Searches for third generation squarks, and for electroweak production of charginos and neutralinos in ATLAS

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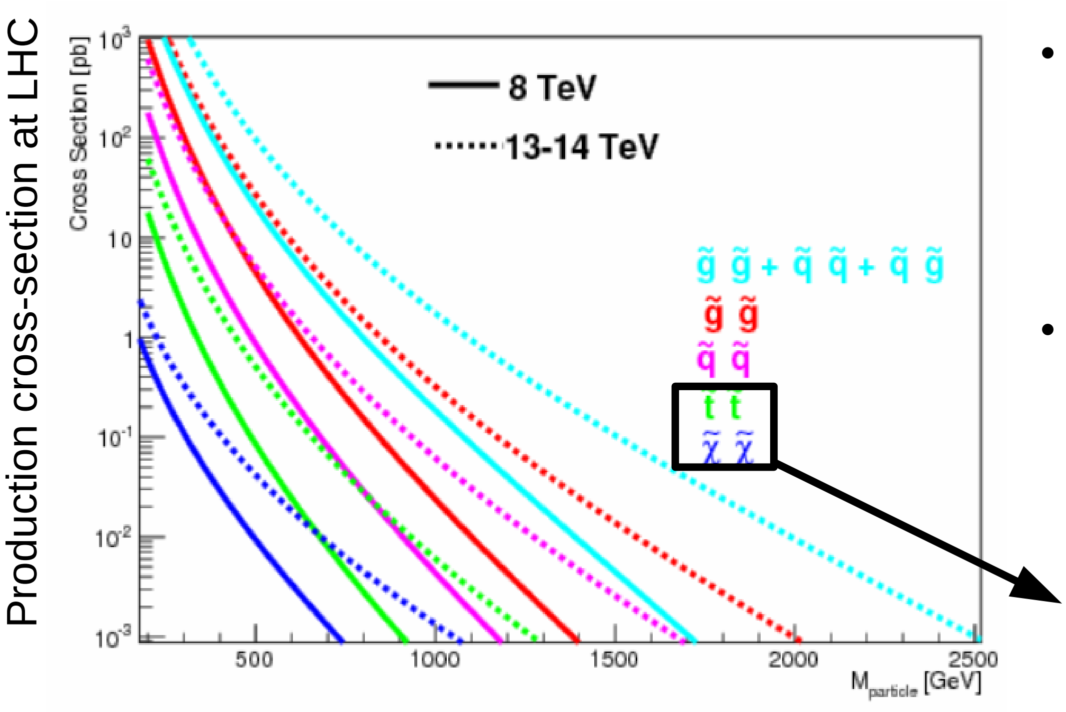
on behalf of the ATLAS collaboration

SUSY searches in ATLAS

- First- and second-generation squarks and gluinos have highest production cross-sections → covered by previous talk
- Naturalness arguments favour light partners of the third generation quarks (and higgsinos): stop$_L$, stop$_R$, sbottom$_L$
- If strong production is suppressed, EWK processes may be the key to finding SUSY at the LHC
  - SM backgrounds suppressed compared to strong production searches

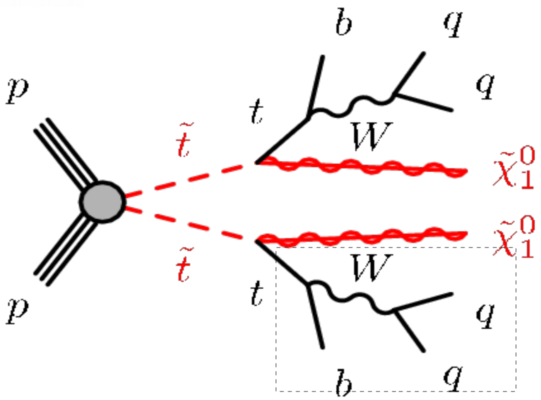


- R-parity conservation (RPC):
  - LSP stable → dark matter candidate
  - Large Missing Transverse Energy (MET)
- R-parity violation (RPV)
  - LSP not necessaily neutral and stable

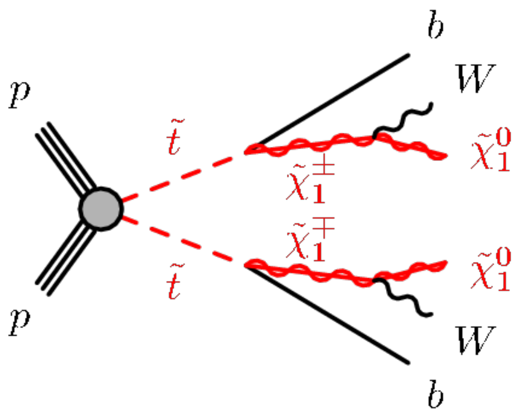
Search for production of stops, charginos, neutralinos in both R-parity conserving and violating models

Third generation

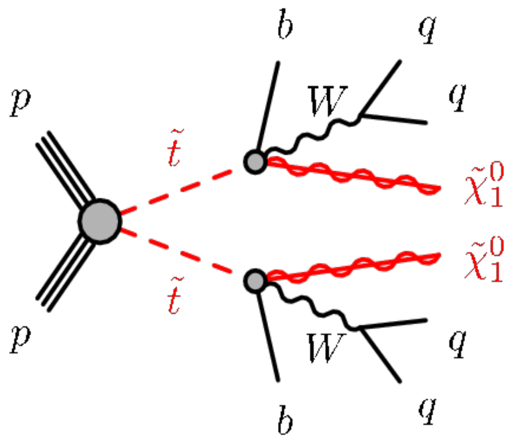
Stop 0L: analysis strategy



- SRs requiring 2 b-jets, large MET, and 2 reclustered R=1.0 jets, compatible with two tops, one top and a W, and one top only



- SRs requiring 2 b-jets, 2 R=0.4 jets, large MET significance and vetoing events compatible with tops



- SRs for ΔM(stop-N1) ~top mass, requiring Initial State Radiation (ISR) jet

$$R_{\mathrm{ISR}} \equiv \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{p_{\mathrm{T}}^{\mathrm{ISR}}} \sim \frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{t}}}$$

+ highly boosted stop, + in association with DM production

- *Background estimation:*
  - Z(→nunu)+b-jets, ttbar(+W/Z), W+b-jets: semi-data driven, simultaneous fit of MC normalization to data in dedicated control regions
  - Multi-jet: from data with jet smearing method

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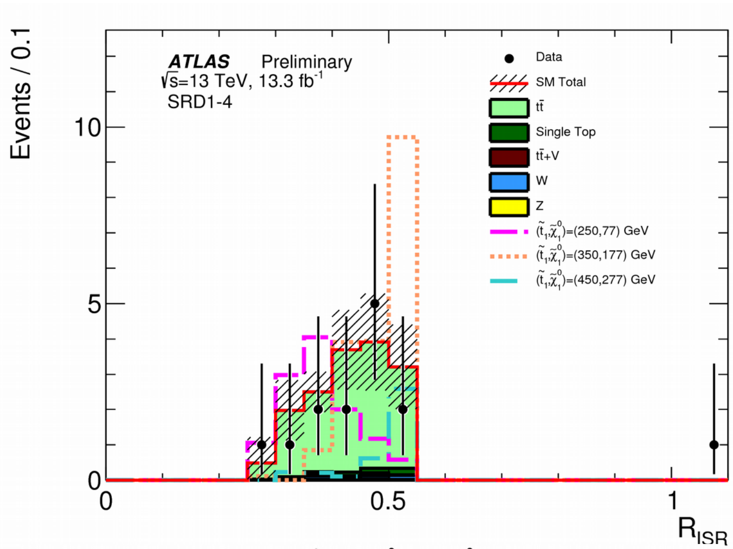
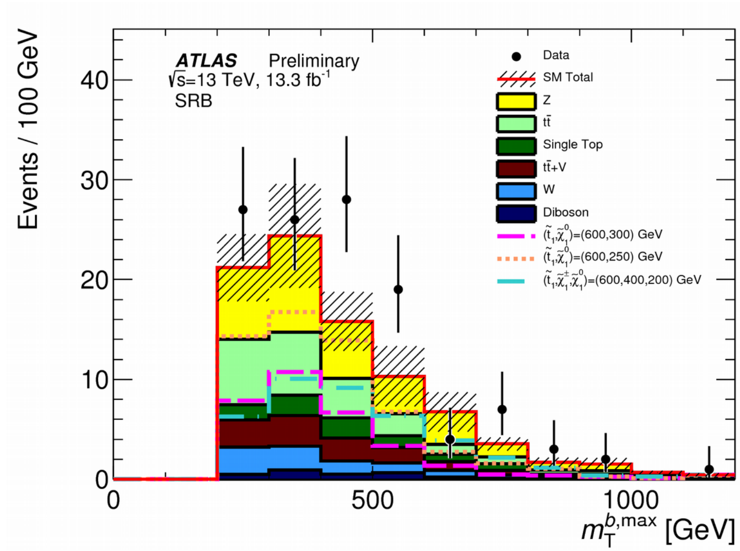
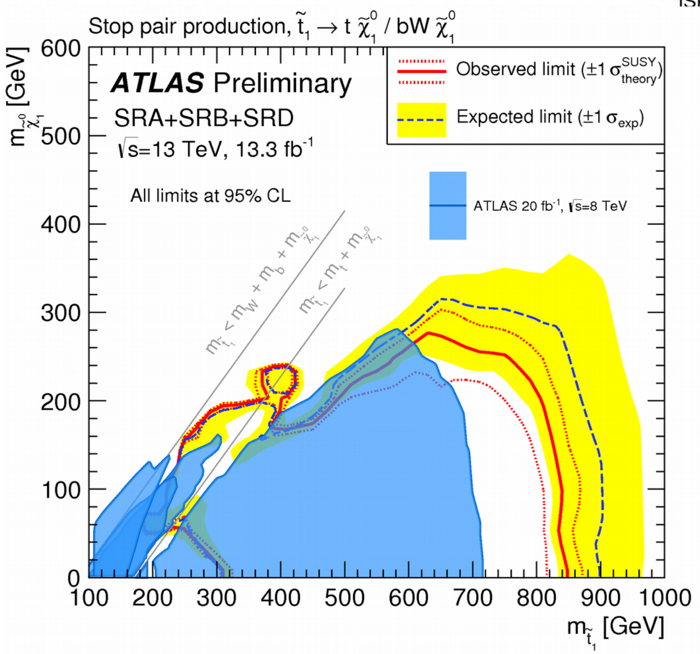
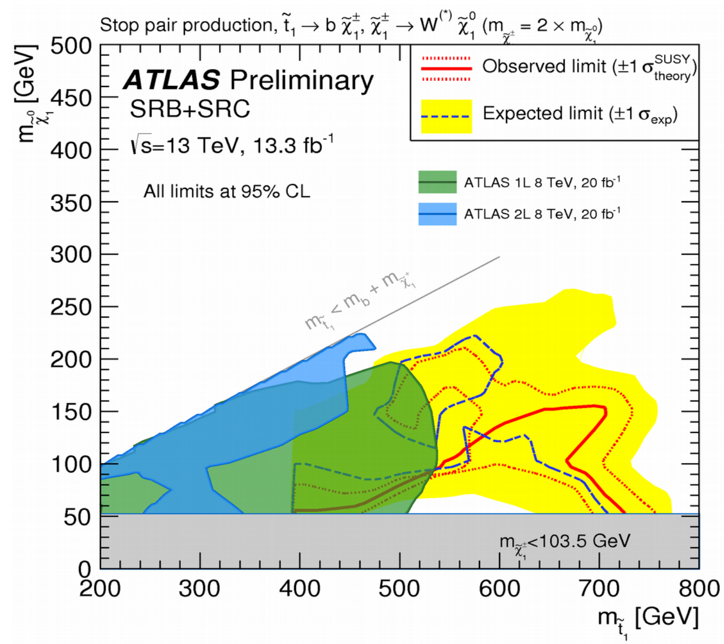
Stop 0L: results

