SR
- Stop masses up to 490 GeV with low neutralino masses are excluded



Signal regions summary

Analysis name and corresponding reference	Analysis acronym	Original signal region name	Model targeted
Multijet final states	t0L	SRA1-4	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
		SRB	$\tilde{t}_1 \tilde{t}_1 \rightarrow b\tilde{t}\tilde{\chi}_1^0\tilde{\chi}_1^\pm$ with $m_{\tilde{\chi}_1^\pm} = 2m_{\tilde{\chi}_1^0}$
		SRC1-3	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ with $m_{\tilde{t}_1} \sim m_t + m_{\tilde{\chi}_1^0}$
One-lepton final states	t1L	tN_diag	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
		tN_med, tN_high, tN_boost	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
		bCa_low, bCa_med, bCb_med1, bCb_high, bCb_med2, bCc_diag	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$
		bCd_bulk, bCd_high1, bCd_high2	$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$
Two-lepton final states	t2L	3body	$\tilde{t}_1 \rightarrow bW\tilde{\chi}_1^0$ (three-body decay)
		tNbC_mix	$\tilde{t}_1 \tilde{t}_1 \rightarrow b\tilde{\chi}_1^0\tilde{\chi}_1^\pm$ with $m_{\tilde{\chi}_1^\pm} = 2m_{\tilde{\chi}_1^0}$
		L90, L100, L110, L120, H160	$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$, three-body decay
Final states from compressed stop decays	tc	M1-4	$\tilde{t}_1 \rightarrow \tilde{t}\tilde{\chi}_1^0$
		M1-3	$\tilde{t}_1/\tilde{b}_1 \rightarrow \text{anything}$ with $m_{\tilde{t}_1} \sim m_{\tilde{\chi}_1^0}$
Final states with a Z boson	t2t1Z	C1-2	$\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$
		SR2A, SR2B, SR2C, SR3A, SR3B	$\tilde{t}_2 \rightarrow \tilde{t}_1 Z$ and $\tilde{t}_2 \rightarrow \tilde{t}_1 h$
Final states with two b -jets and E_T^{miss}	b0L	SRA, SRB	$\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$ and $\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$ with $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0}$
Final states with two leptons at intermediate m_{T2}	WW	SR1-7	$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm$ with $m_{\tilde{\chi}_1^\pm} = m_{\tilde{t}_1} - 10 \text{ GeV}$ and $\tilde{t}_1 \rightarrow b\ell\nu\tilde{\chi}_1^0$ (three- and four-body decays)
Final states containing two top quarks and a Higgs boson	t2t1h	—	$\tilde{t}_2 \rightarrow \tilde{t}_1 h$
Final states containing a top and a b -quark	tb	SR1-5	$\tilde{t}_1 \tilde{t}_1 \rightarrow b\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ with $m_{\tilde{\chi}_1^\pm} \sim m_{\tilde{\chi}_1^0}$ and pMSSM models
Final states with three b -jets	g3b	SR-0 ℓ -4j-A, SR-0 ℓ -4j-B, SR-0 ℓ -4j-C, SR-0 ℓ -7j-A, SR-0 ℓ -7j-B, SR-0 ℓ -7j-C, SR-1 ℓ -6j-A, SR-1 ℓ -6j-B, SR-1 ℓ -7j-C	gluino-mediated \tilde{t}_1 and \tilde{b}_1 production, $\tilde{b}_1 \rightarrow \tilde{\chi}_2^0 b \rightarrow \tilde{\chi}_1^0 hb$
Strongly produced final states with two same-sign or three leptons	SS3L	SR3b, SR0b, SR1b, SR3Llow, S3Lhigh	Generic gluino and squark production, $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^\pm$
Spin correlation in $t\bar{t}$ production events	SC	—	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ with $m_{\tilde{t}_1} \sim m_t + m_{\tilde{\chi}_1^0}$
$t\bar{t}$ production cross section	xsec	—	$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, three-body decay