Search for electroweak production of supersymmetric particles in the two and three lepton final state at $\sqrt{s} = 13$ TeV with the ATLAS detector

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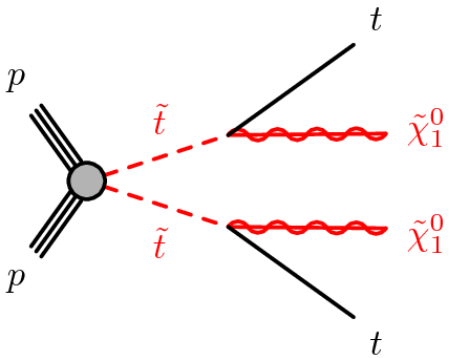
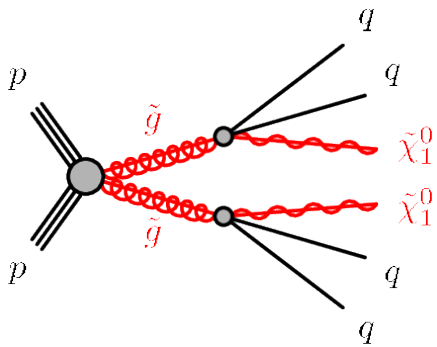
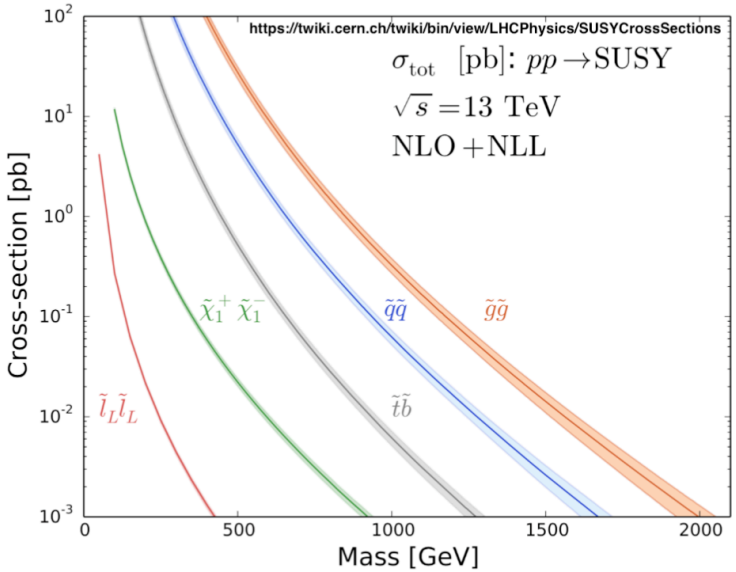
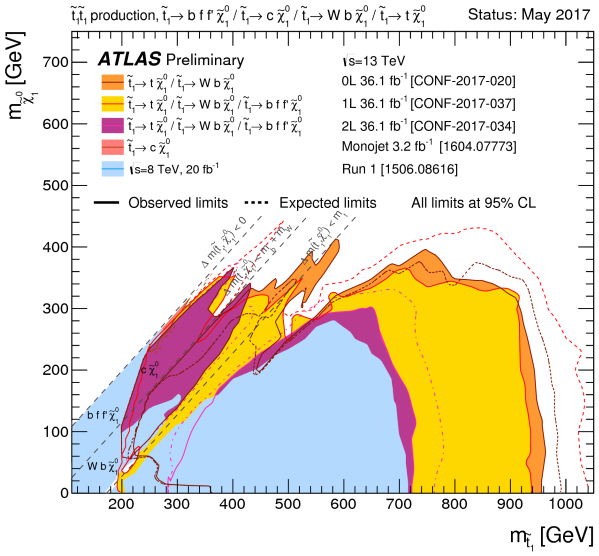
Motivation for Electroweak SUSY

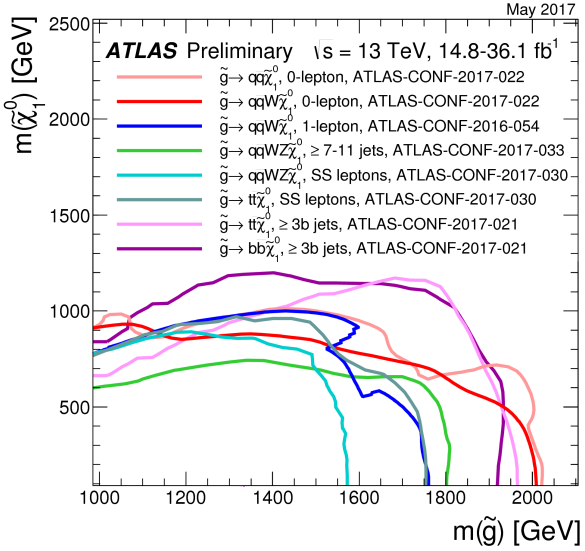




LHC SUSY Cross Sections

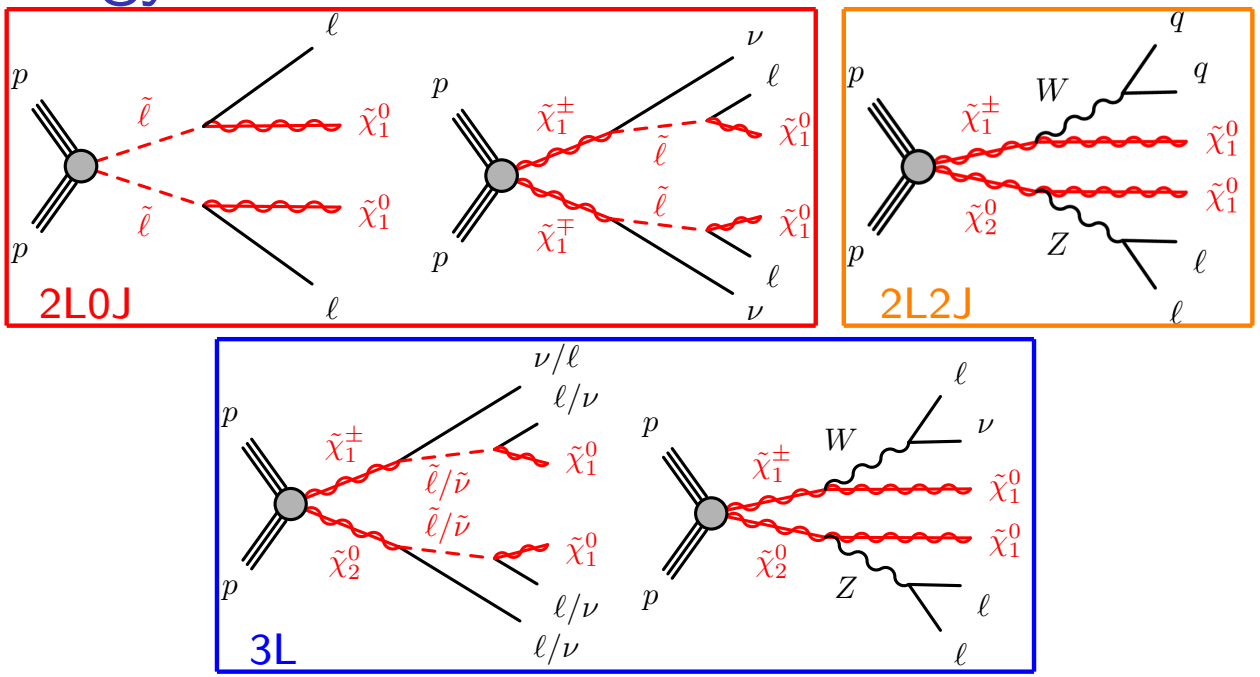






- Stringent limits set on strongly produced SUSY for simplified models.
- If gauginos and higgsinos are light, their production will dominate.
- This can lead to signatures with multiple leptons and E_T^{miss}.

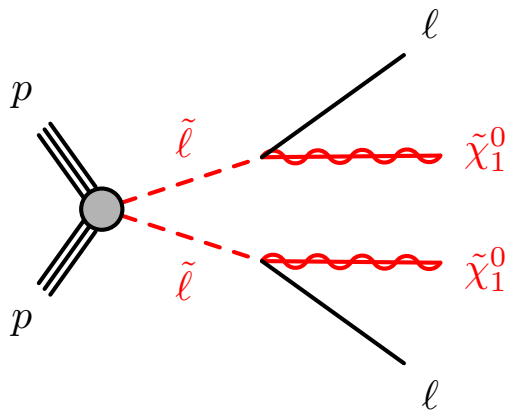
Search Strategy

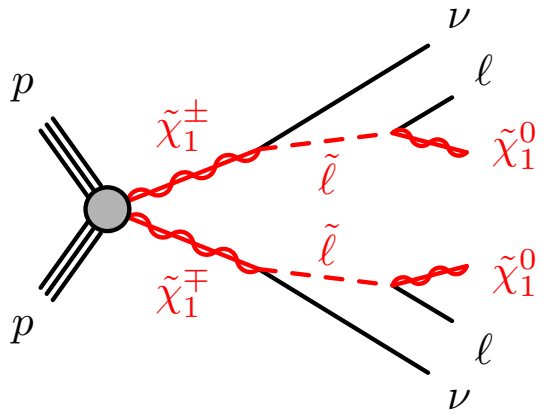


- 3 different final states: 2L+0jets, 2L+2jets, 3L
- Simplified models provide a framework for interpreting the results:
  - Assumptions on sleptons
    - ★ mass halfway between $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$.
    - ★ Assume 100% branching ratio to leptons.
  - Assumptions on gauginos :
    - ★ LSP ($\tilde{\chi}_1^0$) is bino
    - ★ $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ mass degenerate winos.
- Only light flavors (e, μ) are considered here

