Searches for electroweak production of supersymmetric particles with the ATLAS detector

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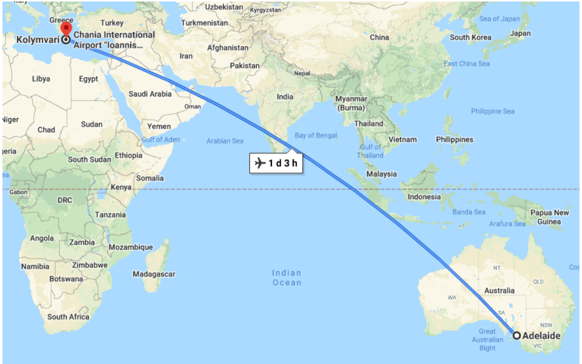
THE UNIVERSITY of ADELAIDE

ATLAS EXPERIMENT

Introduction

This is me! *

This is where I am



* *The one without the eucalyptus leaves*

Electroweak supersymmetry

- In the absence of strong supersymmetry (SUSY) signals at the LHC, electroweak production is an exciting alternative window to the supersymmetric world
- The ATLAS Run 2 dataset is large enough to carry out a variety of searches
- Advances in object definitions such as lower lepton momenta thresholds help to maximise sensitivity
- Today I will cover two recent analyses focusing on 3ℓ and $\geq 4\ell$ lepton final states

Electroweak SUSY model classification

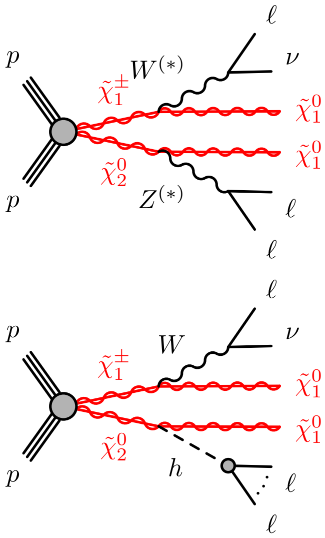
There are a wide range of possible model parameters and final states to probe:

- R-parity conservation (RPC) or violation (RPV)
- Wino-bino or higgsino dominated sparticles
- Symmetry breaking scenarios: different LSPs, mass hierarchies etc

Search for chargino-neutralino pair production in final states with three leptons and missing transverse momentum in $\sqrt{s}$ =13 TeV pp collisions with the ATLAS detector

ATLAS-CONF-2020-015

- Chargino-neutralino ($\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^0$) production is one of the benchmarks for electroweak SUSY searches
- $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ are wino dominated and $\tilde{\chi}_1^0$ is bino dominated
- Decays via W and Z/h bosons
- The 3ℓ final state provides clean signatures to make up for lower branching-ratios
- ISR boosted final states allow for extra missing transverse momentum

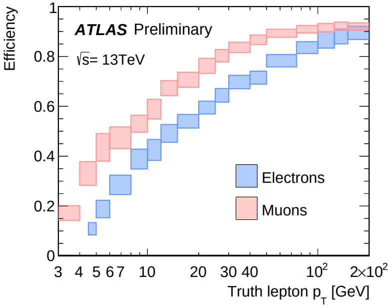


The three selection regimes:

- On-shell WZ- $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$ with 100% branching-ratio for large mass splittings
- Off-shell WZ- $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$ with 100% branching-ratio for mass splittings below m_Z
- Wh- $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$ with 100% branching-ratio for mass splittings above m_h

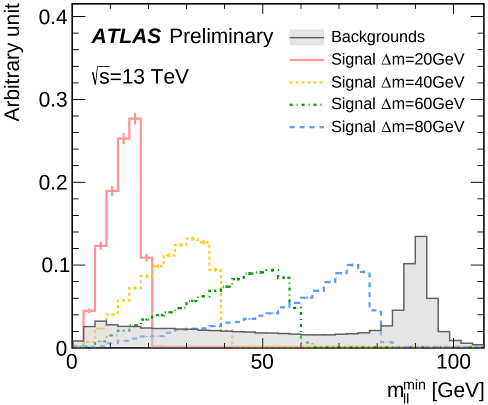
Each SR is binned in some combination of m_{T}, $E_{\mathrm{T}}^{\mathrm{miss}}$, $m_{\ell\ell}^{\mathrm{min}}$, n_{jets}, and H_{T} for sensitivity in a broad range of $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ masses and mass splittings

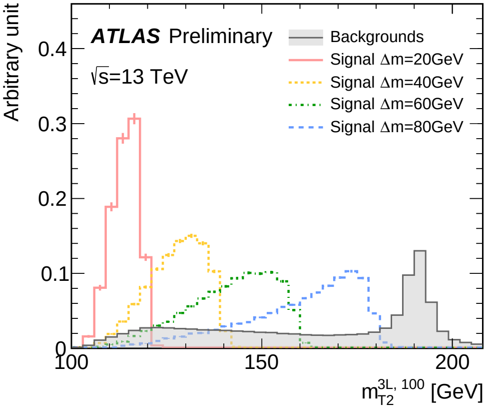
Using leptonic (only electrons and/or muons) or $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers allows for use of lower lepton momenta: 3 GeV for muons, 4.5 GeV for electrons



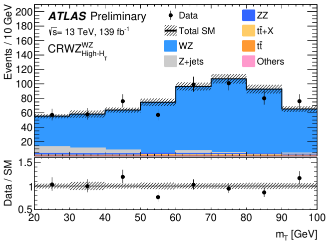
Off-shell discriminating variables

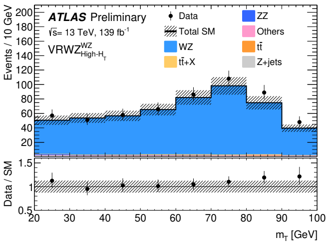
A binned approach targets different mass splittings: here $m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm} = 200$ GeV





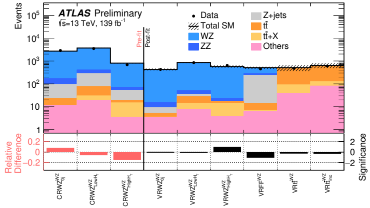
On-shell background estimation

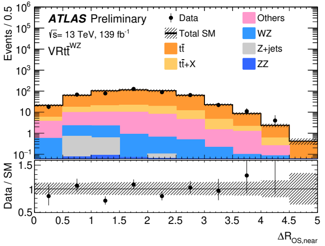


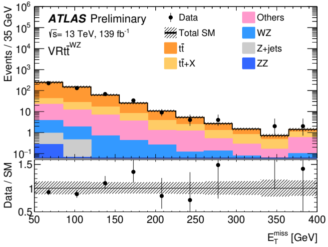


Major backgrounds

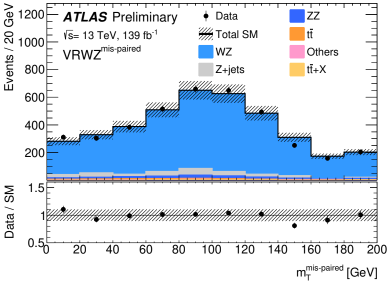
- *WZ* is the main irreducible background
- Contributions from *ZZ*, $t\bar{t}V$
- $t\bar{t}$ with a fake lepton is estimated with MC
- Z+jets estimated using data-driven Fake Factor method

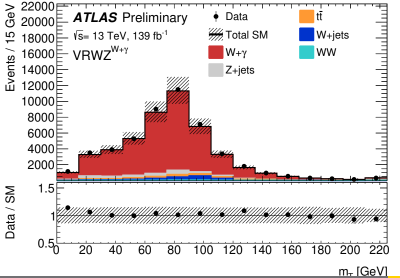




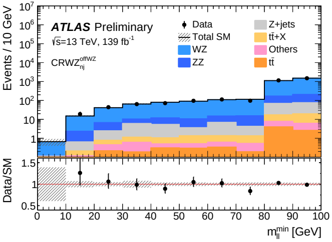


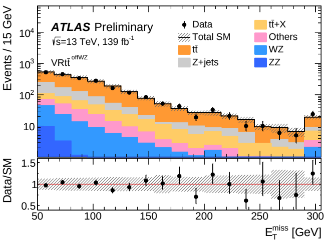
WZ m_{T} modelling





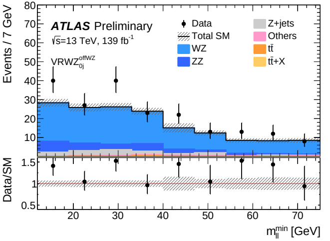
- The performance of $m_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell \mathrm{W}} E_{\mathrm{T}}^{\mathrm{miss}}(1 - \cos(\Delta\phi))}$ is paramount
- Using the wrong lepton to form m_{T} can smear the resolution
- A mis-paired VR is defined with a known wrong lepton choice
- $W\gamma$ is also used to verify the performance of m_{T}
- Both regions show excellent agreement

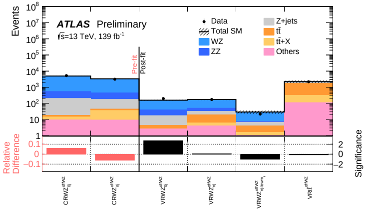


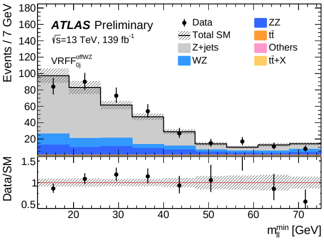


Major backgrounds

- Again *WZ* is the main background
- Care is needed when dealing with ISR- CRs split in jet multiplicity
- Dedicated fake-factor VR

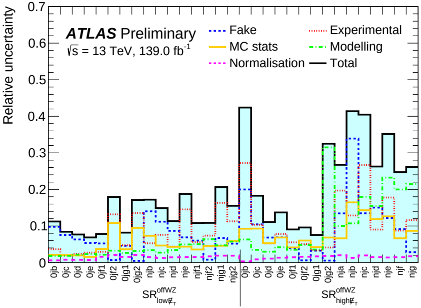


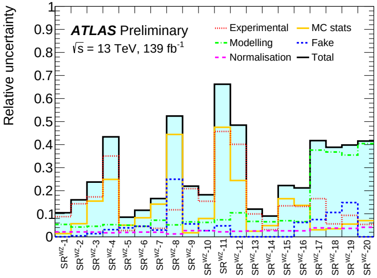


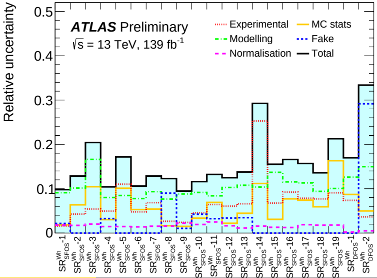


Leading sources of uncertainty vary across the SRs

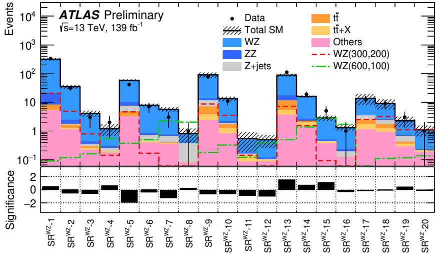
- On-shell- MC statistics and modelling →
- Off-shell- Fakes, modelling, experimental ↓

