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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Introduction

- Presenting an overview of a search for electroweak production of supersymmetric particles in the two and three lepton final state

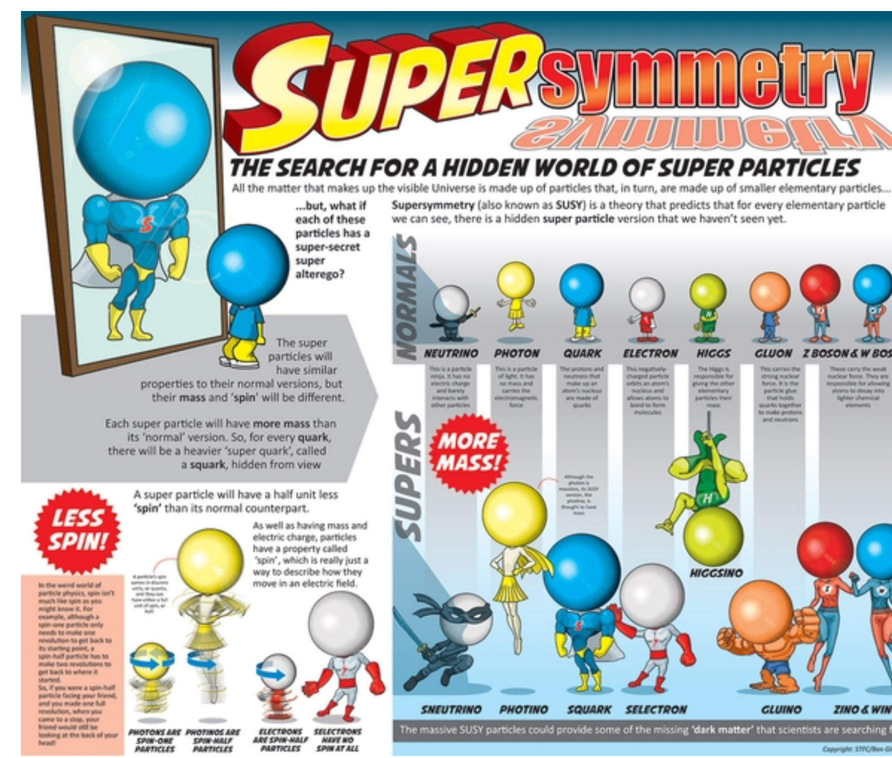
- Based on 2015+2016 data from the LHC – 36.1 fb^{-1} of integrated luminosity taken with the ATLAS detector at $\sqrt{s}$ = 13 TeV

- The results were presented at the LHCP 2017 conference in Shanghai, May 2017
  - ATLAS-CONF-2017-039

Supersymmetry

Supersymmetry (SUSY) is a popular extension of the Standard Model

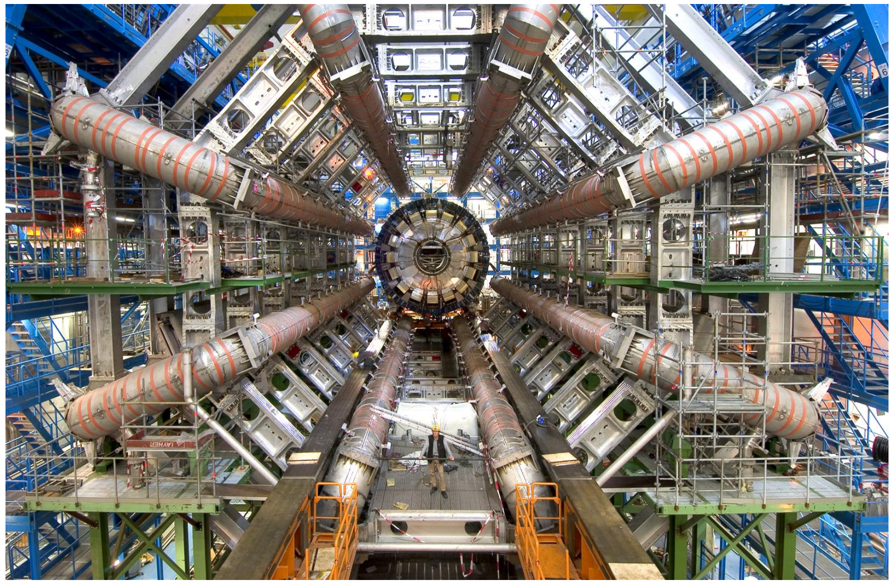
- ❖ Spacetime symmetry between fermions and bosons
- ❖ Predicts a new bosonic (fermionic) superpartner for every SM fermion (boson), plus an extra Higgs doublet
- ❖ Provides elegant solutions to:
  - The hierarchy problem
  - Gauge coupling unification
  - Dark matter candidates
- ❖ If R-parity is conserved: $R = (-1)^{3B+L+2s}$
  - SUSY particles produced in pairs
  - The lightest SUSY particle (LSP) is stable
  - A weakly interacting LSP is a good candidate for dark matter (WIMP)

