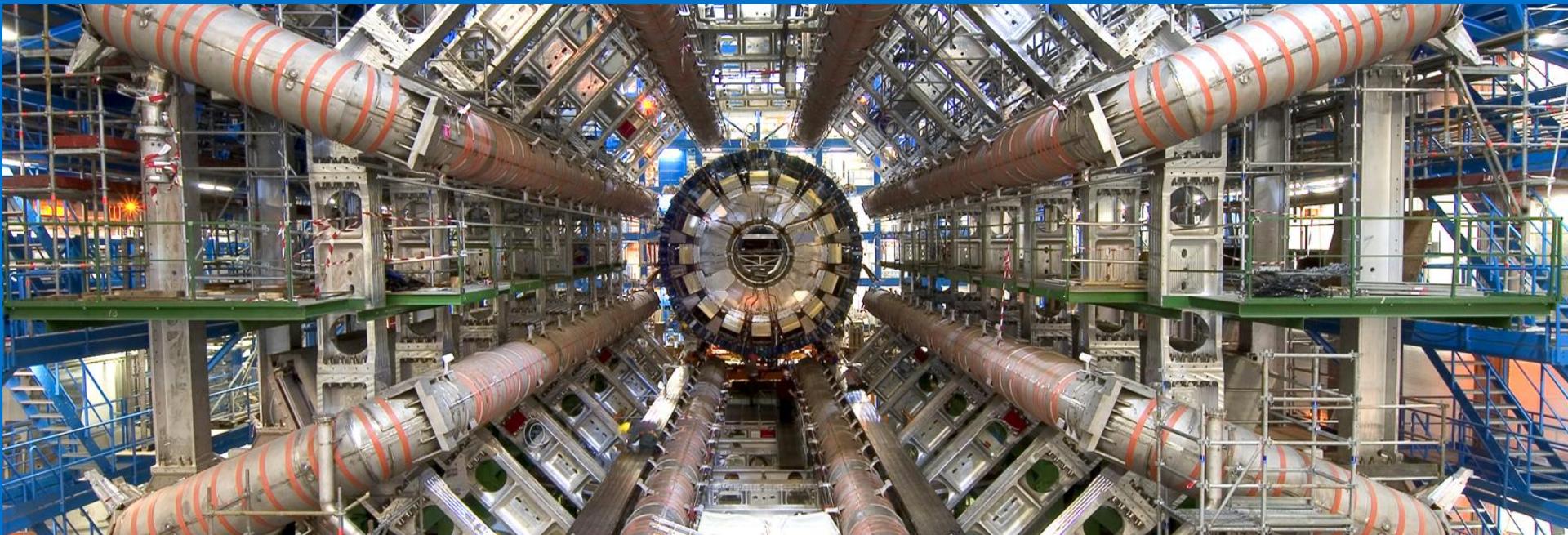


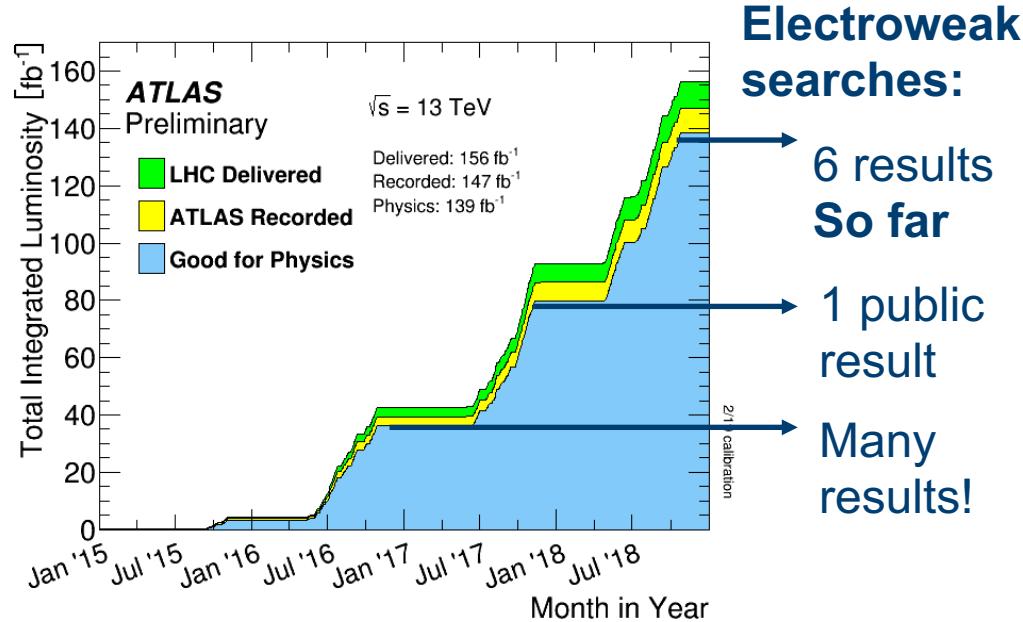
# Searches for charginos, neutralinos and sleptons with ATLAS



Sarah Williams, on behalf of the ATLAS collaboration

# Introduction

- Electroweak production of charginos, neutralinos and sleptons offer avenues for possible SUSY discovery.
- Relevant to the issue naturalness in SUSY and the search for a dark matter candidate.
- Full run II dataset of  $139 \text{ fb}^{-1}$  offers increased sensitivity to many challenging signatures as well as the opportunity to explore new channels.



Although none of the results so far have seen significant deviations from the SM predictions, the use of innovative search methods and new reconstruction techniques have set strong constraints on new physics...

# Simplified models for electroweak production

Reminder: in the MSSM  $M_{1,2}$  = bino (wino) mass parameter,  $\mu$  = higgsino mass parameter

Two simplified scenarios for gaugino mass parameters often considered in MSSM

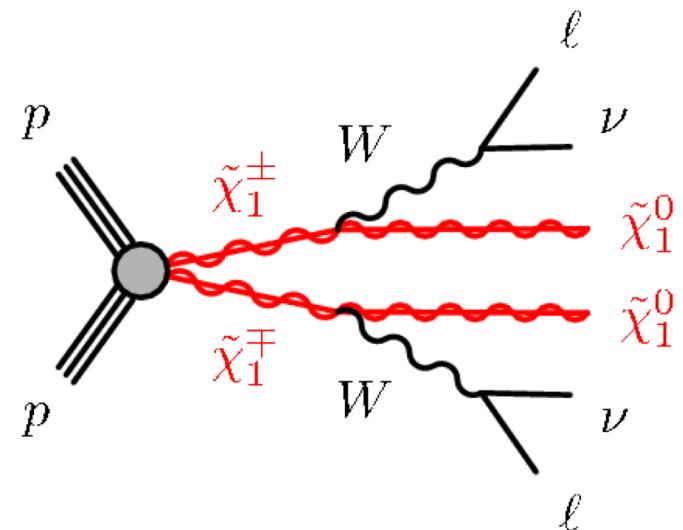
# Simplified models for electroweak production

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1.  $M_1, M_2 \ll \mu \rightarrow$  bino-like  $\tilde{\chi}_1^0$  LSP  
with wino-like  $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$  as (mass-degenerate) NLSPs

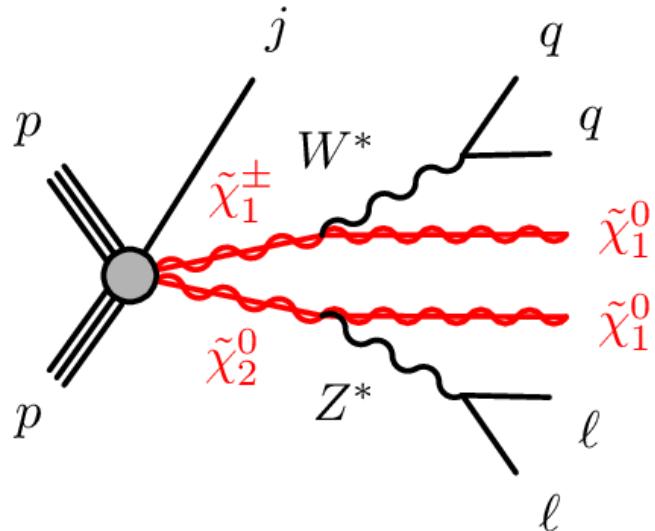
- Leptonic decays give high  $p_T$  leptons that can be triggered on.
- Significant  $\vec{p}_T^{miss}$  for models with high  $\Delta m$



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2.  $M_1, M_2 \gg \mu \rightarrow$  lightest gauginos are a nearly degenerate higgsino triplet  $\{\tilde{\chi}_1^0, \tilde{\chi}_1^\pm, \tilde{\chi}_2^0\}$