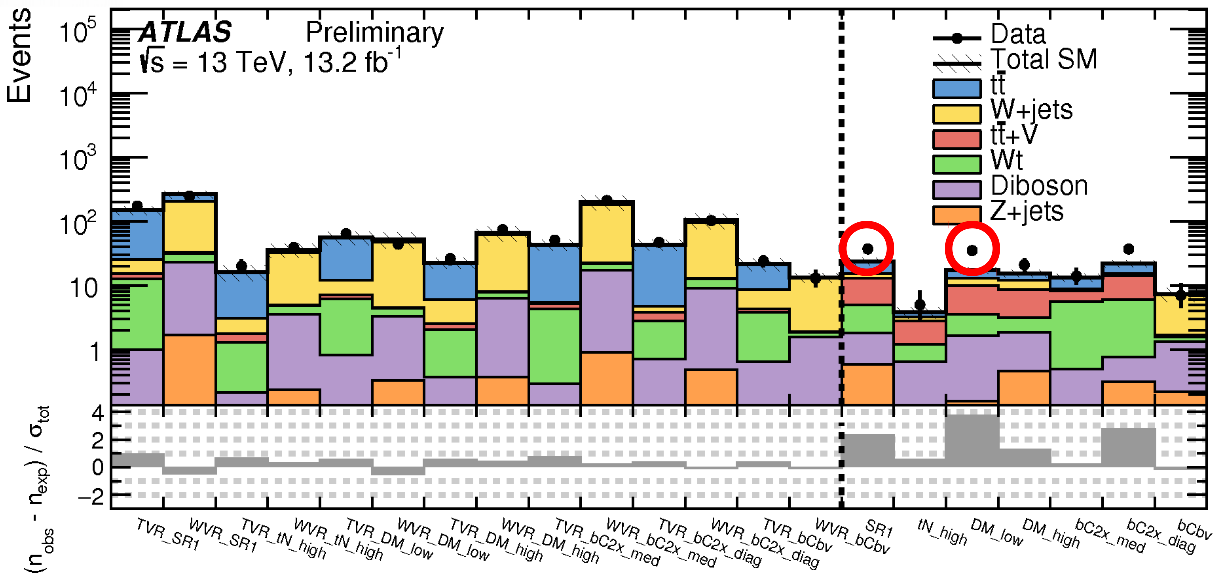








Stop 1L: results



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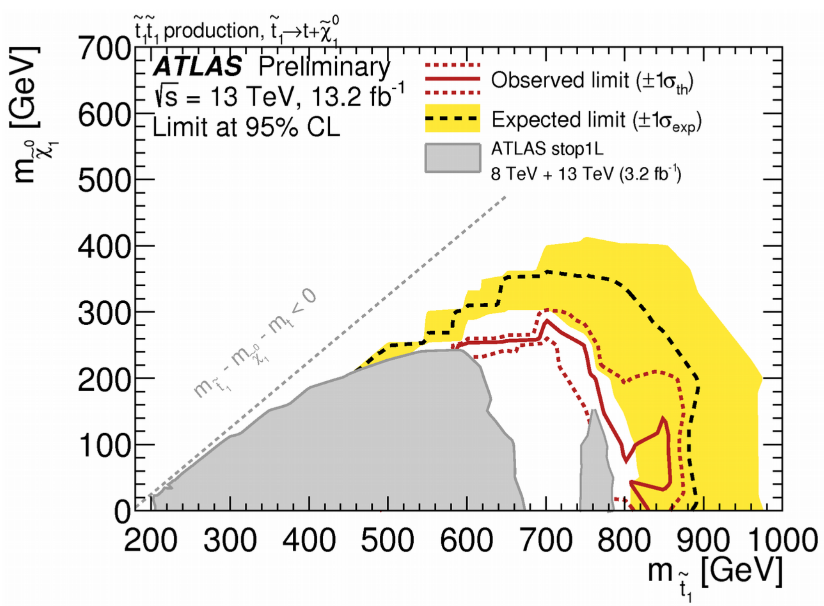
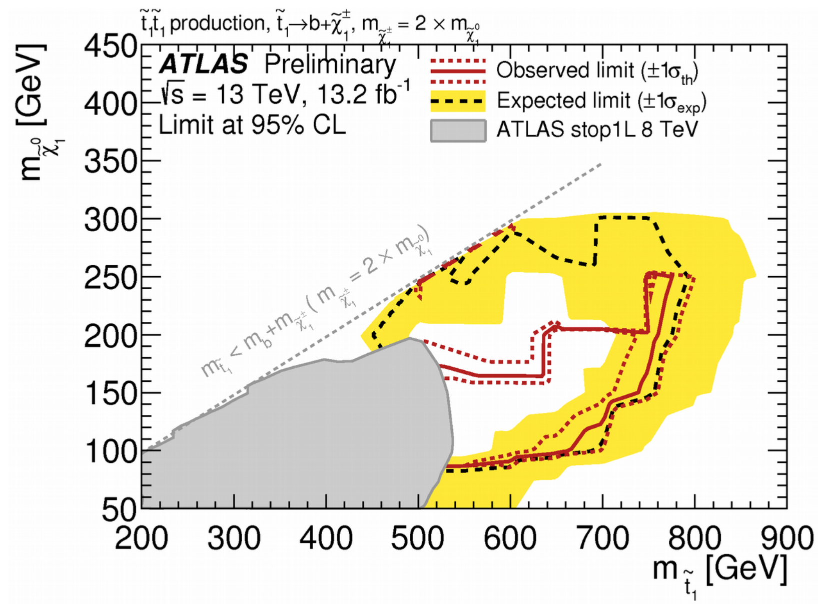
Targets same models as 0L, but requires 1 lepton from W decay

3.3 (2.2) sigma excess in SR DM_low (SR1)





Stop 2L: results

Targets same models as 0-1L, but requires 2 leptons from W

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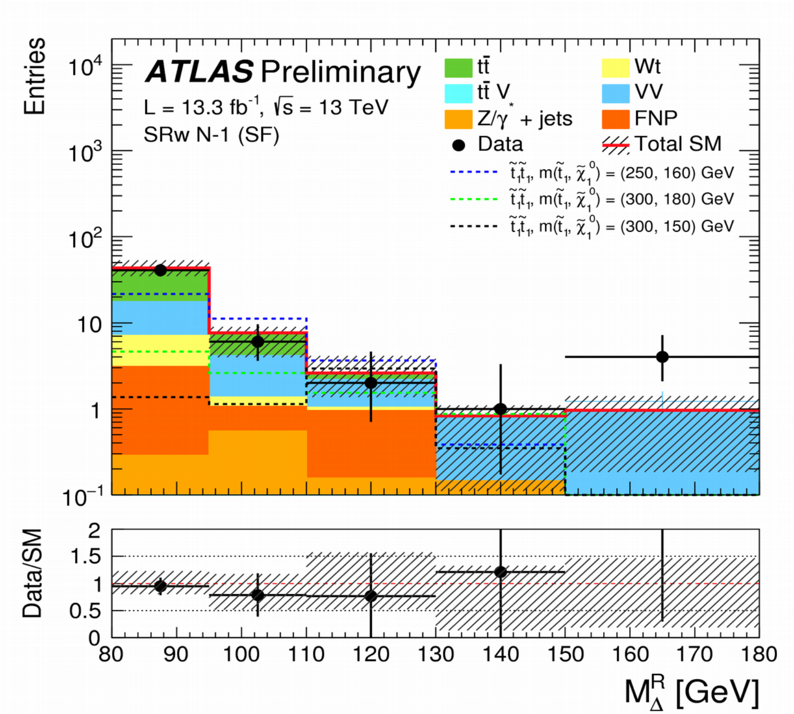
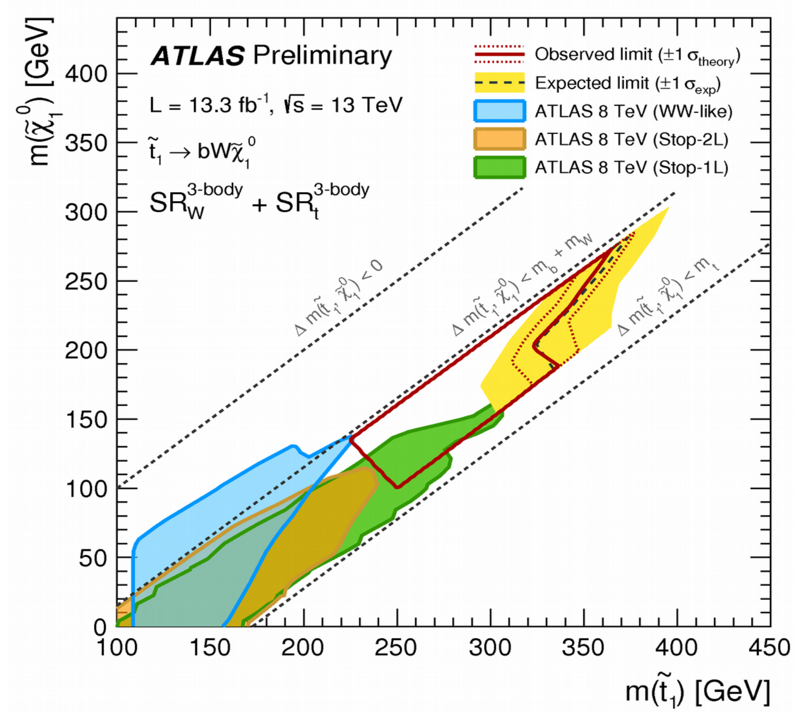
Super-razor variables used to identify a system of two massive particles (the stops) decaying into a set of visible (leptons) and invisible (neutrino and neutralinos)