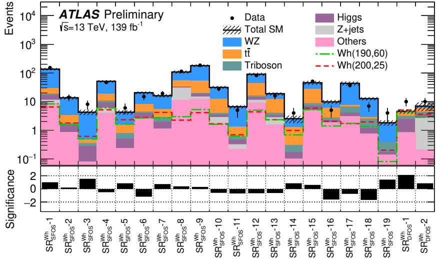






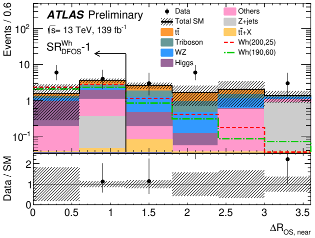
On-shell results

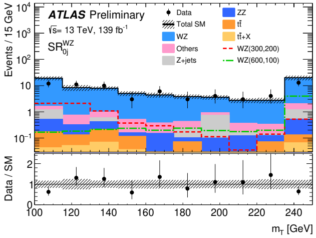




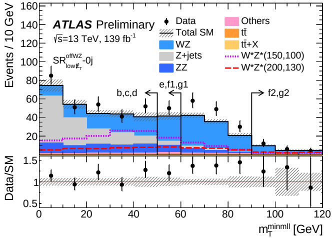
No significant excesses

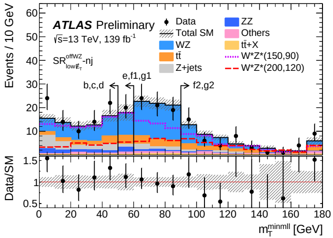
- Explore $\tilde{\chi}_2^0/\tilde{\chi}_1^{\pm}$ masses up to 650 GeV, with a broad range of mass splittings





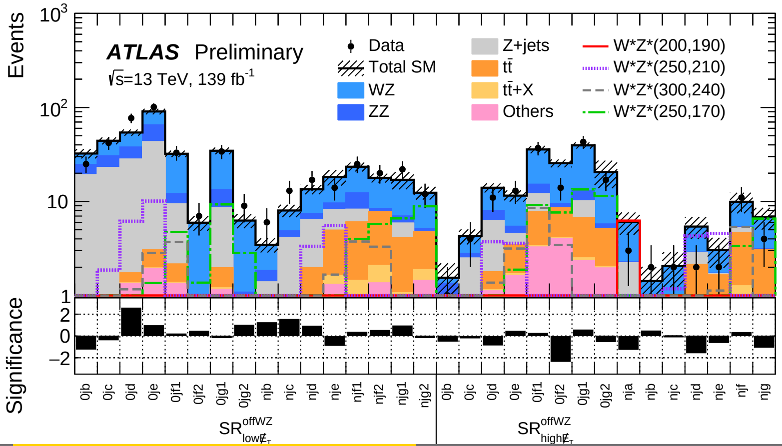
Off-shell results





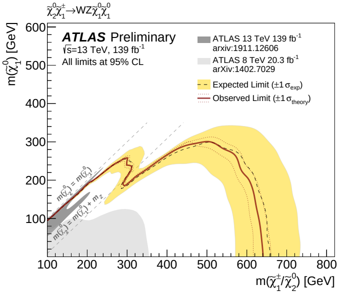
No significant excesses

- Sensitive to mass splittings as low as 10 GeV

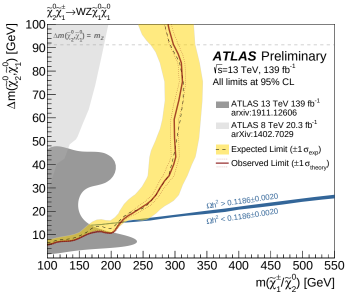


Model dependent limits

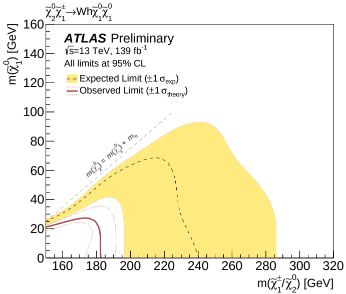
- Excellent reach across all parts of $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ mass plane
- On-shell is excluding $(m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (600, 250)$ GeV
- Off-shell is getting close to $(m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (300, 250)$, and overlapping with dedicated compressed searches



On-shell+off-shell



Off-shell zoom



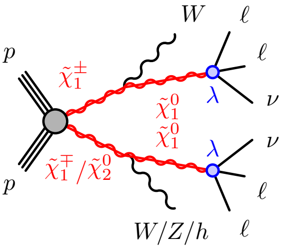
Wh

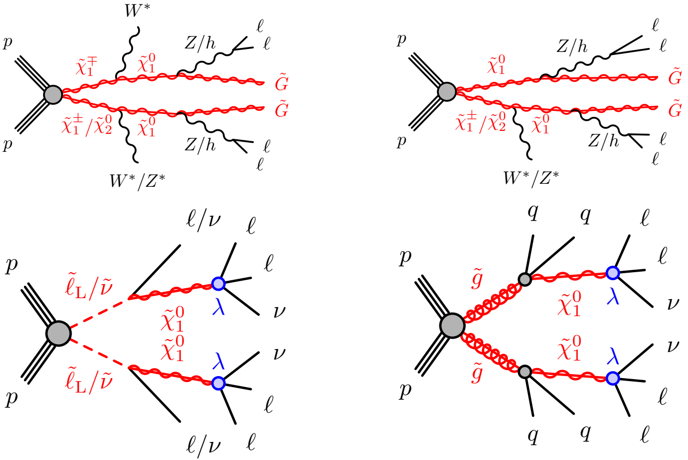
Search for supersymmetry in events with four or more charged leptons in 139 fb^{-1} $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

ATLAS-CONF-2020-040

A variety of models considered

- Simplified models of RPC SUSY inspired by GGM with nearly mass-degenerate higgsinos, and a near-massless gravitino LSP
- RPV models with leptonic R-parity violating terms, and three different kinds of NLSP

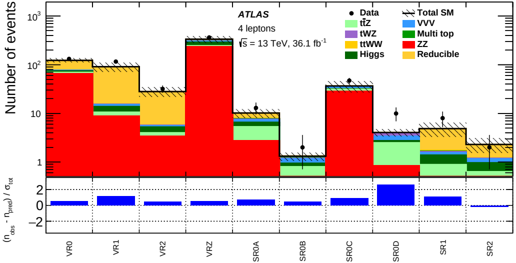




Scenario	$\tilde{\chi}_1^0$ branching ratios		
$LL\bar{E}12k$	$e^+e^-\nu$ (1/4)	$e^{\pm}\mu^{\mp}\nu$ (1/2)	$\mu^+\mu^-\nu$ (1/4)
$LL\bar{E}i33$	$e^{\pm}\tau^{\mp}\nu$ (1/4)	$\tau^+\tau^-\nu$ (1/2)	$\mu^{\pm}\tau^{\mp}\nu$ (1/4)

Analysis strategy

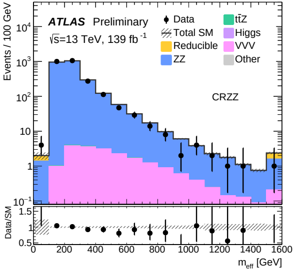
- Now binning SRs in terms of minimum number of light leptons and τs: 4 light, 3 light 1 τ, 2 light 2 τ, and a new ≥ 5 light
- Also binning in Z-mass window or veto thereof, along b-tagged jets
- Two unchanged SRs, $\texttt{SR0-ZZ}^{\text{loose}}$ and $\texttt{SR0-ZZ}^{\text{tight}}$ are excess follow-up regions

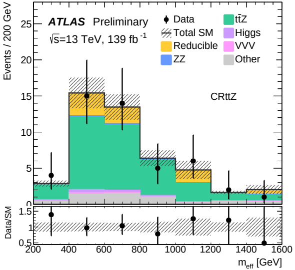


Using 1, 2, and 3 lepton triggers allows for excellent efficiency

Trigger	Offline p_T threshold [GeV] 2015	2016	2017–2018
Single isolated e	25	27	27
Single non-isolated e	61	61	61
Single isolated μ	21	25 or 27	27
Single non-isolated μ	41	41 or 51	51
Double e	13, 13	18, 18	18, 18 or 25, 25
Double μ (symmetric)	11, 11	11, 11 or 15, 15	15, 15
(asymmetric)	19, 9	21, 9 or 23, 9	23, 9
Double $e\mu$	$8(e)$, $25(\mu)$ or $18(e)$, $15(\mu)$	$8(e)$, $25(\mu)$ or $18(e)$, $15(\mu)$ or $27(e)$, $9(\mu)$	$8(e)$, $25(\mu)$ or $18(e)$, $15(\mu)$ or $27(e)$, $9(\mu)$
Triple $e\mu\mu$,$ee\mu$	$13(e)$, $11(2\mu)$ or $13(2e)$, $11(\mu)$	$13(e)$, $11(2\mu)$ or $13(2e)$, $11(\mu)$	$13(e)$, $11(2\mu)$ or $13(2e)$, $11(\mu)$

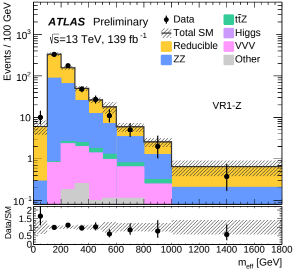
* SUSY-2016-21

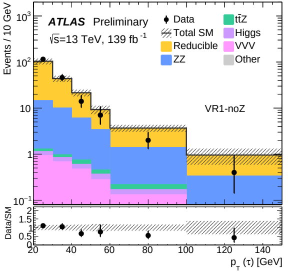




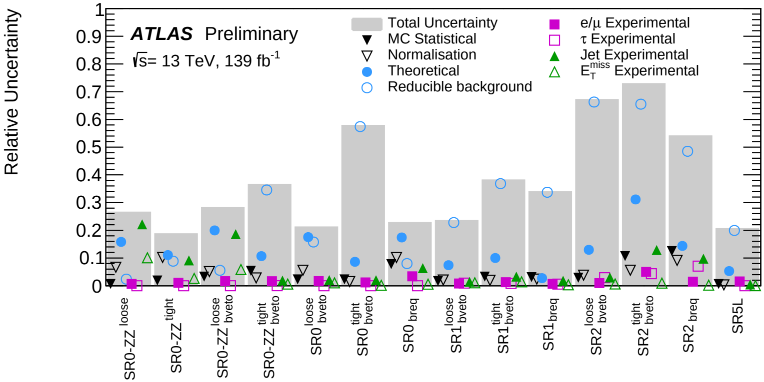
Major backgrounds

- ZZ and $t\bar{t}Z$ are the main irreducible backgrounds
- Smaller contributions from Higgs, VVV, other top processes
- Reducible backgrounds are from $t\bar{t}$, Z+jets, other VV
- The reducible backgrounds are estimated using a hybrid Fake Factor method, with inputs from data and MC