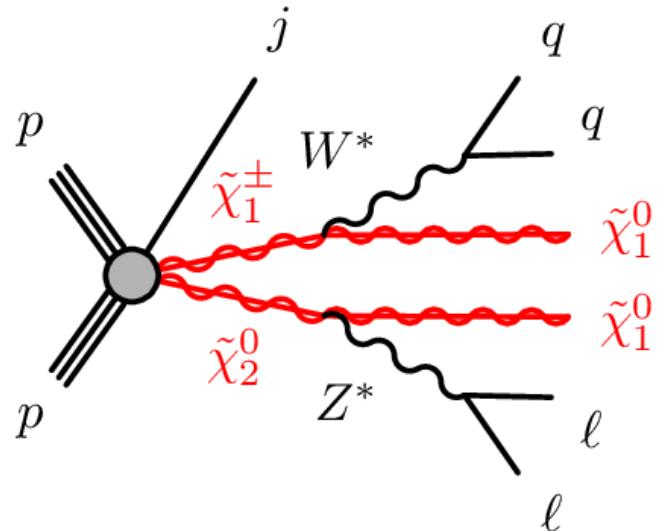
- Soft leptons in final state
- ISR activity required to generate  $\vec{p}_T^{miss}$

=> Next talk, but can also get similar final state with compressed wino production

# Simplified models for electroweak production

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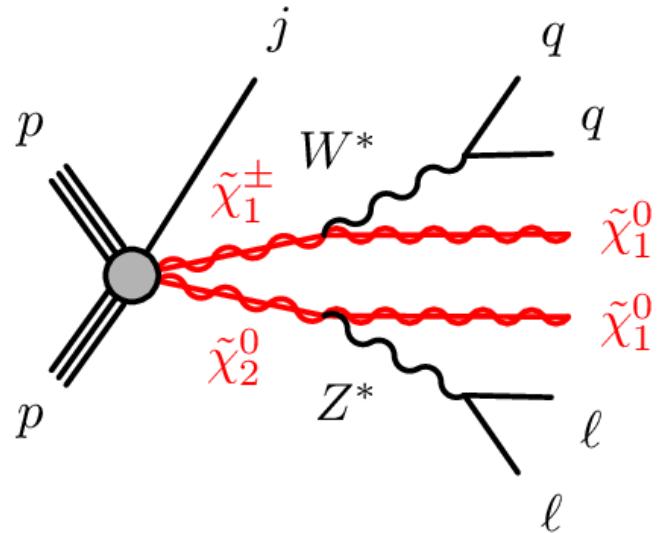
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=> Plus signatures involving direct slepton production under different assumptions about the relative masses of  $\tilde{e}_{L,R}, \tilde{\mu}_{L,R}, \tilde{\tau}_{L,R}$

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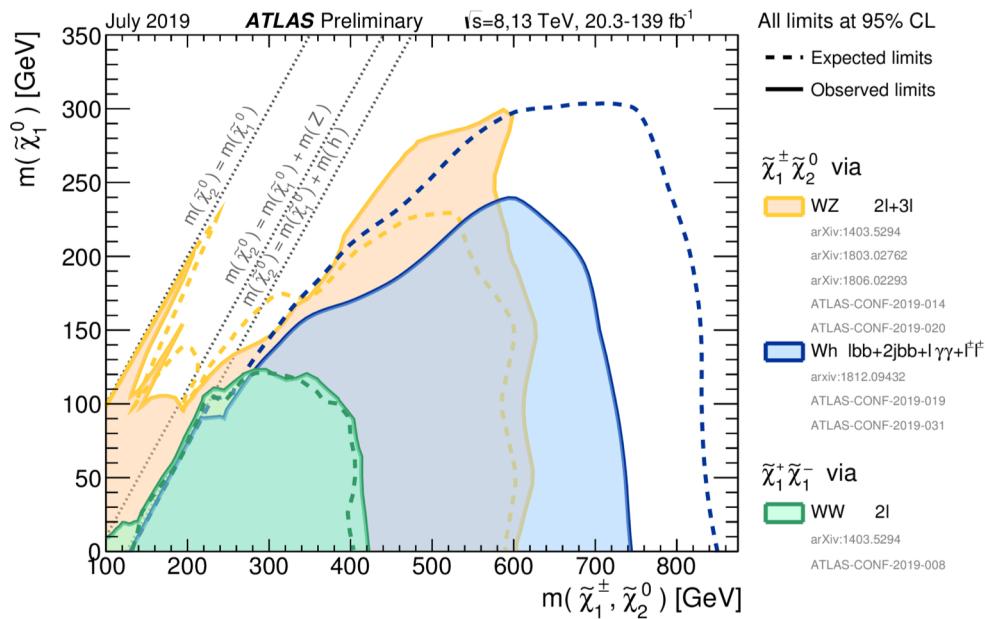
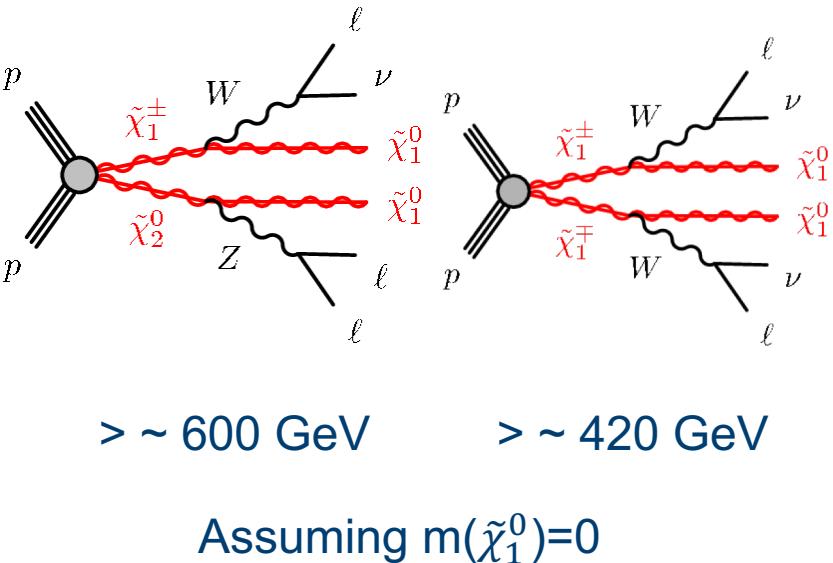
This talk (and the next by Francisco Alonso) will focus on the scenarios where gauginos/sleptons decay promptly. Long-lived SUSY searches in ATLAS will be covered tomorrow by Christian Ohm

# Signature driven approach for end of run II results

Search channel	Targeted signals	Details
2l+0jets + $\vec{p}_T^{miss}$	Wino $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow W^\pm \tilde{\chi}_1^0 W^\mp \tilde{\chi}_1^0$ ( $W \rightarrow l\nu$ ) Wino $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \rightarrow 2 \times \tilde{l}_L \nu (\tilde{\nu}_L l) \rightarrow 2 \times l \nu \tilde{\chi}_1^0$ $\tilde{l}_{L,R} \tilde{l}_{L,R} \rightarrow l^+ \tilde{\chi}_1^0 l^- \tilde{\chi}_1^0$	<a href="#">ATLAS-CONF-2019-008 (*)</a>
2l + ISR + $\vec{p}_T^{miss}$	Higgsino $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp, \tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\chi}_1^0 \tilde{\chi}_2^0$ , Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ ( $\tilde{\chi}_1^\pm \rightarrow W^* \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow Z^* \tilde{\chi}_1^0$ ) $\tilde{l}_{L,R} \tilde{l}_{L,R} \rightarrow l^+ \tilde{\chi}_1^0 l^- \tilde{\chi}_1^0$	<a href="#">ATLAS-CONF-2019-014</a>
3l (+ISR) + $\vec{p}_T^{miss}$	Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow W^\pm \tilde{\chi}_1^0 Z \tilde{\chi}_1^0$ ( $W \rightarrow l\nu, Z \rightarrow ll$ )	<a href="#">ATLAS-CONF-2019-020 (*)</a>
$2\tau + \vec{p}_T^{miss}$	$\tilde{\tau}_{L,R} \tilde{\tau}_{L,R} \rightarrow \tau^+ \tilde{\chi}_1^0 \tau^- \tilde{\chi}_1^0$	<a href="#">ATLAS-CONF-2019-018 (*)</a>
1l + $\gamma\gamma$	Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow W^\pm \tilde{\chi}_1^0 h \tilde{\chi}_1^0$ ( $W \rightarrow l\nu, h \rightarrow \gamma\gamma$ )	<a href="#">ATLAS-CONF-2019-019</a>
1l + $b\bar{b}$	Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow W^\pm \tilde{\chi}_1^0 h \tilde{\chi}_1^0$ ( $W \rightarrow l\nu, h \rightarrow b\bar{b}$ )	<a href="#">ATLAS-CONF-2019-031</a>

This talk will highlight some new and improved searches using the full run II dataset. The remaining will be covered in the next talk!

