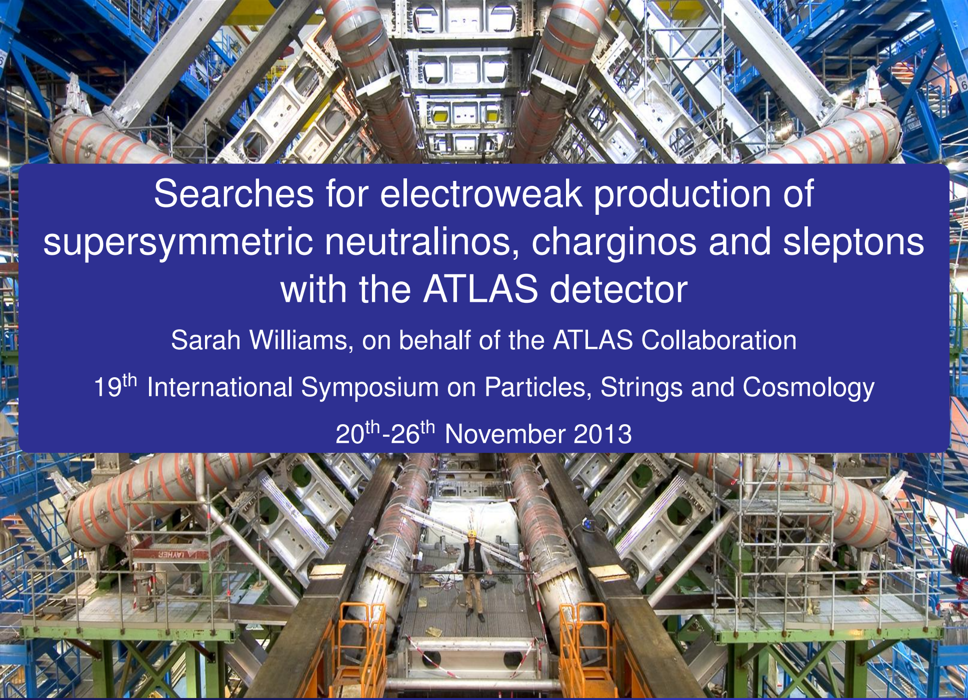

Searches for electroweak production of supersymmetric neutralinos, charginos and sleptons with the ATLAS detector

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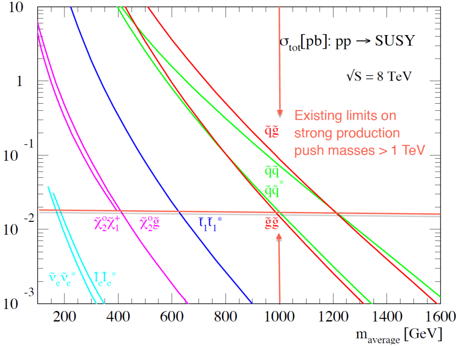
Introduction/Motivation

If they are light, direct gaugino/slepton production could be the dominant SUSY production process at the LHC → potential discovery channel!

"Natural SUSY paradigm"- for SUSY to stabilise the weak scale, the particles that couple directly to the Higgs sector must be relatively light ($<$ 1 TeV) → these are the electro-weakinos and the third generation sfermions.



Typical signature: one or more leptons in the final state arising from the decay of charginos/neutralinos decaying through intermediate sleptons, sneutrinos or gauge bosons.

Search strategy

Use dedicated searches targeting specific final states. Interpret results using Simplified Models containing the process of interest.

Results based on the 2012 dataset: $\int \mathcal{L}dt \approx 20\ \text{fb}^{-1}$, $\sqrt{s} = 8$ TeV.

1. Exactly 3 light leptons (l=e,μ)
   ATLAS-CONF-2013-035 (3L)
   - Chargino-neutralino pair production (with intermediate sleptons/ gauge bosons)
2. 1 light lepton and 2 b-tagged jets
   ATLAS-CONF-2013-093 (1L)
   - Chargino-neutralino pair production (with the neutralino decaying through a Higgs boson)
3. 2 hadronically decaying τ-leptons
   ATLAS-CONF-2013-028 (2τ)
   - Chargino-neutralino and chargino-pair production (with intermediate staus), direct stau-pair production
4. Exactly 2 light leptons
   ATLAS-CONF-2013-049 (2L)
   - Chargino-pair production (with intermediate sleptons/ gauge bosons), direct selectron/smuon-pair production
5. At least 4 light leptons
   ATLAS-CONF-2013-036 (4L)
   - Neutralino-pair production (with intermediate leptons)

Note: For a given production mode (e.g chargino-neutralino production)- consider scenario with/without intermediate sleptons separately. (Intermediate sleptons in decays chains enhance the leptonic branching fraction $\rightarrow$ increase sensitivity)

Choosing the signal region(s)

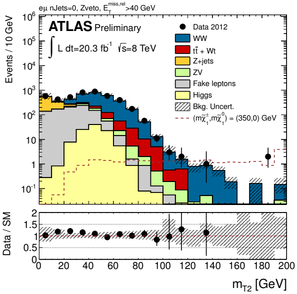
Interesting note: variables initially designed to measure SUSY masses in the case of discovery have proven useful in suppressing SM backgrounds when designing signal regions searching for SUSY...