ATLAS-CONF-2017-03

2 leptons + 0 jets $+E_T^{miss}$





- 2 same flavor opposite sign (SFOS) leptons
- 2 OS leptons (either SF or different flavor (DF))
- Background estimation:
  - Diboson (SF and DF) constrained using a Control Region (CR)
  - $t\bar{t}$ also constrained using a CR
  - Data-driven techniques to estimate W+jets where jet fakes a lepton and photon conversions

2 leptons + 0 jets $+E_T^{miss}$: Signal Regions

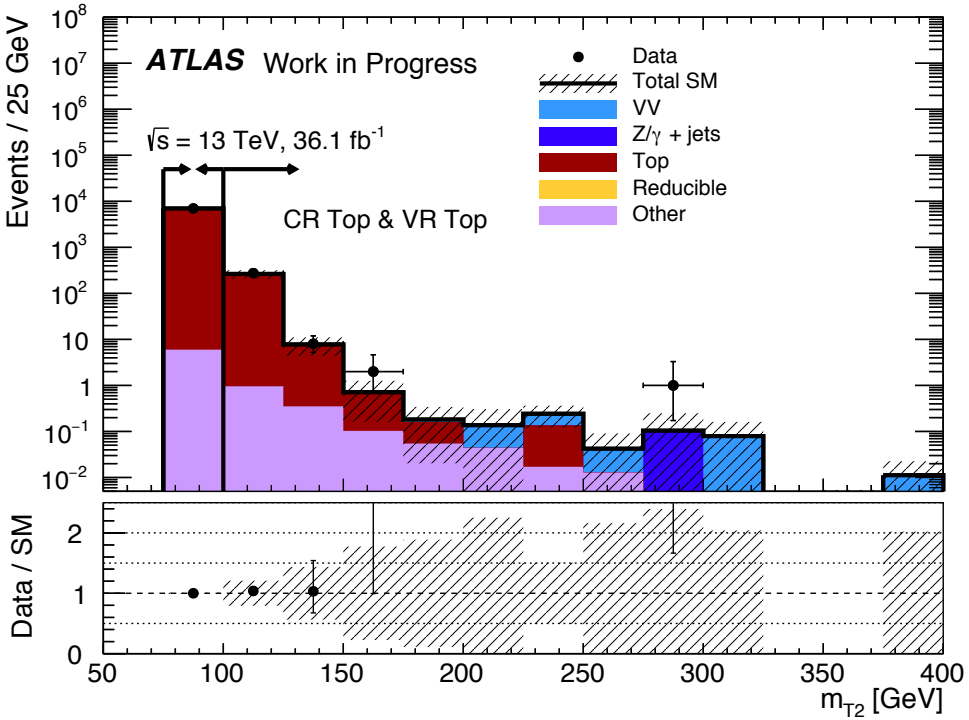
- Invariant mass of the leptons ($m_{\ell\ell}$)
  - in SF regions, provides rejection against Z+jets background
- Stranverse mass (m_{T2})
  - Similar to m_T
  - kinematic edge at W mass for backgrounds
  - for signal, kinematic edge at slepton mass
  - provides rejection against $t\bar{t}$ and WW

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

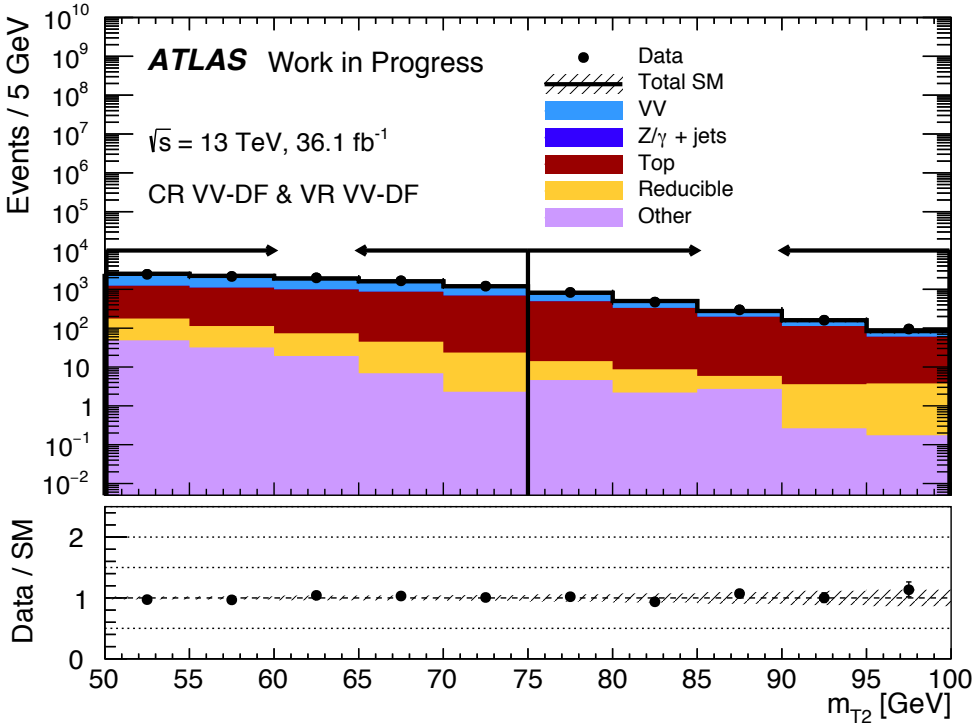
- Binned in m_{T2} and $m_{\ell\ell}$ to increase sensitivity.
- Inclusive SRs to calculate model independent limits.

Modelling of discriminating variables in CRs

CR-top

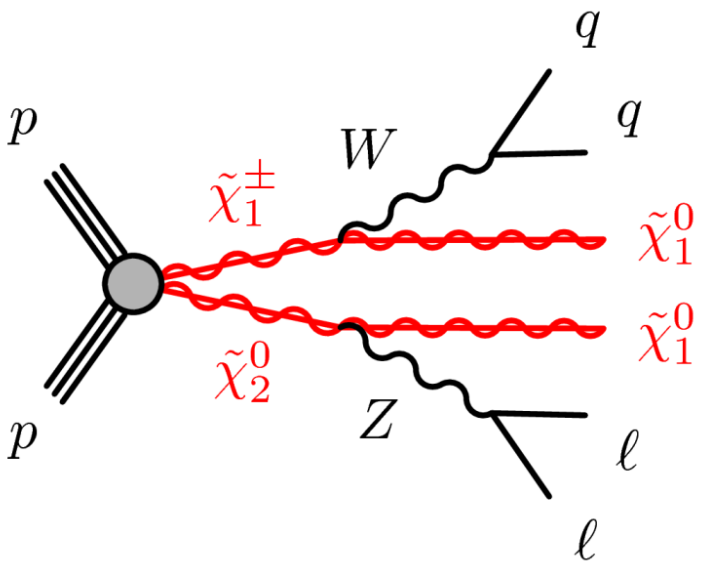


CR-VV-DF



- In CR-top, dominant background: top
- In CR-VV-DF, VV dominant, top subdominant
- Good agreement between data and background.

2 leptons + 2 jets $+E_T^{miss}$



- Z $\rightarrow \ell\ell$, W$\rightarrow$ jj
- 2 SFOS leptons, at least 2 jets, and E_T^{miss}
- Background estimation:
  - $t\bar{t}$ where b-jet fails identification estimated using MC
  - Z-jets where we have fake E_T^{miss} estimated using data-driven technique
  - VV modelling checked in dedicated Validation Regions (VR)

2 leptons + 2 jets $+E_T^{miss}$: Signal Regions

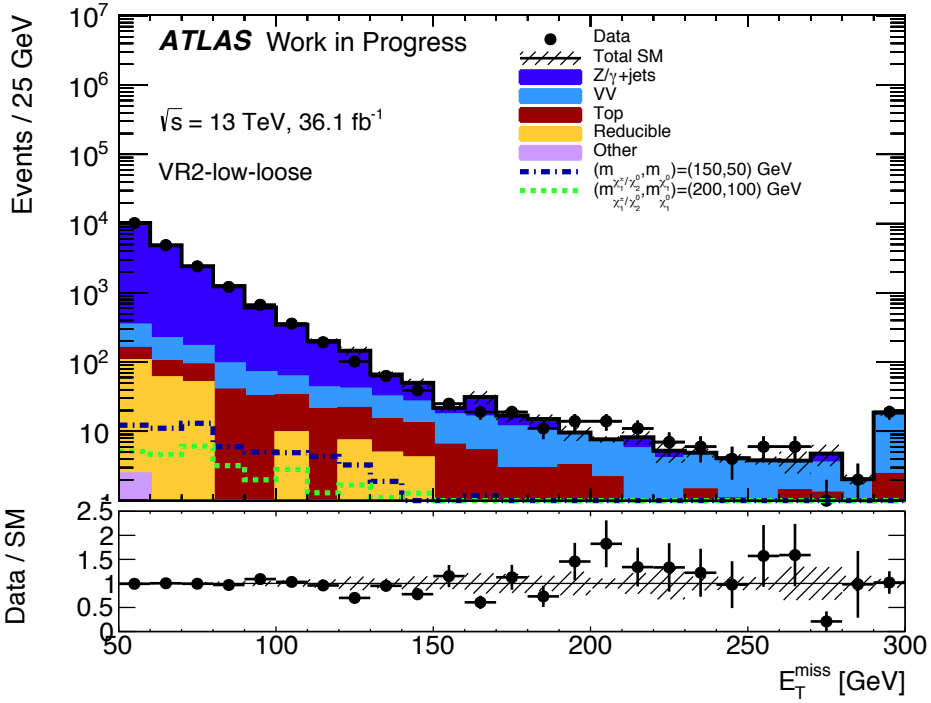
- m_{jj} and $m_{\ell\ell}$ cuts for on-shell Z and W bosons.
- m_{T2} to suppress $t\bar{t}$
- in SR-low, angular variables to select topologies
  - in 2J - W boson recoiling against $Z + E_T^{miss}$
  - in 3J - $W + Z + E_T^{miss}$ recoiling against ISR jets