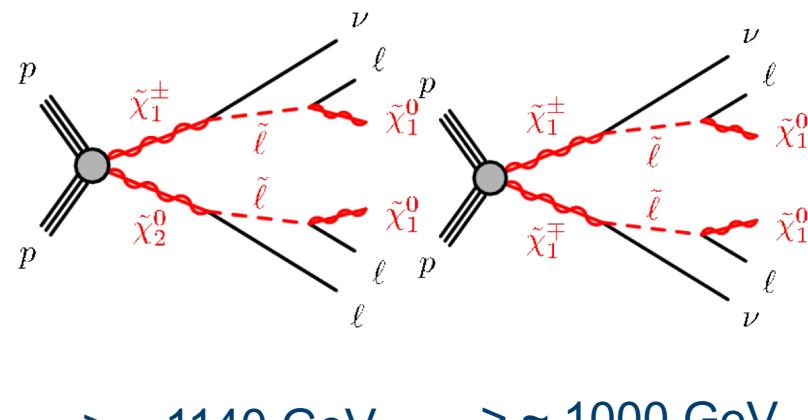
# Summary of ATLAS constraints on gauginos



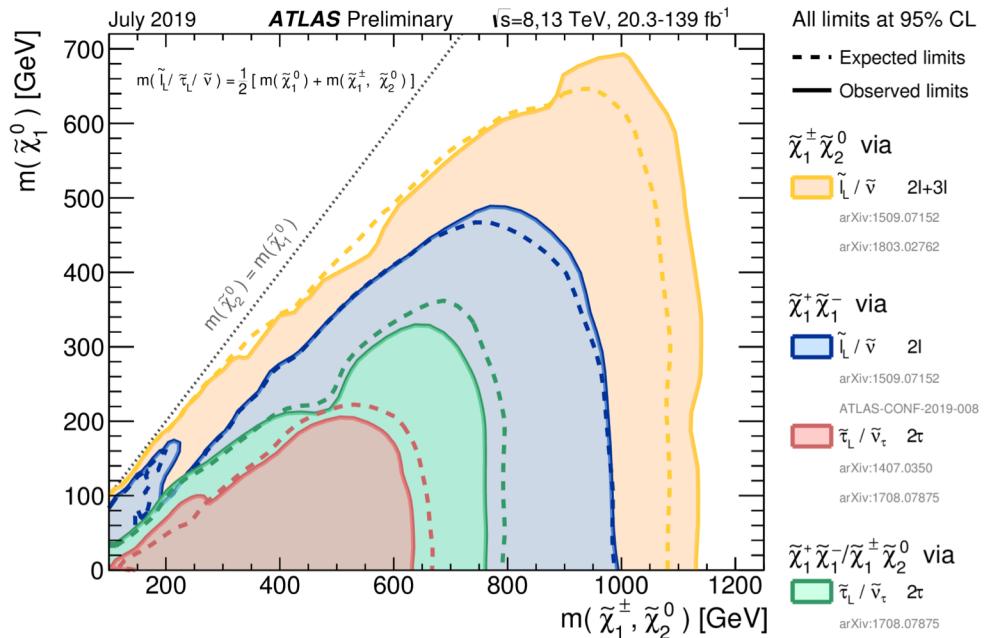
EW direct	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$		$E_T^{\text{miss}}$	36.1	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$	0.205	$m(\tilde{\chi}_1^0)=0$
	2-3 $e,\mu$	$ee,\mu\mu$			$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$		
	$2 e, \mu$		$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm$	0.42	$m(\tilde{\chi}_1^0)=0$
	$0+e,\mu$	$2 b/2 \gamma$	$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ Forbidden	0.74	$m(\tilde{\chi}_1^0)=70 \text{ GeV}$
	$\tilde{\chi}_1^+\tilde{\chi}_1^0$ via $Wh$		$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm$	1.0	$m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
	$\tilde{\chi}_1^+\tilde{\chi}_1^0$ via $\tilde{\tau}_L/\tilde{\nu}$		$E_T^{\text{miss}}$	139	$\tilde{\tau} [\tilde{\tau}_{L,R}]$	0.16-0.3	$m(\tilde{\chi}_1^0)=0$
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$		$E_T^{\text{miss}}$	139	$\tilde{\tau}$	0.12-0.39	$m(\tilde{\chi}_1^0)=0$
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_1^0$		$E_T^{\text{miss}}$	139	$\tilde{\ell}$	0.7	$m(\tilde{\chi}_1^0)=10 \text{ GeV}$
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$		$E_T^{\text{miss}}$	36.1	$\tilde{H}$	0.13-0.23	$\text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G})=1$
	$4 e, \mu$	$\geq 3 b$	$E_T^{\text{miss}}$	36.1	$\tilde{H}$	0.29-0.88	$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G})=1$
		$0 jets$	$E_T^{\text{miss}}$	36.1		0.3	
		$\geq 1$	$E_T^{\text{miss}}$	139			



# Summary of ATLAS constraints on gauginos

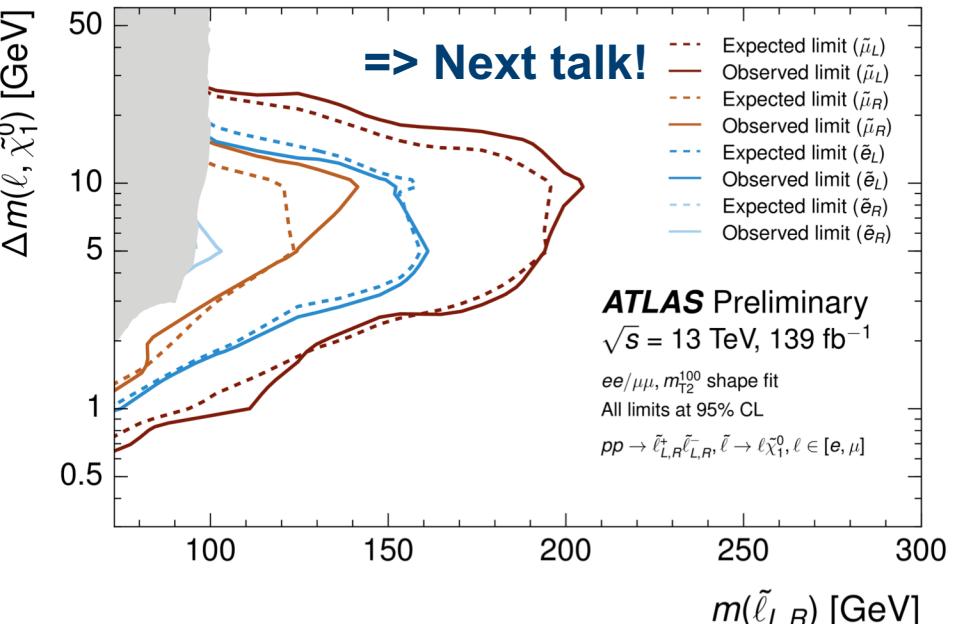
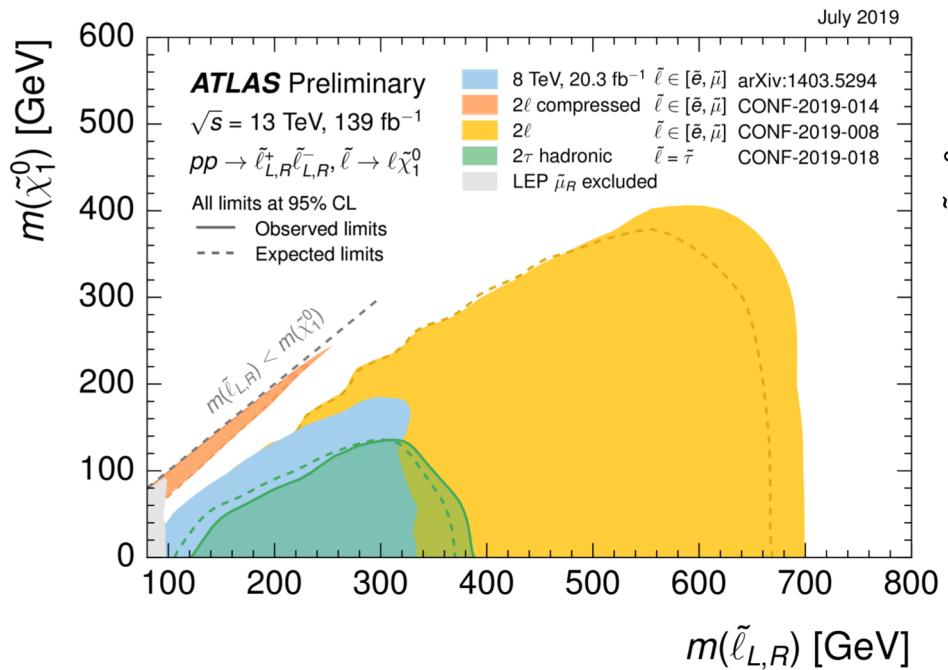
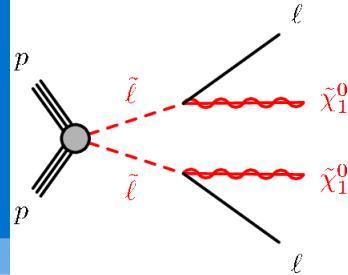