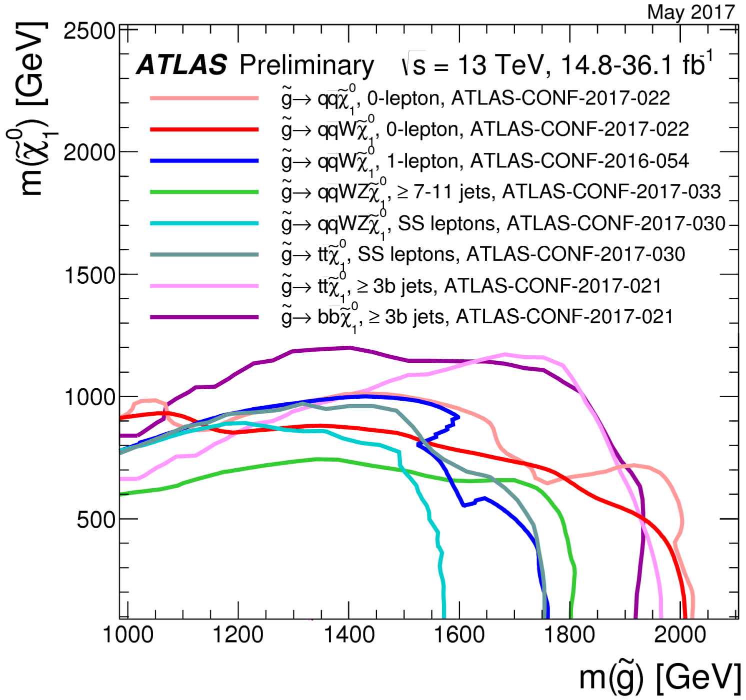


Search for electroweak production of sparticles with the ATLAS detector

Proton-proton collisions at the LHC:

- Color charged sparticles (squarks and gluinos) will have significantly larger production cross-section than non-colored sparticles (charginos, neutralinos and sleptons) of equal masses
- However, if squarks and gluinos are significantly heavier, charginos, neutralinos and sleptons could dominate the production cross-section at the LHC
- No sign of squarks and gluinos up to ~2 TeV yet — electroweak production getting increasingly relevant