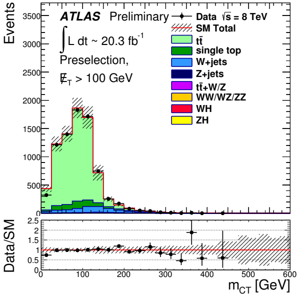
$$E_{\mathrm{T}}^{\mathrm{miss,rel}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \times \sin\Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \end{cases}$$

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

$$m_{\mathrm{CT}}^2(v_1, v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\mathbf{p}_{\mathrm{T}}(v_1) - \mathbf{p}_{\mathrm{T}}(v_2)]^2$$

In the absence of a finite W width, the m_{T2} distribution for well reconstructed di-leptonic $t\bar{t}$ and WW events should fall off rapidly above the W boson mass.





When calculated using the 2 b-jets in the event the m_{CT} distribution $t\bar{t}$ has an expected endpoint at 160 GeV.

Standard Model background estimation

All SUSY searches rely on accurate modelling of the Standard Model backgrounds

- Distinguish between reducible (fake leptons/hadronic taus) and irreducible (sources of real isolated leptons) backgrounds.
- Fake lepton backgrounds usually determined from data (method depends on analysis).
- For dominant irreducible backgrounds, Monte Carlo predictions are obtained from NLO generators or renormalised by defining control regions that are designed to be dominant in a particular background component.

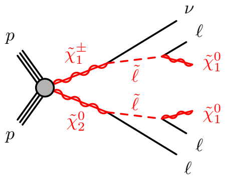
$$\left(N_X^{SR}\right)_{est} = (N_{data}^{CR} - N_{\mathrm{non}-X}^{CR}) \times \mathcal{T}, \qquad \mathcal{T} = N_{MC,X}^{SR} / N_{MC,X}^{CR}$$

- Predictions from these methods are tested in a number of representative validation regions

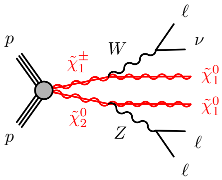
Combined fits over signal regions and all control regions extract background normalisation factors simultaneously by fitting to data.

Chargino-neutralino production (3L)- ATLAS-CONF-2013-035

3-lepton channel has sensitivity to chargino-neutralino production with decays through intermediate sleptons or gauge bosons.



m($\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$) > m($\tilde{e}_L$, $\tilde{\mu}_L$, $\tilde{\tau}_1$, $\tilde{\nu}$)> m($\tilde{\chi}_1^0$)



m($\tilde{l}$, $\tilde{\nu}$) >m($\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$)> m($\tilde{\chi}_1^0$)

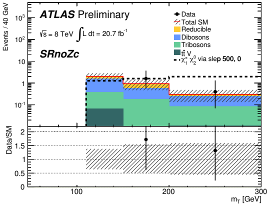
- Wino-like $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$, bino-like $\tilde{\chi}_1^0 \rightarrow$ mass degenerate $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$
- Intermediate slepton scenario: assume flavour democratic, and 50% branching ratios to sleptons and sneutrinos.
- Decays through gauge bosons: assume 100% branching of $\tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0$

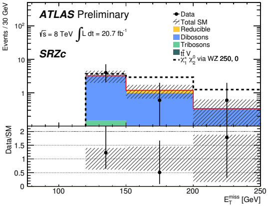
Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
m_{SFOS} [GeV]	<60	60–81.2	<81.2 or >101.2	81.2–101.2	81.2–101.2	81.2–101.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>50	>75	>75	75–120	75–120	>120
m_{T} [GeV]	–	–	>110	<110	>110	>110
p_{T} 3rd ℓ [GeV]	>10	>10	>30	>10	>10	>10
SR veto	SRnoZc	SRnoZc	–	–	–	–

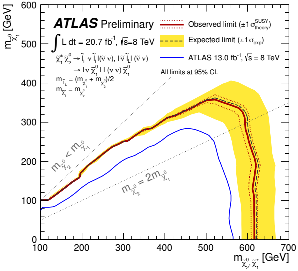
Sensitivity across parameter space achieved with signal regions requiring exactly 3 “light” leptons (e,μ), with/without a Z-veto on a same-flavour opposite-sign pair. $E_{\mathrm{T}}^{\mathrm{miss}}$ and m_{T} used to suppress SM backgrounds.