Assuming  $m(\tilde{\chi}_1^0)=0$



EW direct	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$			$E_T^{\text{miss}}$	36.1	$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$	0.6	$m(\tilde{\chi}_1^\pm)=0$
	2-3 $e, \mu$	$ee, \mu\mu$	$\geq 1$			$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$		
	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via $WW$	$2 e, \mu$		$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm$	0.42	$m(\tilde{\chi}_1^\pm)=0$
	$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $Wh$	$0-1 e, \mu$	$2 b/2 \gamma$	$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ <i>Forbidden</i>	0.74	$m(\tilde{\chi}_1^\pm)=70 \text{ GeV}$
	$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via $\tilde{l}_L / \tilde{v}_r$	$2 e, \mu$		$E_T^{\text{miss}}$	139	$\tilde{\chi}_1^\pm$	1.0	$m(\tilde{l}, \tilde{v})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$	$2 \tau$		$E_T^{\text{miss}}$	139	$\tilde{\tau} [ \tilde{\tau}_{\text{L}}, \tilde{\tau}_{\text{R,L}} ]$	0.16-0.3    0.12-0.39	$m(\tilde{\chi}_1^\pm)=0$
	$\tilde{e}_{\text{L,R}}, \tilde{e}_{\text{L,R}} \rightarrow \ell \tilde{\chi}_1^0$	$2 e, \mu$	$0 \text{ jets}$	$E_T^{\text{miss}}$	139	$\tilde{\ell}$	0.7	$m(\tilde{\chi}_1^\pm)=0$
			$\geq 1$	$E_T^{\text{miss}}$	139	$\tilde{\ell}$	0.256	$m(\tilde{\chi}_1^\pm)=0$
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$	$0 e, \mu$	$\geq 3 b$	$E_T^{\text{miss}}$	36.1	$\tilde{H}$	0.13-0.23	$m(\tilde{\chi}_1^\pm)=10 \text{ GeV}$
		$4 e, \mu$	$0 \text{ jets}$	$E_T^{\text{miss}}$	36.1	$\tilde{H}$	0.3	$\text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G})=1$
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# Summary of constraints on sleptons

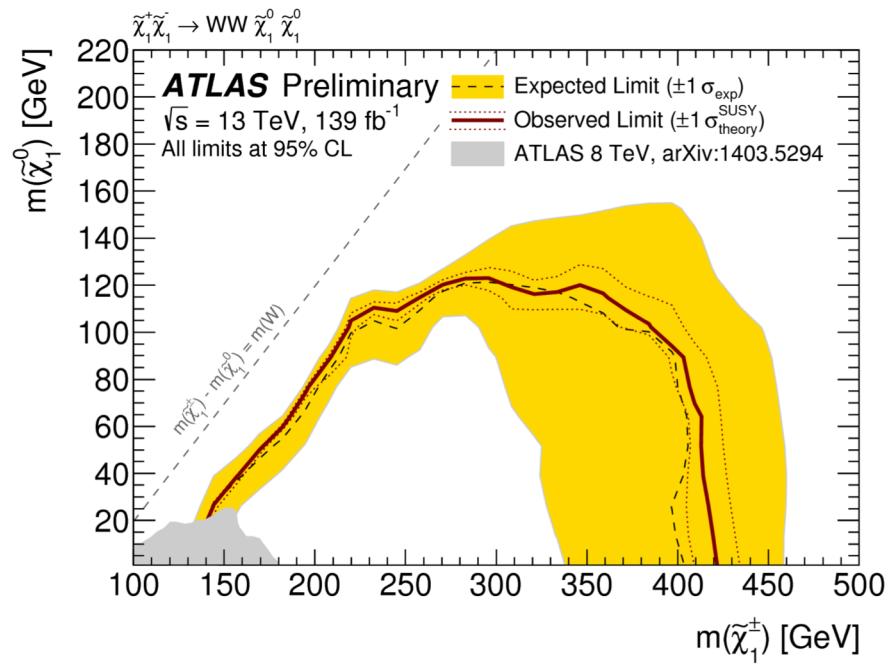
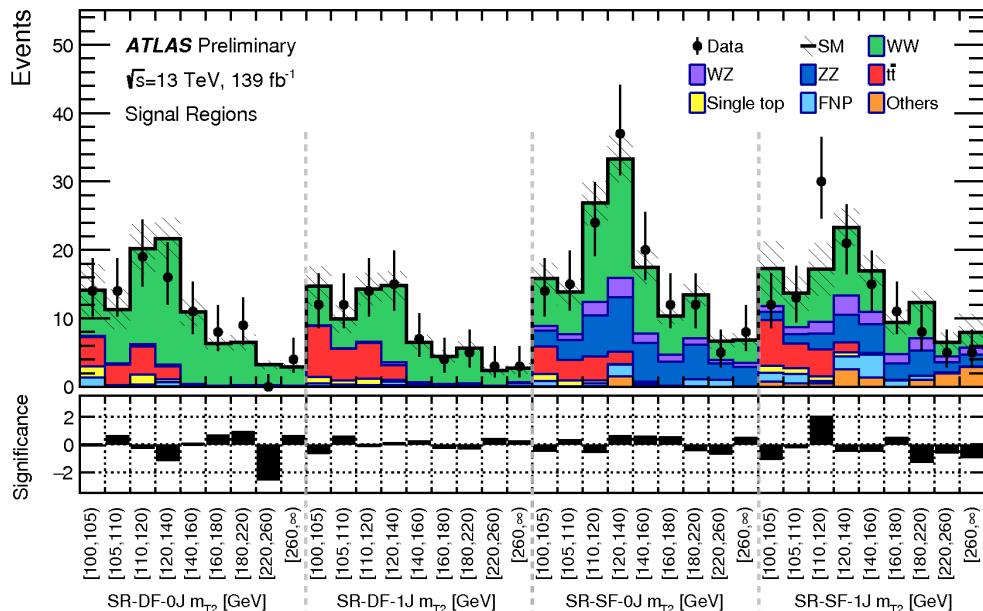


Strong constraints on mass-degenerate  $\tilde{\ell}_{L,R}$ , as well as constraints on individual sleptons  $\tilde{\mu}_L, \tilde{\mu}_R, \tilde{e}_L, \tilde{e}_R$ .

# Search for charginos and sleptons in 2-lepton events

ATLAS-CONF-2019-008

Binned SRs in jet multiplicity and  
“transverse” mass ( $m_{T2}$ ) exploit shape  
differences between signal and background



Large extension of run I limits

Search performed in events with high values of object based missing transverse momentum significance ( $S$ ) which provides strong background suppression.

# Object-based missing transverse momentum significance

ATLAS-CONF-2018-038

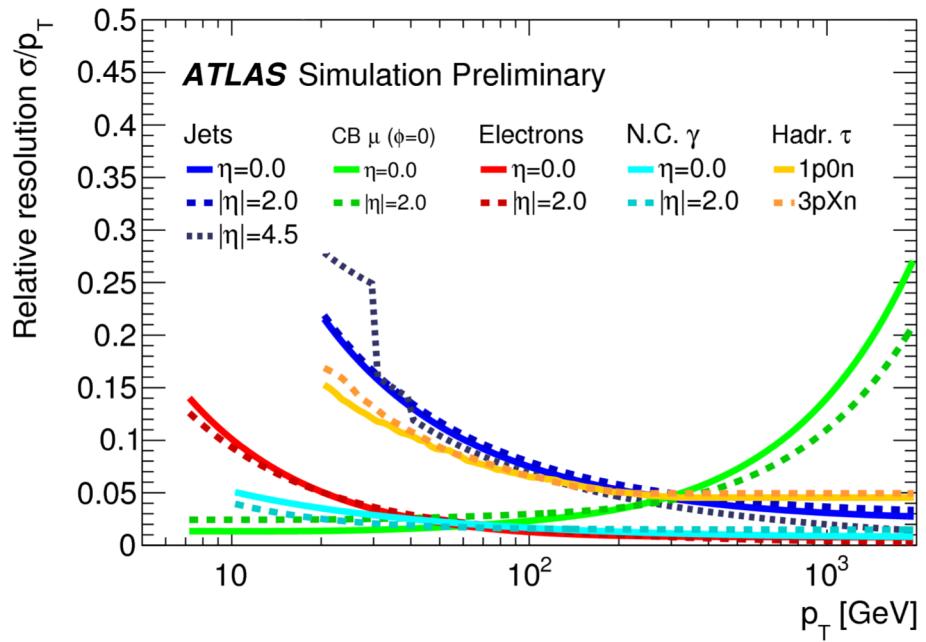
Indicates the degree to which the observed  $E_T^{miss} = |\vec{p}_T^{miss}|$  is consistent with momentum resolution and particle identification inefficiencies.

- **Event based definition:**

$$\mathcal{S} = \frac{E_T^{miss}}{\sqrt{H_T}} \text{ (or similar)}$$

- **Object based definition:**

Determine  $\mathcal{S}$  from the log-likelihood ratio that the reconstructed  $E_T^{miss}$  is consistent with the hypothesis of 0 real  $E_T^{miss}$  based on the full event composition.