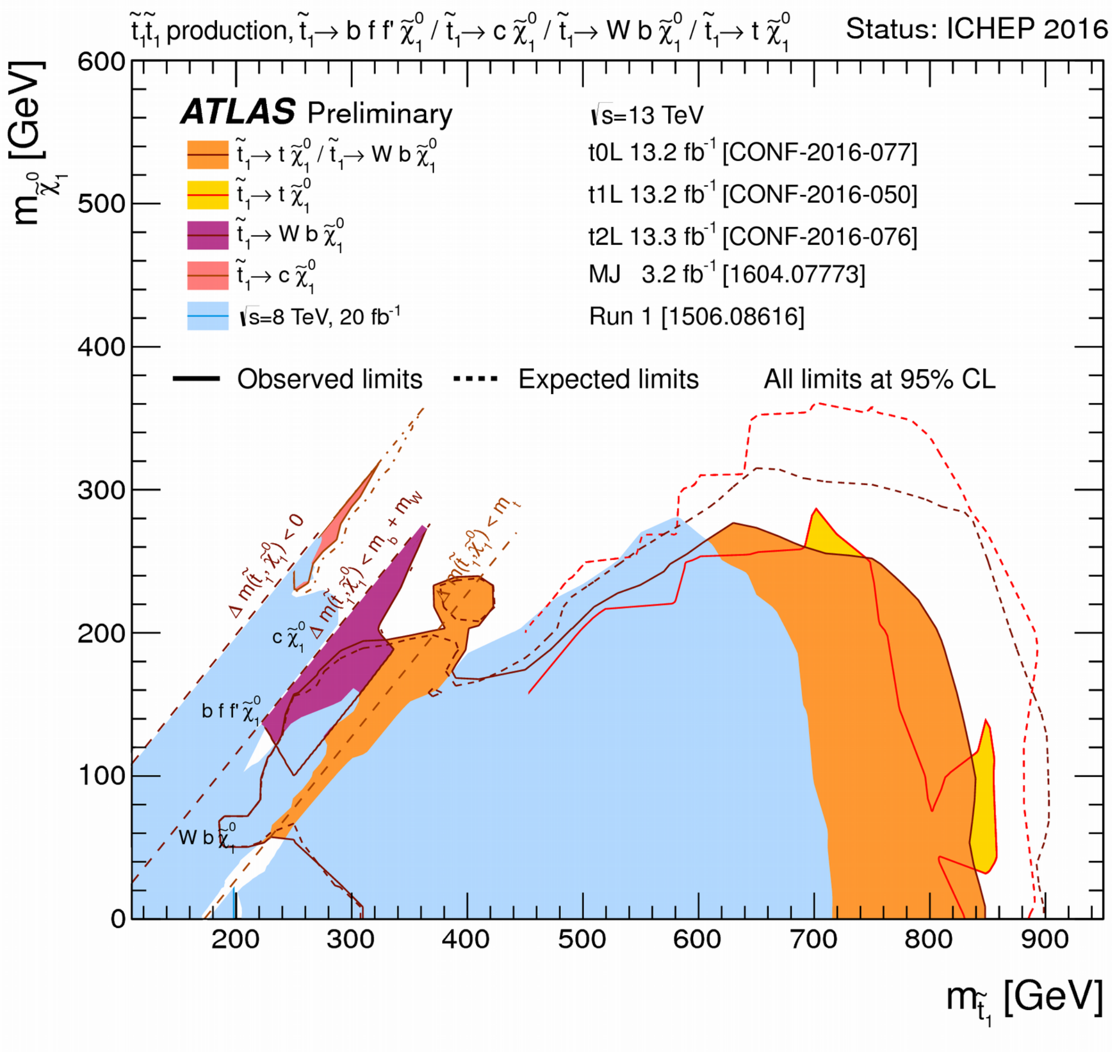
$$M_{\Delta}^{R} = \frac{\sqrt{\hat{s}_R}}{\gamma_{R+1}}$$

- $\sqrt{\hat{s}_R}$: Centre-of-mass energy in razor frame (parent particles)
- γ_{R+1}: Lorentz boost from razor frame to decay products frame





Stop production: summary plot



- *Four decay modes considered separately with 100% BR*
  - stop1 → t+neutralino1
    - the stop1 is mostly right
  - stop1 → W+b+neutralino1
    - 3-body decay for m(stop) < m(top) + m(neutralino1)
  - stop1 → c + neutralino1 and stop1 → f+f'+b+neutralino1 (4-body decay).
    - The latter two decay modes are superimposed
    - Mono-jet analysis not sensitive to stop decay mode
    - driven by run-1 results

Stop 2x2 RPV: analysis strategy

- SR with at least 4 jets, paired according to min ΔR. After pairing:

$$\Delta R_{\min} < 0.003 \cdot m_{\text{avg}}/\text{GeV}$$

where

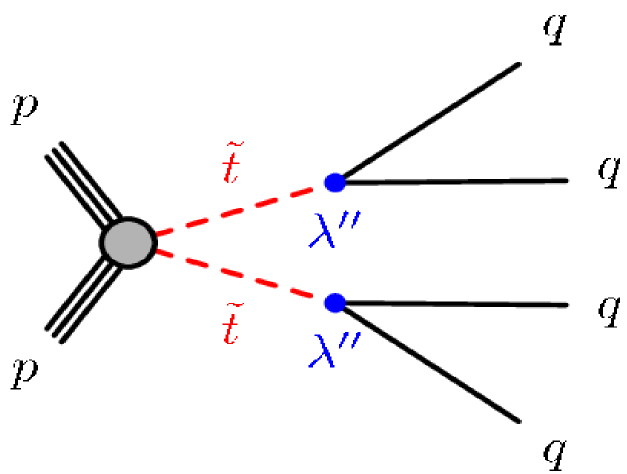
$$m_{\text{avg}} = \frac{1}{2}(m_1 + m_2) \qquad \Delta R_{\min} = \sum_{i=1,2} |\Delta R_i - 1.0|$$

- The *mass asymmetry* between the two candidate resonances

$$A = \frac{m_1 - m_2}{m_1 + m_2} < 0.05$$

- The *stop production angle* in its com frame with respect to the beam line

$$\cos\theta^* < 0.5$$



+ exotics models (colorons)

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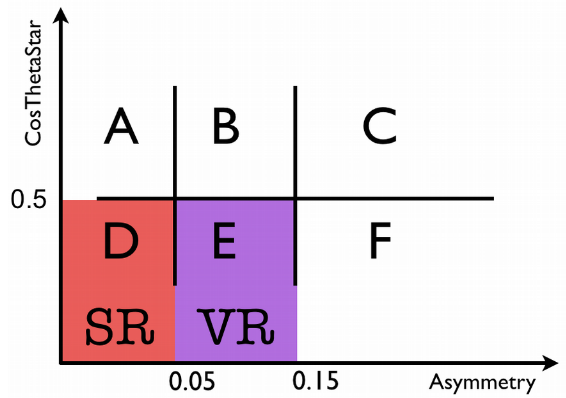
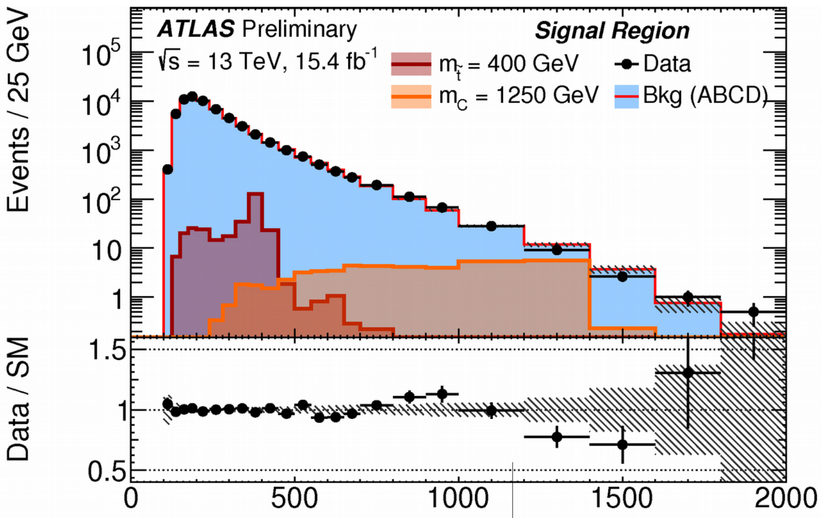
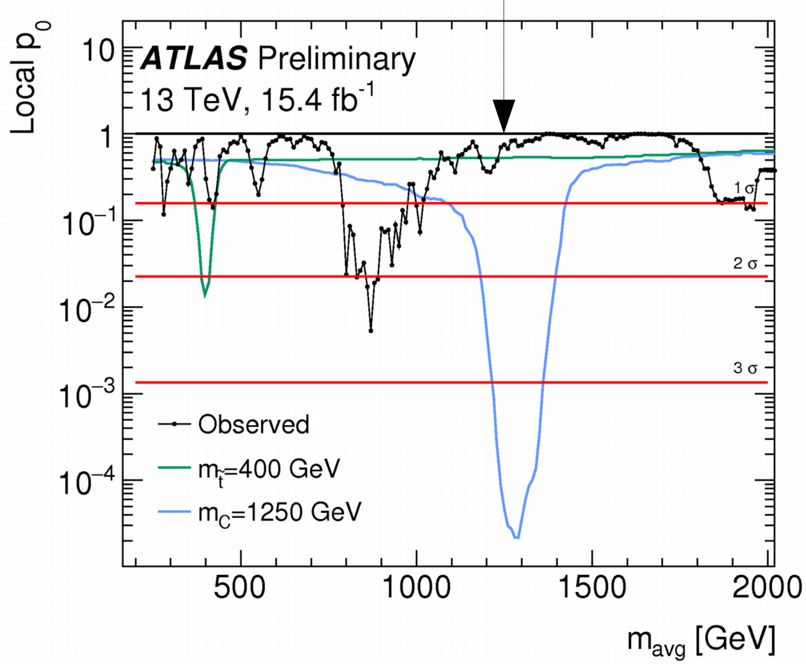
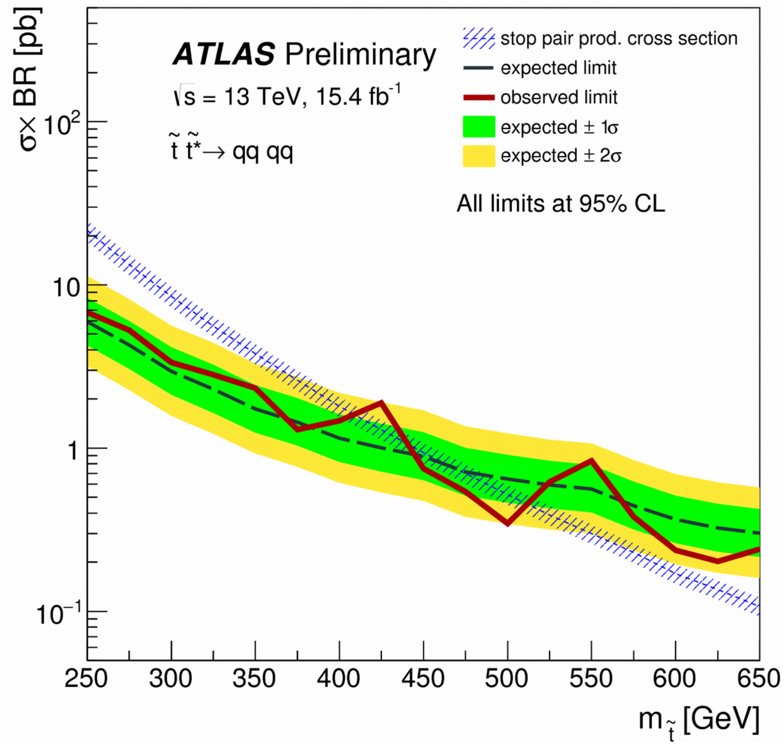
- *Background estimation:*
  - Multi-jets: data driven ABCD method based on mass asymmetry and stop production angle



Stop 2x2 RPV: results







Local p0 value calculated in intervals of 10 GeV

Electro-weak

2-3L(e,μ)+MET: analysis strategy

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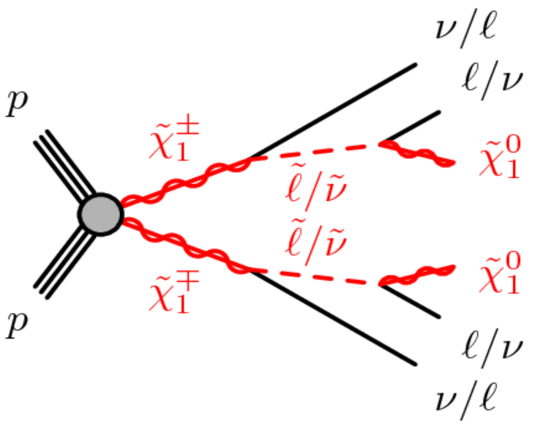
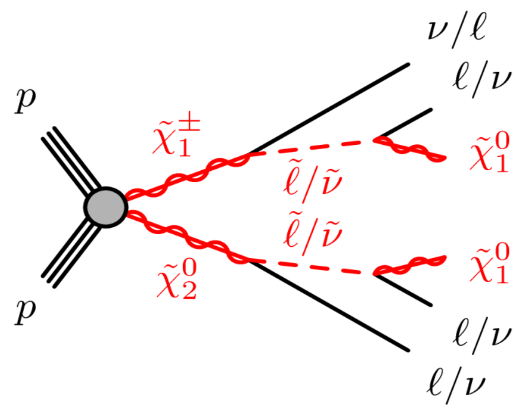