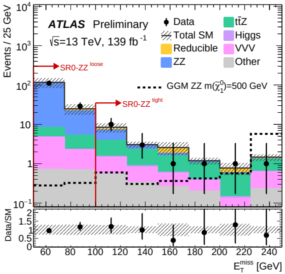


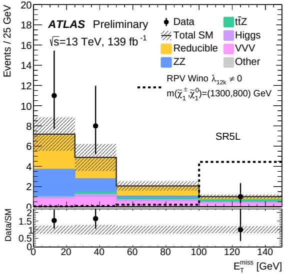


- The major source of uncertainty comes from the reducible background estimation
- These are largely related to the statistical uncertainty in the reducible CRs, and weighted fake factors which include MC uncertainties
- MC theoretical uncertainties and jet experimental systematics also feature in some regions



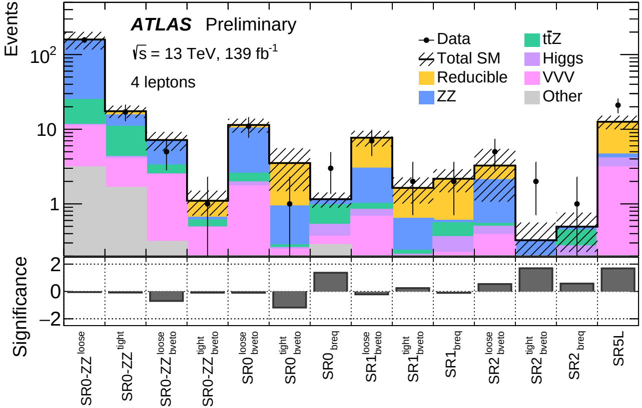
Results

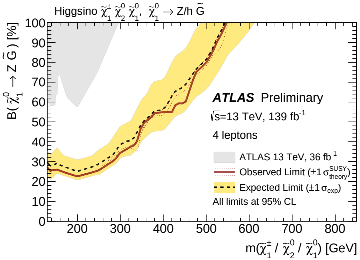


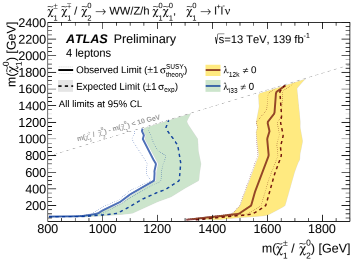


No significant excesses

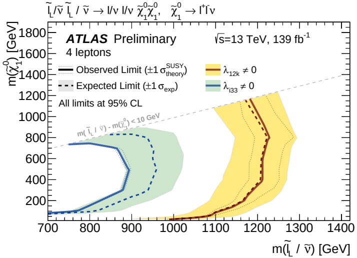
- The previous excesses do not persist

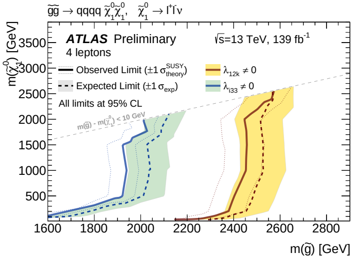


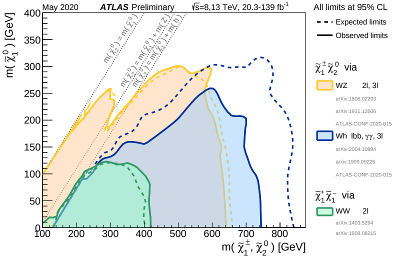


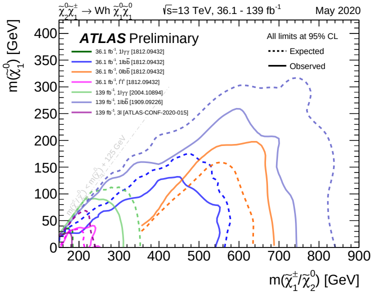


- Exclusion for up to 550 GeV higgsino masses with 100% branching-ratio to Z
- Excellent exclusion for all three NLSP hypotheses (depending on RPV coupling)

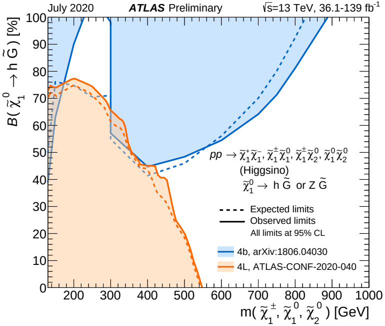








- The analyses presented are covering large areas of the parameter space!
- Leading the way for more full Run 2 electroweak SUSY results



Other recent electroweak SUSY results

- I didn't have the time to discuss all the interesting results
- The table lists other recent ATLAS electroweak SUSY results
- Check out the other ATLAS BSM talks at ICNFP!
- For a complete list of ATLAS SUSY results: ATLAS Public Results

$\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ $H \rightarrow \gamma\gamma$	SUSY-2018-23
3ℓ RPV	ATLAS-CONF-2020-009
3ℓ weak-scale mass splitting	SUSY-2018-06
Compressed 2ℓ	SUSY-2018-16
$\tilde{\tau} \rightarrow \tau$	SUSY-2018-04
$\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ $H \rightarrow b\bar{b}$	SUSY-2019-08
$\tilde{\chi}_1^\pm/\tilde{\chi}_1^\mp$, slepton pairs	SUSY-2018-32

Conclusion

- Presented two recent ATLAS analyses focusing on electroweak SUSY
- Electroweak SUSY is a rich field, with a number of phenomenologically interesting models
- Both analyses exploited the large dataset and object definition improvements from Run 2
- Delivered excellent exclusion limits for a number of models

To the future

- Many more results to come in this sphere on processes and final states not discussed here
- Significant advancements in analysis techniques promise even better results in the future
- Combination efforts are well underway to harmonise the results of a range of analyses

Thanks for your attention!

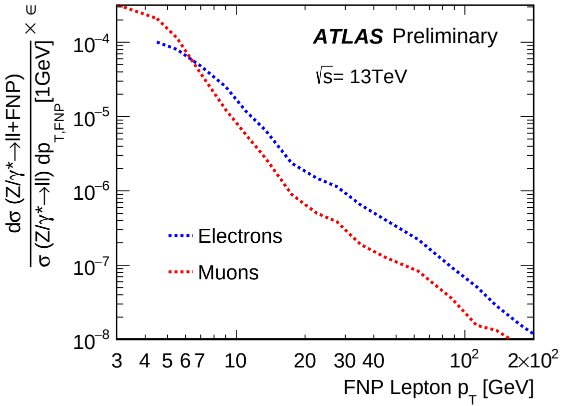
3ℓ additional material

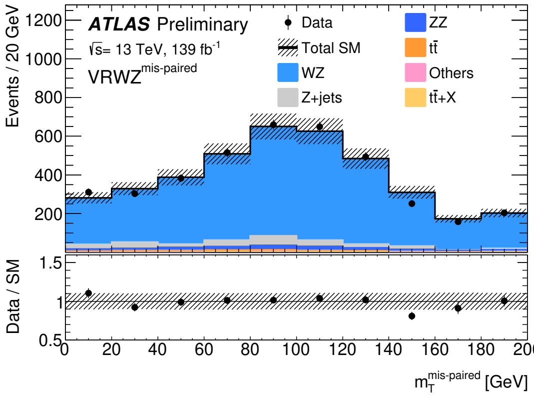
MC samples

Process	Event generator	ME accuracy	ME PDF set	Cross section normalisation
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	MadGraph 2.6 [51]	0,1,2@LO[2]	NNPDF2.3lo [52]	NLO+NLL [53–58]
Diboson [59]	Sherpa 2.2.2 [60]	0, 1j@NLO + 2,3j@LO	NNPDF3.0nlo [61]	-
Triboson [59]	Sherpa 2.2.2	0j@NLO + 1,2j@LO	NNPDF3.0nlo	-
Triboson (alternative) [59]	Sherpa 2.2.1	0,1j@LO	NNPDF2.3lo	-
Z+jets [62]	Sherpa 2.2.2	0,1,2j@NLO + 3,4j@LO	NNPDF3.0nlo	NNLO[2] [63]
$t\bar{t}$ [64]	Powheg-Box 2.2 [65–67]	NLO	NNPDF3.0nlo	NNLO+NNLL[2] [68–74]
tW [75]	Powheg-Box 2.2	NLO	NNPDF3.0nlo	NLO+NNLL [76, 77]
single-t (t-channel [78], s-channel [79])	Powheg-Box 2.2	NLO	NNPDF3.0nlo	NLO [80, 81]
$t\bar{t}H$ [82]	Powheg-Box 2.2	NLO	NNPDF3.0nlo	NLO [83]
$t\bar{t}V$, tZ, tWZ	MadGraph5_aMC@NLO 2.3	NLO	NNPDF3.0nlo	-
$t\bar{t}$ ($t \to Wb\ell\ell$)	MadGraph5_aMC@NLO 2.3	LO	NNPDF2.3lo	-
$t\bar{t}\,VV$, 3-top, 4-top	MadGraph5_aMC@NLO 2.2	LO	NNPDF2.3lo	-
Higgs (ggF)	Powheg-Box 2.2	NNLO+NNLL	NNPDF3.0nlo	NNNLO[2]+NLO(EWK) [83–89]
Higgs (VBF)	Powheg-Box 2.2	NLO+NNLL	NNPDF3.0nlo	NNLO+NLO(EWK) [83, 90–92]
Higgs (VH)	Powheg-Box 2.2	NLO	NNPDF3.0nlo	NNLO+NLO(EWK) [83]

Process	PS and hadronization	PS PDF set	PS tune
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$	Pythia 8.2 [93]	NNPDF2.3lo	A14 [94]
Diboson, Triboson, Z+jets	Sherpa 2.2.2	default Sherpa [95]	default Sherpa
Triboson (alternative)	Sherpa 2.2.1	default Sherpa	default Sherpa
$t\bar{t}$, tW, single-t, $t\bar{t}H$	Pythia 8.2	NNPDF2.3lo	A14
$t\bar{t}V$, tZ, tWZ, $t\bar{t}$ ($t \to Wb\ell\ell$)	Pythia 8.2	NNPDF2.3lo	A14
$t\bar{t}\,VV$, 3-top, 4-top	Pythia 8.1	NNPDF2.3lo	A14
Higgs (ggF, VBF, VH)	Pythia 8.2	CTEQ6L1 [96]	AZNLO [97]

Non-prompt eff. & $W\gamma$





Preselection definitions

Variable	Preselection requirements			
	$\mathrm{SR^{WZ}}$	$\mathrm{SR^{Wh}_{SFOS}}$	$\mathrm{SR^{Wh}_{DFOS}}$	$\mathrm{CR^{WZ}/VR^{WZ}}$
$n_{\mathrm{lep}}^{\mathrm{baseline}}, n_{\mathrm{lep}}^{\mathrm{signal}}$		$= 3$		$= 3$
trigger		di-lepton		di-lepton
$p_{\mathrm{T}}^{\ell_1}, p_{\mathrm{T}}^{\ell_2}, p_{\mathrm{T}}^{\ell_3}$ [GeV]		$> 25, 20, 10$		$> 25, 20, 10$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]		> 50		-
$n_{\mathrm{b-jets}}$		$= 0$		-
resonance veto $m_{\ell\ell}$ [GeV]		> 12		-
n_{SFOS}	≥ 1	≥ 1	$= 0$	-
$m_{\ell\ell}$ [GeV]	$\in [75, 105]$	$\notin [75, 105]$	$\notin [75, 105]$	-
$\lvert m_{3\ell} - m_Z \rvert$ [GeV]	> 15	> 15	-	-