Significantly reduces fake-  $E_T^{miss}$  backgrounds, particularly in 1-jet events

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ATLAS-CONF-2018-038

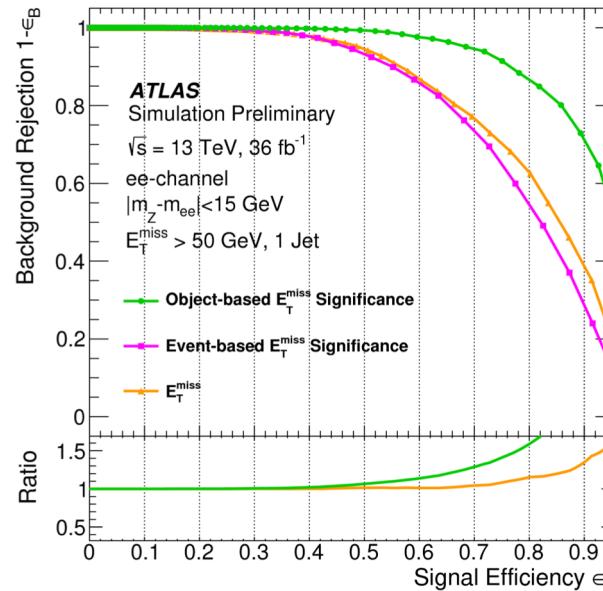
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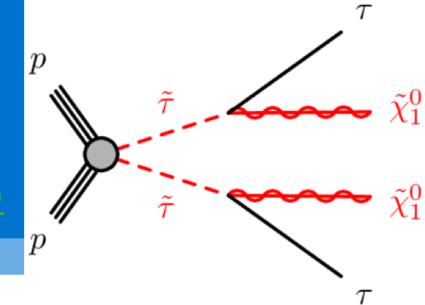
Background:  $Z \rightarrow ee$

Signal:  $ZZ \rightarrow eeev$

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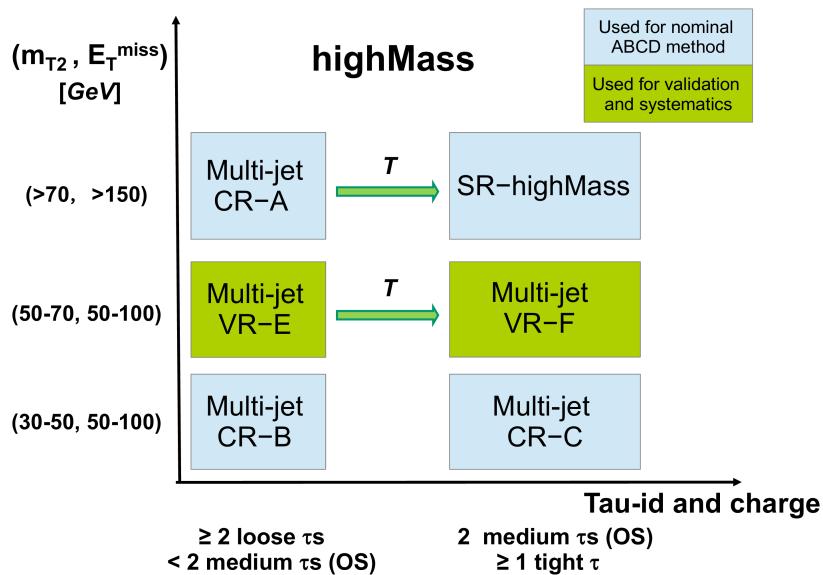
# Final states with taus

ATLAS-CONF-2019-018



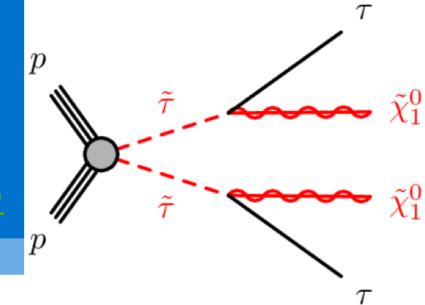
Search for direct stau production in events with two hadronically decaying taus (identified using a BDT) with two orthogonal SRs targeting high and low stau masses

- Small signal cross-sections with large backgrounds.
- Challenging QCD background estimated using ABCD method that inverts the  $\tau$  – identification/charge requirements.
- First LHC limits on direct non-degenerate stau production assuming  $\tilde{\tau}_L$  only.



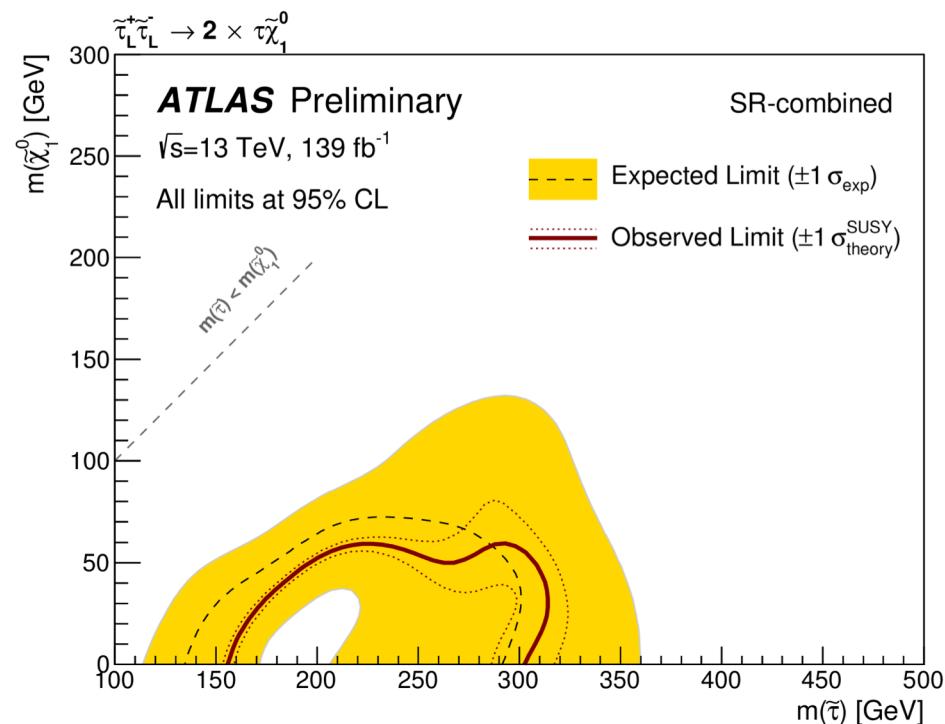
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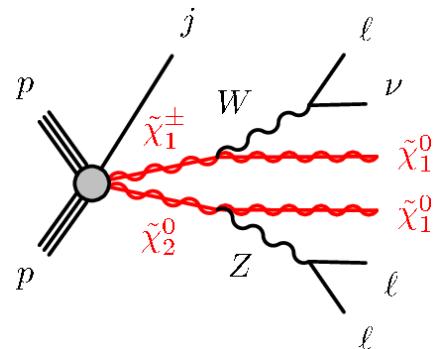
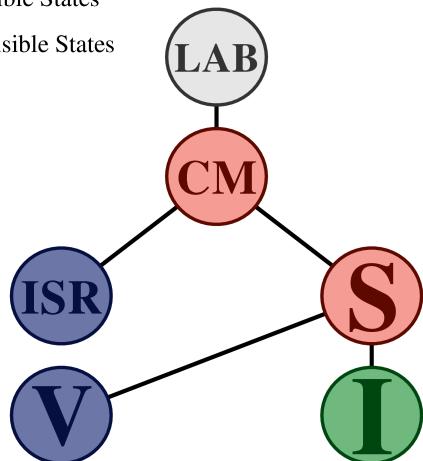


# Emulated Recursive Jigsaw Reconstruction (eRJR)

[ATLAS-CONF-2019-020](#)

Follow-up on excesses in  $36 \text{ fb}^{-1}$  Recursive Jigsaw Reconstruction search by emulating variables using lab-frame observables for the low and ISR SRs.

- Lab State
- Decay States
- Visible States
- Invisible States



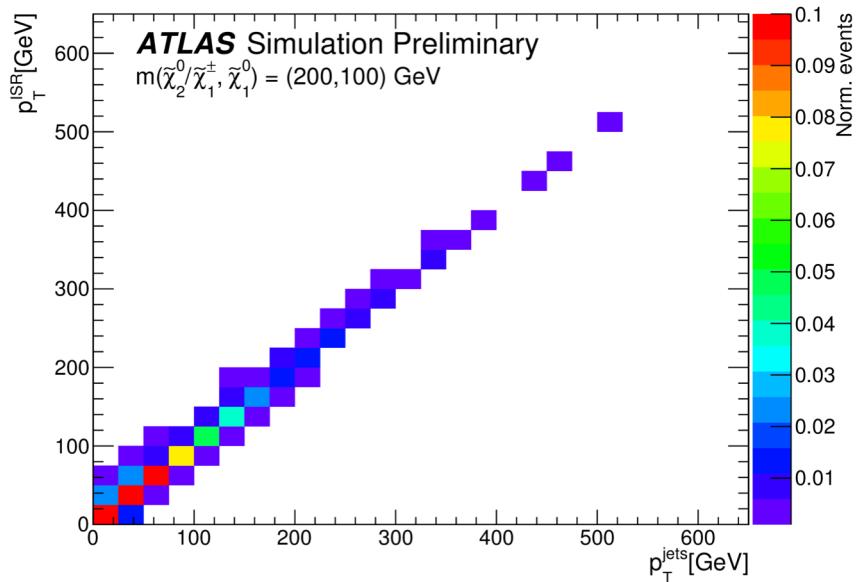
- RJR technique aims constructs approximate boosts to access kinematic information in rest frames of an assumed decay tree.
- eRJR analysis emulates RJR variables in the lab frame and repeats the search in the 3L SRs.

Consistently reproduce excesses in the low- and ISR- SRs for 2015+2016 data, with no significant deviations in the full run II dataset. Exclusion limits calculated for on-shell models.