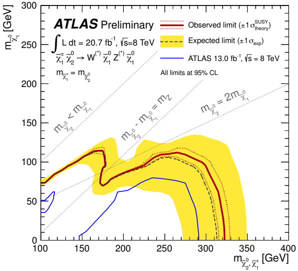
Chargino-neutralino production (3L)- ATLAS-CONF-2013-035

No excess above the Standard Model expectation was observed → calculate model independent limits on the visible cross-section in the signal regions, and model dependent exclusion contours.





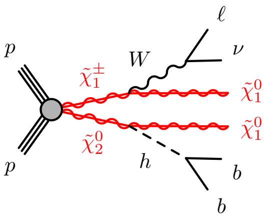




Improved sensitivity at low chargino masses and along the diagonal $m(\tilde{\chi}_2^0)-m(\tilde{\chi}_1^0)=m_Z$.

Hot off the press- this was the first LHC search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production with decays via Higgs- released August 2013!

- Wino-like $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$, bino-like $\tilde{\chi}_1^0$ $\rightarrow$ mass degenerate $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$
- Assume 100% branching of $\tilde{\chi}_1^{\pm}$ via $W^{\pm}$ and $\tilde{\chi}_2^0$ via 125 GeV SM-like lightest higgs.
- For on-shell Higgs: $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) > 125$ GeV
- 125 GeV SM-like Higgs has highest BR for h $\rightarrow b\bar{b}$



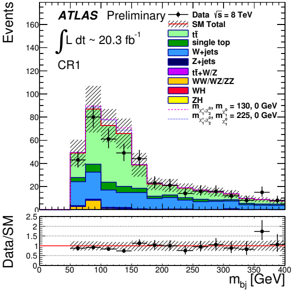
$m(\tilde{l}, \tilde{\nu}) > m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0) > m(\tilde{\chi}_1^0)$

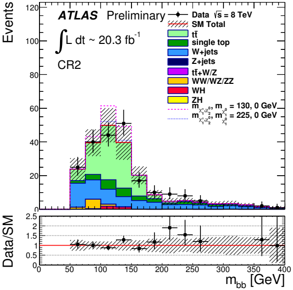
Searched for events with one charged lepton (e,μ), missing transverse momentum and 2 b-tagged jets consistent with a Standard Model Higgs boson at $m_H = 125$ GeV

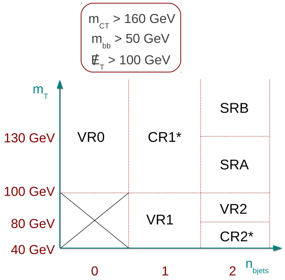
Chargino-neutralino production (1L)- ATLAS-CONF-2013-093

2 signal regions designed targeting large $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$

Control regions defined for $t\bar{t}$ and W+jets $\rightarrow$ extract background normalisation factors from simultaneous fit.



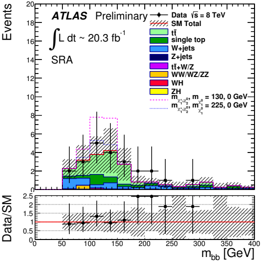


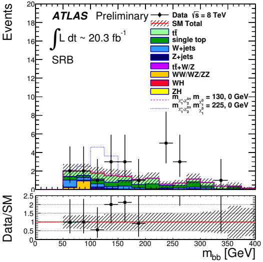


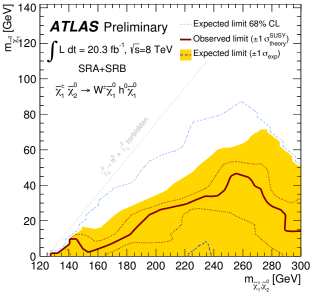
For the simultaneous fit, split all regions into 5 bins in m_{bb}. For the control regions exclude $m_{bb} = 105 - 135$ GeV to avoid signal contamination.

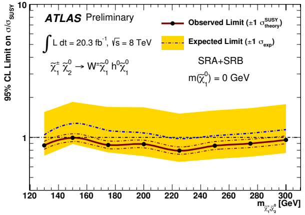
Chargino-neutralino production (1L)- ATLAS-CONF-2013-093