On-shell *WZ* SR definitions

Selection requirements				
$n_{jets} = 0$				
m_T [GeV]	E_T^{miss} [GeV]			
[100,160]	SR^{WZ}-1: [50,100]	SR^{WZ}-2: [100,150]	SR^{WZ}-3: [150,200]	SR^{WZ}-4: > 200
> 160	SR^{WZ}-5: [50,150]	SR^{WZ}-6: [150,200]	SR^{WZ}-7: [200,350]	SR^{WZ}-8: > 350
$n_{jets} > 0$, $H_T < 200$ GeV				
m_T [GeV]	E_T^{miss} [GeV]			
[100,160]	SR^{WZ}-9: [100,150]	SR^{WZ}-10: [150,250]	SR^{WZ}-11: [250,300]	SR^{WZ}-12: > 300
> 160	SR^{WZ}-13: [50,150]	SR^{WZ}-14: [150,250]	SR^{WZ}-15: [250,400]	SR^{WZ}-16: > 400
$n_{jets} > 0$, $H_T > 200$ GeV, $H_T^{lep} < 350$ GeV				
m_T [GeV]	E_T^{miss} [GeV]			
> 100	SR^{WZ}-17: [150,200]	SR^{WZ}-18: [200,300]	SR^{WZ}-19: [300,400]	SR^{WZ}-20: > 400

On-shell Wh SR definitions

Selection requirements			
$m_{\ell\ell} \leq 75$ GeV, $n_{\mathrm{jets}} = 0$			
m_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]		
[0,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-1: [50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-2: [100,150]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-3 > 150
[100,160]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-4: [50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-5: > 100	
> 160	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-6: [50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-7: > 100	
$m_{\ell\ell} \leq 75$ GeV, $n_{\mathrm{jets}} > 0$, $H_{\mathrm{T}} < 200$			
m_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]		
[0,50]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-8: [50,100]		
[50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-9: [50,100]		
[0,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-10: [100,150]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-11: > 150	
[100,160]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-12: [50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-13: [100,150]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-14: > 150
> 160	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-15: [50,150]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-16: > 150	
$m_{\ell\ell} \geq 105$ GeV, $n_{\mathrm{jets}} = 0$			
m_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]		
> 100	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-17: [50,100]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-18: [100,200]	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{SFOS}}$-19: > 200

	Selection requirements	
Variable	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{DFOS}}$-1	$\mathrm{SR}^{\mathrm{Wh}}_{\mathrm{DFOS}}$-2
n_{jets}	$= 0$	$\in [1, 2]$
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	> 8	> 8
$p_{\mathrm{T}}^{\ell_3}$ [GeV]	> 15	> 20
$\Delta R_{\mathrm{OS,near}}$	< 1.2	< 1.0

On-shell WZ CR/VR definitions

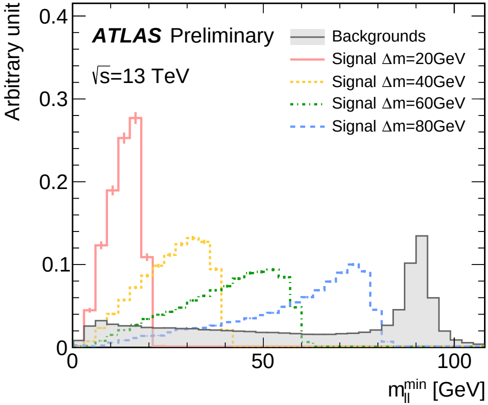
Variable	$\mathtt{CRWZ}^{\mathtt{WZ}}$			$\mathtt{VRWZ}^{\mathtt{WZ}}$		
	0j	low-H_T	high-H_T	0j	low-H_T	high-H_T
n_{jets}	=0	≥ 1	≥ 1	=0	≥ 1	≥ 1
H_T [GeV]	-	< 200 GeV	> 200 GeV	-	< 200 GeV	> 200 GeV
n_{SFOS}		≥ 1			≥ 1	
m_T [GeV]		$\in [20, 100]$			$\in [20, 100]$	
$m_{\ell\ell}$ [GeV]		$\in [75, 105]$			$\in [75, 105]$	
$\lvert m_{3\ell} - m_Z \rvert$ [GeV]		> 15			> 15	
E_T^{miss} [GeV]		$\in [50, 100]$			> 100	

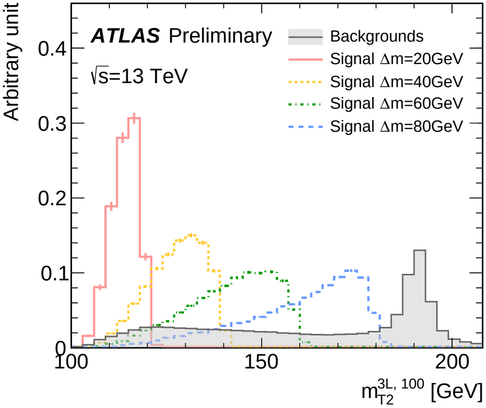
On-shell WZ CR/VR definitions 2

Variable	$\mathtt{VRt\bar{t}}^{\mathtt{WZ}}$	$\mathtt{VRt\bar{t}}^{\mathtt{WZ}}_{\mathrm{incl}}$	$\mathtt{CRFF}^{\mathtt{WZ}}$	$\mathtt{VRFF}^{\mathtt{WZ}}$
n_{SFOS}	$= 0$	$= 0$	≥ 1	≥ 1
$n_{b\text{-jets}}$	$\in [1, 2]$	-	=0	=0
$\lvert m_{\ell\ell} - m_Z\rvert$ [GeV]	-	-	< 15	< 15
$p_{\mathrm{T}}^{\ell_{Z1}}$, $p_{\mathrm{T}}^{\ell_{Z2}}$ [GeV]	-	-	$> 25, > 20$	-
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 50	> 50	$\in [20, 50]$	$\in [50, 100]$
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	-	< 8	-	-
m_{T} [GeV]	-	-	< 20	< 20
$m_{3\ell}$ [GeV]	-	-	-	$\in [105, 160]$

Variable	Preselection requirements				
	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}E_T^{\mathrm{miss}}}$-0j	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}E_T^{\mathrm{miss}}}$-nj	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0j	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-nj	$\mathrm{CR}^{\mathrm{offWZ}}/\mathrm{VR}^{\mathrm{offWZ}}$
$n^{\mathrm{baseline}}_{\mathrm{lep}}$, $n^{\mathrm{signal}}_{\mathrm{lep}}$	$= 3$				$= 3$
n_{SFOS}	≥ 1				-
$m_{\ell\ell}$, $m^{\mathrm{max}}_{\ell\ell}$ [GeV]	< 75				-
$m^{\mathrm{min}}_{\ell\ell}$ [GeV]	$\in [1, 75]$				-
$n_{b\text{-jets}}$	$= 0$				-
min $\Delta R_{3\ell}$	> 0.4				> 0.4
resonance veto $m^{\mathrm{min}}_{\ell\ell}$ [GeV]	$\notin [3, 3.2], \notin [9, 12]$			-	$\notin [3, 3.2], \notin [9, 12]$
trigger	(multi-)lepton		((multi-)lepton || E_T^{miss})		((multi-)lepton || E_T^{miss})
$n^{30\ \mathrm{GeV}}_{\mathrm{jets}}$	$= 0$	≥ 1	$= 0$	≥ 1	-
E_T^{miss} [GeV]	< 50	< 200	> 50	> 200	-
E_T^{miss} significance	> 1.5	> 3.0	> 3.0	> 3.0	-
$\lvert m_{3\ell} - m_Z \rvert$ [GeV]	> 20 ($l_W = e$ only)		-		-
min ΔR_{SFOS}	$[0.6, 2.4]$ ($l_W = e$ only)		-		-

Off-shell SR variable modelling





Off-shell SRs

Variable	a	b	c	d	e	f1	f2	g1	g2
	Selection requirements								
$m_{\ell\ell}^{\min}$ [GeV]	[1,12]	[12,15]	[15,20]	[20,30]	[30,40]	[40,60]		[60,75]	
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{low}\not{E}_T}$ common								
$m_{\ell\ell}^{\max}$ [GeV]	$\times$	< 60	< 60	< 60	< 60	-	-	-	-
$m_{\mathrm{T}}^{\mathrm{mllmin}}$ [GeV]	$\times$	< 50	< 50	< 50	< 60	< 60	< 90	< 60	> 90
m_{T2}^{100} [GeV]	$\times$	< 115	< 120	< 130	-	-	-	-	-
$\min \Delta R_{\mathrm{SFOS}}$	$\times$	< 1.6	< 1.6	< 1.6	-	-	-	-	-
$p_{\mathrm{T}}^{\ell_1}, p_{\mathrm{T}}^{\ell_2}, p_{\mathrm{T}}^{\ell_3}$ [GeV]	$\times$	> 10	> 10	> 10	> 10	> 15	> 15	> 15	> 15
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{low}\not{E}_T}$-0j								
$\lvert\mathbf{p}_{\mathrm{T}}^{\mathrm{lep}}\rvert / E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	< 1.1	< 1.1	< 1.1	< 1.3	< 1.4	< 1.4	< 1.4	< 1.4
$m_{3\ell}$ [GeV]	$\times$	-	-	-	-	> 100	> 100	> 100	> 100
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{low}\not{E}_T}$-nj								
$\lvert\mathbf{p}_{\mathrm{T}}^{\mathrm{lep}}\rvert / E_{\mathrm{T}}^{\mathrm{miss}}$	$\times$	< 1.0	< 1.0	< 1.0	< 1.0	< 1.2	< 1.2	< 1.2	< 1.2
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{high}\not{E}_T}$ common								
m_{T2}^{100} [GeV]	< 112	< 115	< 120	< 130	< 140	< 160	< 160	< 175	< 175
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{high}\not{E}_T}$-0j								
$p_{\mathrm{T}}^{\ell_1}, p_{\mathrm{T}}^{\ell_2}, p_{\mathrm{T}}^{\ell_3}$ [GeV]	-	$> 25, > 15, > 10$							
$m_{\mathrm{T}}^{\mathrm{mllmin}}$ [GeV]	-	< 50	< 50	< 60	< 60	< 70	> 90	< 70	> 90
	$\mathrm{SR}^{\mathtt{offWZ}}_{\mathtt{high}\not{E}_T}$-nj								
						f		g	
$\lvert\mathbf{p}_{\mathrm{T}}^{\mathrm{lep}}\rvert / E_{\mathrm{T}}^{\mathrm{miss}}$	< 0.2	< 0.2	< 0.3	< 0.3	< 0.3	< 1.0		< 1.0	