2ℓ+jets signal region definitions				
	SR2-int	SR2-high	SR2-low-2J	SR2-low-3J
$n_{\text{non-b-tagged jets}}$	≥ 2		2	3-5
$m_{\ell\ell}$ [GeV]	81-101		81-101	86-96
m_{jj} [GeV]	70-100		70-90	70-90
E_T^{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			
$\Delta\phi_{(E_T^{miss},Z)}$			< 0.8	
$\Delta\phi_{(E_T^{miss},W)}$	0.5-3.0		> 1.5	< 2.2
E_T^{miss}/p_T^Z			$0.6 - 1.6$	
E_T^{miss}/p_T^W			< 0.8	
$\Delta\phi_{(E_T^{miss},\text{ISR})}$				> 2.4
$\Delta\phi_{(E_T^{miss},\text{jet1})}$				> 2.6
E_T^{miss}/ISR				0.4-0.8
$\lvert\eta(Z)\rvert$				< 1.6
p_T^{jet3} [GeV]				> 30

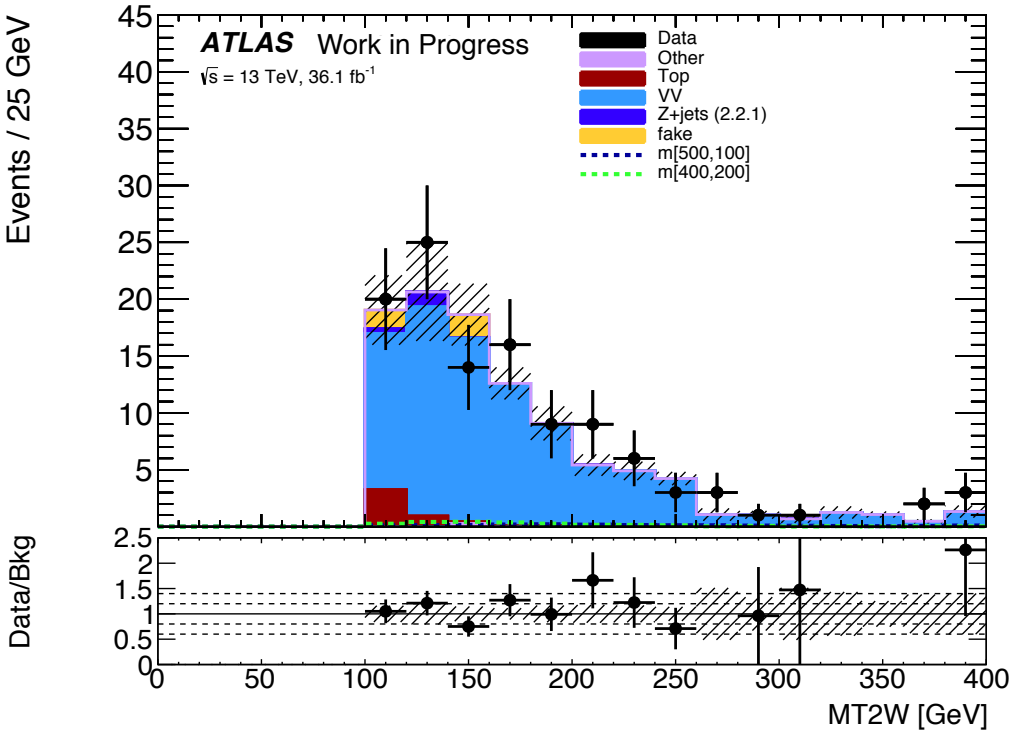
- SR-int/high targeting large mass splittings between $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$.
- SR-low targeting mass splitting around m_Z.

Modelling of discriminating variables

VR-low

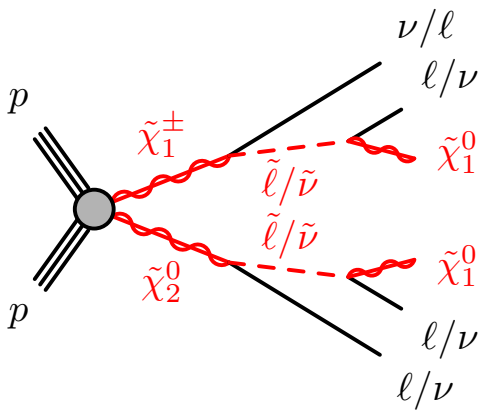


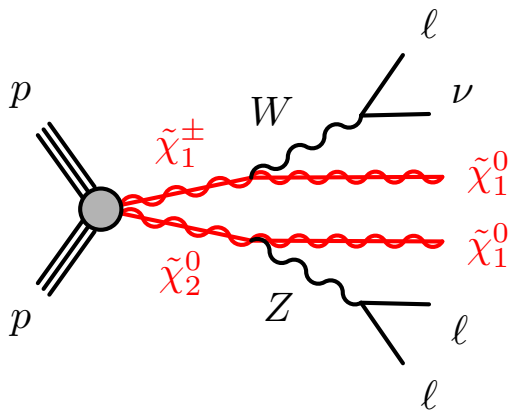
VR-int



- In VR-low, Z/γ+jets dominant, VV subdominant
- In VR-int, VV dominant
- Good agreement between data and background.

3 leptons $+E_T^{miss}$





- off Z-peak requirement
- Z $\rightarrow \ell\ell$, W$\rightarrow \ell\nu$
- on Z-peak requirement

- 3 leptons, 1 SFOS pair, and E_T^{miss}
- Background estimation:
  - WZ and top-like backgrounds constrained using a CR
  - Z+jets/ Z+γ where jet or γ fakes a lepton estimated using data driven technique