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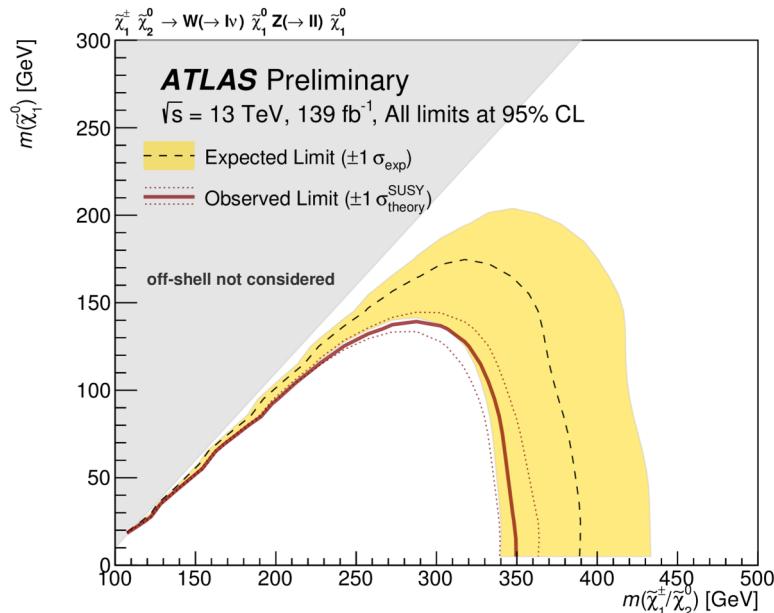
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# Conclusions



Early searches for charginos, neutralinos and sleptons have shown no significant deviations from the SM.

Improved search methods and new reconstruction techniques have enabled strong constraints in SUSY simplified models.

Only at the “tip of the iceberg” in terms of potential for EWK searches using the run II dataset, with much more to come

Thanks for listening, and all members of the ATLAS collaboration who contributed to these early results! Any questions?

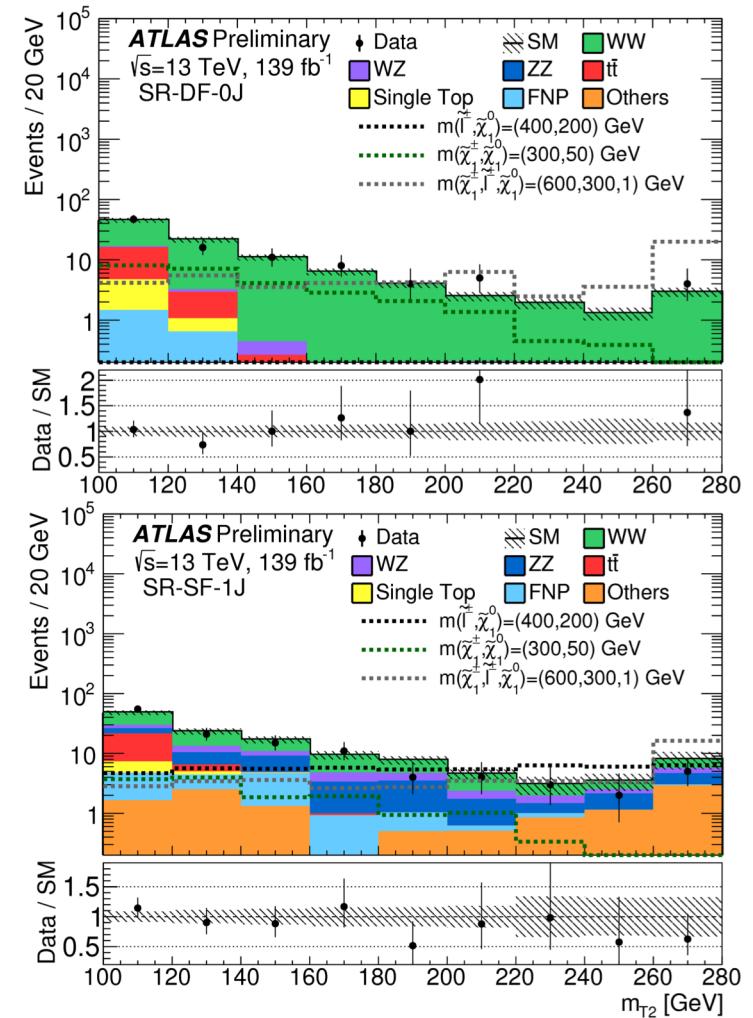
# Backup: 2l+0jets search strategy

[ATLAS-CONF-2019-008](#)

DF(SF) = different (same)- flavour

Signal region (SR)	SR-DF-0J	SR-DF-1J	SR-SF-0J	SR-SF-1J
$n_{\text{non-}b\text{-tagged jets}}$	= 0	= 1	= 0	= 1
$m_{\ell\ell}$ [GeV]		>100		>121.2
$E_T^{\text{miss}}$ [GeV]			>110	
$E_T^{\text{miss}}$ significance			>10	
$n_b\text{-tagged jets}$			= 0	
Binned SRs				
$m_{T2}$ [GeV]	$\in [100, 105)$			
	$\in [105, 110)$			
	$\in [110, 120)$			
	$\in [120, 140)$			
	$\in [140, 160)$			
	$\in [160, 180)$			
	$\in [180, 220)$			
	$\in [220, 260)$			
	$\in [260, \infty)$			
Inclusive SRs				
$m_{T2}$ [GeV]	$\in [100, \infty)$			
	$\in [160, \infty)$			
	$\in [100, 120)$			
	$\in [120, 160)$			

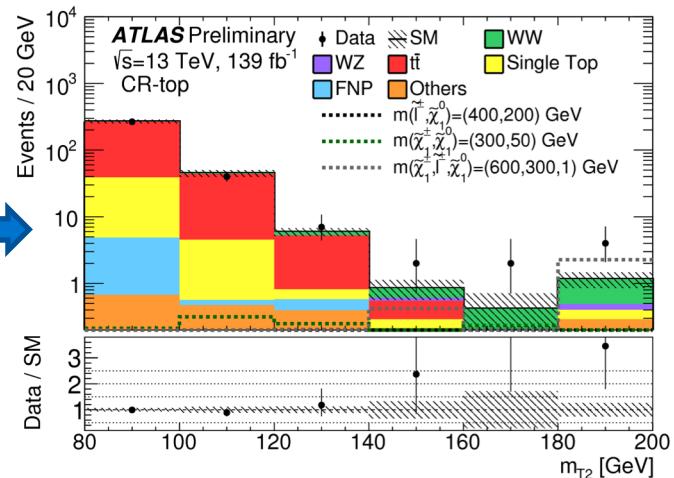
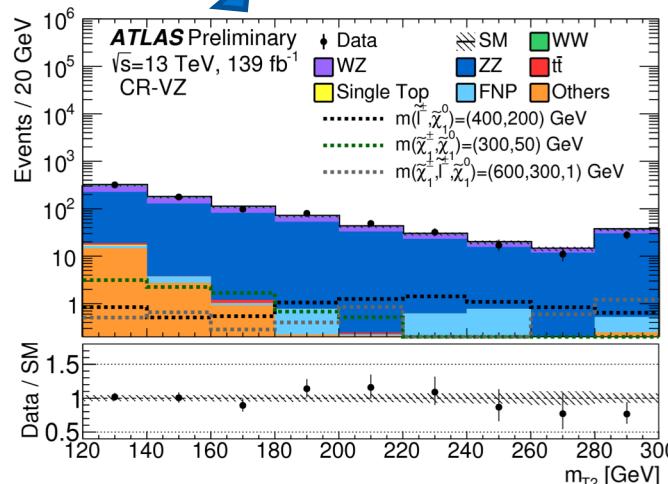
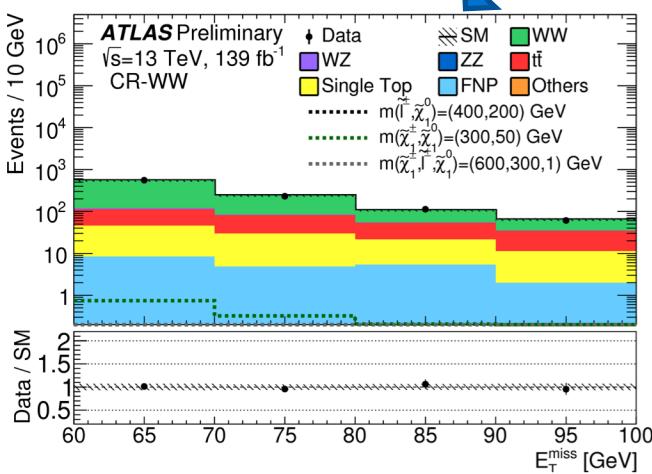
$$m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1} + \mathbf{q}_{T,2} = \mathbf{q}_T} \{ \max[ m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2}) ] \}$$