Off-shell CR/VR

Variable	$\mathtt{CRWZ}^{\mathtt{offWZ}}_{\mathtt{0j}}$	$\mathtt{CRWZ}^{\mathtt{offWZ}}_{\mathtt{nj}}$	$\mathtt{VRWZ}^{\mathtt{offWZ}}_{\mathtt{0j}}$	$\mathtt{VRWZ}^{\mathtt{offWZ}}_{\mathtt{nj}}$	$\mathtt{VRWZ}^{\mathtt{offWZ}}_{\mathtt{nj\text{-}lowm_{ll}}}$	$\mathtt{VRt\bar{t}}^{\mathtt{offWZ}}$
n_{SFOS}	≥ 1		≥ 1			≥ 1
$n_{b\text{-jets}}$	$= 0$		$= 0$			≥ 1
$m_{\ell\ell}$ [GeV]	$\in [81, 101]$		< 75			< 75
$n_{\mathrm{jets}}^{30\ \mathrm{GeV}}$	$= 0$	≥ 1	$= 0$	≥ 1	≥ 1	-
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	< 50	< 50	< 50	< 80	> 80	> 50
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	-		> 1.5	> 1.5	> 1.5	-
m_{T} [GeV]	> 50	> 50	$\in [60, 90]$		> 30	-
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	-		$\in [12, 75]$		$\in [1, 12]$	$\in [1, 75]$
resonance veto $m_{\ell\ell}^{\mathrm{min}}$ [GeV]	-		-	-	$\notin [3, 3.2], \notin [9, 12]$	$\notin [3, 3.2], \notin [9, 12]$
$p_{\mathrm{T}}^{\ell_1}, p_{\mathrm{T}}^{\ell_2}, p_{\mathrm{T}}^{\ell_3}$ [GeV]	> 10		> 10	> 10	-	-
min ΔR	-		$[0.6, 2.4]$ ($l_W = e$ only)		-	-
$\lvert m_{3\ell} - m_Z \rvert$ [GeV]	-		> 20 ($l_W = e$ only)		-	-
$m_W^{\mathrm{reco}\, WZ}$ [GeV]	-		> 75	-	-	-
$\Delta R(\ell_W, E_{\mathrm{T}}^{\mathrm{miss}})$	-		> 2.6	-	-	-
$\lvert \mathbf{p}_{\mathrm{T}}^{\mathrm{lep}} \rvert / E_{\mathrm{T}}^{\mathrm{miss}}$	-		-	-	> 0.3	-

Off-shell CR/VR Z+jets

Variable	$\mathtt{CRFF}^{\mathtt{offWZ}}$	$\mathtt{CRt\bar{t}}^{\mathtt{offWZ}}_{\text{anti-ID}}$	$\mathtt{VRFF}^{\mathtt{offWZ}}_{\mathtt{0j}}$	$\mathtt{VRFF}^{\mathtt{offWZ}}_{\mathtt{nj}}$	$\mathtt{VRFF}^{\mathtt{offWZ}}_{\mathtt{nj\text{-}lowp_T}}$
n_{SFOS}	≥ 1	$= 0$		≥ 1	
$n_{b\text{-jets}}$	$= 0$	$= 0$ or ≥ 1		$= 0$	
$m_{\ell\ell}$ [GeV]	$\in [81, 101]$	-		< 75	
$n_{\text{jets}}^{30\text{ GeV}}$	≤ 1 if $p_{\text{T}}^{l_W=\mu} > 30$ GeV $= 0$ otherwise	-	$= 0$	≥ 1	≥ 1
$E_{\text{T}}^{\text{miss}}$ [GeV]	< 40	> 50	< 50	< 200	$\in [50, 200]$
$E_{\text{T}}^{\text{miss}}$ significance	-	-	$\in [0.5, 1.5]$	$\in [0.5, 3.0]$	$\in [0.5, 3.0]$
$p_{\text{T}}^{\ell_1}, p_{\text{T}}^{\ell_2}, p_{\text{T}}^{\ell_3}$ [GeV]	-	> 10	> 10	> 10	< 10
$m_{\ell\ell}^{\text{min}}$ [GeV]	-	-	$\in [12, 75]$	$\in [12, 75]$	$\in [1, 75]$
m_{T} [GeV]	< 30	-		< 50	
min ΔR	-	-		$[0.6, 2.4]$ ($l_W = e$ only)	
$m_{3\ell}$ [GeV]	> 105	-		$[81.2, 101.2]$ ($l_W = e$ only)	

On-shell *WZ* SR yields

Regions	SR^{WZ}-1	SR^{WZ}-2	SR^{WZ}-3	SR^{WZ}-4	SR^{WZ}-5	SR^{WZ}-6	SR^{WZ}-7
Observed	331	31	3	2	42	7	3
Fitted SM	314 ± 33	35 ± 6	4.1 ± 1.0	1.2 ± 0.5	58 ± 5	8.0 ± 0.9	5.8 ± 1.0
WZ	294 ± 31	32 ± 5	3.7 ± 0.9	0.9 ± 0.5	48 ± 4	7.1 ± 0.8	5.0 ± 0.9
ZZ	12.1 ± 3.1	0.66 ± 0.35	0.08 ± 0.04	0.04 ± 0.02	2.3 ± 0.6	0.12 ± 0.04	0.08 ± 0.03
$t\bar{t}$	2.8 ± 0.8	0.36 ± 0.26	0.04 ± 0.01	$0.00\pm^{0.01}_{0.00}$	1.4 ± 0.4	$0.00\pm^{0.01}_{0.00}$	0.04 ± 0.02
Z+jets	0.01 ± 0.01	0.14 ± 0.14	0.05 ± 0.06	0.06 ± 0.04	2.8 ± 2.3	0.3 ± 0.4	0.26 ± 0.17
$t\bar{t}$ +X	0.16 ± 0.06	0.13 ± 0.05	0.03 ± 0.04	0.01 ± 0.01	0.10 ± 0.06	0.05 ± 0.03	0.01 ± 0.01
Others	5.1 ± 0.8	1.1 ± 0.4	0.21 ± 0.06	0.17 ± 0.06	3.2 ± 0.5	0.38 ± 0.11	0.34 ± 0.10

Regions	SR^{WZ}-8	SR^{WZ}-9	SR^{WZ}-10	SR^{WZ}-11	SR^{WZ}-12	SR^{WZ}-13	SR^{WZ}-14
Observed	1	77	11	0	0	111	19
Fitted SM	0.8 ± 0.4	90 ± 19	13.4 ± 2.4	0.5 ± 0.4	0.49 ± 0.24	89 ± 11	16.0 ± 1.4
WZ	0.44 ± 0.32	77 ± 18	11.3 ± 2.4	0.37 ± 0.31	0.38 ± 0.22	72 ± 9	13.4 ± 1.3
ZZ	0.01 ± 0.01	1.9 ± 0.9	0.24 ± 0.13	0.01 ± 0.01	0.01 ± 0.01	5.8 ± 2.8	0.39 ± 0.18
$t\bar{t}$	$0.00\pm^{0.01}_{0.00}$	3.3 ± 0.9	0.45 ± 0.28	$0.00\pm^{0.01}_{0.00}$	$0.00\pm^{0.01}_{0.00}$	6.0 ± 1.4	0.24 ± 0.17
Z+jets	0.28 ± 0.20	4 ± 5	0.2 ± 0.4	0.02 ± 0.03	0.02 ± 0.03	0.02 ± 0.03	0.02 ± 0.03
$t\bar{t}$ +X	0 ± 0	1.3 ± 0.4	0.40 ± 0.14	0.05 ± 0.04	0.02 ± 0.01	1.6 ± 0.5	0.56 ± 0.16
Others	0.08 ± 0.06	2.3 ± 0.5	0.79 ± 0.22	0.08 ± 0.05	0.08 ± 0.03	3.5 ± 0.7	1.37 ± 0.33

Regions	SR^{WZ}-15	SR^{WZ}-16	SR^{WZ}-17	SR^{WZ}-18	SR^{WZ}-19	SR^{WZ}-20
Observed	5	1	13	9	3	1
Fitted SM	2.8 ± 0.6	1.30 ± 0.28	14 ± 6	9.2 ± 3.5	2.3 ± 0.9	1.1 ± 0.5
WZ	2.3 ± 0.6	1.07 ± 0.24	10 ± 5	6.7 ± 3.4	1.6 ± 0.8	0.9 ± 0.5
ZZ	0.07 ± 0.04	0.04 ± 0.03	0.13 ± 0.06	0.10 ± 0.04	0.02 ± 0.01	0.02 ± 0.01
$t\bar{t}$	$0.00\pm^{0.01}_{0.00}$	$0.00\pm^{0.01}_{0.00}$	0.77 ± 0.32	0.45 ± 0.26	$0.00\pm^{0.01}_{0.00}$	$0.00\pm^{0.01}_{0.00}$
Z+jets	0.02 ± 0.02	0.07 ± 0.08	1 ± 1	0.7 ± 1.0	0.25 ± 0.34	0.02 ± 0.02
$t\bar{t}$ +X	0.07 ± 0.03	$0.00^{0.03}_{0.00}$	0.53 ± 0.17	0.33 ± 0.10	0.07 ± 0.04	0.03 ± 0.02
Others	0.37 ± 0.11	0.12 ± 0.04	1.1 ± 0.8	0.9 ± 0.7	0.27 ± 0.07	0.18 ± 0.05

On-shell *Wh* SR yields

Regions	SR^{Wh}_{SFOS}-1	SR^{Wh}_{SFOS}-2	SR^{Wh}_{SFOS}-3	SR^{Wh}_{SFOS}-4	SR^{Wh}_{SFOS}-5	SR^{Wh}_{SFOS}-6	SR^{Wh}_{SFOS}-7
Observed	152	14	8	47	6	15	19
Fitted SM	136 ± 13	13.5 ± 1.7	4.3 ± 0.9	50 ± 5	4.3 ± 0.7	20.2 ± 2.1	16.0 ± 2.1
WZ	107 ± 12	10.2 ± 1.7	3.8 ± 0.8	32 ± 4	2.7 ± 0.6	12.3 ± 1.6	10.8 ± 1.7
$t\bar{t}$	10.3 ± 2.5	1.6 ± 0.6	0.13 ± 0.12	7.7 ± 1.9	0.74 ± 0.34	3.5 ± 1.0	2.5 ± 0.7
Z+jets	2.5 ± 2.9	$0.00\pm^{0.02}_{0.00}$	$0.00\pm^{0.02}_{0.00}$	2.0 ± 1.6	$0.00\pm^{0.04}_{0.00}$	$0.00\pm^{0.04}_{0.00}$	$0.00\pm^{0.02}_{0.00}$
Higgs	5.7 ± 0.6	0.69 ± 0.07	0.20 ± 0.03	3.12 ± 0.31	0.26 ± 0.05	1.29 ± 0.14	0.81 ± 0.09
VVV	1.9 ± 0.5	0.22 ± 0.07	0.07 ± 0.02	1.4 ± 0.4	0.28 ± 0.09	0.61 ± 0.18	0.83 ± 0.24
Others	8.6 ± 1.9	0.84 ± 0.11	0.08 ± 0.05	4.0 ± 0.5	0.23 ± 0.24	2.54 ± 0.22	1.11 ± 0.15