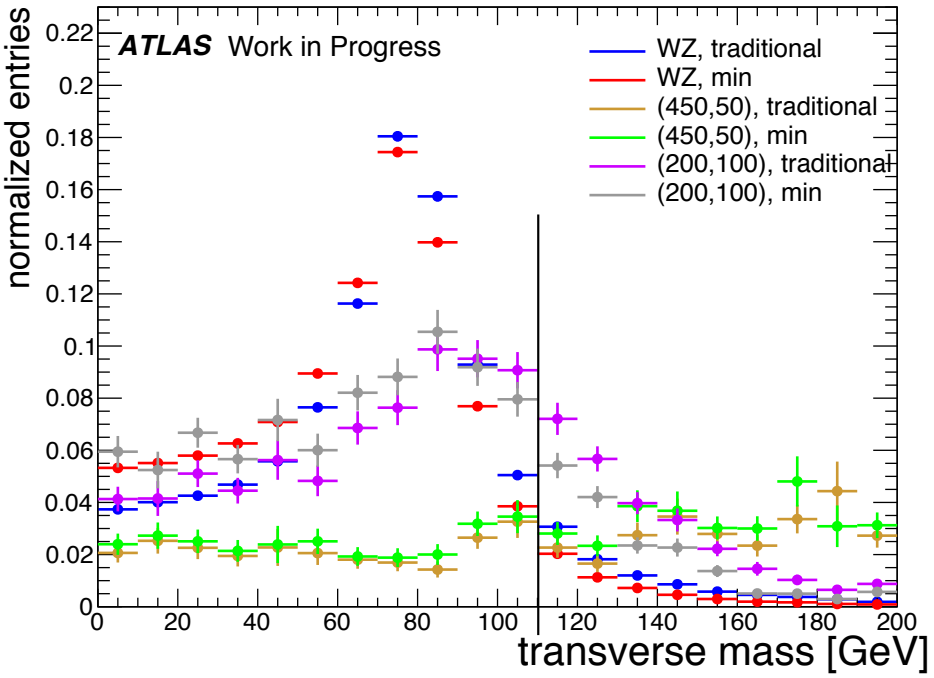
3 leptons $+E_T^{miss}$: Signal Regions

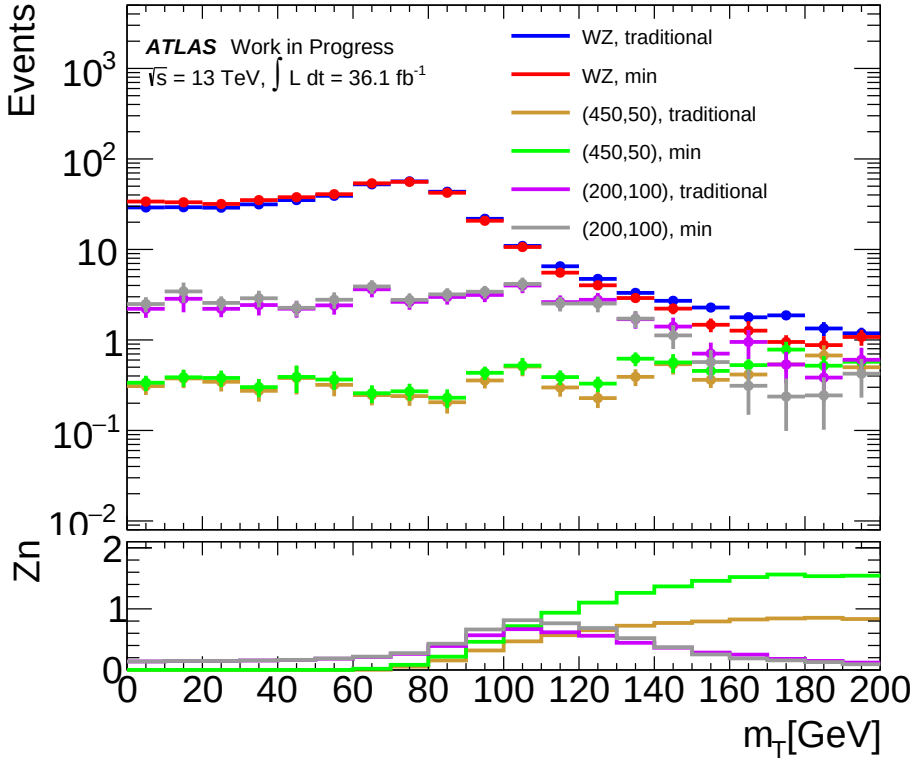
3ℓ binned signal region definitions							
m_{SFOS} [GeV]	E_T^{miss} [GeV]	$p_{\mathrm{T}}^{\ell_3}$ [GeV]	$n_{\mathrm{non-b-tagged\ jets}}$	m_T^{min} [GeV]	$p_{\mathrm{T}}^{\ell\ell\ell}$ [GeV]	p_T^{jet1} [GeV]	Bins
<81.2	> 130	20-30 > 30		> 110			SR3-slep-a SR3-slep-b
>101.2	> 130	20-50 50-80 > 80		> 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

- Slepton SR
  - 3rd lepton p_T used to probe different mass splitting models
  - Off the Z-peak requirement
- WZ SR
  - m_T^{min} used to reject WZ background
  - E_T^{miss} to target different mass splittings
  - ISR jet used to gain sensitivity to smaller mass splittings

Assignment of leptons using m_T^{min}

- Traditionally, assign leptons with $m_{\ell\ell}$ closest to m_Z to Z boson.
- In min. assignment, assign the lepton that yields minimum transverse mass to W boson.

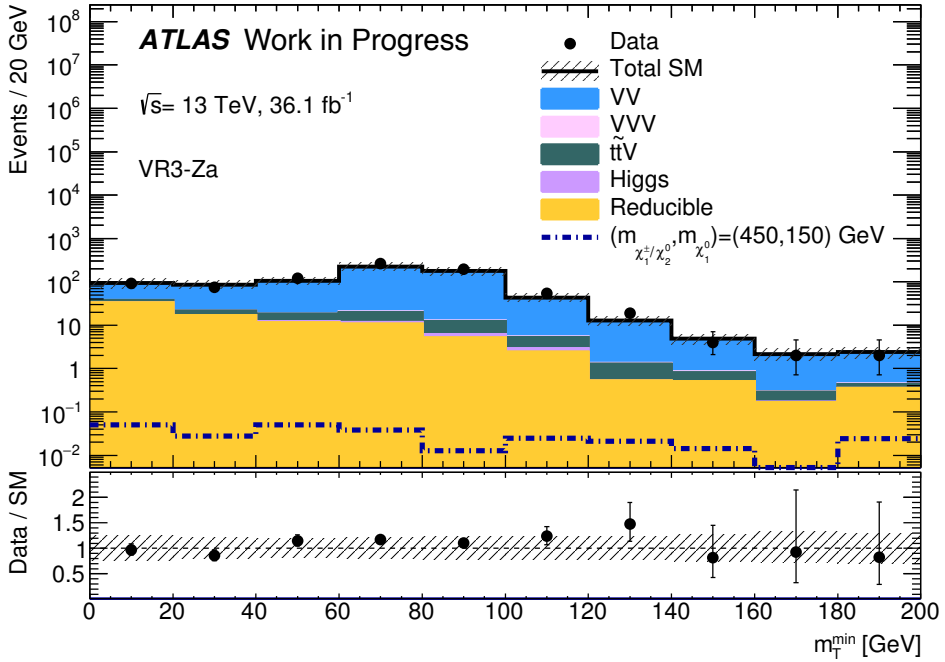




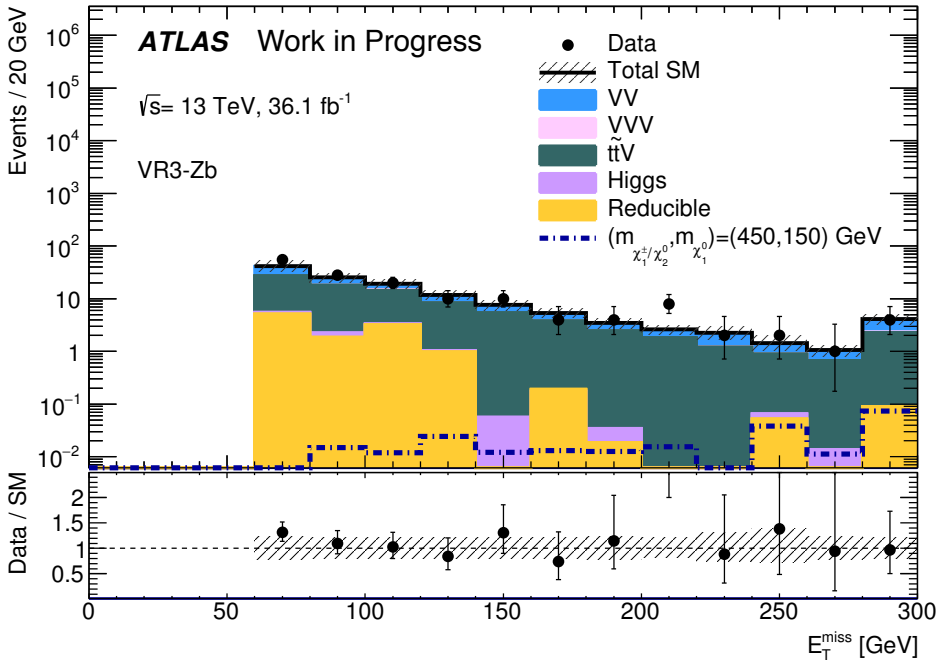
- In the projection on m_T plot, at higher values of m_T:
  - less WZ background using m_T^{min}
  - signal remains flat for both assignments for larger mass splitting.
- Greater improvement in significance when using m_T^{min} assignment.

Modelling of discriminating variables in VV-VR

Low E_T^{miss}

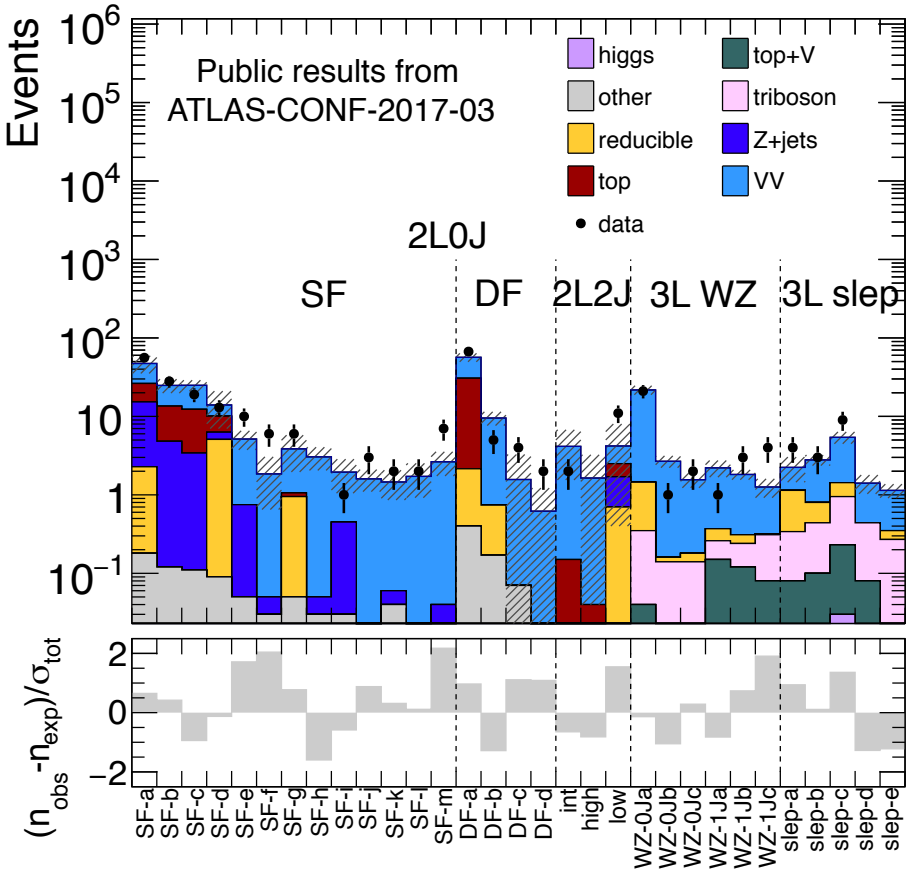


High E_T^{miss}



- At low E_T^{miss}, VV dominant, fakes subdominant
- At high E_T^{miss}, VV dominant, ttV subdominant
- Good agreement between data and background.