No excess above the Standard Model expectation observed





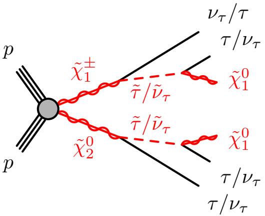




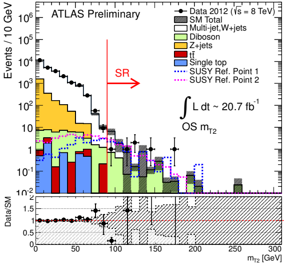
	SRAh	SRBh
Observed $\sigma^{95}_{\mathrm{vis}}$ (Asymptotic)	0.32 fb	0.21 fb
Observed S^{95}_{obs} (Asymptotic)	6.5	4.4
Expected S^{95}_{exp} (Asymptotic)	$7.0^{+3.1}_{-1.9}$	$4.4^{+2.5}_{-1.5}$
Observed $\sigma^{95}_{\mathrm{vis}}$ (Pseudo-experiments)	0.34 fb	0.21 fb
Observed S^{95}_{obs} (Pseudo-experiments)	6.9	4.4
Expected S^{95}_{exp} (Pseudo-experiments)	$7.0^{+2.8}_{-1.6}$	$4.4^{+1.8}_{-0.8}$

Note: For model independent limits, for SRA/B consider only m_{bb}= 105-135 GeV. For model dependent exclusion limits consider $m_{bb} > 50$ GeV and statistically combine regions.

First search for electroweak production with taus in ATLAS



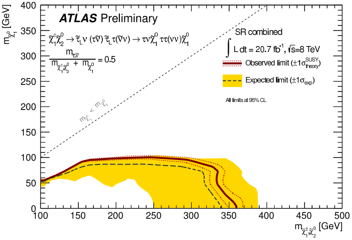
- Simplified model for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$. 50 % BR through both intermediate sleptons and sneutrinos.
- Assume wino-like $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$ and bino-like $\tilde{\chi}_1^0$ $\rightarrow$ mass degenerate $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$



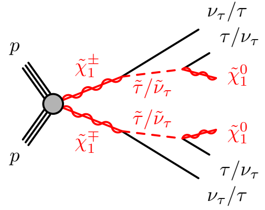
$m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0) > m(\tilde{\tau}_1, \tilde{\nu}_\tau) > m(\tilde{\chi}_1^0)$

- 2-lepton analysis based on reconstructing hadronically decaying taus.
- 2 signal regions defined based on m_{T2}, with and without a b-jet veto.

Signal region	requirements
OS m_{T2}	at least 1 OS tau pair jet veto Z-veto $E_T^{miss} > 40$ GeV $m_{T2} > 90$ GeV
OS m_{T2}-nobjet	at least 1 OS tau pair b-jet veto Z-veto $E_T^{miss} > 40$ GeV $m_{T2} > 100$ GeV

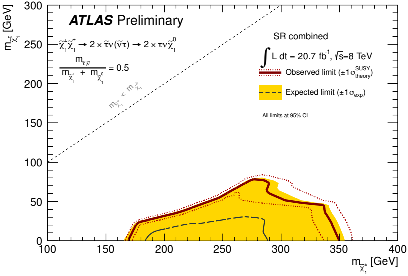


$m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0) > m(\tilde{\tau}_1, \tilde{\nu}_\tau) > m(\tilde{\chi}_1^0)$



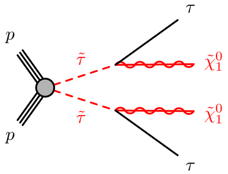
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ pair-production. 100 % BR $\tilde{\chi}_1^{\pm} \rightarrow \tau^{\pm}\nu\tilde{\chi}_1^0$

Assume wino-like $\tilde{\chi}_1^{\pm}$ and bino-like $\tilde{\chi}_1^0$



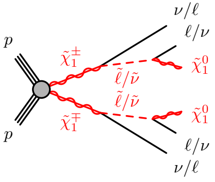
Direct Stau Production

- Challenging signal to target (low cross-section) $\rightarrow$ set upper limits on cross-section.
- For $\tilde{\tau}$ mass of 140 GeV and $\tilde{\chi}_1^0$ mass of 10 GeV. Theoretical cross-section= 0.04 pb, compared to upper limit on cross-section of 0.17 pb.



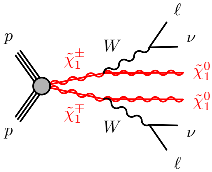
Chargino pair-production (2L)- ATLAS-CONF-2013-049

$m(\tilde{\chi}_1^\pm) > m(\tilde{e}_L, \tilde{\mu}_L, \tilde{\tau}_1, \tilde{\nu}) > m(\tilde{\chi}_1^0)$

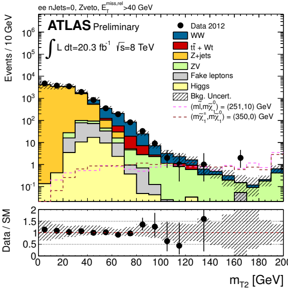


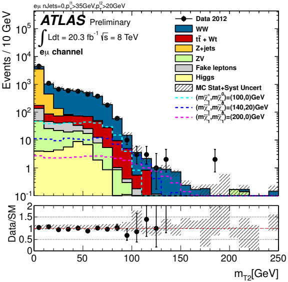
Targetted by SR-$m_{\mathrm{T2},90}$ and SR-$m_{\mathrm{T2},110}$