Regions	SR^{Wh}_{SFOS}-8	SR^{Wh}_{SFOS}-9	SR^{Wh}_{SFOS}-10	SR^{Wh}_{SFOS}-11	SR^{Wh}_{SFOS}-12	SR^{Wh}_{SFOS}-13	SR^{Wh}_{SFOS}-14
Observed	113	184	28	5	82	16	4
Fitted SM	108 ± 13	180 ± 17	31 ± 4	6.6 ± 0.9	90 ± 11	18.7 ± 2.6	2.5 ± 0.7
WZ	54 ± 6	127 ± 13	19.3 ± 2.3	5.3 ± 0.8	47 ± 6	6.8 ± 1.7	1.26 ± 0.26
$t\bar{t}$	21 ± 6	33 ± 10	8.2 ± 2.3	0.7 ± 0.5	28 ± 8	8.0 ± 2.2	0.9 ± 0.5
Z+jets	19 ± 10	2.3 ± 1.9	1.0 ± 1.3	0.10 ± 0.21	2.1 ± 3.1	1.2 ± 0.7	$0.00\pm^{0.12}_{0.00}$
Higgs	1.91 ± 0.19	3.63 ± 0.35	0.67 ± 0.06	0.15 ± 0.02	2.98 ± 0.25	0.61 ± 0.07	0.07 ± 0.07
VVV	0.79 ± 0.24	1.4 ± 0.4	0.41 ± 0.13	0.12 ± 0.05	1.6 ± 0.5	0.56 ± 0.18	0.13 ± 0.05
Others	11.1 ± 2.2	12.2 ± 2.2	1.8 ± 0.4	0.22 ± 0.05	9.0 ± 1.1	1.6 ± 0.7	0.10 ± 0.05

Regions	SR^{Wh}_{SFOS}-15	SR^{Wh}_{SFOS}-16	SR^{Wh}_{SFOS}-17	SR^{Wh}_{SFOS}-18	SR^{Wh}_{SFOS}-19	SR^{Wh}_{DFOS}-1	SR^{Wh}_{DFOS}-2
Observed	51	5	37	7	4	10	10
Fitted SM	46 ± 7	9.8 ± 1.6	43 ± 7	12.6 ± 1.7	1.8 ± 0.4	4.5 ± 0.8	7.0 ± 2.3
WZ	18.9 ± 2.2	3.9 ± 0.8	35 ± 6	9.8 ± 1.6	1.44 ± 0.32	0.44 ± 0.14	1.05 ± 0.20
$t\bar{t}$	18 ± 6	3.2 ± 1.3	1.00 ± 0.34	0.33 ± 0.17	$0.00\pm^{0.01}_{0.00}$	1.0 ± 0.6	1.7 ± 1.1
Z+jets	$0.00\pm^{0.12}_{0.00}$	$0.00\pm^{0.12}_{0.00}$	$0.00\pm^{0.12}_{0.00}$	$0.00\pm^{0.12}_{0.00}$	$0.00\pm^{0.12}_{0.00}$	$0.00\pm^{0.20}_{0.00}$	2.5 ± 2.0
Higgs	2.06 ± 0.23	0.36 ± 0.05	1.02 ± 0.12	0.44 ± 0.05	0.05 ± 0.05	1.59 ± 0.22	0.96 ± 0.11
VVV	1.5 ± 0.4	0.53 ± 0.17	2.5 ± 0.7	1.3 ± 0.4	0.2 ± 0.1	0.66 ± 0.15	0.64 ± 0.16
Others	5.0 ± 0.6	1.8 ± 0.5	3.0 ± 0.7	0.73 ± 0.15	0.14 ± 0.05	0.81 ± 0.09	0.21 ± 0.07

Off-shell low-MET SR yields

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jb	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jc	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jd	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0je	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jf1	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jf2
Observed	25	42	77	101	33	7
Fitted SM events	32 ± 4	44 ± 4	54 ± 4	91 ± 6	32.2 ± 2.5	5.9 ± 1.1
WZ	7.6 ± 0.9	13.8 ± 1.3	16.3 ± 1.9	25.6 ± 1.8	20.1 ± 1.5	4.9 ± 1.0
ZZ	5.5 ± 1.3	7.4 ± 1.2	9.6 ± 1.6	21.8 ± 3.2	2.7 ± 1.1	0.43 ± 0.14
Z+jets	19.1 ± 3.2	22.7 ± 3.4	26.5 ± 3.5	40 ± 5	7.2 ± 1.7	$0.00 \pm^{0.04}_{0.00}$
$t\bar{t}$	$0.05 \pm^{0.18}_{0.05}$	$0.11 \pm^{0.17}_{0.11}$	0.38 ± 0.22	1.1 ± 0.4	0.78 ± 0.29	$0.08 \pm^{0.10}_{0.08}$
$t\bar{t} + X$	$0.007 \pm^{0.019}_{0.007}$	$0.002 \pm^{0.008}_{0.002}$	$0.009 \pm^{0.019}_{0.009}$	$0.019 \pm^{0.026}_{0.019}$	$0.026 \pm^{0.026}_{0.026}$	$0.010 \pm^{0.015}_{0.010}$
Others	0.045 ± 0.031	0.30 ± 0.12	1.3 ± 0.6	1.9 ± 0.6	1.4 ± 0.4	0.51 ± 0.18

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jg1	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0jg2	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njb	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njc	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njd	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nje
Observed	34	9	6	13	17	14
Fitted SM events	34.7 ± 2.8	6.3 ± 1.1	3.5 ± 0.6	8.0 ± 1.2	13.5 ± 1.5	18.2 ± 3.4
WZ	21.4 ± 2.1	5.2 ± 1.0	1.62 ± 0.30	3.2 ± 0.6	6.0 ± 0.8	8.6 ± 1.3
ZZ	4.7 ± 1.4	0.45 ± 0.14	0.45 ± 0.13	0.72 ± 0.22	1.00 ± 0.28	1.4 ± 0.9
Z+jets	6.6 ± 1.6	$0.001 \pm^{0.029}_{0.001}$	1.2 ± 0.5	3.7 ± 0.9	4.5 ± 1.2	3.3 ± 1.3
$t\bar{t}$	0.8 ± 0.4	0.36 ± 0.21	0.15 ± 0.13	0.28 ± 0.14	1.5 ± 0.4	3.3 ± 0.9
$t\bar{t} + X$	0.039 ± 0.025	$0.003 \pm^{0.008}_{0.003}$	0.030 ± 0.013	0.052 ± 0.019	0.24 ± 0.06	0.33 ± 0.07
Others	1.16 ± 0.27	0.27 ± 0.09	0.006 ± 0.004	$0.14 \pm^{0.34}_{0.14}$	0.21 ± 0.06	$1.3 \pm^{1.8}_{1.3}$

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njf1	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njf2	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njg1	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-njg2
Observed	25	20	22	12
Fitted SM events	23.4 ± 2.5	17.9 ± 1.9	17.0 ± 3.5	12.4 ± 1.9
WZ	11.1 ± 1.2	9.4 ± 1.1	10.0 ± 1.2	7.3 ± 1.3
ZZ	4.0 ± 1.6	0.66 ± 0.25	$1.1 \pm^{2.6}_{1.1}$	0.34 ± 0.11
Z+jets	2.2 ± 1.4	$0.00 \pm^{0.14}_{0.00}$	1.8 ± 1.1	$0.0 \pm^{0.6}_{0.0}$
$t\bar{t}$	4.6 ± 1.1	5.7 ± 1.2	3.0 ± 0.8	2.9 ± 0.7
$t\bar{t} + X$	0.44 ± 0.09	0.72 ± 0.11	0.36 ± 0.08	0.44 ± 0.09
Others	1.0 ± 0.4	1.4 ± 0.9	0.71 ± 0.21	1.4 ± 0.6

Off-shell high-MET SR yields

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jb	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jc	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jd	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0je	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jf1
Observed	1	4	11	13	37
Fitted SM events	1.5 ± 0.7	4.3 ± 0.8	14.0 ± 1.6	11.5 ± 1.6	35.7 ± 3.2
WZ	$0.20 \pm ^{0.27}_{0.20}$	1.5 ± 0.5	6.0 ± 0.9	6.1 ± 1.1	20.5 ± 2.1
ZZ	$0.5 \pm ^{0.5}_{0.5}$	0.31 ± 0.12	1.8 ± 0.8	0.89 ± 0.24	3.1 ± 1.0
Z+jets	0.81 ± 0.31	1.7 ± 0.4	4.4 ± 1.0	1.1 ± 0.8	4.3 ± 1.4
$t\bar{t}$	$0.05 \pm ^{0.05}_{0.05}$	0.45 ± 0.17	0.64 ± 0.28	1.8 ± 0.6	4.4 ± 1.0
$t\bar{t} + X$	$0.003 \pm ^{0.014}_{0.003}$	$0.009 \pm ^{0.013}_{0.009}$	0.029 ± 0.015	0.08 ± 0.04	0.11 ± 0.05
Others	$0.014 \pm ^{0.018}_{0.014}$	$0.3 \pm ^{0.4}_{0.3}$	1.1 ± 0.4	1.6 ± 0.4	3.3 ± 0.8

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jf2	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jg1	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-0jg2	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-nja	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-njb
Observed	14	43	17	3	2
Fitted SM events	25.5 ± 2.4	39.5 ± 3.0	21 ± 7	6.0 ± 1.6	1.4 ± 0.6
WZ	16.0 ± 2.3	26.4 ± 2.2	15 ± 7	3.8 ± 1.2	0.57 ± 0.18
ZZ	0.95 ± 0.35	3.0 ± 0.9	0.58 ± 0.17	0.044 ± 0.023	0.009 ± 0.005
Z+jets	$0.00 \pm ^{0.15}_{0.00}$	3.4 ± 1.3	$0.00 \pm ^{0.11}_{0.00}$	1.5 ± 0.8	$0.5 \pm ^{0.5}_{0.5}$
$t\bar{t}$	4.4 ± 1.0	4.3 ± 0.9	3.1 ± 0.7	0.6 ± 0.5	$0.14 \pm ^{0.15}_{0.14}$
$t\bar{t} + X$	0.109 ± 0.030	0.16 ± 0.05	0.09 ± 0.04	0.16 ± 0.06	$0.014 \pm ^{0.025}_{0.014}$
Others	4.0 ± 1.0	2.3 ± 0.8	2.0 ± 0.5	0.038 ± 0.030	$0.22 \pm ^{0.22}_{0.22}$

Region	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-njc	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-njd	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-nje	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-njf	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}E_T^{\mathrm{miss}}}$-njg
Observed	2	2	2	11	4
Fitted SM events	2.1 ± 0.8	5.4 ± 1.4	3.0 ± 1.1	9.9 ± 2.5	6.8 ± 1.8
WZ	1.25 ± 0.25	2.5 ± 0.4	1.31 ± 0.25	4.5 ± 0.7	3.7 ± 0.6
ZZ	0.020 ± 0.011	0.014 ± 0.013	0.029 ± 0.014	0.081 ± 0.033	0.050 ± 0.020
Z+jets	$0.04 \pm ^{0.28}_{0.04}$	$0.7 \pm ^{0.8}_{0.7}$	$0.0 \pm ^{0.4}_{0.0}$	$0.6 \pm ^{0.9}_{0.6}$	$0.00 \pm ^{0.19}_{0.00}$
$t\bar{t}$	0.6 ± 0.5	1.3 ± 0.8	1.2 ± 1.0	3.4 ± 2.0	2.5 ± 1.6
$t\bar{t} + X$	0.027 ± 0.023	$0.08 \pm ^{0.08}_{0.08}$	0.09 ± 0.04	0.31 ± 0.08	0.21 ± 0.07
Others	$0.14 \pm ^{0.36}_{0.14}$	0.8 ± 0.6	0.33 ± 0.21	1.0 ± 0.4	$0.3 \pm ^{0.4}_{0.3}$

