Electroweak SUSY Searches At ATLAS

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ATLAS EXPERIMENT

Outline

- **Motivation and strategy**

- **Results from Run-2 EWK SUSY searches**

NEW

✧ 2 or 3 light leptons (e,μ)
✧ 2 hadronically decaying taus

R-parity-conserving

✧ 4 leptons

R-parity-violating

- **Conclusions**

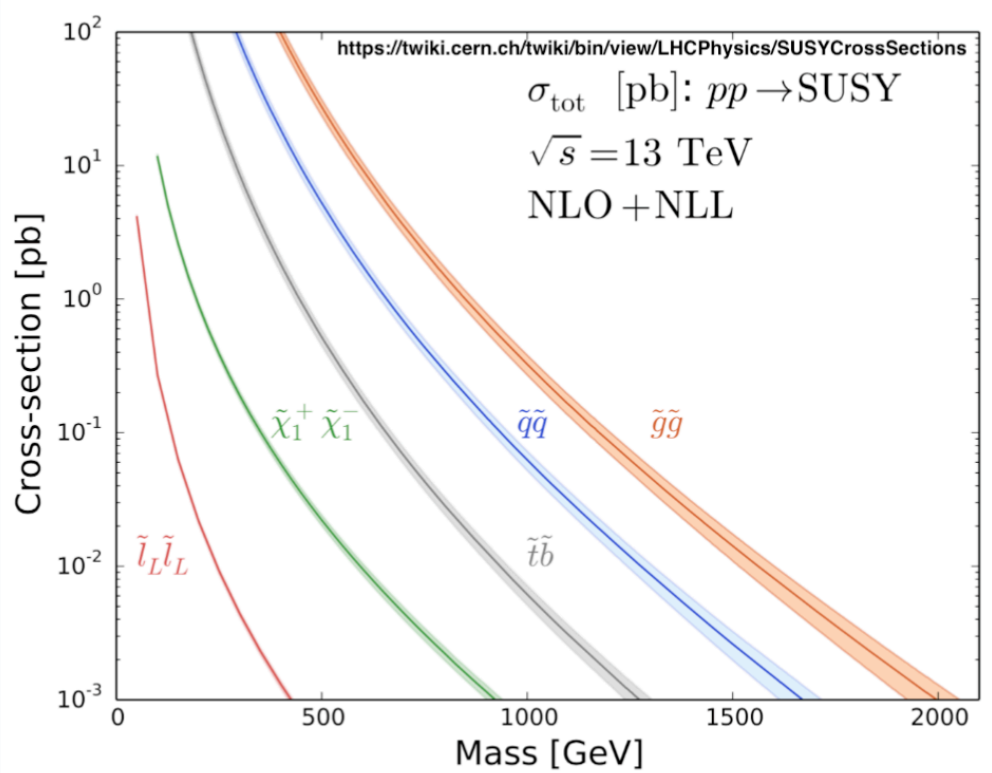
This is NOT an Intro to SUSY

You're welcome.

(The only neutralino you'll see all week… →)

Electroweak SUSY Production

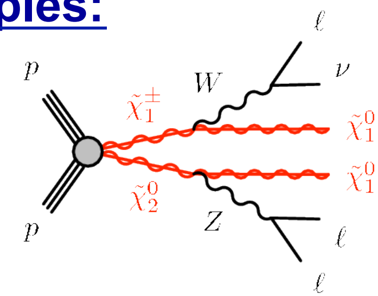
- If coloured sparticles (including 3rd gen. squarks) have very large masses, **direct EWK-ino production becomes dominant**
- **Leptonic decays of charginos, neutralinos, sleptons** are a main feature of EWK SUSY searches
- **Distinctiveness of multileptonic signatures** counterbalance low cross sections x BR
  - High-efficiency triggering and effective SM background suppression
- Available Run-2 data already sufficient to **probe significant portions of the parameter space**

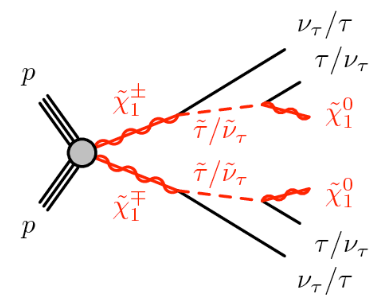


Overall Strategy

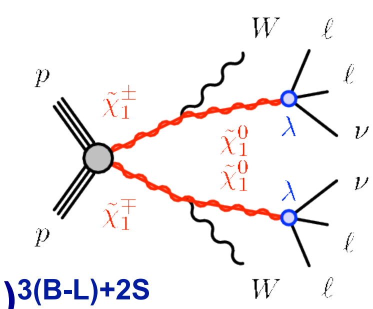
- **Signature-based analyses** are classified by **lepton multiplicity**
- **Simplified models** provide a framework for the interpretation of results
  - Specific processes are simulated as individual “building blocks”
    - Minimal particle content
    - 100% BR
    - Relevant sparticle masses the only free parameters
- Scenarios with **R-parity-conserving** (RPC) and **R-parity-violating** (RPV) decays are both being examined