$m(\tilde{l}, \tilde{\nu}) > m(\tilde{\chi}_1^\pm) > m(\tilde{\chi}_1^0)$



Targetted by SR-WWa, SR-WWb, and SR-WWc





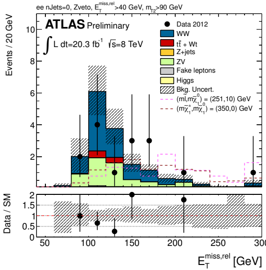
Assume wino like $\tilde{\chi}_1^\pm$, bino-like $\tilde{\chi}_1^0$.

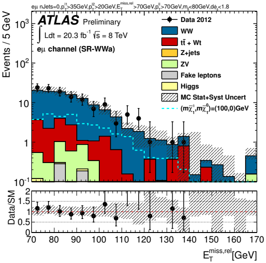
	SR-$m_{\mathrm{T2},90}$	SR-$m_{\mathrm{T2},110}$	SR-WWa	SR-WWb	SR-WWc
lepton flavour	e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$		$e^\pm\mu^\mp$		
$p_T^{\ell 1}$	—		> 35 GeV		
$p_T^{\ell 2}$	—		> 20 GeV		
$m_{\ell\ell}$	Z veto		< 80 GeV	< 130 GeV	—
$p_{T,\ell\ell}$	—		> 70 GeV	< 170 GeV	< 190 GeV
$\Delta\phi_{\ell\ell}$	—		< 1.8 rad		
$E_T^{\mathrm{miss,rel}}$	> 40 GeV		> 70 GeV	—	
m_{T2}	> 90 GeV	> 110 GeV	—	> 90 GeV	> 100 GeV

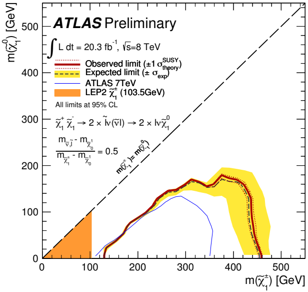
All regions also included a jet-veto on all jets with $p_T > 20$ GeV and $|\eta| < 2.4$ or $p_T > 30$ GeV and $|\eta| < 4.5$, as well as a veto on b-jets with $p_T > 20$ GeV and $|\eta| < 2.4$

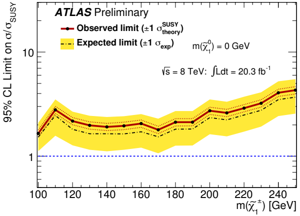
Chargino pair-production (2L)- ATLAS-CONF-2013-049

No excess above SM expectation observed in any signal region



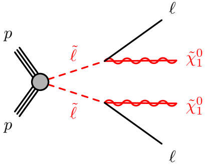






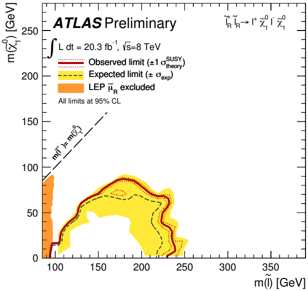
	SR-WWa	SR-WWb	SR-WWc
Observed	123	16	9
Background total	117.9 ± 14.6	13.6 ± 2.3	7.4 ± 1.5
Top	15.2 ± 6.6	2.7 ± 1.1	1.0 ± 0.7
WW	98.6 ± 14.6	10.2 ± 2.1	5.9 ± 1.3
ZV ($V = W$ or Z)	3.4 ± 0.8	$0.26^{+0.31}_{-0.26}$	0.29 ± 0.14
Higgs	0.76 ± 0.14	0.21 ± 0.06	0.10 ± 0.04
fake	$0.02^{+0.33}_{-0.02}$	$0.26^{+0.30}_{-0.26}$	$0.12^{+0.17}_{-0.12}$

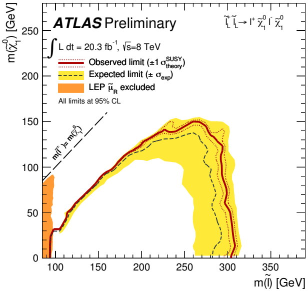
Used SR-$m_{\mathrm{T2},90}$ and SR-$m_{\mathrm{T2},110}$ to calculate exclusions for left-handed and right-handed sleptons separately.