On-shell inclusive SR definitions

	$\mathrm{SR}^{\mathtt{WZ}}$ ($m_{\ell\ell} \in [75, 105]$ GeV)			
	$n_{\mathrm{jets}} = 0$		$n_{\mathrm{jets}} > 0$	
m_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]			
[100,160]	$\mathtt{incSR}^{\mathtt{WZ}}$-1: [100,200]	$\mathtt{incSR}^{\mathtt{WZ}}$-2: > 200	$\mathtt{incSR}^{\mathtt{WZ}}$-3: [150,250]	$\mathtt{incSR}^{\mathtt{WZ}}$-4: > 250
> 160	$\mathtt{incSR}^{\mathtt{WZ}}$-5: > 200		$\mathtt{incSR}^{\mathtt{WZ}}$-6: > 200	
	$\mathrm{SR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$ ($m_{\ell\ell} \leq 75$ GeV)			
	$n_{\mathrm{jets}} = 0$		$n_{\mathrm{jets}} > 0$	
m_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]			
[0,100]	$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$-7: > 50		-	
[100, 160]	$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$-8: > 50		$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$-9: > 75	
> 160	$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$-10: > 50		$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{SFOS}}$-11: > 75	
	$\mathrm{SR}^{\mathtt{Wh}}_{\mathtt{DFOS}}$			
	$\mathtt{incSR}^{\mathtt{Wh}}_{\mathtt{DFOS}}$-12: $n_{\mathrm{jets}} \in [0, 2]$, $\Delta R_{\mathrm{OS,near}} < 1.2$, 3rd lepton p_{T} >20 GeV			

Off-shell inclusive SR definitions

	$\mathrm{incSR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj			
	a	b	c1	c2
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	[1,12]	[12,15]	[1,20]	[15,20]
	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[a]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[a-c]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[c]

	$\mathrm{incSR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$		$\mathrm{incSR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$	
	b	c	b	c
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	[12,15]	[12,20]	[12,15]	[12,20]
	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[b], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[b]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[b-c], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[b-c]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[b], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[b-c], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b-c]

	$\mathrm{incSR}^{\mathrm{offWZ}}$				
	d	e1	e2	f1	f2
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	[12,30]	[12,40]	[20,40]	[12,60]	[30,60]
	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[b-d], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[b-d], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[b-d], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b-d]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[b-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[b-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[b-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b-e]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[c-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[c-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[c-e], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[c-e]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[c-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[c-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[c-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[c-f]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[e-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[e-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[e-f2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[e-f]

	$\mathrm{incSR}^{\mathrm{offWZ}}$			
	g1	g2	g3	g4
$m_{\ell\ell}^{\mathrm{min}}$ [GeV]	[12,75]	[30,75]	[40,75]	[60,75]
	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[b-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[b-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[b-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[b-g]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[e-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[e-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[e-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[e-g]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[f1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[f1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[f1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[f1-g]	$\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-0j[g1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{low}\not{E}_T}$-nj[g1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-0j[g1-g2], $\mathrm{SR}^{\mathrm{offWZ}}_{\mathrm{high}\not{E}_T}$-nj[g]

On-shell inclusive SR yields

SR	N_{obs}	N_{exp}	σ^{95}_{vis}[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_b	$p(s=0)$ (Z)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-1}$	34	38 ± 5	0.10	13.5	$15.7^{+6.7}_{-4.1}$	0.32	0.50 (0.00)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-2}$	2	1.2 ± 0.5	0.04	5.0	$4.0^{+1.6}_{-0.7}$	0.76	0.23 (0.73)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-3}$	4	6.5 ± 1.1	0.03	4.8	$6.5^{+2.6}_{-1.8}$	0.19	0.50 (0.00)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-4}$	25	31 ± 6	0.09	12.4	$15.4^{+6.0}_{-4.1}$	0.25	0.50 (0.00)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-5}$	1	5.2 ± 1.1	0.03	3.9	$5.8^{+2.2}_{-1.4}$	0.03	0.50 (0.00)
$\texttt{incSR}^{\texttt{WZ}}\texttt{-6}$	23	16 ± 2	0.12	17.0	$10.3^{+3.9}_{-3.0}$	0.93	0.07 (1.48)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{SFOS}}\texttt{-7}$	174	150 ± 14	0.41	57.6	$37.8^{+15.1}_{-10.6}$	0.90	0.10 (1.27)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{SFOS}}\texttt{-8}$	53	55 ± 5	0.12	17.1	$18.3^{+7.4}_{-4.6}$	0.42	0.50 (0.00)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{SFOS}}\texttt{-9}$	34	36 ± 4	0.10	13.8	$15.0^{+6.2}_{-4.2}$	0.40	0.50 (0.00)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{SFOS}}\texttt{-10}$	56	55 ± 7	0.16	21.7	$20.5^{+8.3}_{-5.8}$	0.55	0.41 (0.22)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{SFOS}}\texttt{-11}$	41	45 ± 6	0.11	15.5	$17.9^{+7.2}_{-4.8}$	0.34	0.50 (0.00)
$\texttt{incSR}^{\texttt{Wh}}_{\texttt{DFOS}}\texttt{-12}$	18	11 ± 3	0.12	17.0	$10.5^{+4.2}_{-2.7}$	0.92	0.07 (1.48)

Off-shell inclusive SR yields

SR	N_{obs}	N_{exp}	σ_{vis}^{95} [fb]	S_{obs}^{95}	S_{exp}^{95}	CL_b	$p(s=0)$ (Z)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-nja	3	6.0 ±1.6	0.03	4.6	$6.3^{+2.4}_{-2.0}$	0.16	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-njb	2	1.4 ±0.6	0.03	4.8	$4.0^{+1.6}_{-0.7}$	0.71	0.30 (0.53)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-njc1	7	9.5 ±2.2	0.05	7.0	$8.4^{+2.9}_{-2.2}$	0.28	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-njc2	2	2.1 ±0.8	0.03	4.7	$4.6^{+1.8}_{-1.1}$	0.52	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{low}E_T^{miss}}$-b	31	36 ±4	0.09	12.1	$14.9^{+5.7}_{-4.4}$	0.25	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-b	3	3.0 ±0.9	0.04	5.4	$5.2^{+2.0}_{-1.3}$	0.53	0.05 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{low}E_T^{miss}}$-c	86	88 ±7	0.17	23.1	$24.4^{+9.1}_{-6.8}$	0.44	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}_{\mathtt{high}E_T^{miss}}$-c	9	9.3 ±1.5	0.06	7.7	$7.7^{+3.4}_{-1.8}$	0.50	0.50 (0.00)
$\mathtt{incSR}^{\mathtt{offWZ}}$-d	202	184 ±12	0.37	51.0	$37.0^{+14.1}_{-10.8}$	0.84	0.16 (0.99)
$\mathtt{incSR}^{\mathtt{offWZ}}$-e1	332	308 ±17	0.49	68.0	$49.3^{+19.1}_{-14.8}$	0.84	0.16 (1.00)
$\mathtt{incSR}^{\mathtt{offWZ}}$-e2	298	269 ±15	0.50	69.1	$45.5^{+17.2}_{-13.6}$	0.90	0.10 (1.29)
$\mathtt{incSR}^{\mathtt{offWZ}}$-f1	479	457 ±22	0.56	77.6	$62.7^{+22.1}_{-19.6}$	0.77	0.23 (0.75)
$\mathtt{incSR}^{\mathtt{offWZ}}$-f2	277	272 ±13	0.33	45.7	$41.9^{+17.0}_{-11.8}$	0.60	0.37 (0.34)
$\mathtt{incSR}^{\mathtt{offWZ}}$-g1	620	593 ±28	0.69	96.0	$74.3^{+28.7}_{-22.0}$	0.77	0.21 (0.79)
$\mathtt{incSR}^{\mathtt{offWZ}}$-g2	418	408 ±20	0.46	63.8	$56.7^{+22.9}_{-15.1}$	0.65	0.32 (0.47)
$\mathtt{incSR}^{\mathtt{offWZ}}$-g3	288	285 ±16	0.35	48.4	$46.6^{+18.6}_{-11.9}$	0.55	0.38 (0.30)
$\mathtt{incSR}^{\mathtt{offWZ}}$-g4	141	136 ±10	0.25	34.5	$30.6^{+13.1}_{-7.5}$	0.64	0.35 (0.39)

4ℓ additional material

MC samples

Process	Generator(s)	Cross-section calculation	Tune	PDF set
ZZ, WZ, WW	SHERPA 2.2.2 [76]	NLO [77]	SHERPA default	NNPDF30NNLO [78]
VVV	SHERPA 2.2.1	NLO [77]	SHERPA default	NNPDF30NNLO
ggH	POWHEG v2 [79–81] + PYTHIA 8.212 [73]	NNNLO+NNLL [82–88]	AZNLO [89]	CTEQ6L1 [90]
$t\bar{t}H$	POWHEG v2 + PYTHIA 8.230	NLO [82]	A14 [91]	NNPDF23LO [92]
$t\bar{t}Z$	MADGRAPH5_aMC@NLO 2.3.3 [93] + PYTHIA 8.210	NLO [94]	A14	NNPDF23LO
$t\bar{t}WW$	MADGRAPH5_aMC@NLO 2.2.2 + PYTHIA 8.186	NLO [94]	A14	NNPDF23LO
$t\bar{t}WZ$, tWZ	MADGRAPH5_aMC@NLO 2.3.3 + PYTHIA 8.212	NLO [94]	A14	NNPDF23LO
$t\bar{t}ZZ$, $t\bar{t}WH$, $t\bar{t}HH$	MADGRAPH5_aMC@NLO 2.6.7 + PYTHIA 8.240	NLO [94]	A14	NNPDF23LO
$t\bar{t}tW$, $t\bar{t}t\bar{t}$	MADGRAPH5_aMC@NLO 2.2.2 + PYTHIA 8.186	NLO [93]	A14	NNPDF23LO
$t\bar{t}$	POWHEG v2 + PYTHIA 8.230	NNLO+NNLL [95–101]	A14	NNPDF23LO
Z+jets, W+jets	POWHEG v1 + PYTHIA 8.186	NNLO [102]	AZNLO	CTEQ6L1
SUSY signal	MADGRAPH5_aMC@NLO 2.2.2 + PYTHIA 8.230	NLO+NLL [60–67]	A14	NNPDF23LO