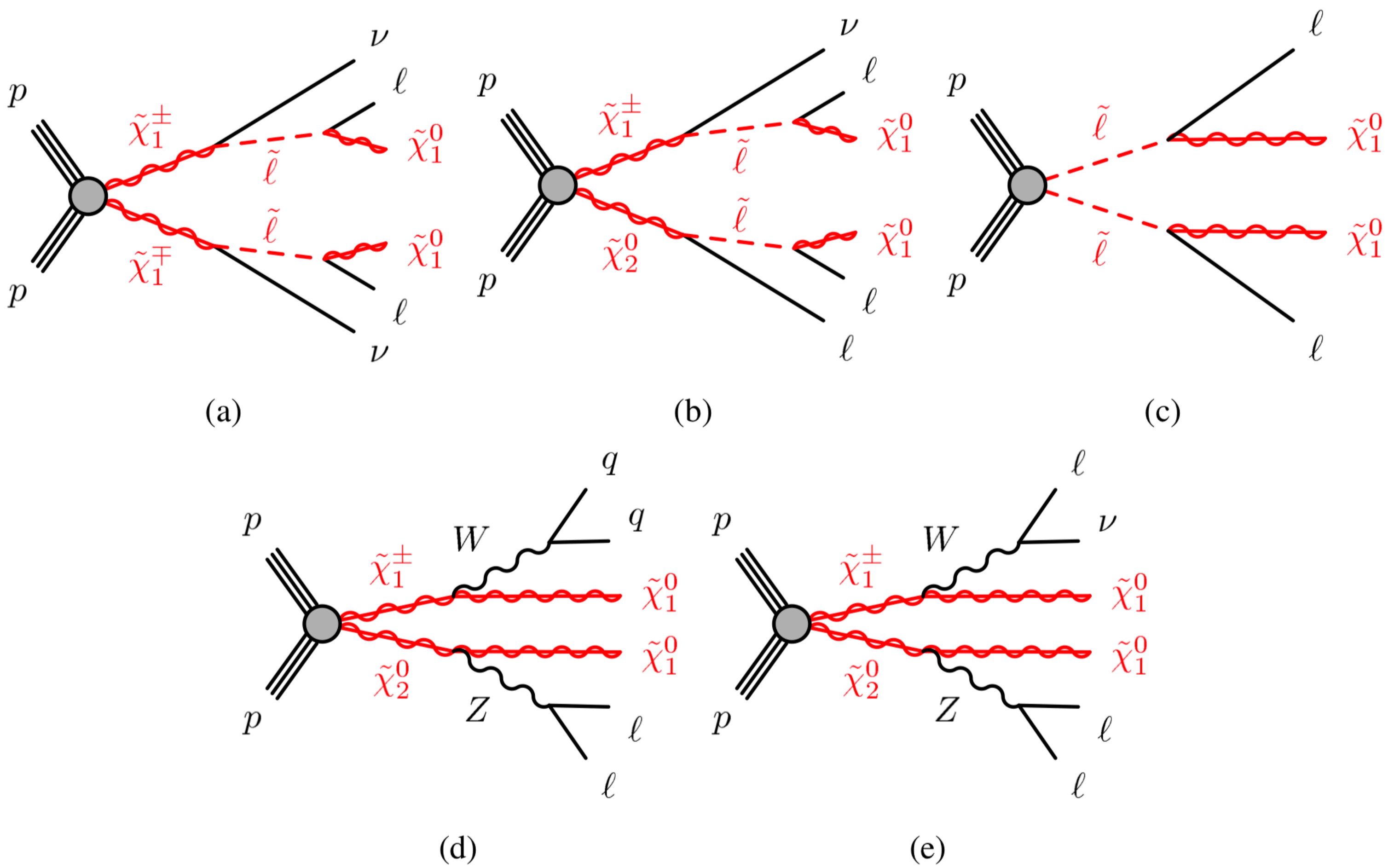




Signal models

- The Minimal Supersymmetric Standard Model (MSSM) adds over 100 free parameters to the SM — impossible to explore all scenarios in a search

- Simplified models:
    - Assuming 100 % branching fraction to the decay modes in the model
    - Only 2 free parameters: mass of pair produced sparticles and mass of the LSP