Examples:





RPC

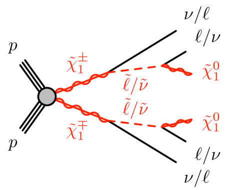
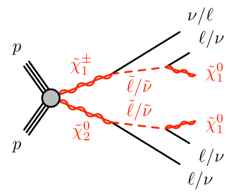
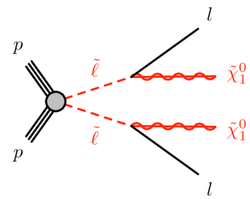
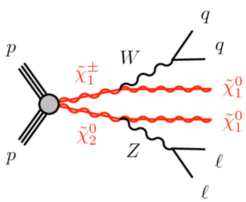
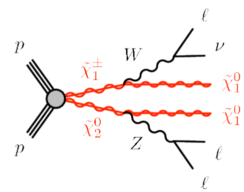


RPV

$\mathbf{R_P = (-1)^{3(B-L)+2S}}$

2/3 L (e, μ) + MET (+ jets) – Strategy

[ATLAS-CONF-2017-039]
[36.1 fb^{-1}]

	2L		3L
C1C1 & C1N2 (via slepton)			
Direct Sleptons			
C1N2 (via WZ)			
	MET + >=2J	MET + 0J	MET (+ 0/>=1J)

C1 = $\tilde{\chi}_1^{\pm}$
N1 = $\tilde{\chi}_1^{0}$
N2 = $\tilde{\chi}_2^{0}$

C1 and N2 = wino-like
N1 = bino-like
m(C1) = m(N2)
m(slep) = m(sneutrino)
= [m(C1)+m(N1)]/2

C1C1, C1N2, slep-slep decays can give rise to signals with 2 or 3 leptons in the final state

- Plus missing tranverse energy (MET)
- With or without additional light jets (J), from W decay or ISR

C1/N2 decays can proceed via intermediate sleptons or SM gauge bosons

- Leptonic decays via intermediate sleptons have higher yields

Only light flavours (e, μ) are considered here

- Hadronic tau signatures discussed separately

2 L (e, μ) + 0J + MET

[ATLAS-CONF-2017-039]
[36.1 fb^{-1}]

2 opposite-sign (OS) leptons, split between **same-flavour (SF)** and **different-flavour (DF)** leptons

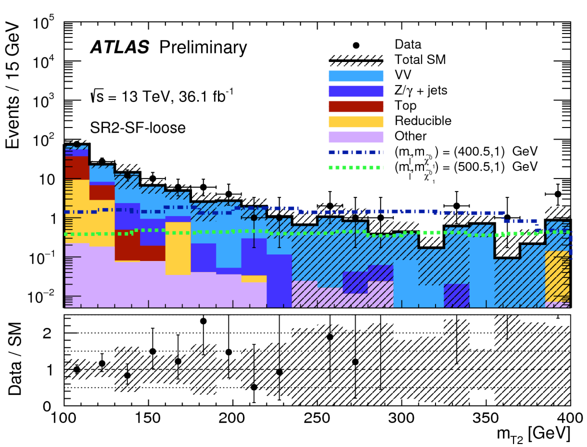
- ✧ to target different SM background components separately

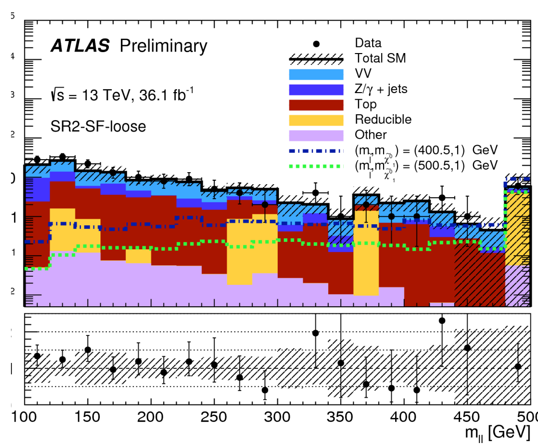
Signal regions (SRs) are **binned** in **stransverse mass m_{T2}** and (for SF) **dilepton mass m_{ll}** to increase sensitivity

- ✧ After a preselection on **2-lep invariant mass** and a **jet veto**

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

$$m_T(\mathbf{p}_T, \mathbf{q}_T) = \sqrt{2(p_T q_T - \mathbf{p}_T \cdot \mathbf{q}_T)}.$$





2ℓ+0jets binned signal region definitions			
m_{T2} [GeV]	$m_{\ell\ell}$ [GeV]	SF bin	DF bin
100-150	111-150	SR2-SF-a	SR2-DF-a
	150-200	SR2-SF-b	
	200-300	SR2-SF-c	
	> 300	SR2-SF-d	
150-200	111-150	SR2-SF-e	SR2-DF-b
	150-200	SR2-SF-f	
	200-300	SR2-SF-g	
	> 300	SR2-SF-h	
200-300	111-150	SR2-SF-i	SR2-DF-c
	150-200	SR2-SF-j	
	200-300	SR2-SF-k	
	> 300	SR2-SF-l	
> 300	> 111	SR2-SF-m	SR2-DF-d
2ℓ+0jets inclusive signal region definitions			
> 100	> 111	SR2-SF-loose	-
> 130	> 300	SR2-SF-tight	-
> 100	-	-	SR2-DF-100
> 150	-	-	SR2-DF-150
> 200	-	-	SR2-DF-200
> 300	-	-	SR2-DF-300