# Backup: 2l+0jets background estimation

ATLAS-CONF-2019-008

Region	CR-WW	CR-VZ	CR-top
Lepton flavour	DF	SF	DF
$n_b$ -tagged jets	= 0	= 0	= 1
$n_{\text{non-}b\text{-tagged jets}}$	= 0	= 0	= 0
$m_{T2}$ [GeV]	$\in [60, 65]$	$> 120$	$> 80$
$E_T^{\text{miss}}$ [GeV]	$\in [60, 100]$	$> 110$	$> 110$
$E_T^{\text{miss}}$ significance	$\in [5, 10]$	$> 10$	$> 10$
$m_{\ell\ell}$ [GeV]	$> 100$	$\in [61.2, 121.2]$	$> 100$



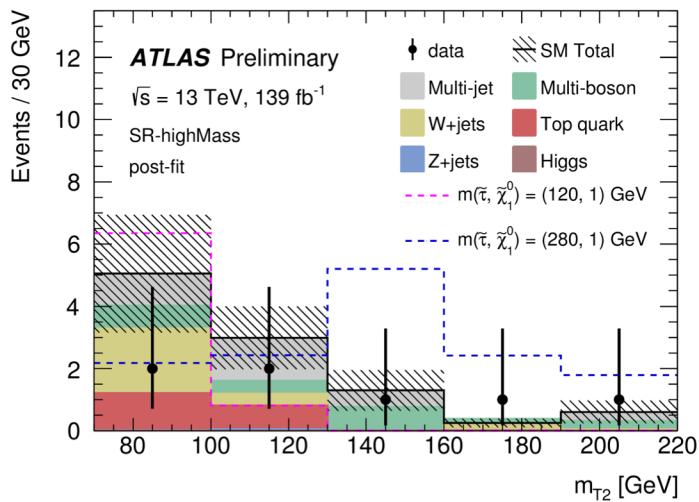
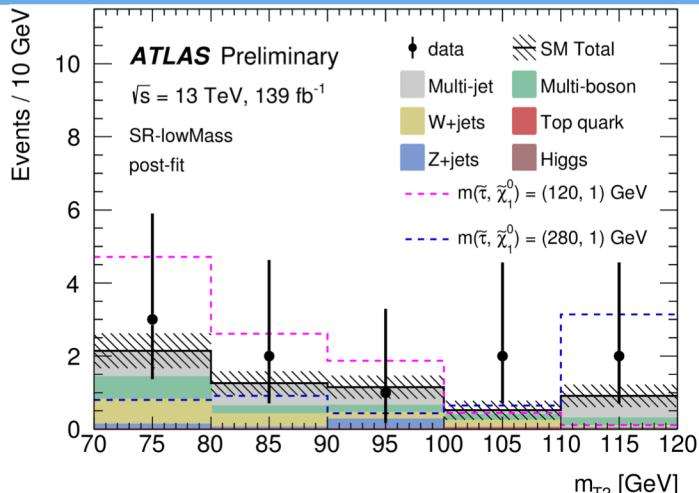
**Data-driven normalization factors for all major backgrounds extracted from simultaneous fit to data in three control regions (CRs)**

# Backup: $2\tau$ search strategy

[ATLAS-CONF-2019-018](#)

SR-lowMass	SR-highMass
2 tight $\tau$ s (OS) asymmetric di-tau trigger $75 < E_T^{\text{miss}} < 150 \text{ GeV}$ tau $p_T$ and $E_T^{\text{miss}}$ cuts described in Section 5 light lepton veto and 3rd medium $\tau$ veto $b$ -jet veto $Z/H$ veto ( $m(\tau_1, \tau_2) > 120 \text{ GeV}$ ) $\Delta R(\tau_1, \tau_2) < 3.2$ $ \Delta\phi(\tau_1, \tau_2)  > 0.8$ $m_{T2} > 70 \text{ GeV}$	2 medium $\tau$ s (OS), $\geq 1$ tight $\tau$ di-tau+ $E_T^{\text{miss}}$ trigger $E_T^{\text{miss}} > 150 \text{ GeV}$
<b>W-CR</b>	<b>W-VR</b>
1 medium $\tau$ and 1 isolated $\mu$ (OS) single-muon trigger $p_T(\tau) > 60 \text{ GeV}, p_T(\mu) > 50 \text{ GeV}$ $E_T^{\text{miss}} > 60 \text{ GeV}$ $b$ -jet veto and top-tagged events veto $m(\mu, \tau) > 70 \text{ GeV}$ $1 < \Delta R(\mu, \tau) < 3.5$ $50 < m_{T,\mu} < 150 \text{ GeV}$ $m_{T,\mu} + m_{T,\tau} > 250 \text{ GeV}$ $30 < m_{T2} < 70 \text{ GeV}$	$m_{T2} > 70 \text{ GeV}$

=> In addition to ABCD method for QCD extract data-driven normalization for W+jets background



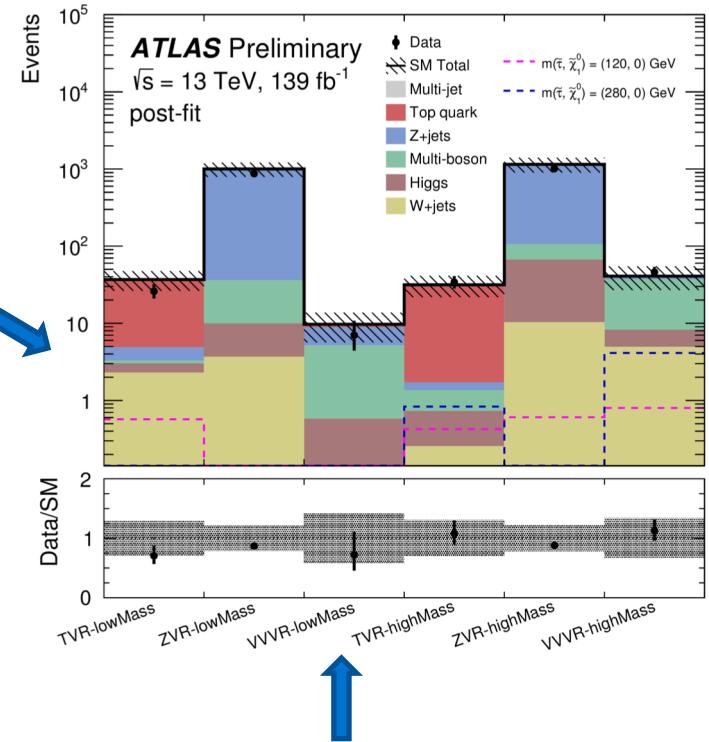
# Backup: $2\tau$ background modelling validation

[ATLAS-CONF-2019-018](#)

Selections	TVR -lowMass	ZVR -lowMass	VVVR -lowMass	TVR -highMass	ZVR -highMass	VVVR -highMass
$\geq 2$ medium $\tau$ s (OS), $\geq 1$ tight $\tau$						
$m(\tau_1, \tau_2)$	$\geq 1$ b-jet	b-jet veto		$\geq 1$ b-jet	b-jet veto	
$\Delta R(\tau_1, \tau_2)$	–	$< 70$ GeV	$< 110$ GeV	–	$< 60$ GeV	$< 110$ GeV
$m_{T,\tau_1} + m_{T,\tau_2}$	$> 1.2$	$< 1$	–	$> 1.2$	$< 1$	–
$m_{T2}$	$> 60$ GeV	$< 60$ GeV	$> 250$ GeV	$> 60$ GeV	$< 60$ GeV	$> 200$ GeV
Trigger	asymmetric di-tau trigger $60 < E_T^{\text{miss}} < 150$ GeV			di-tau+ $E_T^{\text{miss}}$ trigger $E_T^{\text{miss}} > 150$ GeV		
	tau $p_T$ and $E_T^{\text{miss}}$ cuts described in Section 5					

=> High-mass and low-mass validation regions for all non-negligible backgrounds taken from MC

SM process	Multi-jet CR -lowMass	Multi-jet CR -highMass	W-CR	W-VR	SR -lowMass	SR -highMass
Diboson	$1.4 \pm 0.6$	$1.9 \pm 1.0$	$63 \pm 18$	$37 \pm 11$	$1.4 \pm 0.8$	$2.6 \pm 1.2$
$W+jets$	$13 \pm 5$	$4^{+7}_{-4}$	$850 \pm 70$	$370 \pm 120$	$1.5 \pm 0.7$	$2.5 \pm 1.9$
Top quark	$2.7 \pm 0.9$	$3.3 \pm 1.6$	$170 \pm 40$	$114 \pm 31$	$0.04^{+0.80}_{-0.04}$	$2.0 \pm 0.5$
$Z+jets$	$0.3^{+1.4}_{-0.3}$	$1.5 \pm 0.7$	$13 \pm 7$	$27 \pm 20$	$0.4^{+0.5}_{-0.4}$	$0.04^{+0.13}_{-0.04}$
Higgs	$0.01^{+0.33}_{-0.01}$	$0.01 \pm 0.01$	$1.1^{+1.8}_{-1.1}$	$0.5^{+1.0}_{-0.5}$	$0.01^{+0.02}_{-0.01}$	–
Multi-jet	$55 \pm 10$	$16 \pm 7$	$3.1 \pm 3.1$	–	$2.6 \pm 0.7$	$3.1 \pm 1.5$
SM total	$72 \pm 8$	$27 \pm 5$	$1099 \pm 33$	$540 \pm 130$	$6.0 \pm 1.7$	$10.2 \pm 3.3$
Observed	72	27	1099	552	10	7