$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 100% wino

$\tilde{\chi}_1^0$ 100% bino



- SRs requiring 2 OS leptons, no jets, and with (binned) MT2

$$m_{T2} = \min_{\mathbf{q}_T} \left[\max \left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T) \right) \right],$$

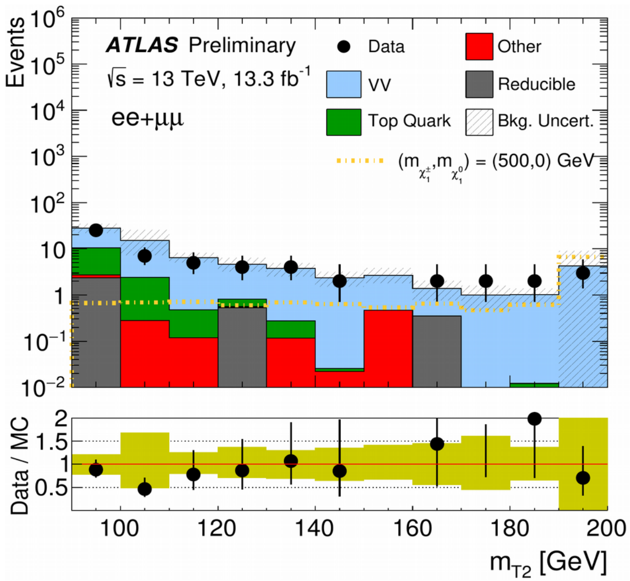
- SRs requiring 3 leptons, with 1 OS pair, no b-jets, and with (binned) MET and 3rd lepton pt cuts

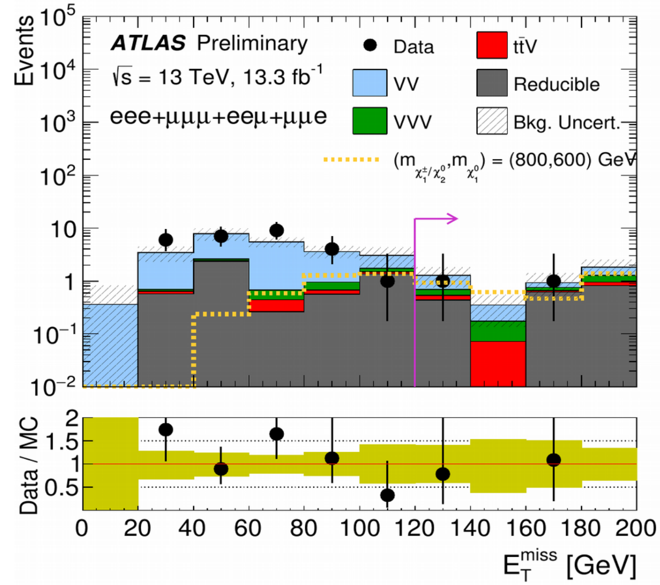
- *Background estimation 2L:*
  - WW, WZ: semi-data driven, simultaneous fit of MC normalization to data in dedicated control regions
  - top: from MC, validated in dedicated VR

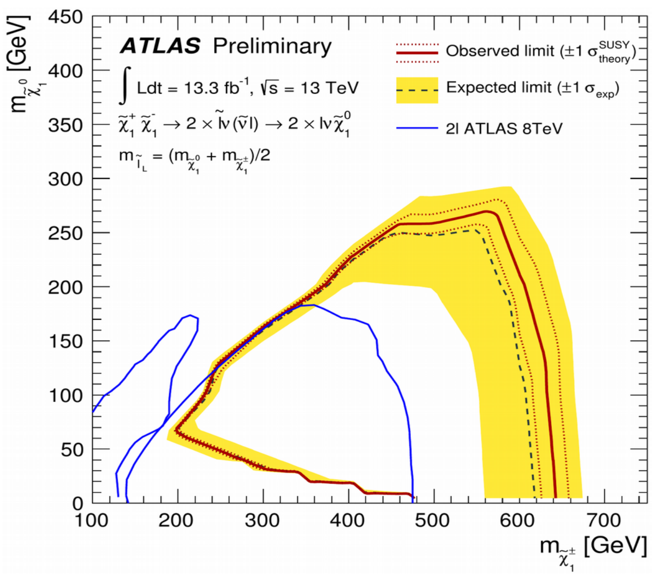
- *Background estimation 3L:*
  - Irreducible backgrounds (WZ, ZZ, VVV, ttbar+V, tZ, Higgs): from MC simulation, validated in regions kinematically close to SRs

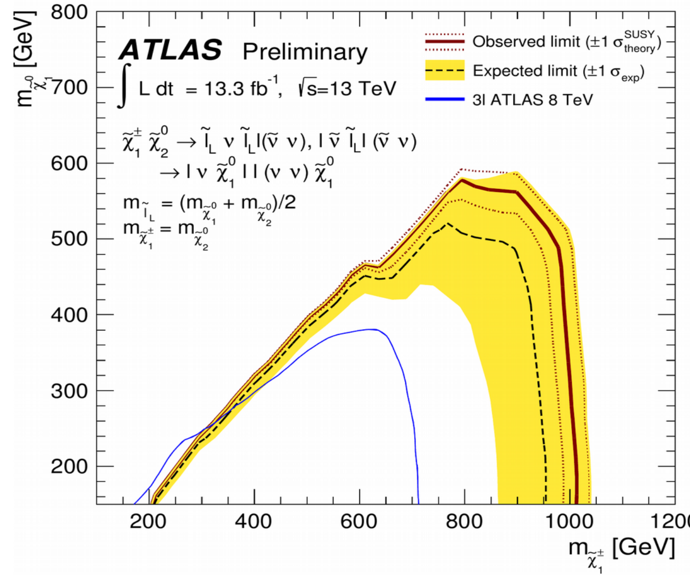
- Non-prompt leptons: from semi-data driven with Matrix Method (based on lepton reconstruction efficiencies and mis-identification rates)

2-3L(e,μ)+MET - Results









$\geq 2\tau$ + MET: analysis strategy

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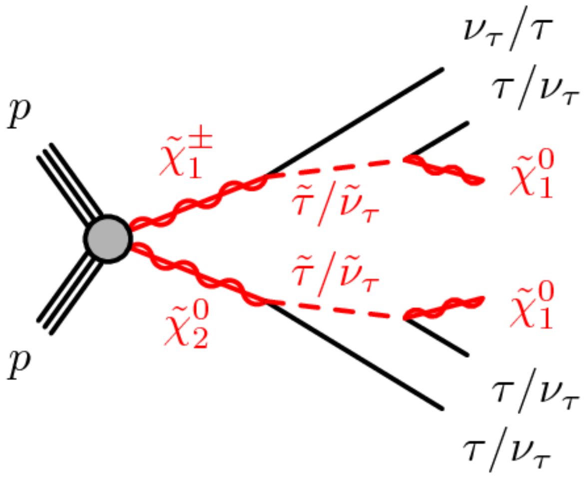
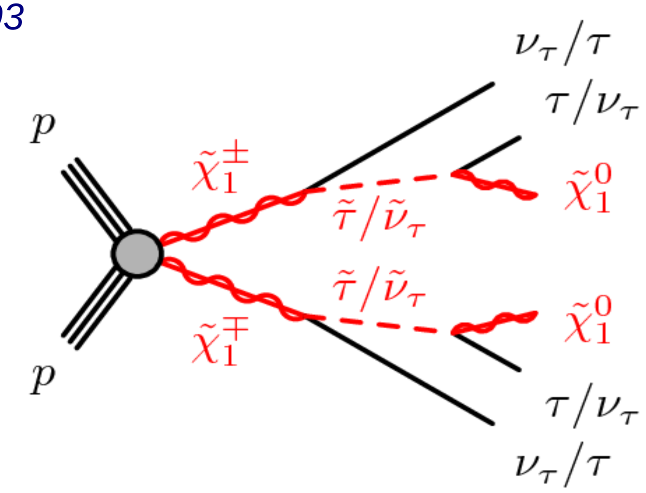


$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 100% wino

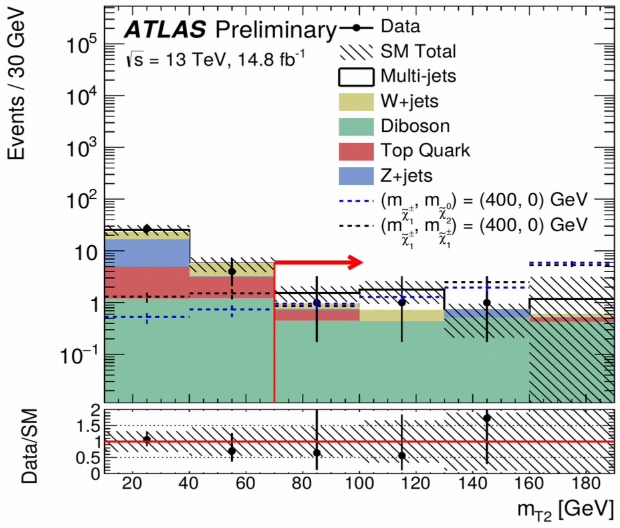
$\tilde{\chi}_1^0$ 100% bino

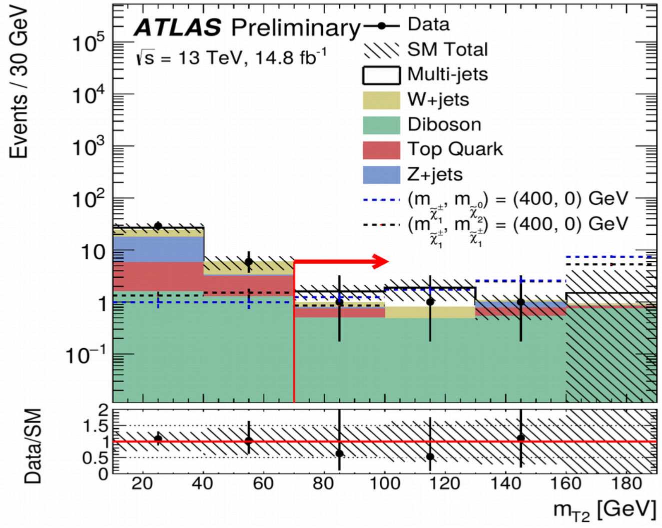


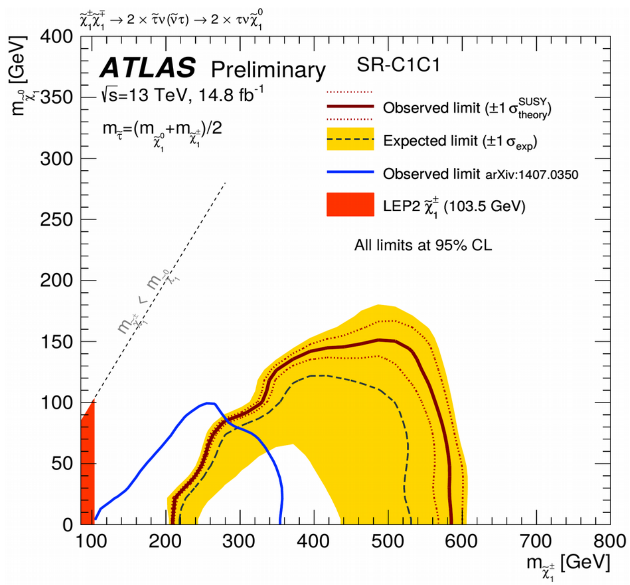
- SRs requiring 2 OS taus, no b-jets, and with large MT2 and MET cuts