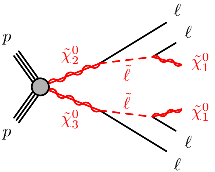
- Assume slepton pair production with 100% branching to $\tilde{l}^{\pm} \rightarrow l^{\pm}\tilde{\chi}_1^0$
- Degenerate selections, smuons.
- Assume bino-like $\tilde{\chi}_1^0$.

$$m_{\mathrm{T2}}^{\mathrm{max}} = \sqrt{\left(m_{\tilde{l}}^2 - m_{\tilde{\chi}_1^0}^2\right)\left(1 - \frac{m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{l}}^2}\right)}$$

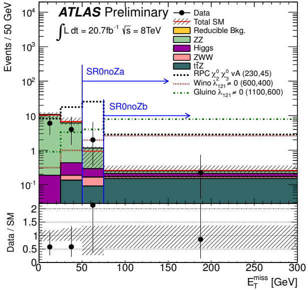


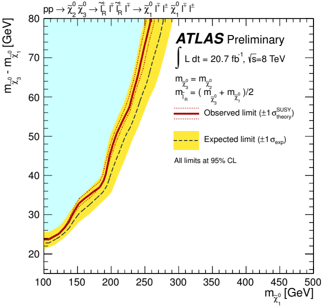


4-lepton channel- powerful search channel for many SUSY scenarios- very low SM background. Analysis contained 5 signal regions targeting different models, requiring at least 4 leptons, and E_T^{miss} and/or m_{eff}.



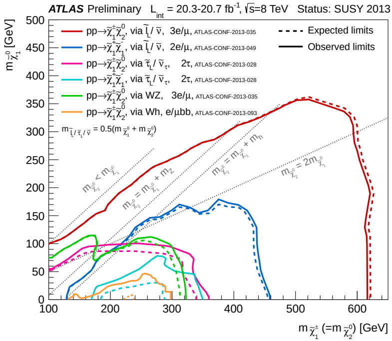
$m(\tilde{\chi}_2^0) > m(\tilde{e}_R, \tilde{\mu}_R) > m(\tilde{\chi}_1^0)$





SR	N($\ell = e, \mu$)	N(τ)	Z Candidate	E_T^{miss}[GeV]	m_{eff}[GeV]	Scenario
SR0noZa	≥4	≥0	extended veto	>50		RPC

Summary/Conclusions



- The results released so far based on the 2012 dataset have excluded large areas of parameter space in the models under consideration.
- Although no evidence of SUSY has been observed so far- the story is far from over!
- There's still lots to be done - increase the sensitivity of our existing searches, explore new channels, and prepare for the 2015 run at $\sqrt{s} = 13$ TeV!

Light gauginos are favoured by naturalness, so, perhaps electroweak SUSY could be just around the corner...

Signal region results:

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	**96 ± 19**	**29 ± 6**	**4.4 ± 1.8**	**249 ± 35**	**22 ± 5**	**6.3 ± 1.5**
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5
N_{signal} excluded (exp)	39.3	16.3	6.2	67.9	13.2	6.7
N_{signal} excluded (obs)	41.8	18.0	6.8	83.7	13.9	6.5
σ_{visible} excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
σ_{visible} excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31

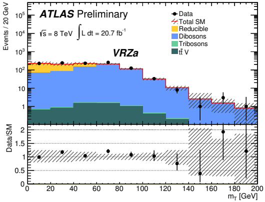
Validation region definitions:

Selection	VRnoZa	VRnoZb	VRZa	VRZb
m_{SFOS} [GeV]	<81.2 or >101.2	<81.2 or >101.2	81.2–101.2	81.2–101.2
b-jet	veto	request	veto	request
$E_{\text{T}}^{\text{miss}}$ [GeV]	35–50	>50	30–50	>50
Dominant process	WZ^*, Z^*Z^*, Z^*+jets	$t\bar{t}$	WZ, Z+jets	WZ

The irreducible “fake lepton” background was evaluated using a data-driven “matrix method”.

Standard Model Background Modelling:

- Dominant backgrounds were irreducible top/WZ contributions.
- All irreducible backgrounds were taken directly from NLO Monte Carlo which was checked in a number of validation regions..

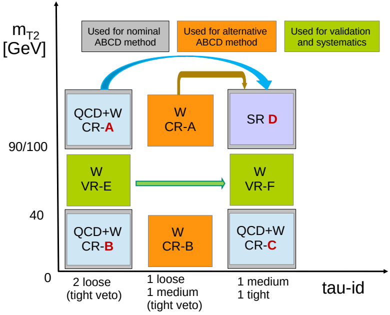


Signal region results:

SM process	SR OS m_{T2}	SR OS m_{T2} -nobjet
top	$0.2 \pm 0.5 \pm 0.1$	$1.6 \pm 0.8 \pm 1.2$
Z+jets	$0.28 \pm 0.26 \pm 0.23$	$0.4 \pm 0.3 \pm 0.3$
diboson	$2.2 \pm 0.5 \pm 0.5$	$2.5 \pm 0.5 \pm 0.9$
multi-jet & W+jets	$8.4 \pm 2.6 \pm 1.4$	$12 \pm 3 \pm 3$
SM total	$11.0 \pm 2.7 \pm 1.5$	$17 \pm 4 \pm 3$
data	6	14

- Irreducible backgrounds (Z+jets, diboson, top)- taken from directly from MC prediction.
- Reducible background- 1-2 fake taus- evaluated using data-driven ABCD method.