2 L (e, μ) + >=2J + MET

[ATLAS-CONF-2017-039]
[36.1 fb^{-1}]

2 same-flavour opposite sign (SFOS) leptons and **>= 2 light jets**
- Plus a **b-jet veto**

Two inclusive SRs to target **intermediate / large mass splittings between C1/N2 and N1**

Two other orthogonal regions to target **lower mass splittings**

Cuts to select **leptons from Z decay** and **jets from W decay**

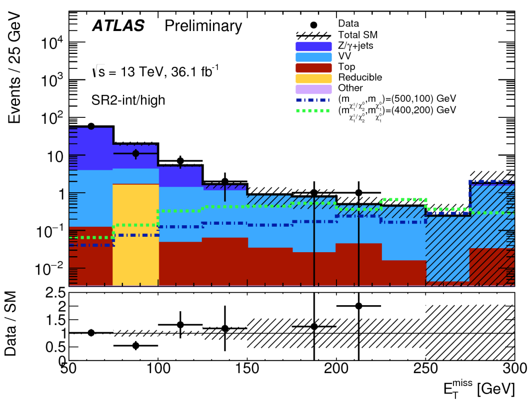
m_{T2} cut to suppress ttbar, **E_T^{miss}** cut to boost signal significance

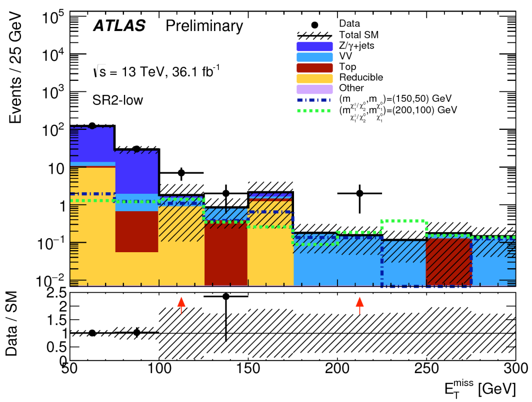
SR-low (2-jets): assumes the two jets come from the W boson.

SR-low(3-5 jets): assumes the C1N2 recoils against ISR jets.

2ℓ+jets signal region definitions

	SR2-int	SR2-high	SR2-low-2J	SR2-low-3J
$n_{\mathrm{non-b-tagged\ jets}}$	≥ 2		2	3-5
$m_{\ell\ell}$ [GeV]	81-101		81-101	86-96
m_{jj} [GeV]	70-100		70-90	70-90
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>150	> 250	>100	>100
p_{T}^{Z} [GeV]	>80		> 60	> 40
p_{T}^{W} [GeV]	>100			
m_{T2} [GeV]	>100			
$\Delta R_{(jj)}$	<1.5			<2.2
$\Delta R_{(\ell\ell)}$	<1.8			
$\Delta\phi_{(\vec{E}_{\mathrm{T}}^{\mathrm{miss}},Z)}$			< 0.8	
$\Delta\phi_{(\vec{E}_{\mathrm{T}}^{\mathrm{miss}},W)}$	0.5-3.0		> 1.5	< 2.2
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{Z}$			0.6 – 1.6	
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{W}$			< 0.8	
$\Delta\phi_{(\vec{E}_{\mathrm{T}}^{\mathrm{miss}},\mathrm{ISR})}$				> 2.4
$\Delta\phi_{(\vec{E}_{\mathrm{T}}^{\mathrm{miss}},\mathrm{jet1})}$				> 2.6
$E_{\mathrm{T}}^{\mathrm{miss}}/\mathrm{ISR}$				0.4-0.8
$\lvert\eta(Z)\rvert$				< 1.6
$p_{\mathrm{T}}^{\mathrm{jet3}}$ [GeV]				> 30





3 L (e, μ) + MET

[ATLAS-CONF-2017-039]
[36.1 fb^{-1}]

Exactly **3 light leptons (2 SFOS)**, **b-jet veto**

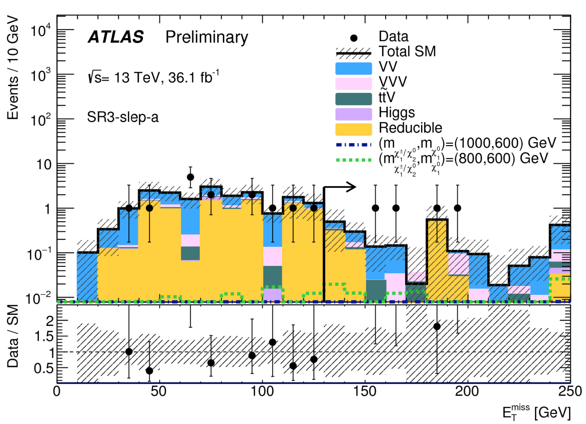
Target **C1N2 decays via sleptons or WZ** separately, using kinematic variables to define binned SRs, including:

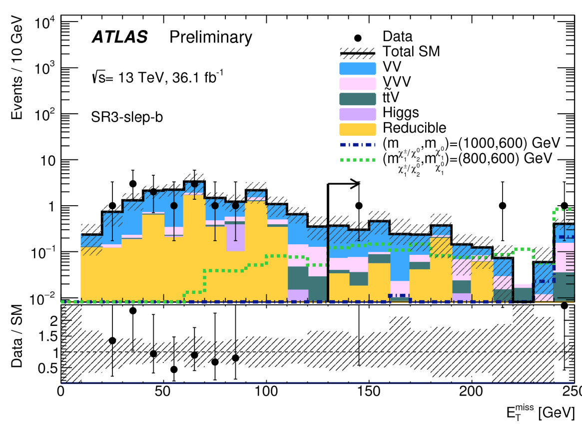
- ✧ **Missing transverse energy**
- ✧ **(Minimum) transverse mass**
- ✧ **SFOS pair invariant mass**

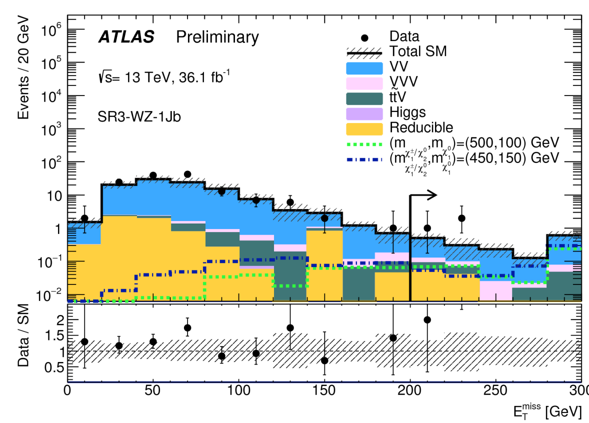
In WZ scenarios, **SFOS-pair invariant mass** must be consistent with on-shell Z boson, and **light-jet multiplicity** is also used in SR binning

3ℓ binned signal region definitions

m_{SFOS} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$p_{\mathrm{T}}^{\ell_3}$ [GeV]	$n_{\mathrm{non-b-tagged\ jets}}$	$m_{\mathrm{T}}^{\mathrm{min}}$ [GeV]	$p_{\mathrm{T}}^{\ell\ell\ell}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{jet1}}$ [GeV]	Bins
<81.2	> 130	20-30 > 30		> 110			SR3-slep-a SR3-slep-b
>101.2	> 130	20-50 50-80 > 80		> 110			SR3-slep-c SR3-slep-d SR3-slep-e
81.2-101.2	60-120 120-170 > 170		0	> 110			SR3-WZ-0Ja SR3-WZ-0Jb SR3-WZ-0Jc
81.2-101.2	120-200 > 200	> 35	≥ 1	> 110 110-160 > 160	< 120	> 70	SR3-WZ-1Ja SR3-WZ-1Jb SR3-WZ-1Jc







2/3 L (e, μ) + MET (+ jets) – Backgrounds

[ATLAS-CONF-2017-039]
[36.1 fb⁻¹]

Irreducible backgrounds

i.e. processes leading to events with prompt and isolated leptons, such as

- ✧ **Dibosons**, **Z+jets**, **ttbar**
  (plus: higgs, tribosons, top+V)

Reducible backgrounds

i.e. events that either have at least one "fake" lepton, or where mis-measurement of objects (usually jets) leads to significant "fake" E_T^{miss}

- ✧ **Multijets**, **W+jets**, **single-top**, **Z+jets** – (2/3L)
- ✧ **ttbar**, **WW** – (3L only)

SM background estimates in the signal regions are based on:

- ✧ **Data-driven methods**
- ✧ **MC predictions**

Backgrounds fits in **control regions** (CRs) are extrapolated to **dedicated validation regions** (VRs) and to **signal regions** (SRs)

Model verified in VRs prior to unblinding in SRs

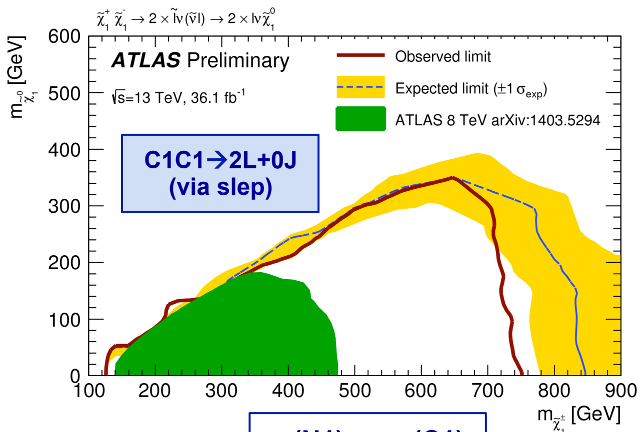
Background estimation summary			
Channel	2ℓ+0jets	2ℓ+jets	3ℓ
Fake leptons	Matrix method (MM)		Fake factor method (FF)
$t\bar{t}+Wt$	CR	MC	FF
VV	CR	MC	CR (WZ-only)
Z/γ+jets	MC	γ+jet template	FF
Higgs/ VVV/ top+V	MC		