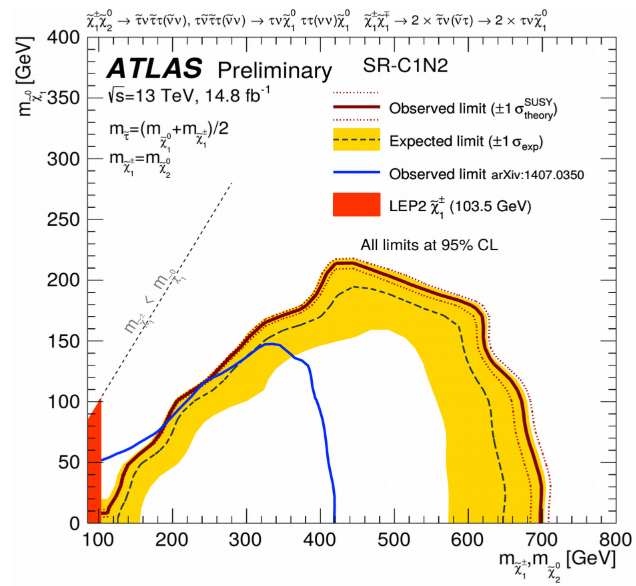
- *Background estimation:*
  - W+jets: semi-data driven, simultaneous fit of MC normalization to data in dedicated control region in tau+mu channel
  - ttbar, Z+jets, diboson, Higgs: from MC and validated in dedicated VRs (top and Z in tau-tau channel, WW in e-mu channel)
  - Multi-jet: data driven with ABCD Method (extrapolating in MET and MT2 from SS region)

≥2τ + MET: - Results

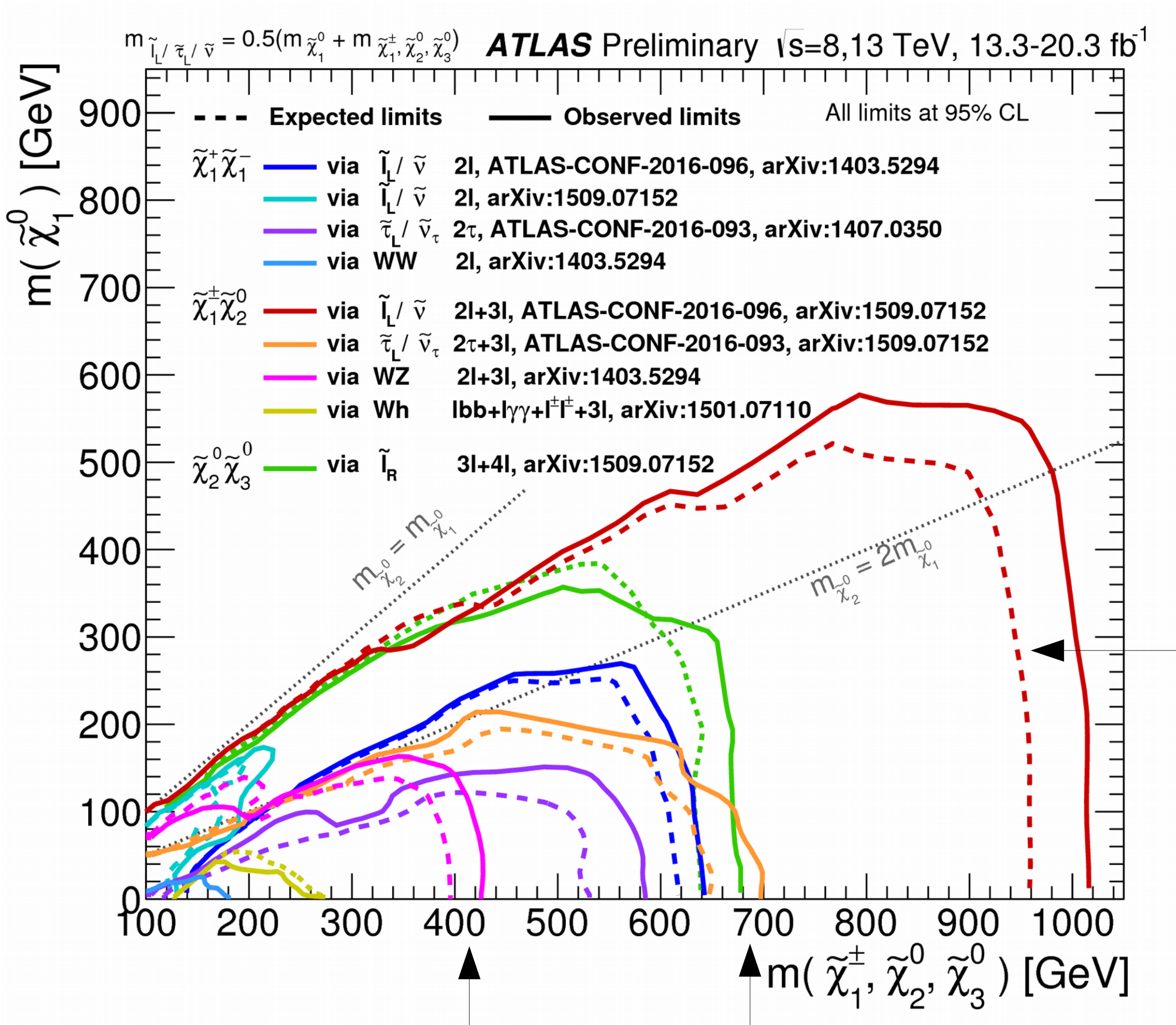








EWK production: summary plot



via sleptons

via SM bosons

via staus

$\geq$ 4L RPV: analysis & results

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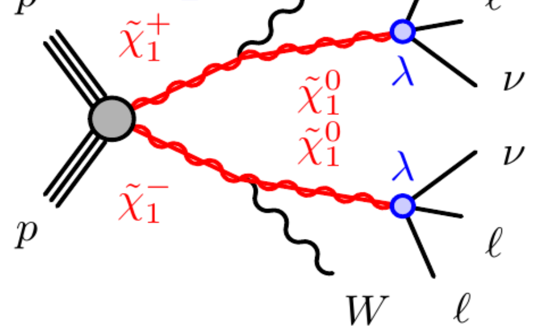
- SRs requiring at least 4 leptons (e,mu), Z veto (based on Mll), and large Meff

$$m_{\text{eff}} = \sum_{\ell=e,\mu} p_{\text{T}}(\ell) + \sum_{\tau} p_{\text{T}}(\tau) + \sum_{p_{\text{T}}(j)>40\text{ GeV}} p_{\text{T}}(j) + E_{\text{T}}^{\text{miss}}$$

- ***Background estimation:***
  - Irreducible backgrounds (ZZ, VVV, ttbar+Z, Higgs): from MC simulation, validated in regions close to SRs
  - Non-prompt leptons: semi-data driven with Fake Factor method (based on mis-identification rates)

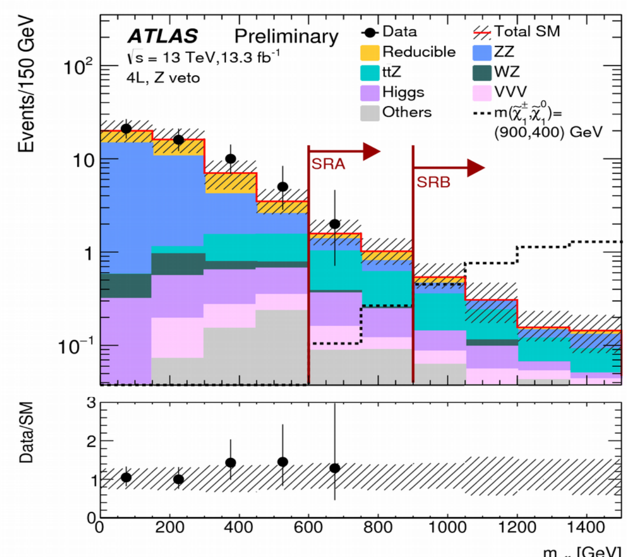
$$W = \frac{\lambda_{ijk}}{2} LL\bar{E}$$

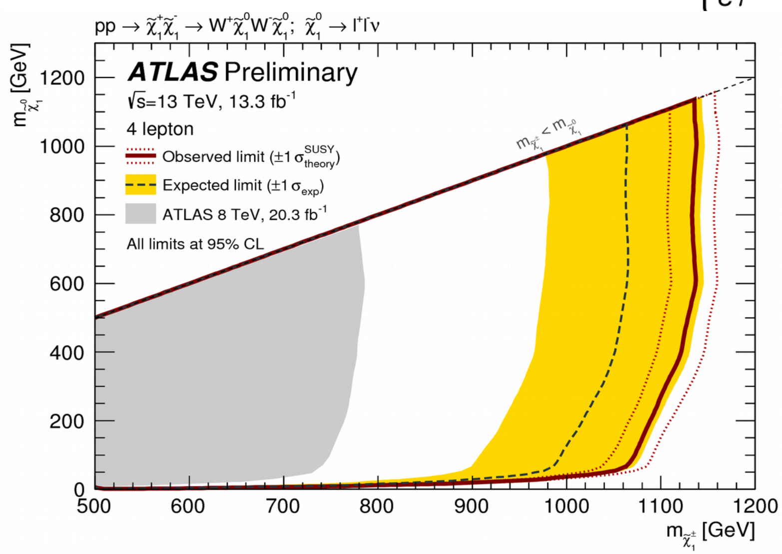


- $\tilde{B}$-like $\tilde{\chi}_1^0$ decays via possible RPV interactions

$$\tilde{\chi}_1^0 \rightarrow \nu_{j/i}\ell^{\mp}_{i/j}\ell^{\pm}_k$$

- Equal BR between the 3 decay modes: $\begin{cases} ee & e\mu & \mu\mu & \lambda_{12k} \\ e\tau & \mu\tau & \tau\tau & \lambda_{i33} \end{cases}$





Conclusion

Searches for third generation squarks and electroweak production of SUSY particles in both RPC and RPV models with ATLAS data:

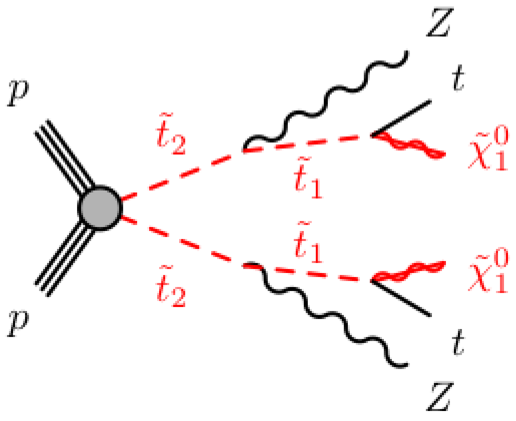
- Many analyses covering several production modes and final states
- <u>No deviation</u> of observed event yields from SM predictions → limits set on several models
- Updated results coming soon with full 2016 dataset