Regions used for ABCD method:



Model independent limits:

Signal Region	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	CL_B	$p(s=0)$
SR-OSm_{T2}	0.27	5.6	$8.9^{+2.7}_{-3.2}$	0.14	0.42
SR-OSm_{T2}-nobjet	0.50	10.4	$10.4^{+0.6}_{-1.7}$	0.48	0.39

Backup- ATLAS-CONF-2013-049 (2L)

Signal region estimates for SR-$m_{\mathrm{T2},90}$ and SR-$m_{\mathrm{T2},110}$:

SR-$m_{\mathrm{T2},90}$	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Observed	15	19	19	53
Background total	16.6 ± 2.3	20.7 ± 3.2	22.4 ± 3.3	59.7 ± 7.3
WW	9.3 ± 1.6	14.1 ± 2.2	12.6 ± 2.0	36.1 ± 5.1
ZV ($V = W$ or Z)	6.3 ± 1.5	0.8 ± 0.3	7.3 ± 1.7	14.4 ± 3.2
Top	$0.9^{+1.1}_{-0.9}$	5.6 ± 2.1	2.5 ± 1.8	8.9 ± 3.9
Higgs	0.11 ± 0.04	0.19 ± 0.05	0.08 ± 0.04	0.38 ± 0.08
Fake	$0.00^{+0.18}_{-0.00}$	$0.00^{+0.14}_{-0.00}$	$0.00^{+0.15}_{-0.00}$	$0.00^{+0.28}_{-0.00}$

SR-$m_{\mathrm{T2},110}$	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Observed	4	5	4	13
Background total	6.1 ± 2.2	4.4 ± 2.0	6.3 ± 2.4	16.9 ± 6.0
WW	2.7 ± 1.5	3.6 ± 2.0	2.9 ± 1.6	9.1 ± 4.9
ZV ($V = W$ or Z)	2.7 ± 1.4	0.2 ± 0.1	3.4 ± 1.8	6.3 ± 3.3
Top	0.7 ± 0.7	0.6 ± 0.4	0.0 ± 0.0	1.3 ± 1.0
Higgs	0.05 ± 0.03	0.12 ± 0.04	0.05 ± 0.02	0.22 ± 0.05
Fake	$0.00^{+0.09}_{-0.00}$	$0.00^{+0.13}_{-0.00}$	$0.00^{+0.12}_{-0.00}$	$0.00^{+0.28}_{-0.00}$

SM background modelling:

- Dominant irreducible MC backgrounds- renormalised Monte Carlo predictions to data in control regions.
- Others taken directly from MC.
- Reducible fake background (1/2 fake leptons)- used data-driven “Matrix method”.

Control region definitions:

$$N_B^{\mathrm{SR}} = \left[\frac{N^{\mathrm{CR}} - N^{\mathrm{CR}}_{\mathrm{other}}}{N^{\mathrm{CR}}_{B,\mathrm{MC}}} \right] \times N^{\mathrm{SR}}_{B,\mathrm{MC}},$$

SR	SR-$m_{\mathrm{T2},90}$	SR-$m_{\mathrm{T2},110}$	SR-WWa	SR-WWb	SR-WWc
WW CR					
lepton flavour	$e^\pm\mu^\mp$		$e^\pm\mu^\mp$		
$m_{\ell\ell}$	Z veto		—		
$\Delta\phi_{\ell\ell}$	—		< 1.8 rad		
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$	> 40 GeV		< 70 GeV	—	
m_{T2}	50–90 GeV		—	< 90 GeV	
Top CR					
b-tagged jets	≥ 1		≥ 1		
signal jets	≥ 2		≥ 1		
lepton flavour	e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$		$e^\pm\mu^\mp$		
$m_{\ell\ell}$	Z veto		< 80 GeV	< 130 GeV	
$p_{\mathrm{T},\ell\ell}$	—		> 70 GeV	< 170 GeV	< 190 GeV
$\Delta\phi_{\ell\ell}$	—		< 1.8 rad		
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$	> 40 GeV		> 70 GeV	—	
m_{T2}	—		—	> 90 GeV	> 100 GeV
ZV CR					
lepton flavour	e^+e^-, $\mu^+\mu^-$		not defined		
$m_{\ell\ell}$	Z select				
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$	> 40 GeV				
m_{T2}	> 90 GeV	> 110 GeV			