2/3 L (e, μ) + MET (+ jets) – Results

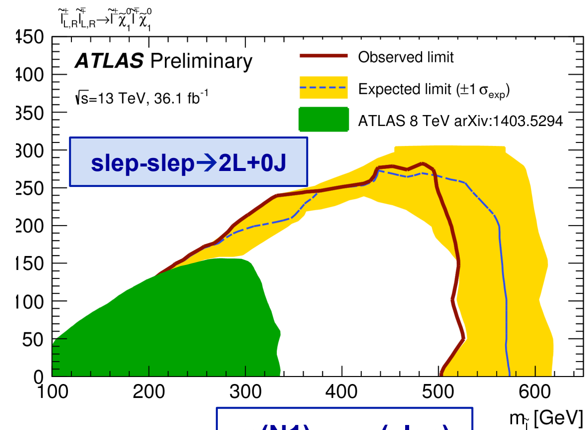
[ATLAS-CONF-2017-039]
[36.1 fb^{-1}]

No significant excess above SM expectations in any of the considered channels
➔ **Stringent limits on C1/N2 and slepton masses**

Substantial improvements on existing limits for via-slepton C1C1 and C1N2 signals

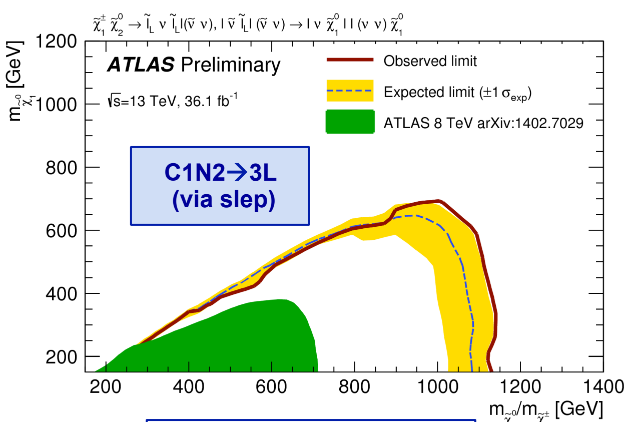


m(N1) vs m(C1)

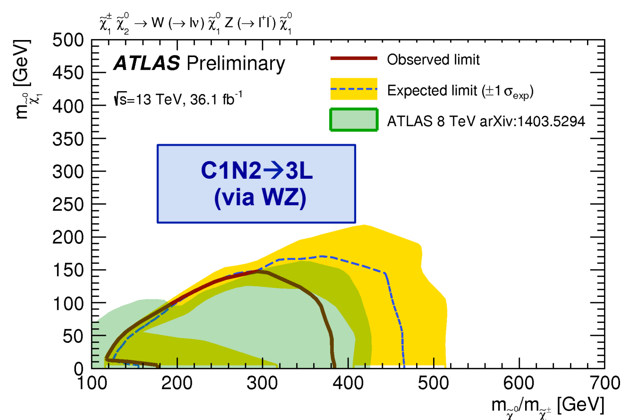


m(N1) vs m(slep)

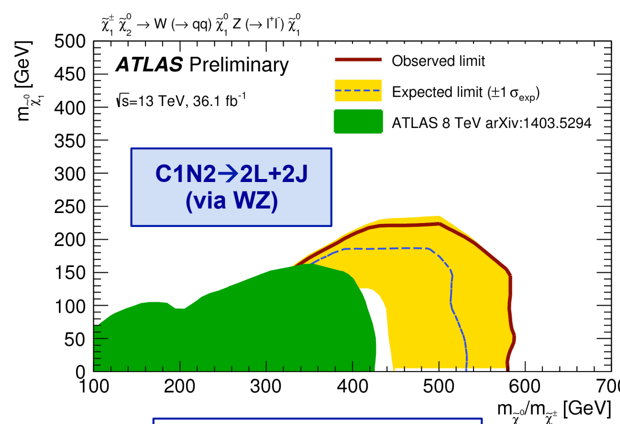
New Run-2 results from slepton-slepton and C1N2(via WZ)



m(N1) vs m(C1)=m(N2)



m(N1) vs m(C1)=m(N2)



m(N1) vs m(C1)=m(N2)