SR definitions

Name	Signal Region	$N(e,\mu)$	$N(\tau_{had})$	$N(b\text{-tagged jets})$	Z boson	Selection	Target
$4L0T$	SR0-ZZ$^{loose}_{bveto}$	≥ 4	≥ 0	$= 0$	require 1st & 2nd	$E_T^{miss} > 100$ GeV	higgsino GGM
	SR0-ZZ$^{tight}_{bveto}$	≥ 4	≥ 0	$= 0$	require 1st & 2nd	$E_T^{miss} > 200$ GeV	higgsino GGM
	SR0-ZZ^{loose}	≥ 4	≥ 0	≥ 0	require 1st & 2nd	$E_T^{miss} > 50$ GeV	Excess from Ref. [18]
	SR0-ZZ^{tight}	≥ 4	≥ 0	≥ 0	require 1st & 2nd	$E_T^{miss} > 100$ GeV	Excess from Ref. [18]
	SR0$^{loose}_{bveto}$	≥ 4	≥ 0	$= 0$	veto	$m_{eff} > 600$ GeV	General
	SR0$^{tight}_{bveto}$	≥ 4	≥ 0	$= 0$	veto	$m_{eff} > 1250$ GeV	RPV $LL\bar{E}12k$
	SR0$_{breq}$	≥ 4	≥ 0	≥ 1	veto	$m_{eff} > 1300$ GeV	RPV $LL\bar{E}12k$
$3L1T$	SR1$^{loose}_{bveto}$	$= 3$	≥ 1	$= 0$	veto	$m_{eff} > 600$ GeV	General
	SR1$^{tight}_{bveto}$	$= 3$	≥ 1	$= 0$	veto	$m_{eff} > 1000$ GeV	RPV $LL\bar{E}i33$
	SR1$_{breq}$	$= 3$	≥ 1	≥ 1	veto	$m_{eff} > 1300$ GeV	RPV $LL\bar{E}i33$
$2L2T$	SR2$^{loose}_{bveto}$	$= 2$	≥ 2	$= 0$	veto	$m_{eff} > 600$ GeV	General
	SR2$^{tight}_{bveto}$	$= 2$	≥ 2	$= 0$	veto	$m_{eff} > 1000$ GeV	RPV $LL\bar{E}i33$
	SR2$_{breq}$	$= 2$	≥ 2	≥ 1	veto	$m_{eff} > 1100$ GeV	RPV $LL\bar{E}i33$
$5L0T$	SR5L	≥ 5	≥ 0	≥ 0	–	–	General

CR definitions

Region	$N(e,\mu)$	$N(\tau_{had})$	$N(b$-tagged jets$)$	Z boson	Selection
CRZZ	≥ 4	≥ 0	$= 0$	require 1st & 2nd	$E_{T}^{miss} < 50$ GeV
CRttZ	≥ 4	≥ 0	≥ 1	require 1st & veto 2nd	$E_{T}^{miss} > 100$ GeV

Reducible Estimation for	Control Region	$N(e,\mu)$ signal	$N(e,\mu)$ loose	$N(\tau_{had})$ signal	$N(\tau_{had})$ loose
$4L0T$	CR1_LLLl	$= 3$	≥ 1	≥ 0	≥ 0
	CR2_LLll	$= 2$	≥ 2	≥ 0	≥ 0
$3L1T$	CR1_LLLt	$= 3$	$= 0$	$= 0$	≥ 1
	CR1_LLTl	$= 2$	$= 1$	≥ 1	≥ 0
	CR2_LLlt	$= 2$	$= 1$	$= 0$	≥ 1
$2L2T$	CR1_LLTt	$= 2$	$= 0$	$= 1$	≥ 1
	CR2_LLtt	$= 2$	$= 0$	$= 0$	≥ 2
$5L0T$	CR1_LLLLl	$= 4$	≥ 1	≥ 0	≥ 0

VR definitions

Name	Validation Region	$N(e,\mu)$	$N(\tau_{\text{had}})$	$N(b-\text{jets})$	Z boson	Selection	Target
$4L0T$	VRZZ	≥ 4	$= 0$	$= 0$	require 1st & veto 2nd	–	$ZZ^{(*)}$
	VRttZ	≥ 4	$= 0$	≥ 0	veto	$400 < m_{\text{eff}} < 1300\,\text{GeV}$	$t\bar{t}Z^{(*)}$
	VR0-noZ	≥ 4	$= 0$	$= 0$	veto	$m_{\text{eff}} < 600\,\text{GeV}$	$t\bar{t}$, Z+jets, $Z^{(*)}Z^{(*)}$
$3L1T$	VR1-noZ	$= 3$	≥ 1	$= 0$	veto	$m_{\text{eff}} < 600\,\text{GeV}$	$t\bar{t}$, Z+jets
	VR1-Z	$= 3$	≥ 1	$= 0$	require 1st	–	Z+jets
$2L2T$	VR2-noZ	$= 2$	≥ 2	$= 0$	veto	$m_{\text{eff}} < 600\,\text{GeV}$	$t\bar{t}$, Z+jets
	VR2-Z	$= 2$	≥ 2	$= 0$	require 1st	–	Z+jets

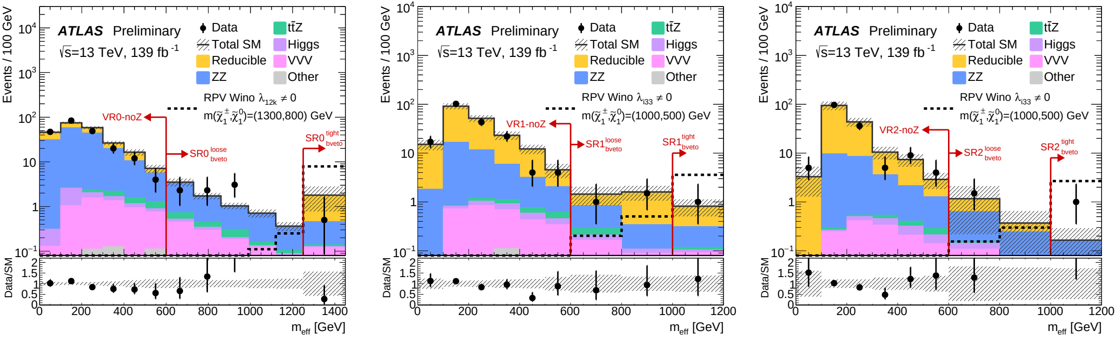
VR yields

	VRZZ	VRttZ	VR0-noZ	VR1-noZ	VR1-Z	VR2-noZ	VR2-Z
Observed	874	42	216	192	620	156	505
Total SM	923 ± 39	38 ± 5	229 ± 12	198 ± 25	614 ± 57	162 ± 29	472 ± 26
ZZ	738 ± 22	2.7 ± 0.9	160 ± 8	36.8 ± 1.9	201 ± 9	23.3 ± 1.3	119 ± 7
$t\bar{t}Z$	4.7 ± 1.3	15 ± 4	1.7 ± 0.5	0.75 ± 0.22	2.1 ± 0.7	0.3 ± 0.09	0.12 ± 0.04
Higgs	76 ± 29	5.5 ± 1.2	2.9 ± 0.8	0.79 ± 0.19	0.2 ± 0.06	0.42 ± 0.09	0.036 ± 0.008
VVV	26 ± 5	0.43 ± 0.11	5.4 ± 1.1	2.8 ± 0.6	8.7 ± 1.9	1.23 ± 0.26	1.52 ± 0.33
Other	2.2 ± 0.5	3.0 ± 0.4	0.43 ± 0.08	0.22 ± 0.08	0.97 ± 0.26	0.117 ± 0.035	0.065 ± 0.016
Reducible	76 ± 10	12 ± 4	59 ± 9	156 ± 24	401 ± 56	137 ± 29	351 ± 25

SR yields

	SR0-ZZ^{loose}	SR0-ZZ^{tight}	SR0-ZZ$^{loose}_{bveto}$	SR0-ZZ$^{tight}_{bveto}$	SR0$^{loose}_{bveto}$	SR0$^{tight}_{bveto}$	SR0$_{breq}$
Observed	157	17	5	1	11	1	3
Total SM	159 ± 42	17.4 ± 3.3	7.2 ± 2.0	1.1 ± 0.4	11.4 ± 2.4	3.5 ± 2.0	1.16 ± 0.26
ZZ	125 ± 42	4.6 ± 2.2	3.7 ± 1.8	0.05 ± 0.05	7.7 ± 1.6	0.64 ± 0.28	0.19 ± 0.18
$t\bar{t}Z$	13.1 ± 3.3	6.6 ± 1.7	0.78 ± 0.22	0.12 ± 0.04	0.61 ± 0.17	0.023 ± 0.012	0.44 ± 0.12
Higgs	0.47 ± 0.09	0.23 ± 0.05	0.029 ± 0.005	0.0044 ± 0.0019	0.21 ± 0.05	0.012 ± 0.004	0.16 ± 0.05
VVV	7.9 ± 1.9	2.4 ± 0.6	2.2 ± 0.5	0.44 ± 0.12	1.6 ± 0.4	0.21 ± 0.06	0.083 ± 0.027
Other	3.1 ± 0.6	1.63 ± 0.34	0.31 ± 0.09	0.038 ± 0.008	0.117 ± 0.026	0.034 ± 0.013	0.28 ± 0.05
Reducible	9 ± 4	2.1 ± 1.6	$0.17^{+0.4}_{-0.17}$	0.4 ± 0.4	$1.2^{+1.8}_{-1.2}$	2.6 ± 2.0	$0.00^{+0.09}_{-0.00}$

	SR1$^{loose}_{bveto}$	SR1$^{tight}_{bveto}$	SR1$_{breq}$	SR2$^{loose}_{bveto}$	SR2$^{tight}_{bveto}$	SR2$_{breq}$	SR5L
Observed	7	2	2	5	2	1	21
Total SM	7.7 ± 1.8	1.6 ± 0.6	2.2 ± 0.7	3.3 ± 2.2	0.33 ± 0.24	0.5 ± 0.27	12.6 ± 2.6
ZZ	2.0 ± 0.4	0.39 ± 0.15	0.042 ± 0.026	1.54 ± 0.33	0.23 ± 0.1	0.06 ± 0.04	0.49 ± 0.04
$t\bar{t}Z$	0.17 ± 0.08	$0.027^{+0.035}_{-0.027}$	0.19 ± 0.06	0.044 ± 0.02	0.0 ± 0.0	0.17 ± 0.06	0.031 ± 0.009
Higgs	0.16 ± 0.05	0.024 ± 0.01	0.14 ± 0.05	0.112 ± 0.032	0.015 ± 0.006	0.2 ± 0.06	0.96 ± 0.15
VVV	0.66 ± 0.16	0.16 ± 0.04	0.021 ± 0.007	0.38 ± 0.1	0.084 ± 0.025	0.024 ± 0.008	3.0 ± 0.7
Other	0.0058 ± 0.0018	0.024 ± 0.012	0.2 ± 0.034	0.0 ± 0.0	0.0 ± 0.0	0.047 ± 0.012	0.083 ± 0.02
Reducible	4.7 ± 1.8	1.0 ± 0.6	1.6 ± 0.7	$1.2^{+2.2}_{-1.2}$	$0.00^{+0.21}_{-0.00}$	$0.00^{+0.24}_{-0.00}$	8.0 ± 2.5


ATLAS Preliminary
√s=13 TeV, 139 fb⁻¹
Data
Total SM
Reducible
ZZ
tt̄Z
Higgs
VVV
Other
RPV Wino λ12k ≠ 0
m(χ̃1±,χ̃1⁰)=(1300,800) GeV
VR0-noZ
SR0 loose bveto
SR0 tight bveto
RPV Wino λi33 ≠ 0
m(χ̃1±,χ̃1⁰)=(1000,500) GeV
VR1-noZ
SR1 loose bveto
SR1 tight bveto
VR2-noZ
SR2 loose bveto
SR2 tight bveto
Events / 100 GeV
Data/SM
meff [GeV]

SR distributions