3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	$\tilde{b}_1$	840 GeV	$m(\tilde{\chi}_1^0)$<100 GeV
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	13.2	$\tilde{b}_1$	325-685 GeV	$m(\tilde{\chi}_1^0)$<150 GeV, m(
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV; 200-720 GeV	$m(\tilde{\chi}_1^\pm) = 2m(\tilde{\chi}_1^0)$, m(
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	90-198 GeV; 205-850 GeV	$m(\tilde{\chi}_1^0)$=1 GeV
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$	90-323 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$=5 GeV
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-600 GeV	$m(\tilde{\chi}_1^0)$>150 GeV
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	13.3	$\tilde{t}_2$	290-700 GeV	$m(\tilde{\chi}_1^0)$<300 GeV
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$	320-620 GeV	$m(\tilde{\chi}_1^0)$=0 GeV
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-335 GeV	$m(\tilde{\chi}_1^0)$=0 GeV
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm$	640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5(m(
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	14.8	$\tilde{\chi}_1^\pm$	580 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	1.0 TeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	425 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	270 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	635 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Spare slides

More stop searches



- SRs with 3 leptons and large MET
- Main backgrounds: ttbar+Z, WZ

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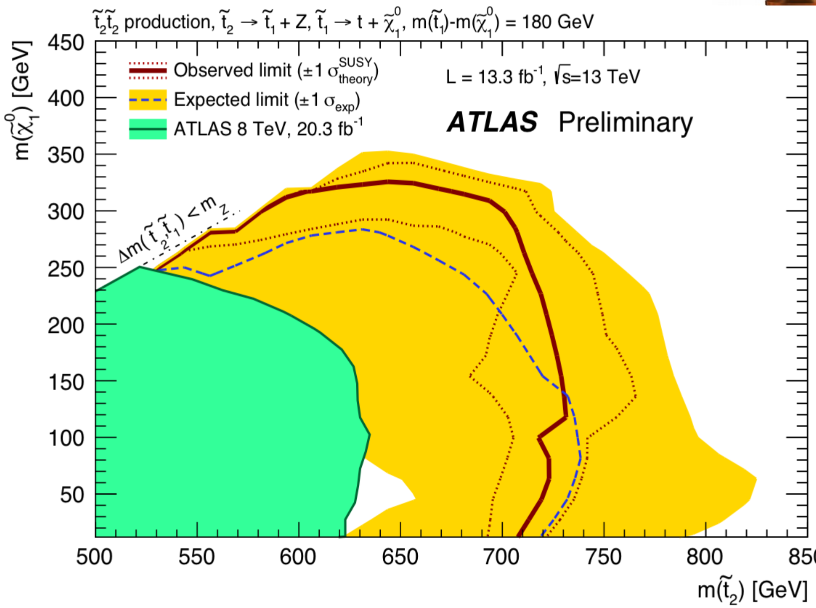

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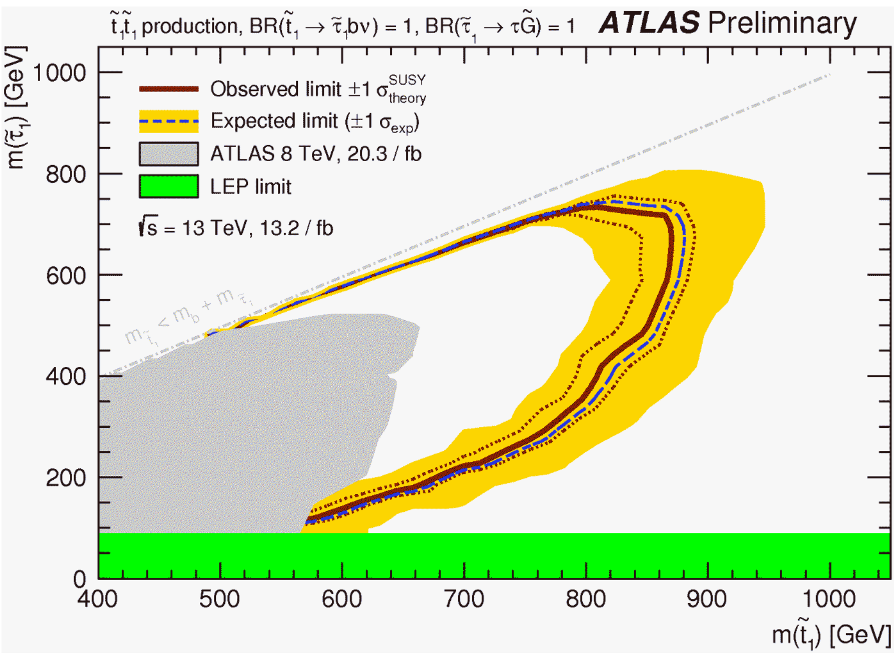
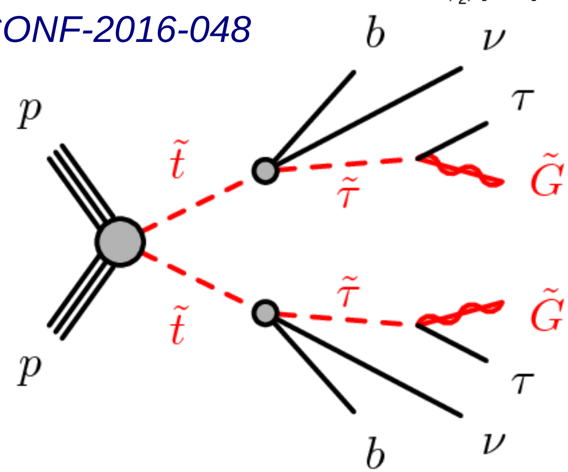


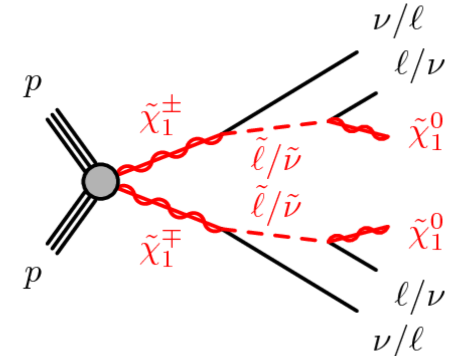
- SR based on large MT2
- Main background: ttbar

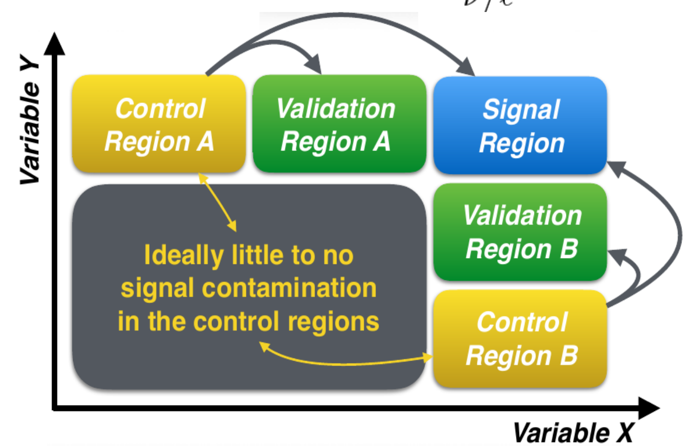


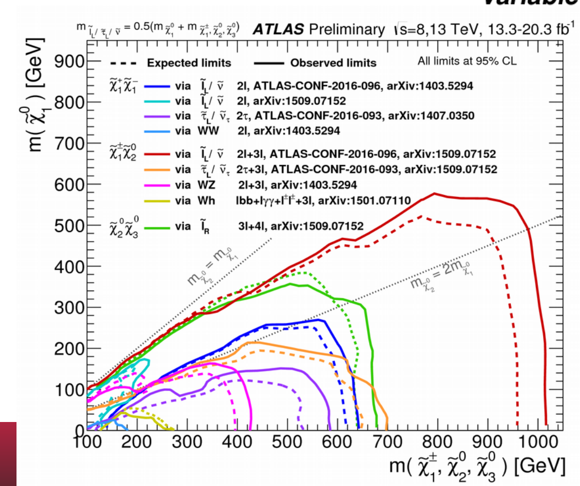
$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{miss} - \mathbf{q}_T)\right)\right],$$

ATLAS SUSY searches in a nutshell

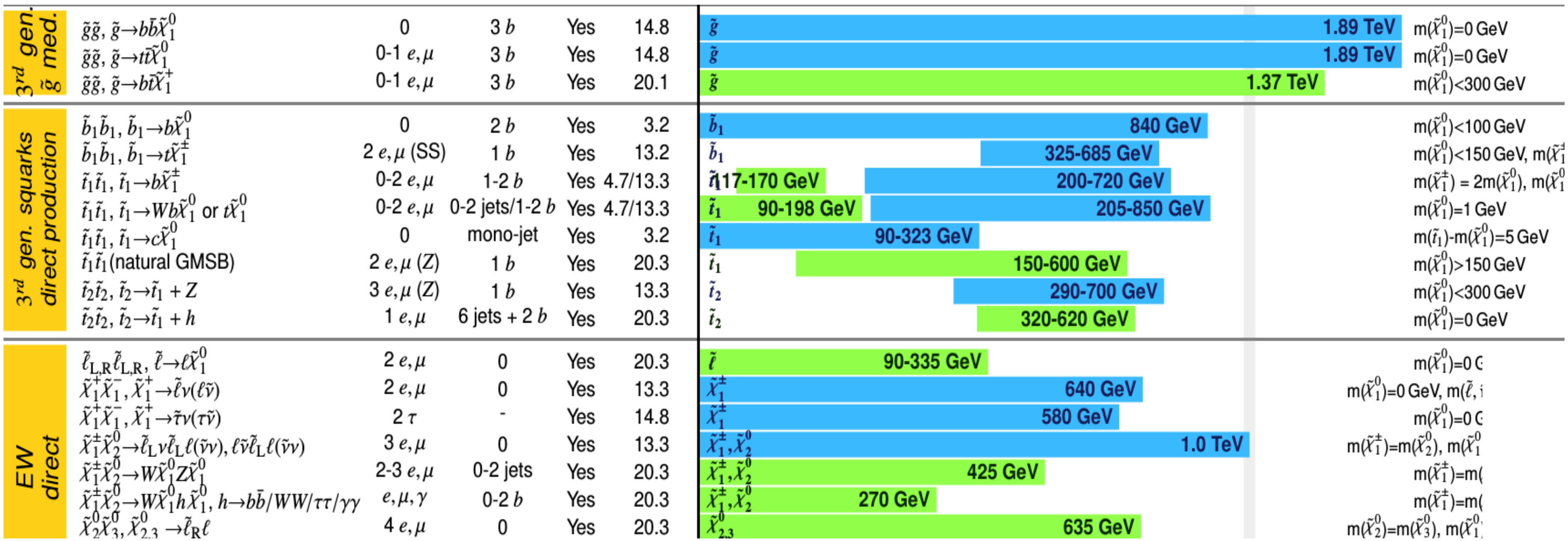
- SUSY signal:
  - most searches use **simplified model** (bottom-up) approach:
    - Consider a single production process, typically producing one given pair of sparticles
    - Fix sparticle decays, typically assuming 100% BR
    - Sparticle masses are usually free and independent parameters to scan over
- SM backgrounds:
  - (Semi) data-driven estimations
  - MC simulation for minor backgrounds
- Statistical interpretation of results:
  - Consistency between observed data and expected background events quantified as a *p*-value
  - Model-dependent limits are set on signal strength/production cross-section