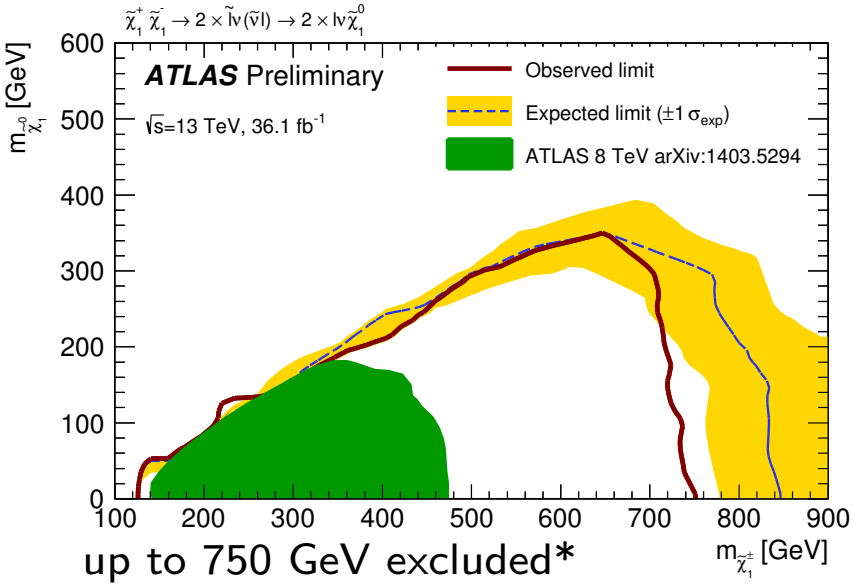
Results



- Dominant systematics: Public Results from ATLAS-CONF-2017-03
  - diboson modelling
  - jet energy scale and jet energy resolution (for 2L0J, 3L)
  - uncertainties associated with E_T^{miss} modelling (for 2L0J, 3L)
  - uncertainties associated with the data-driven Z+jets estimate (2L2J)
- No significant excess observed. ATLAS Supersymmetry Public Results

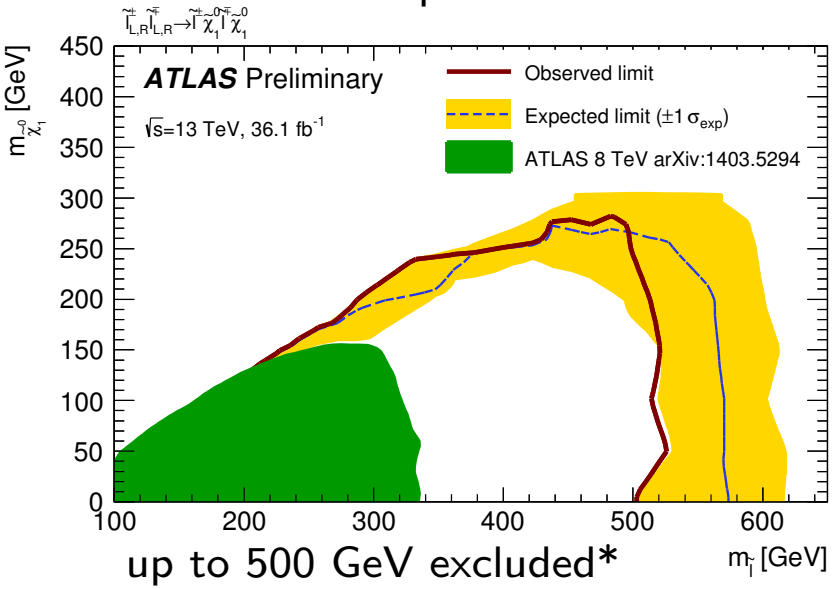
Run 2 ATLAS limits decays via sleptons

$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via $\tilde{\ell}$



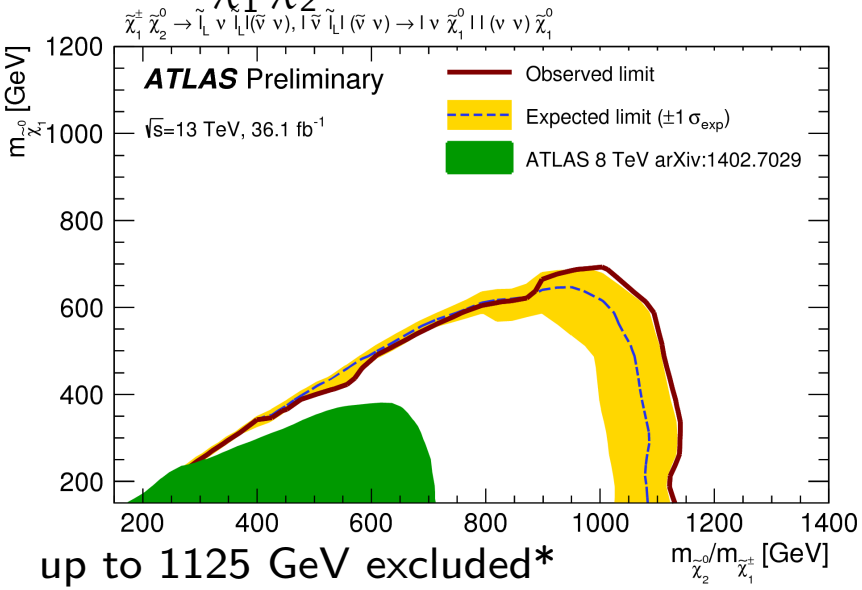
up to 750 GeV excluded*

direct $\tilde{\ell}$ production



up to 500 GeV excluded*

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via $\tilde{\ell}$ to 3L



up to 1125 GeV excluded*

*for massless lightest neutralino

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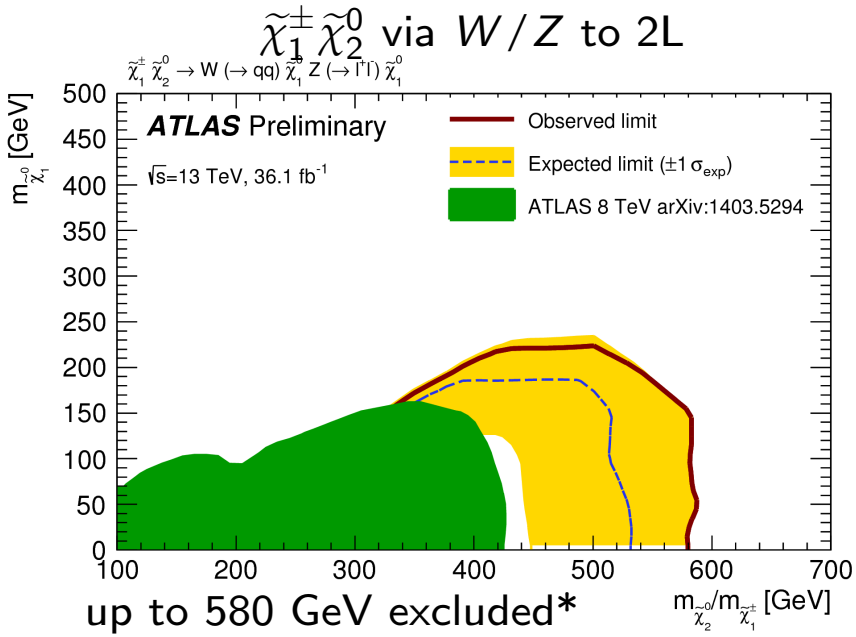
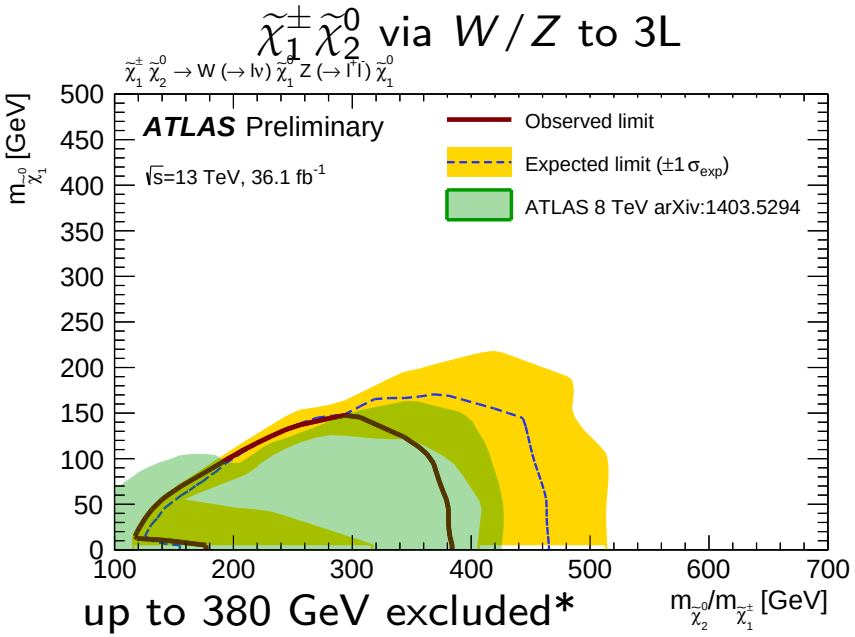
Run 2 ATLAS limits decays via W/Z



up to 580 GeV excluded*



up to 380 GeV excluded*

*for massless lightest neutralino

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- Limits set on different simplified model scenarios.
- Limits expanded with respect to Run 1 results.