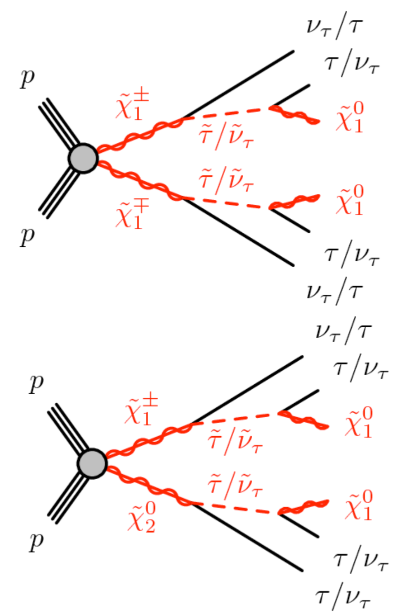
2 τ (OS) + MET – Strategy

[ATLAS-CONF-2017-035]
[36.1 fb^{-1}]

SR-lowMass	SR-highMass	
at least one opposite sign tau pair		
b-jet veto		
Z-veto		
at least two medium tau candidates	at least one medium and one tight tau candidates	
	$m(\tau_1,\tau_2) > 110$ GeV	
$m_{T2} > 70$ GeV	$m_{T2} > 90$ GeV	
di-tau+E_T^{miss} trigger	di-tau+E_T^{miss} trigger	asymmetric di-tau trigger
$E_T^{miss} > 150$ GeV	$E_T^{miss} > 150$ GeV	$E_T^{miss} > 110$ GeV
$p_{T,\tau_1} > 50$ GeV	$p_{T,\tau_1} > 80$ GeV	$p_{T,\tau_1} > 95$ GeV
$p_{T,\tau_2} > 40$ GeV	$p_{T,\tau_2} > 40$ GeV	$p_{T,\tau_2} > 65$ GeV

C1 and N2 = pure wino
N1 = pure bino
m(C1) = m(N2)
m(stau) = m(tau sneutrino)
= [m(C1)+m(N1)]/2

2τ (OS) + MET



At least two OS *hadronically* decaying taus
With b-jet and Z-boson vetoes

Two signal regions (not mutually exclusive)
To target scenarios with high/low Δm(C1/N2,N1) mass splittings

m_{T2} is the most powerful discriminating variable

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

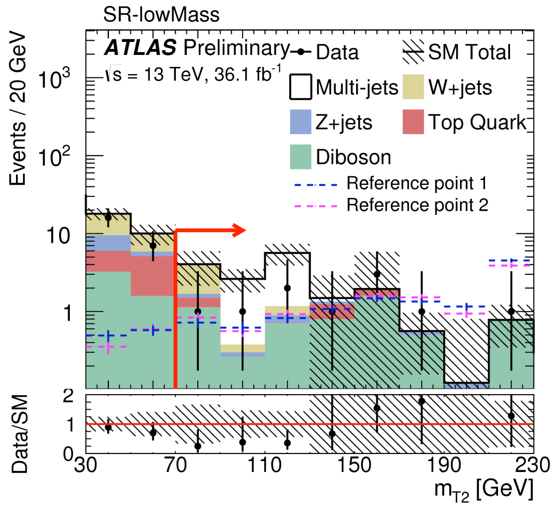
Backgrounds:

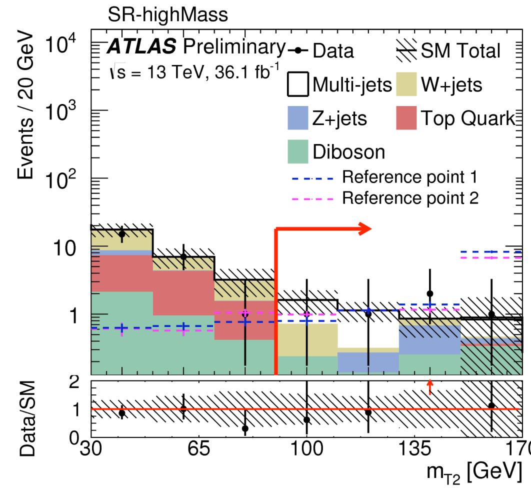
W+jets: semi-data-driven, estimated from MC and normalised to data in a dedicated CR
top, Z+jets, dibosons: from MC + VR validation
Multijets: derived from data (ABCD method).

2 τ (OS) + MET – Results

[ATLAS-CONF-2017-035]
[36.1 fb^{-1}]