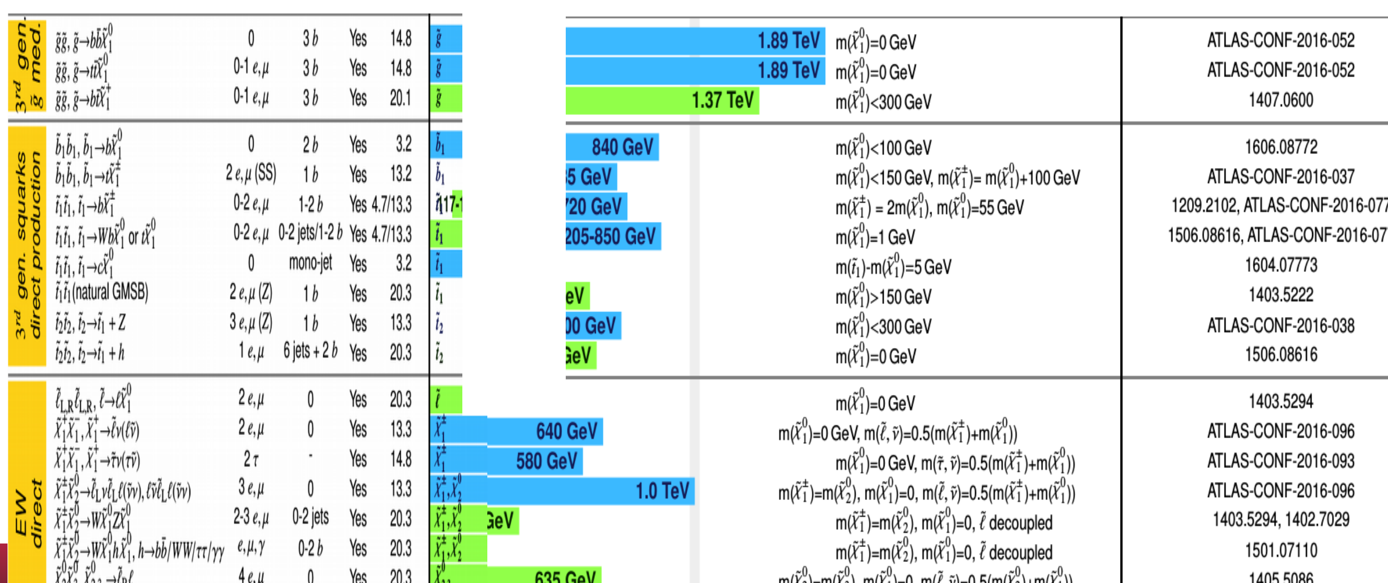






Summary





	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt$ [fb^{-1}]	Mass limit		Conditions	Reference
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.37 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	$\tilde{b}_1$	840 GeV	$m(\tilde{\chi}_1^0)$<100 GeV	1606.08772
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	13.2	$\tilde{b}_1$	325-685 GeV	$m(\tilde{\chi}_1^0)$<150 GeV, $m(\tilde{\chi}_1^\pm)$= $m(\tilde{\chi}_1^0)$+100 GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	117-170 GeV, 200-720 GeV	$m(\tilde{\chi}_1^\pm)$ = 2$m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{t}_1$	90-198 GeV, 205-850 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$	90-323 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-600 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	13.3	$\tilde{t}_2$	290-700 GeV	$m(\tilde{\chi}_1^0)$<300 GeV	ATLAS-CONF-2016-038
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$	320-620 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-335 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm$	640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	14.8	$\tilde{\chi}_1^\pm$	580 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-093
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	13.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	1.0 TeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^\pm)$+$m(\tilde{\chi}_1^0)$)	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	425 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$	270 GeV	$m(\tilde{\chi}_1^\pm)$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	635 GeV	$m(\tilde{\chi}_2^0)$=$m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_2^0)$+$m(\tilde{\chi}_1^0)$)	1405.5086

Signal regions: ≥4L, 2-3L(e,μ), ≥2τ

Sample	$N(e,\mu)$ signal	$N(e,\mu)$ loose	Z boson	m_{eff} [GeV]
SRA	>= 4	>= 0	veto	> 600
CR-SRA	= 2	>= 2	veto	> 600
SRB	>= 4	>= 0	veto	> 900
CR-SRB	= 2	>= 2	veto	> 900
VR	>= 4	>= 0	veto	< 600
CR-VR	= 2	>= 2	veto	< 600

Variable	SR2ℓ	
lepton	$\ell^+\ell^-$	
lepton flavour	SF	DF
central light jets	0_{20}	0_{30}
central b-jets	0_{20}	0_{20}
forward jets	0_{30}	0_{30}
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 10	–
m_{T2} [GeV]	> 90, 120, 150	

SR-C1C1	SR-C1N2
light lepton veto	-
at least two medium taus	
at least one opposite sign tau pair	
b-jet veto	
Z-veto	
$E_{\text{T}}^{\text{miss}} > 150$ GeV	
$m_{\text{T2}} > 70$ GeV	

Variable	SR3ℓ-I	SR3ℓ-H
lepton	$\ell^+\ell^-\ell$	
b-tagged jet	veto	
$m_{\text{T}} >$	110	
m_{SFOS}	$\notin [81.2, 101.2]$	>101.2
$p_{\text{T}}^{3^{rd}\ell} >$	30	80
$E_{\text{T}}^{\text{miss}} >$	120	60

$$m_{\text{T2}} = \min_{\mathbf{q}_{\text{T}}} \left[\max \left(m_{\text{T}}(\mathbf{p}_{\text{T}}^{\ell 1}, \mathbf{q}_{\text{T}}), m_{\text{T}}(\mathbf{p}_{\text{T}}^{\ell 2}, \mathbf{p}_{\text{T}}^{\text{miss}} - \mathbf{q}_{\text{T}}) \right) \right]$$

$$m_{\text{T}}(\mathbf{p}_{\text{T}}, \mathbf{q}_{\text{T}}) = \sqrt{2(p_{\text{T}} q_{\text{T}} - \mathbf{p}_{\text{T}} \cdot \mathbf{q}_{\text{T}})}$$

Signal regions: stop 0L

Stop → top N1

Signal Region		TT	TW	T0
	$m^0_{\text{jet},R=1.2}$	> 120 GeV	> 120 GeV	> 120 GeV
	$m^1_{\text{jet},R=1.2}$	> 120 GeV	$60 - 120$ GeV	< 60 GeV
SRA	$m^0_{\text{jet},R=0.8}$	> 60 GeV		
	b-tagged jets	≥ 2		
	$m_{\text{T}}^{b,\text{min}}$	> 200 GeV		
	τ-veto	yes		
	$E_{\text{T}}^{\text{miss}}$	> 400 GeV	> 450 GeV	> 500 GeV
SRB	b-tagged jets	≥ 2		
	$m_{\text{T}}^{b,\text{min}}$	> 200 GeV		
	$m_{\text{T}}^{b,\text{max}}$	> 200 GeV		
	τ-veto	yes		
	$\Delta R\,(b,b)$	> 1.2		
	$E_{\text{T}}^{\text{miss}}$	> 250 GeV		

Stop → b W N1

Variable	SRD1	SRD2	SRD3	SRD4	SRD5	SRD6	SRD7	SRD8
min R_{ISR}	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
max R_{ISR}	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
b-tagged jets	≥ 2				≥ 1			
$N^{\text{S}}_{\text{jet}}$	≥ 5							
$p_{\text{T}}^{\text{ISR}}$	> 400 GeV							
$p_{\text{T}}^{b\text{-tag},S}$	> 40 GeV							
$p_{\text{T}}^{\text{jet}\,4,S}$	> 50 GeV							
M_{T}^{S}	> 300 GeV							
$\Delta\phi_{\text{ISR}}$	> 3.0 radians							

Stop → b C1 → b W N1

Variable	SRC-low	SRC-med	SRC-high
m_{bjj}	$> 250 GeV$		
b-tagged jets	≥ 2		
p_{T}^{0}	$> 150GeV$	$> 200GeV$	$> 250GeV$
p_{T}^{1}	$> 100GeV$	$> 150GeV$	$> 150GeV$
$m_{\text{T}}^{b,\text{min}}$	$> 250GeV$	$> 300GeV$	$> 350GeV$
$m_{\text{T}}^{b,\text{max}}$	$> 350GeV$	$> 450GeV$	$> 500GeV$
$\Delta R(b,b)$	> 0.8		
$E_{\text{T}}^{\text{miss}}/\sqrt{H_{\text{T}}}$	$[5,12]\sqrt{GeV}$	$[5,12]\sqrt{GeV}$	$[5,17]\sqrt{GeV}$
$E_{\text{T}}^{\text{miss}}$	$> 250GeV$		

Stop +DM production

Variable	SRE	SRF
b-tagged jets	≥ 2	
$m^0_{\text{jet},R=1.2}$	> 140 GeV	-
$m^1_{\text{jet},R=1.2}$	> 60 GeV	-
$m^0_{\text{jet},R=0.8}$	-	> 120 GeV
$m^1_{\text{jet},R=0.8}$	-	> 60 GeV
$m_{\text{T}}^{b,\text{min}}$	> 200 GeV	> 175 GeV
$\tau-$veto	yes	no
$\Delta R(b,b)$	> 1.5	-
$E_{\text{T}}^{\text{miss}}$	> 300 GeV	> 250 GeV
H_{T}	-	> 1100 GeV
$E_{\text{T}}^{\text{miss}}/\sqrt{H_{\text{T}}}$	$> 14\sqrt{GeV}$	$> 15\sqrt{GeV}$

Highly boosted stops

Signal regions: stop 1L

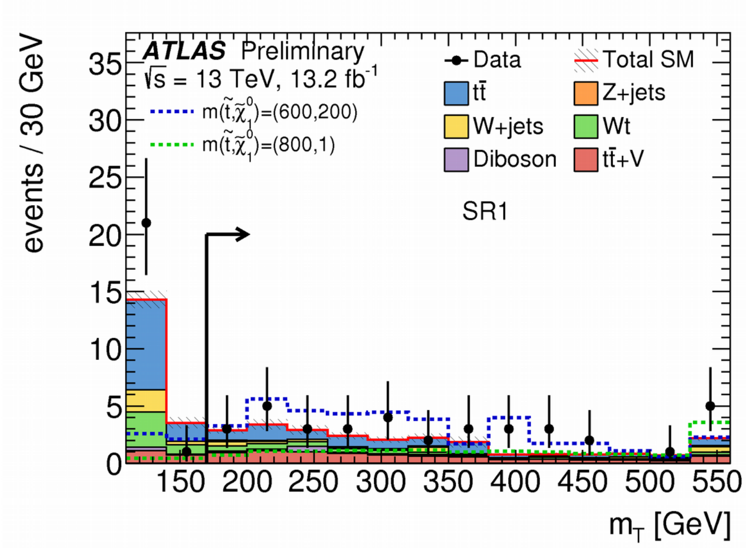
Common event selection	
Trigger	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons
Jets	at least two signal jets, and $\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert > 0.4$ for $i \in \{1,2\}$
Hadronic τ veto*	veto events with a hadronic τ decay and $m_{\mathrm{T2}}^{\tau} < 80\,\mathrm{GeV}$