Conclusion

- EWK SUSY searches are complementary to strong SUSY searches
  - LHC limits on strong production is at 900 GeV for simplified models.
  - if gauginos are light, their production will dominate.
- Run 2 results for EWK SUSY decaying to two or three leptons has improved on Run 1 limits.
  - ATLAS Supersymmetry Public Results
  - ATLAS-CONF-2017-03
- However, there is still phase space that is uncovered and will require more statistics.
  - Sensitivity to EWK SUSY will increase with increased luminosity.
  - Probe even smaller mass splittings.
  - The search for SUSY will continue on.

Backup

Object Definition

Cut	Value/description
Baseline Electron	
Acceptance	$p_T > 10$ GeV, $\lvert\eta^{clust}\rvert < 2.47$
PID Quality	`LooseAndBLayerLLH`
Signal Electron	
Acceptance	$p_T > 10$ GeV, $\lvert\eta^{cluster}\rvert < 2.47$
PID Quality	`LLHMedium`
Isolation	`GradientLoose`
Impact parameter	$\lvert z_0 \sin\theta\rvert < 0.5$ mm
	$\lvert d_0/\sigma_{d_0}\rvert < 5$

Cut	Value/description
Baseline Muon	
Acceptance	$p_T > 10$ GeV, $\lvert\eta\rvert < 2.4$
PID Quality	`Medium`
Signal Muon	
Acceptance	$p_T > 10$ GeV, $\lvert\eta\rvert < 2.4$
PIDQuality	`Medium`
Isolation	`GradientLoose`
Impact parameter	$\lvert z_0 \sin\theta\rvert < 0.5$ mm
	$\lvert d_0/\sigma_{d_0}\rvert < 3$

Cut	Value/description
Baseline jet	
Collection	`AntiKt4EMTopo`
Acceptance	$p_T > 20$ GeV , $\lvert\eta\rvert < 4.5$
Signal jet	
JVT	$\lvert$JVT$\rvert > 0.59$ for jets with $p_T < 60$ GeV and $\lvert\eta\rvert < 2.4$
Acceptance (3L analyses)	$p_T > 20$ GeV , $\lvert\eta\rvert < 2.4$
Signal b-jet	
b-tagger Algorithm	MV2c10
Efficiency	77 %
Acceptance (3L analyses)	$p_T > 20$ GeV , $\lvert\eta\rvert < 2.4$

Trigger Definition

Lepton p_T	Trigger	
	Data15	Data16
Di-electron channel		
$p_T(e_{1(2)}) > 25$ GeV	HLT_2e12_lhloose_L12EM10VH	HLT_2e17_lhvloose_nod0
Di-muon channel		
$p_T(\mu_{1(2)}) > 25$ GeV	HLT_mu18_mu8noL1	HLT_mu22_mu8noL1
Electron-muon channel		
$p_T(e) > 25$ GeV and $p_T(\mu) > 25$ GeV	HLT_e17_lhloose_mu14	HLT_e17_lhloose_nod0_mu14

Background Strategy

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		

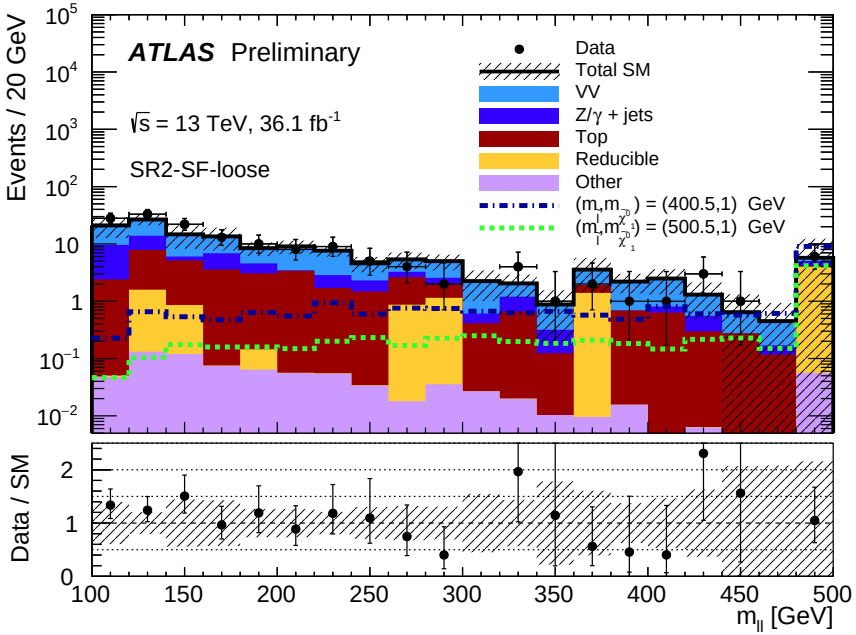
Variables definitions

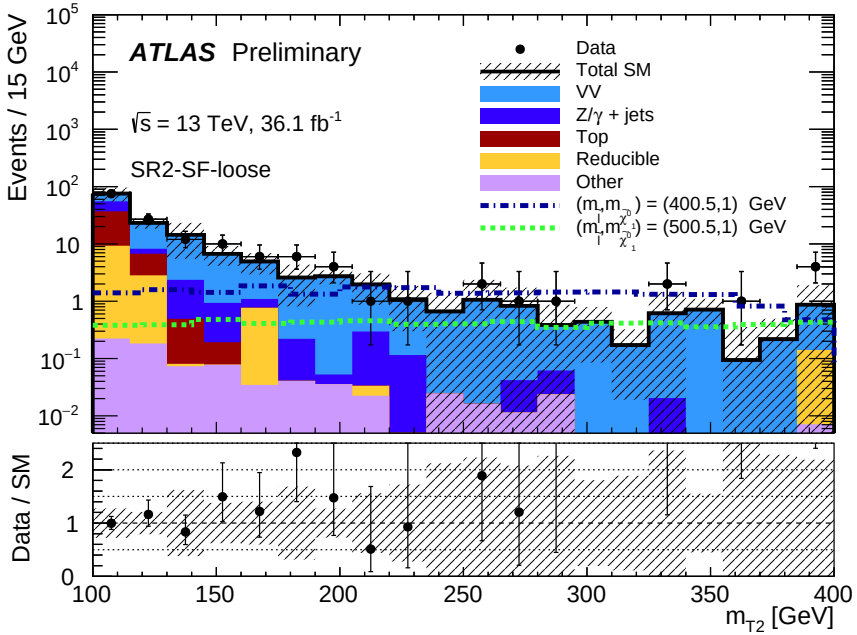
- m_T : bound mass of particle which decays to one visible and one invisible component. Defined as:
  $m_T(\vec{p}_T, \vec{q}_T) = \sqrt{2(p_T q_T - \vec{p}_T \cdot \vec{q}_T)}$
- m_{T2} : bound mass of pair produced particles which decay to visible and invisible component. Defined as:
  $m_{T2} = min_{\vec{q}_T}[max(m_T(\vec{p}_T^{\ell 1}, \vec{q}_T), m_T(\vec{p}_T \ell 2, \vec{p}_T^{miss} - \vec{q}_T))]$

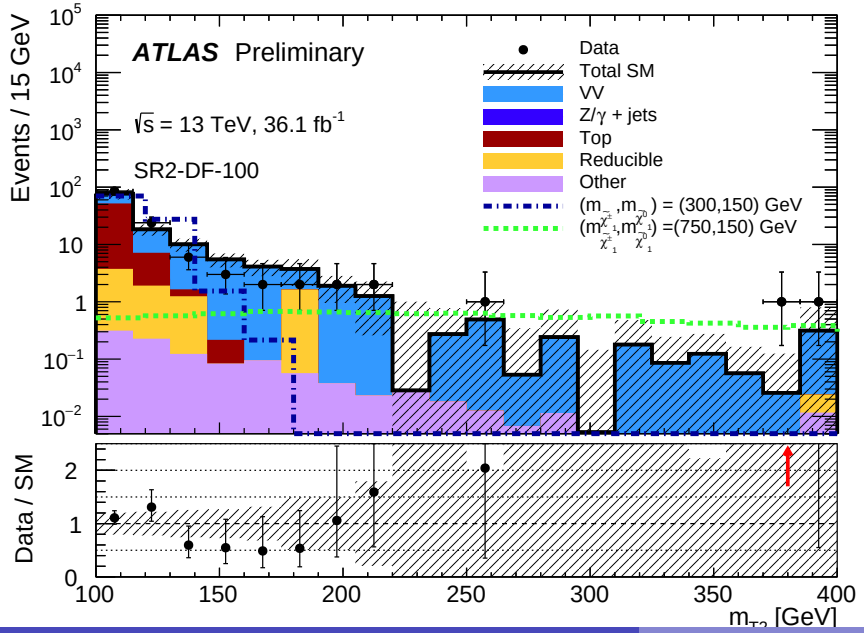
2 leptons + 0 jets + E_T^{miss}: CR and VR

2ℓ+0jets control and validation region definitions					
Region	CR2-VV-DF	CR2-VV-SF	CR2-Top	VR2-VV-SF/DF	VR2-Top
lepton flavour	SF	DF	DF	SF (DF)	DF
$n_{\text{central non-b-tagged jets}}$	0	0	0	0	0
$n_{\text{central b-tagged jets}}$	0	0	≥ 1	0	≥ 1
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	< 20	—	—	> 20 (–)	—
m_{T2} [GeV]	> 130	$50 - 75$	$75 - 100$	$75 - 100$	> 100