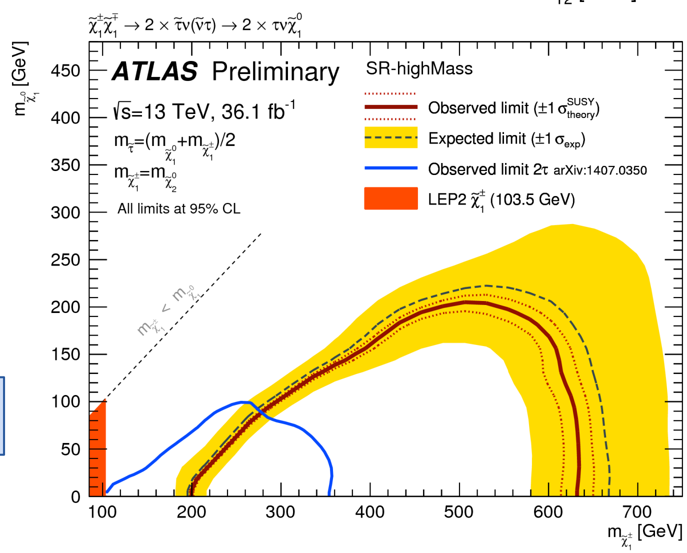
High-mass

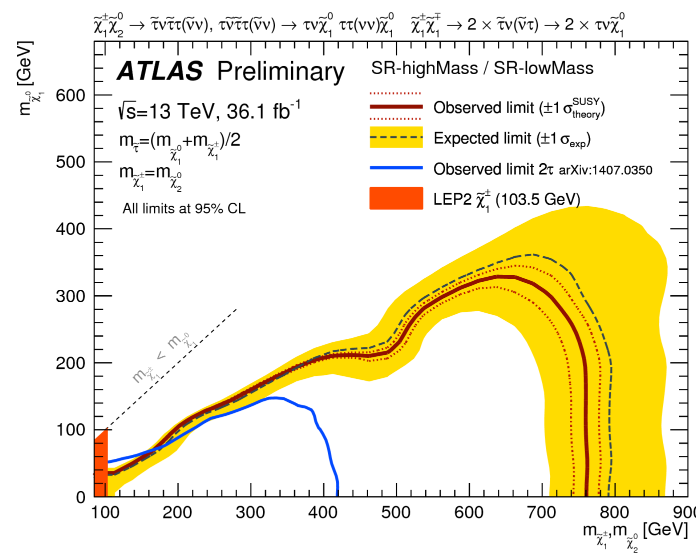




Low-mass

C1C1





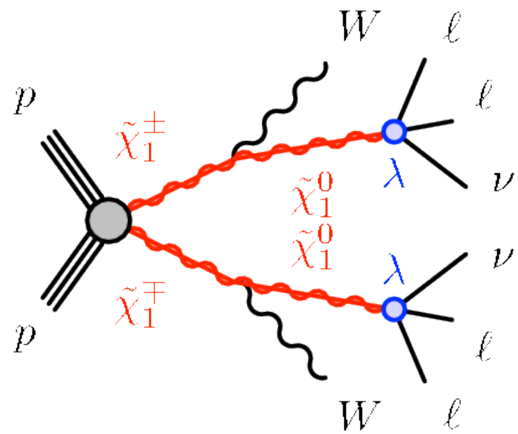
C1C1+ C1N2

RPV 4L – Strategy

[ATLAS-CONF-2016-075]
[13.3 fb⁻¹]

RPC C1C1 production
RPV N1 decays

- ✧ Four light leptons (e, μ)
- ✧ Leptonic triggers
- ✧ Z-boson veto
- ✧ Large effective mass, m_{eff}



RPV potential $\frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k$

C1 = wino-like
N1 = bino-like
BR(ee) = BR(μμ) = BR(eμ)=1/3

Irreducible backgrounds

- ✧ ZZ, ttZ, VVZ, ttWW, higgs
- ✧ From **MC simulations**

Reducible backgrounds

(1 or 2 fake leptons)

- ✧ WZ, WWW, ttW; ttbar, Z+jets
- ✧ **1-fake:** from **MC simulations**
- ✧ **2-fakes:** from **data-driven method** (fake factor)
- ✧ Background model validated in VR prior to unblinding in SRs

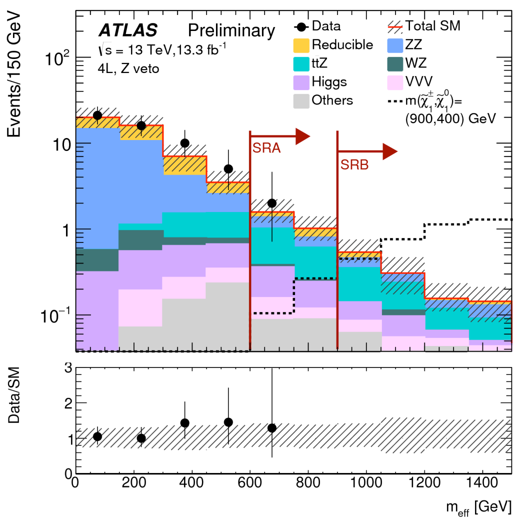
$$m_{eff} = E_T^{miss} + \sum_{\ell} p_T(\ell) + \sum_{J} \left[p_T(J) \right]_{>40\,GeV}$$