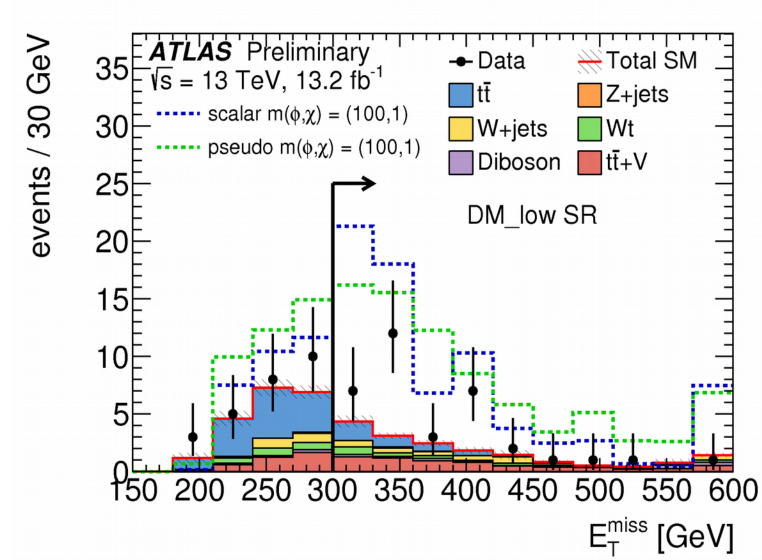
Variable	bC2x_diag	bC2x_med	bCbv
Number of (jets, b-tags)	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$
Jet $p_{\mathrm{T}} >$ [GeV]	(70 60 55 25)	(170 110 25 25)	(120 80)
b-tagged jet $p_{\mathrm{T}} >$ [GeV]	(25 25)	(105 100)	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 230	> 210	> 360
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 7	> 16
m_{T} [GeV]	> 170	> 140	> 200
am_{T2} [GeV]	> 170	> 210	–
$\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert (i=1)$	> 1.2	> 1.0	> 2.0
$\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert (i=2)$	> 0.8	> 0.8	> 0.8
Leading large-R jet mass [GeV]	–	–	$[70, 100]$
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	–	–	> 1.2

Variable	DM_low	DM_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_{\mathrm{T}} >$ [GeV]	(60 60 40 25)	(50 50 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300	> 330
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 9.5
m_{T} [GeV]	> 120	> 220
am_{T2} [GeV]	> 140	> 170
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet}_i))$ $(i \in \{1-4\})$	> 1.4	> 0.8
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	> 0.8	–

Variable	SR1	tN_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_{\mathrm{T}} >$ [GeV]	(80 50 40 40)	(120 80 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 260	> 450
$E_{T,\perp}^{\mathrm{miss}}$ [GeV]	–	> 180
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 22
m_{T} [GeV]	> 170	> 210
am_{T2} [GeV]	> 175	> 175
topness	> 6.5	–
m_{top}^{χ} [GeV]	< 270	–
$\Delta R(b, \ell)$	< 3.0	< 2.4
Leading large-R jet p_{T} [GeV]	–	> 290
Leading large-R jet mass [GeV]	–	> 70
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, 2^{\mathrm{nd}}\text{large-R jet})$	–	> 0.6

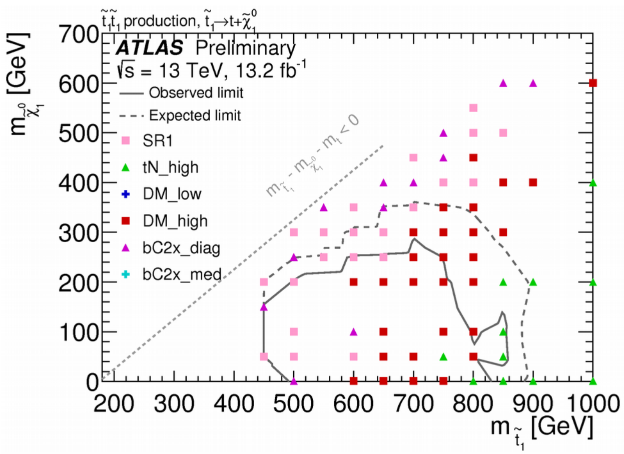
Excess: stop 1L

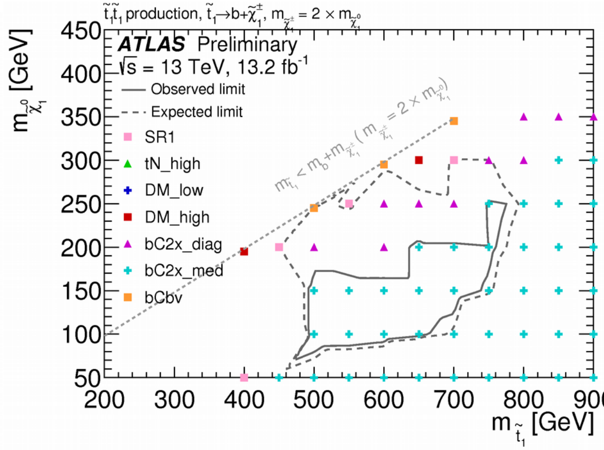


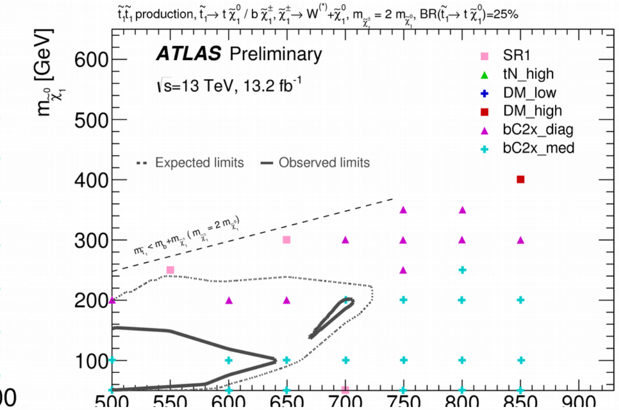


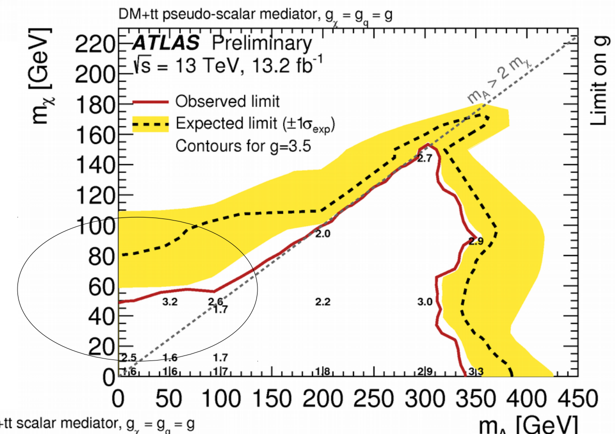
Signal region	SR1	tN_high	bC2x_diag	bC2x_med	bCbv	DM_low	DM_high
Observed	37	5	37	14	7	35	21
Total background	24 ± 3	3.8 ± 0.8	22 ± 3	13 ± 2	7.4 ± 1.8	17 ± 2	15 ± 2
$t\bar{t}$	8.4 ± 1.9	0.60 ± 0.27	6.5 ± 1.5	4.3 ± 1.0	0.26 ± 0.18	4.2 ± 1.3	3.3 ± 0.8
W+jets	2.5 ± 1.1	0.15 ± 0.38	1.2 ± 0.5	0.63 ± 0.29	5.4 ± 1.8	3.1 ± 1.5	3.4 ± 1.4
Single top	3.1 ± 1.5	0.57 ± 0.44	5.3 ± 1.8	5.1 ± 1.6	0.24 ± 0.23	1.9 ± 0.9	1.3 ± 0.8
$t\bar{t} + V$	7.9 ± 1.6	1.6 ± 0.4	8.3 ± 1.7	2.7 ± 0.7	0.12 ± 0.03	6.4 ± 1.4	5.5 ± 1.1
Diboson	1.2 ± 0.4	0.61 ± 0.26	0.45 ± 0.17	0.42 ± 0.20	1.1 ± 0.4	1.5 ± 0.6	1.4 ± 0.5
Z+jets	0.59 ± 0.54	0.03 ± 0.03	0.32 ± 0.29	0.08 ± 0.08	0.22 ± 0.20	0.16 ± 0.14	0.47 ± 0.44
$t\bar{t}$ NF	1.03 ± 0.07	1.06 ± 0.15	0.89 ± 0.10	0.95 ± 0.12	0.73 ± 0.22	0.90 ± 0.17	1.01 ± 0.13
W+jets NF	0.76 ± 0.08	0.78 ± 0.08	0.87 ± 0.07	0.85 ± 0.06	0.97 ± 0.12	0.94 ± 0.13	0.91 ± 0.07
Single top NF	1.07 ± 0.30	1.30 ± 0.45	1.26 ± 0.31	0.97 ± 0.28	–	1.36 ± 0.36	1.02 ± 0.32
$t\bar{t} + W/Z$ NF	1.43 ± 0.21	1.39 ± 0.22	1.40 ± 0.21	1.30 ± 0.23	–	1.47 ± 0.22	1.42 ± 0.21
p_0 (σ)	0.012 (2.2)	0.26 (0.6)	0.004 (2.6)	0.40 (0.3)	0.50 (0)	0.0004 (3.3)	0.09 (1.3)
$N^{\rm limit}_{\rm non-SM}$ exp. (95% CL)	$12.9^{+5.5}_{-3.8}$	$5.5^{+2.8}_{-1.1}$	$12.4^{+5.4}_{-3.7}$	$9.0^{+4.2}_{-2.7}$	$7.3^{+3.5}_{-2.2}$	$11.5^{+5.0}_{-3.4}$	$9.9^{+4.6}_{-2.9}$
$N^{\rm limit}_{\rm non-SM}$ obs. (95% CL)	26.0	7.2	27.5	9.9	7.2	28.3	15.6

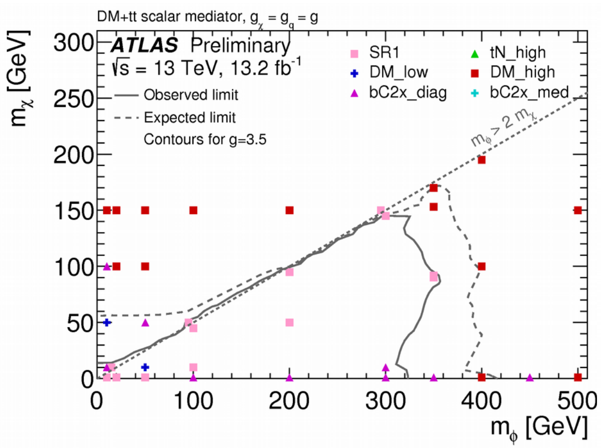
Excess: stop 1L, interpretations

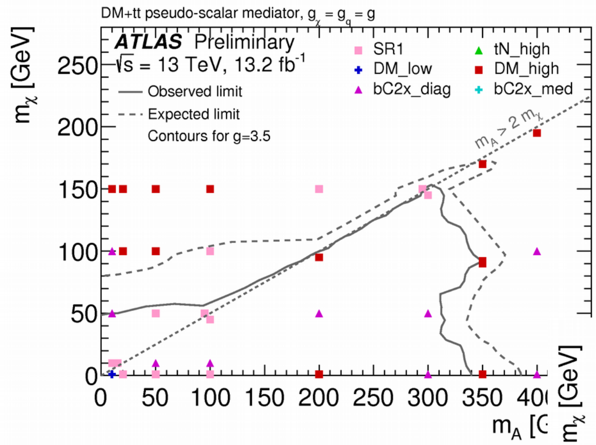


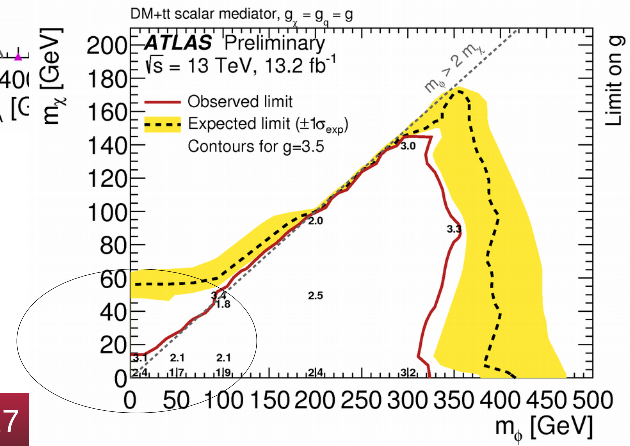












SR DM-low only used for DM interpretation