Backup- ATLAS-CONF-2013-036 (4L)

Definitions and results for all signal regions:

SR	$N(\ell = e, \mu)$	$N(\tau)$	Z Candidate	E_T^{miss} [GeV]		m_{eff} [GeV]	Scenario
SR0noZa	≥4	≥0	extended veto	>50			RPC
SR0noZb	≥4	≥0	extended veto	>75	or	>600	RPV
SR1noZ	=3	≥1	extended veto	>100	or	>400	RPV
SR0Z	≥4	≥0	request	>75			GGM
SR1Z	=3	≥1	request	>100			GGM

$$m_{eff} = E_T^{miss} + \sum_{\mu} p_T^{\mu} + \sum_{e} p_T^{e} + \sum_{\tau} p_T^{\tau} + \sum_{j} p_T^{j},$$

Sample	SR0noZa	SR0noZb	SR1noZ	SR0Z	SR1Z
ZZ	0.6 ± 0.5	0.50 ± 0.26	0.19 ± 0.05	1.2 ± 0.4	0.49 ± 0.10
ZWW	0.12 ± 0.12	0.08 ± 0.08	0.05 ± 0.05	0.6 ± 0.6	0.13 ± 0.13
$t\bar{t}Z$	0.73 ± 0.34	0.75 ± 0.35	0.16 ± 0.12	2.3 ± 0.9	0.29 ± 0.24
Higgs	0.26 ± 0.07	0.22 ± 0.07	0.23 ± 0.06	0.58 ± 0.15	0.14 ± 0.05
Irreducible Bkg.	1.7 ± 0.8	1.6 ± 0.6	0.62 ± 0.21	4.8 ± 1.8	1.1 ± 0.4
Reducible Bkg.	$0^{+0.16}_{-0}$	$0.05^{+0.14}_{-0.05}$	1.4 ± 1.3	$0^{+0.14}_{-0}$	$0.3^{+1.0}_{-0.3}$
Total Bkg.	1.7 ± 0.8	1.6 ± 0.6	2.0 ± 1.3	4.8 ± 1.8	$1.3^{+1.0}_{-0.5}$
Data	2	1	4	8	3
p_0-value	0.29	0.5	0.15	0.08	0.13
N_{signal} Excluded (exp)	3.9	3.6	5.3	6.7	4.5
N_{signal} Excluded (obs)	4.7	3.7	7.5	10.4	6.5
$\sigma_{visible}$ Excluded (exp) [fb]	0.19	0.17	0.26	0.32	0.22
$\sigma_{visible}$ Excluded (obs) [fb]	0.23	0.18	0.36	0.50	0.31

SM background modelling:

- Irreducible backgrounds from ZZ, $t\bar{t}$+V, VVV, higgs- taken from MC and checked in validation regions.
- Reducible background- 1 or 2 fake leptons- evaluated using data-driven “weighting method”.

Backup- ATLAS-CONF-2013-036 (4L)

Validation region definitions:

VR	$N(\ell = e, \mu)$	$N(\tau)$	Z Candidate	E_T^{miss}[GeV]		m_{eff}[GeV]	Dominant Background
VR0noZ	≥4	≥0	extended veto	<50	and	<400	Z^*Z^*
VR1noZ	=3	≥1	extended veto	<50	and	<400	Z^*Z^*, WZ^*, Z^*+jets
VR0Z	≥4	≥0	request	<50			ZZ
VR1Z	=3	≥1	request	<50			ZZ, WZ, Z+jets

Validation region results:

Sample	VR0noZ	VR1noZ	VR0Z	VR1Z
ZZ	7.2 ± 3.6	1.45 ± 0.30	167 ± 38	8.0 ± 1.2
ZWW	0.031 ± 0.031	0.027 ± 0.027	0.35 ± 0.35	0.10 ± 0.10
$t\bar{t}Z$	$0^{+0.05}_{-0}$	$0^{+0.10}_{-0}$	1.5 ± 0.7	0.18 ± 0.14
Higgs	0.17 ± 0.05	0.23 ± 0.05	4.5 ± 0.9	0.64 ± 0.16
Irreducible Bkg.	7.4 ± 3.6	1.70 ± 0.34	173 ± 39	8.9 ± 1.4
Reducible Bkg.	$0.3^{+0.7}_{-0.3}$	7.9 ± 3.6	$2.0^{+2.6}_{-2.0}$	28 ± 10
Total Bkg.	7.7 ± 3.4	9.6 ± 3.6	175 ± 37	37 ± 10
Data	3	10	201	31
CL_b	0.10	0.54	0.51	0.30