2 leptons + 0 jets + E_T^{miss} : Results





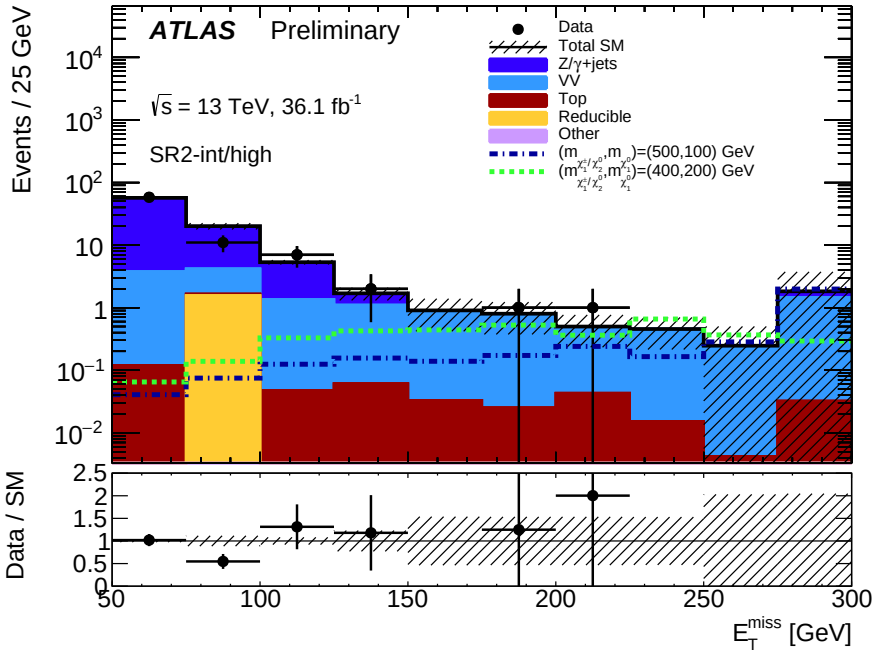


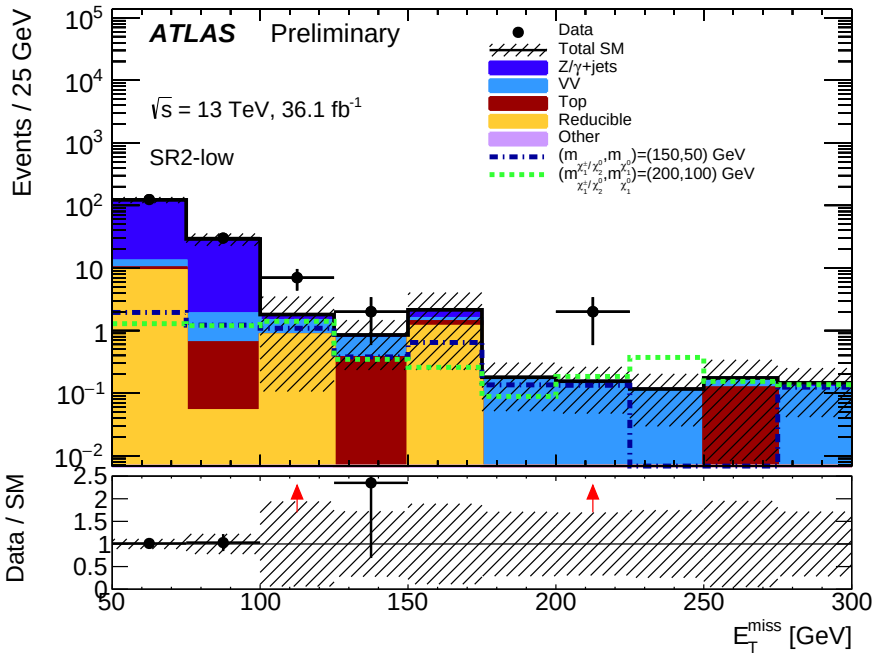
- Dominant systematics:
  - jet energy scale and jet energy resolution
  - diboson modelling
  - uncertainties associated with E_T^{miss} modelling

2 leptons + 2 jets $+E_T^{miss}$: CR and VR

2ℓ+jets validation region definitions				
	VR2-int(high)	VR2-low-2J(3J)	VR2-VV-int	VR2-VV-low
loose selection				
$n_{\text{non-b-tagged jets}}$	≥ 2	2 (3-5)	1	
$E_{\text{T}}^{\text{miss}}$ [GeV]	>150 (250)	>100	>150	>150
$m_{\ell\ell}$ [GeV]	81-101	81-101 (86-96)		81-101
m_{jj} [GeV]	<60,>100	<60,>100		
p_{T}^{Z} [GeV]	>80	> 60(40)		
p_{T}^{W} [GeV]	>100			
$\lvert\eta(Z)\rvert$		(< 1.6)		
$p_{\text{T}}^{\text{jet3}}$ [GeV]		(> 30)		
$\Delta\phi_{(\vec{E}_{\text{T}}^{\text{miss}},\text{jet})}$			>0.4	>0.4
m_{T2} [GeV]	>100[*]		>100	
$\Delta R_{(\ell\ell)}$	<1.8[*]			<0.2
tight selection				
$\Delta R_{(jj)}$	<1.5	(<2.2)		
$\Delta\phi_{(\vec{E}_{\text{T}}^{\text{miss}},W)}$	0.5-3.0	> 1.5(< 2.2)		
$\Delta\phi_{(\vec{E}_{\text{T}}^{\text{miss}},Z)}$		< 0.8(−)		
$E_{\text{T}}^{\text{miss}}/p_{\text{T}}^{W}$		< 0.8(−)		
$E_{\text{T}}^{\text{miss}}/p_{\text{T}}^{Z}$		0.6 − 1.6(−)		
$E_{\text{T}}^{\text{miss}}/\text{ISR}$		(0.4 − 0.8)		
$\Delta\phi_{(\vec{E}_{\text{T}}^{\text{miss}},\text{ISR})}$		(> 2.4)		
$\Delta\phi_{(\vec{E}_{\text{T}}^{\text{miss}},\text{jet1})}$		(> 2.6)		

2 leptons + 2 jets $+E_T^{miss}$: Results



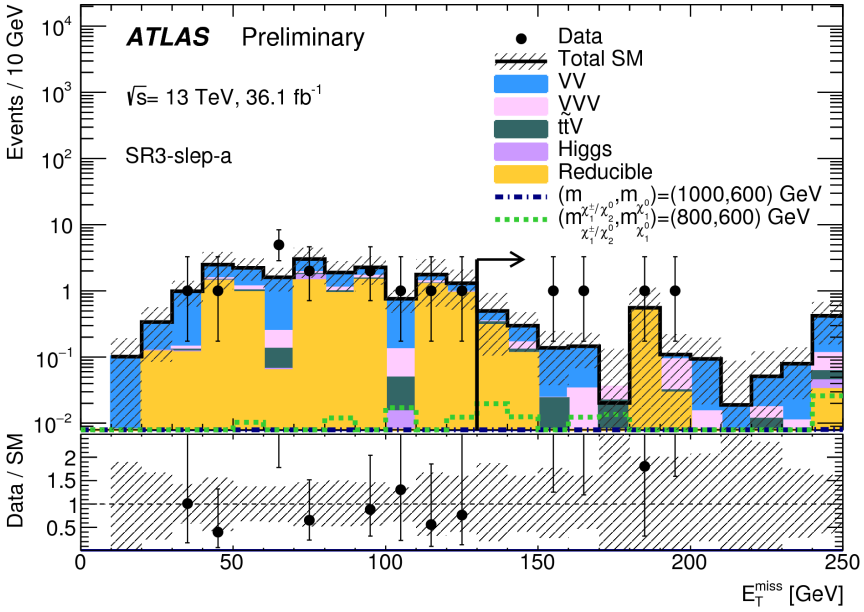


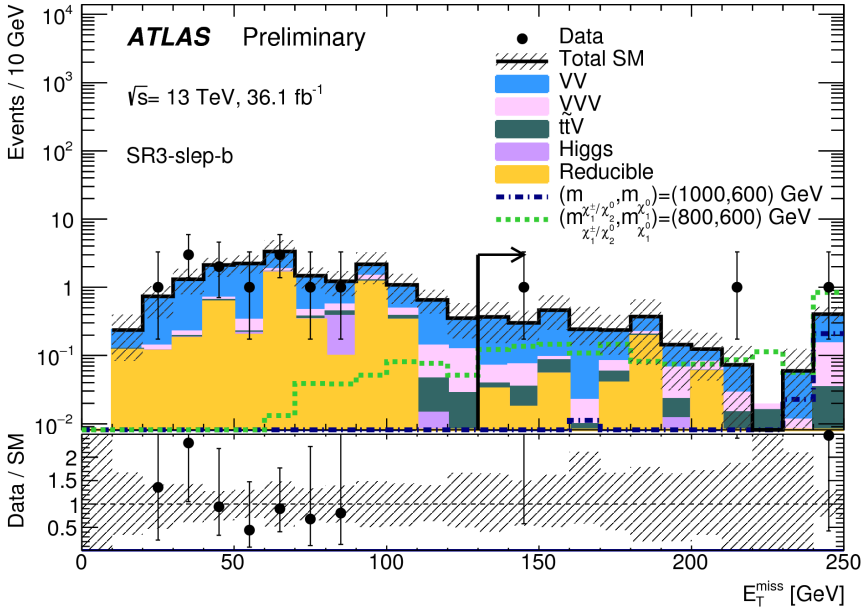
- Dominant systematics:
  - diboson modelling
  - uncertainties associated with the data-driven Z+jets estimate
- There is good agreement between data and background.