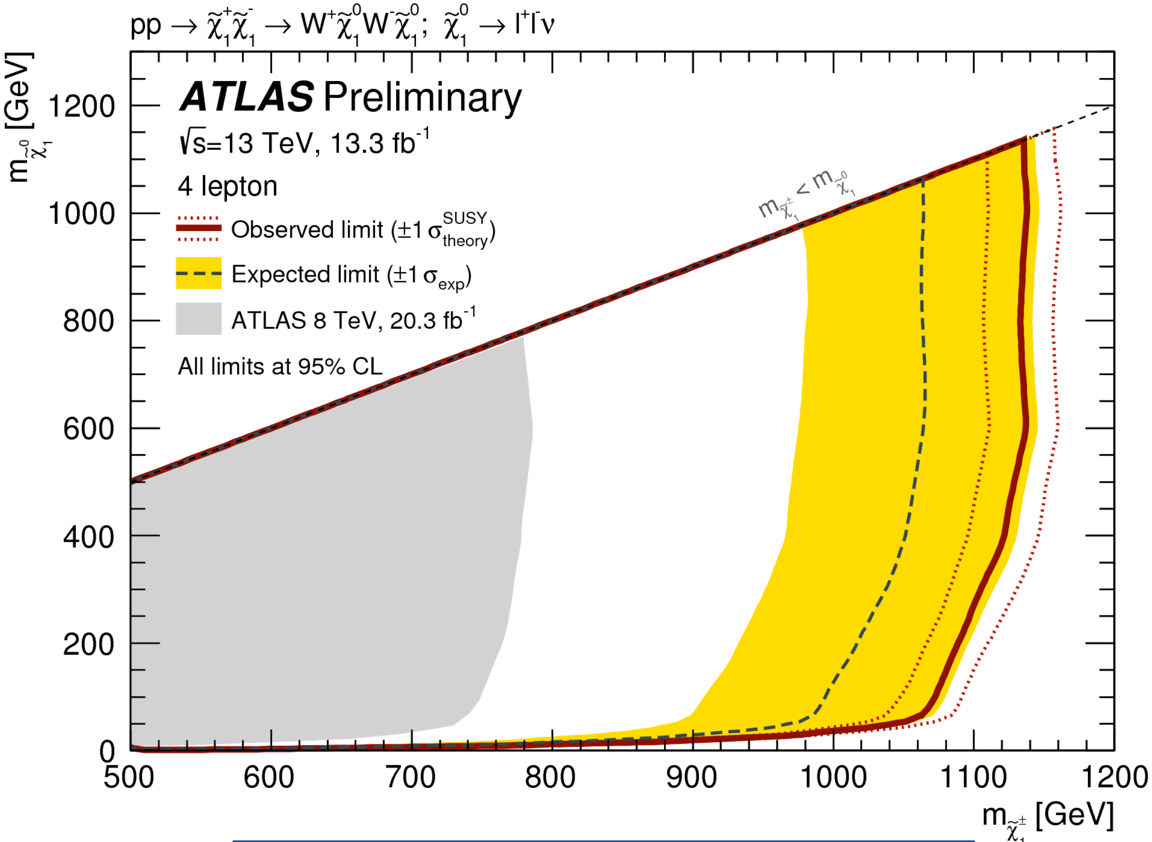
Sample	$N(e,\mu)$ signal	$N(e,\mu)$ loose	Z boson	m_{eff} [GeV]
SRA	>= 4	>= 0	veto	> 600
CR-SRA	= 2	>= 2	veto	> 600
SRB	>= 4	>= 0	veto	> 900
CR-SRB	= 2	>= 2	veto	> 900
VR	>= 4	>= 0	veto	< 600
CR-VR	= 2	>= 2	veto	< 600

RPV 4L – Results

[ATLAS-CONF-2016-075]
[13.3 fb^{-1}]

Sample	VR	SRA	SRB
Irreducible			
ZZ	29 ± 5	0.6 ± 0.4	0.20 ± 0.19
$t\bar{t}Z$	2.05 ± 0.24	1.43 ± 0.23	0.47 ± 0.09
Higgs	1.7 ± 1.4	0.4 ± 0.4	0.11 ± 0.11
VVZ	0.72 ± 0.14	0.31 ± 0.06	0.123 ± 0.027
Others	0.28 ± 0.07	0.32 ± 0.04	0.181 ± 0.022
1-fake ℓ reducible	1.14 ± 0.07	0.168 ± 0.018	0.069 ± 0.014
2-fake ℓ reducible	16 ± 6	0.48 ± 0.24	0.11 ± 0.05
Σ SM	51 ± 6	3.6 ± 0.6	1.26 ± 0.26
Data	53	2	0
p_0	—	0.64	0.80
S^{95}_{obs}	—	4.3	3.0
S^{95}_{exp}	—	$5.4^{+1.6}_{-1.3}$	$3.8^{+1.3}_{-0.8}$
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	—	0.32	0.22
CL_b	—	0.21	0.15





Greatly extended chargino mass limits compared to Run-I results

Conclusions

- **EWK SUSY searches are complementary to strong SUSY searches**
  - ✧ And a key discovery tool if coloured sparticles are too heavy

- **Ongoing analysis of 2015+2016 data already delivering stringent limits on relevant sparticle masses**
  - ✧ Sadly, no SUSY yet

- **These are complex analyses that require large statistics, and we’ve only just began to scratch the surface**
  - ✧ Looking forward to a lot more data