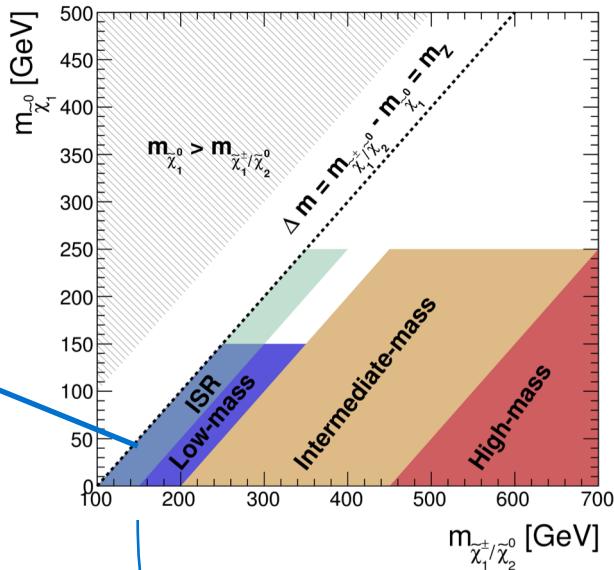
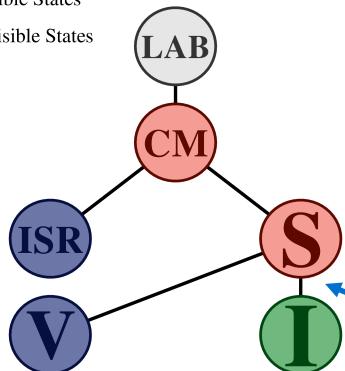


Good agreement between data and prediction in all validation regions.

# Backup: 36 fb<sup>-1</sup> RJR search for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production

[Phys. Rev. D 98 \(2018\) 092012](#)

- Lab State
- Decay States
- Visible States
- Invisible States

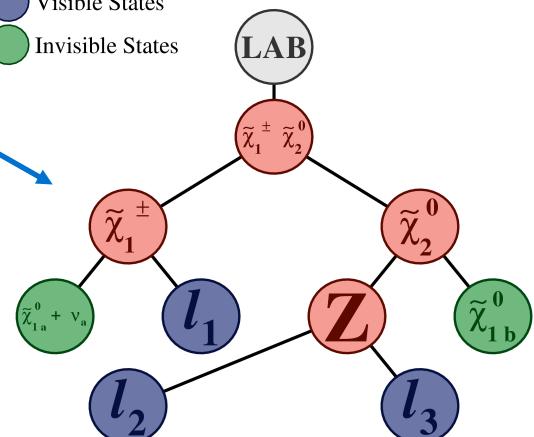


- Use measured event properties to approximate rest frames of intermediate particles in an assumed decay tree.
- RJR technique gives new basis of observables using energies and momenta of objects in these frames.

- Lab State
- Decay States
- Visible States
- Invisible States

Two search channels considered for  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production where  $\tilde{\chi}_1^\pm \rightarrow W^\pm \tilde{\chi}_1^0, \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0$ :

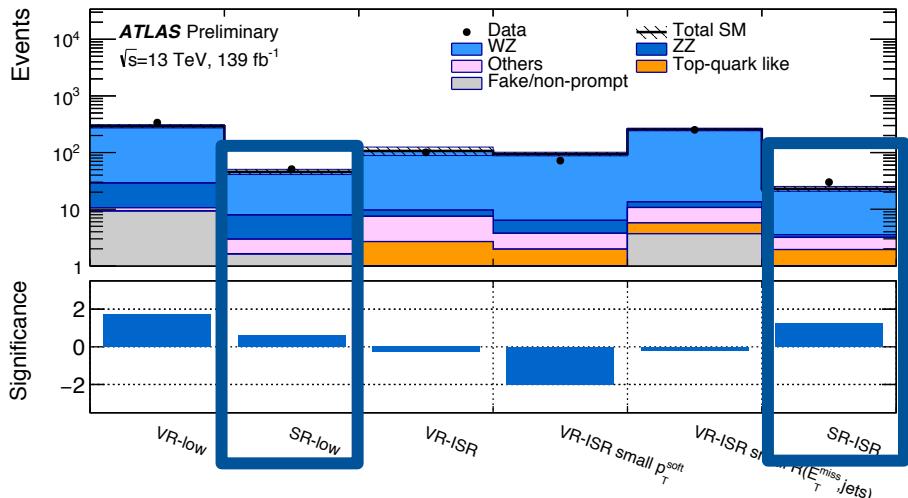
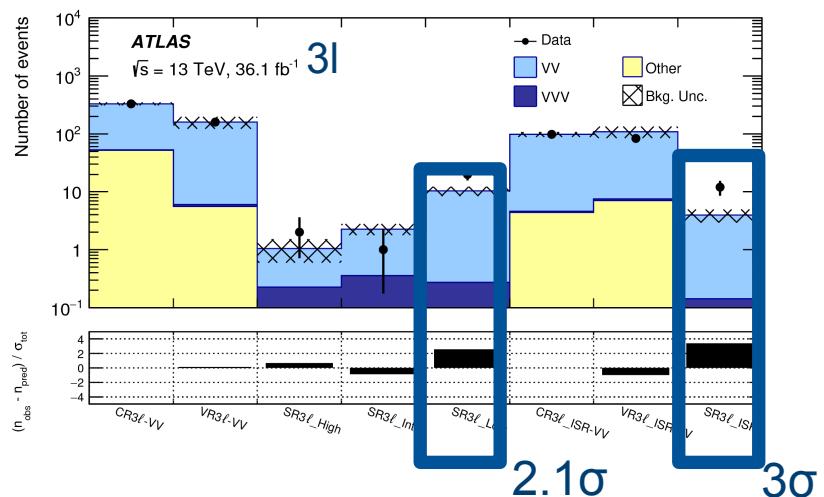
- 3l ( $W \rightarrow l\nu, Z \rightarrow ll$ )
- 2l+jets ( $W \rightarrow qq', Z \rightarrow ll$ )



# Backup: eRJR analysis

ATLAS-CONF-2019-020

36 fb<sup>-1</sup> RJR analysis saw excesses in SRs targeting low and compressed mass splittings: first follow-up with full run II data is an emulation of the technique using lab frame variables



	SR-low	SR-ISR
Observed events	51	30
Fitted SM events	$46 \pm 5$	$23.0 \pm 2.2$
WZ	$38 \pm 5$	$19.5 \pm 2.0$
ZZ	$4.9 \pm 0.6$	$0.38 \pm 0.07$
Others	$1.3 \pm 0.7$	$1.2 \pm 0.7$
Top-quark like	$0.03^{+0.18}_{-0.03}$	$1.9 \pm 0.8$
Fake/non-prompt	$1.6 \pm 1.3$	$0.01^{+0.05}_{-0.01}$

=> No significant deviations from the SM in the full run II dataset.

# Backup: eRJR background estimation

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Dominant WZ background normalized to data in dedicated control regions (CRs) and modelling checked in a set of validation regions (VRs):

Selection Criteria								
Low-mass Region	$p_T^{\ell_1}$ [GeV]	$p_T^{\ell_2}$ [GeV]	$p_T^{\ell_3}$ [GeV]	$m_T$ [GeV]	$E_T^{\text{miss}}$ [GeV]	$H^{\text{boost}}$ [GeV]	$\frac{m^{\text{3}\ell}}{H^{\text{boost}}}$	$\frac{p_T^{\text{soft}}}{p_T + m^{\text{3}\ell}}$
CR-low	> 60	> 40	> 30	$\in (0, 70)$	> 40	> 250	> 0.75	< 0.2
VR-low	> 60	> 40	> 30	$\in (70, 100)$	-	> 250	> 0.75	< 0.2
SR-low	> 60	> 40	> 30	> 100	-	> 250	> 0.9	< 0.05
ISR Region	$p_T^{\ell_1}$ [GeV]	$p_T^{\ell_2}$ [GeV]	$p_T^{\ell_3}$ [GeV]	$m_T$ [GeV]	$E_T^{\text{miss}}$ [GeV]	$ \Delta\phi(E_T^{\text{miss}}, \text{jets}) $	$R(E_T^{\text{miss}}, \text{jets})$	$p_T^{\text{jets}}$ [GeV]
CR-ISR	> 25	> 25	> 20	< 100	> 60	> 2.0	$\in (0.55, 1.0)$	> 80
VR-ISR	> 25	> 25	> 20	> 60	> 60	> 2.0	$\in (0.55, 1.0)$	> 80
VR-ISR-small $p_T^{\text{soft}}$	> 25	> 25	> 20	> 60	> 60	> 2.0	$\in (0.55, 1.0)$	< 25
VR-ISR-small $R(E_T^{\text{miss}}, \text{jets})$	> 25	> 25	> 20	> 60	> 60	> 2.0	$\in (0.30, 0.55)$	> 80
SR-ISR	> 25	> 25	> 20	> 100	> 80	> 2.0	$\in (0.55, 1.0)$	> 100

Fake non-prompt lepton background associated with Z+jets production estimated using data-driven fake-factor method