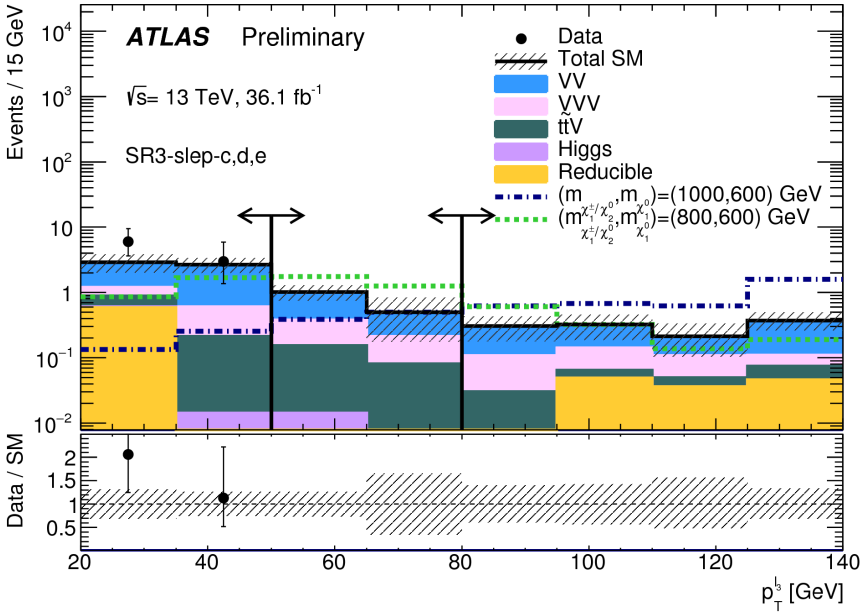
3 leptons $+E_T^{miss}$: CR and VR

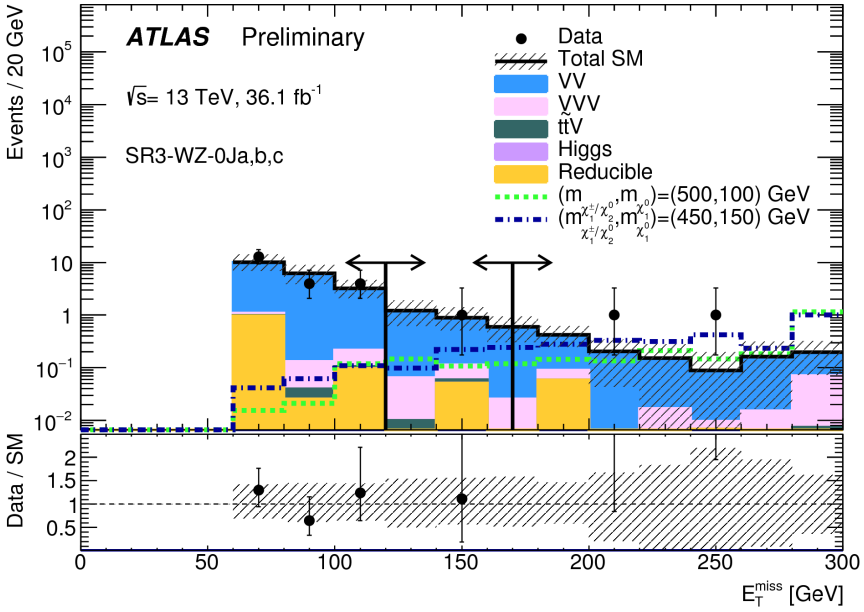
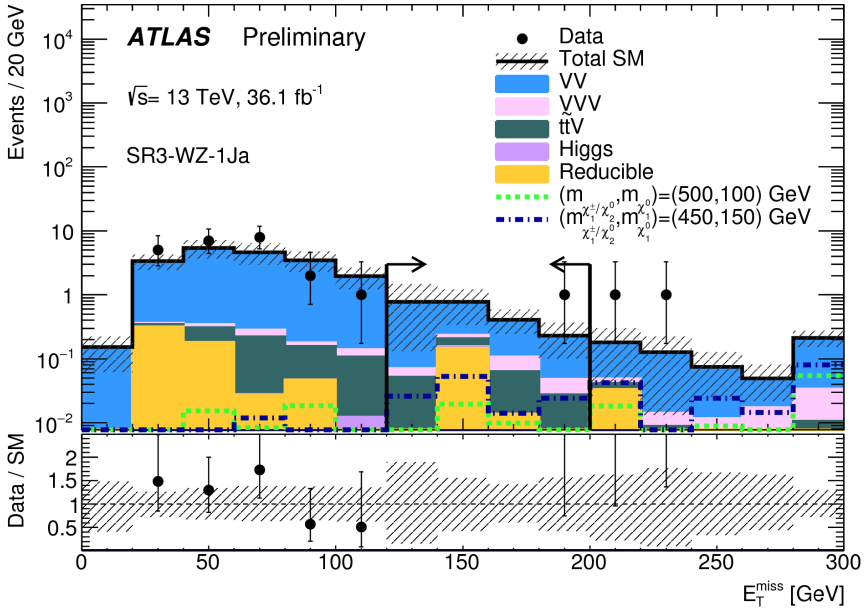
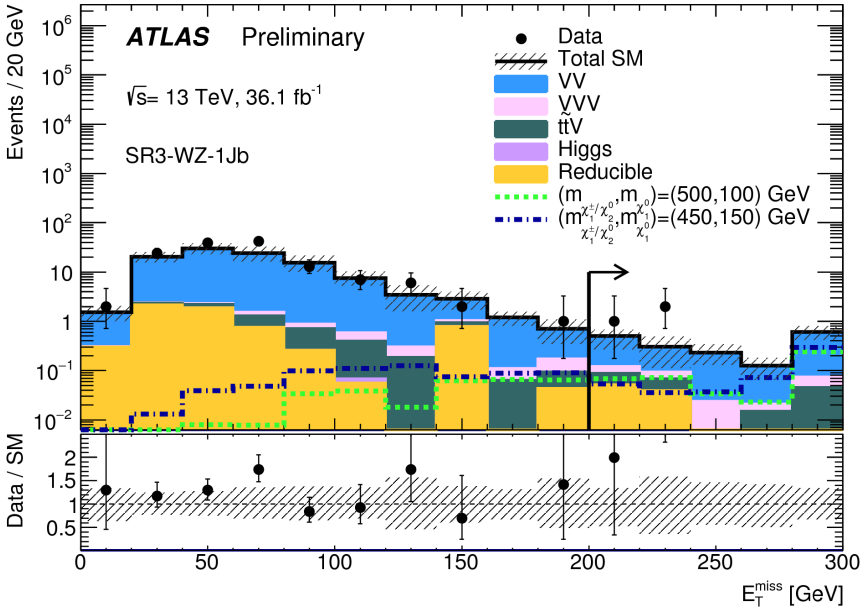
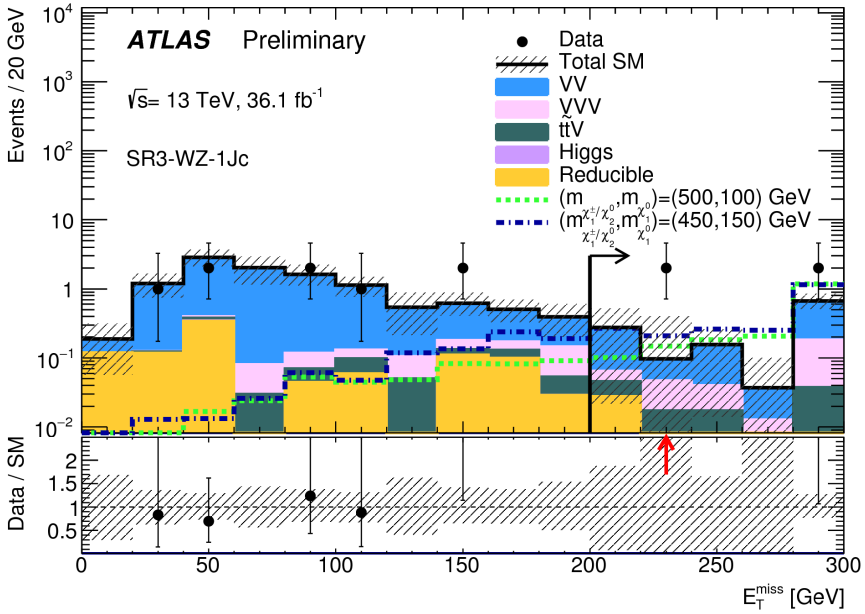
3ℓcontrol and validation region definitions						
	$p_T^{\ell_3}$ [GeV]	m_{SFOS} [GeV]	E_T^{miss} [GeV]	m_T^{min} [GeV]	n non−b−tagged jets	n b−tagged jets
CR3-WZ-inc	> 20	81.2–101.2	> 120	< 110	–	0
CR3-WZ-0j	> 20	81.2–101.2	> 60	< 110	0	0
CR3-WZ-1j	> 20	81.2–101.2	> 120	< 110	> 0	0
VR3-Za	> 30	81.2–101.2	40–60	–	–	–
VR3-Zb	> 30	81.2–101.2	>60	–	–	> 0
VR3-offZa	> 30	$\notin [81.2, 101.2]$	40–60	–	–	–
VR3-offZb	> 20		> 40	–	–	> 0
VR3-Za-0J	> 20	81.2–101.2	40–60	–	0	0
VR3-Za-1J			40–60	–	> 0	0

3 leptons $+E_T^{miss}$ via sleptons: Results







- Dominant systematics:
  - jet energy scale and jet energy resolution
  - diboson modelling
  - uncertainties associated with E_T^{miss} modelling
- There is good agreement between data and background.

3 leptons $+E_T^{miss}$ via W/Z: Results