Background estimation

- Irreducible backgrounds – containing prompt, isolated leptons – are taken from Monte Carlo
- Reducible backgrounds – containing 'fake'/non-prompt leptons from semi-leptonic decays or misidentification of jets, or photon-conversion – are estimated by data-driven methods
- Some of the main background processes are in addition fitted to data in control regions (CRs) and validated in dedicated validation regions (VRs)
- Dominant backgrounds:
  - 2L+0jets: diboson
  - 2L+jets: processes with an on-shell Z-boson – diboson, Z+jets
  - 3L: WZ

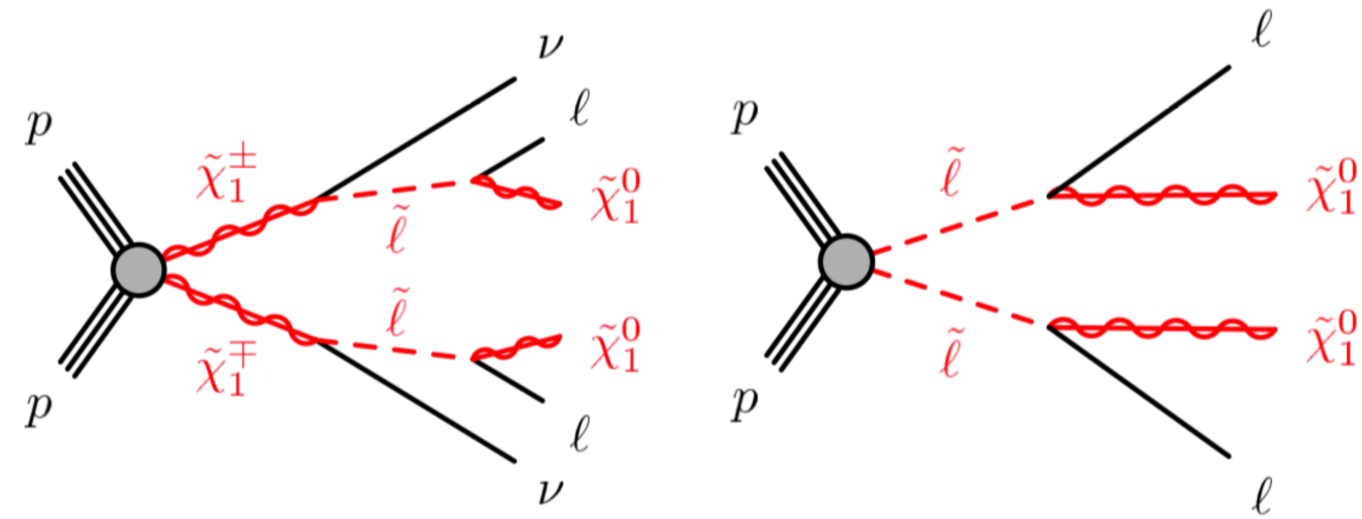
Background estimation summary			
Channel	2ℓ+0jets	2ℓ+jets	3ℓ
Fake leptons	Matrix method (MM)		Fake factor method (FF)
$t\bar{t} + Wt$	CR	MC	FF
VV	CR	MC	CR (WZ-only)
Z/γ+jets	MC	γ+jet template	FF
Higgs/ VVV/ top+V	MC		

Systematic uncertainties

- Largest systematic uncertainties:
  - Diboson modelling
  - Jet energy scale and resolution
  - MET modelling
- Dominant uncertainties in the 2L+jets channel:
  - Diboson modelling (30-40%)
  - Data-driven Z+jets estimation (42-71%)
- The binned SRs in the 2L+0jets and 3L channels are dominated by statistical uncertainties on the background estimates
  - 10 - 70% in the higher mass regions of the 2L+0jets channel
  - 5 - 30% in the 3L channel

Final states with 2L+0jets

- Targets pair production of C1 (lightest chargino) and sleptons
- Jets are vetoed
- Signal regions (SRs) based on the ‘stransverse’ mass m_{T2} and the dilepton invariant mass m_{ll}
  - Binned SRs for exclusion
  - Inclusive SRs for discovery

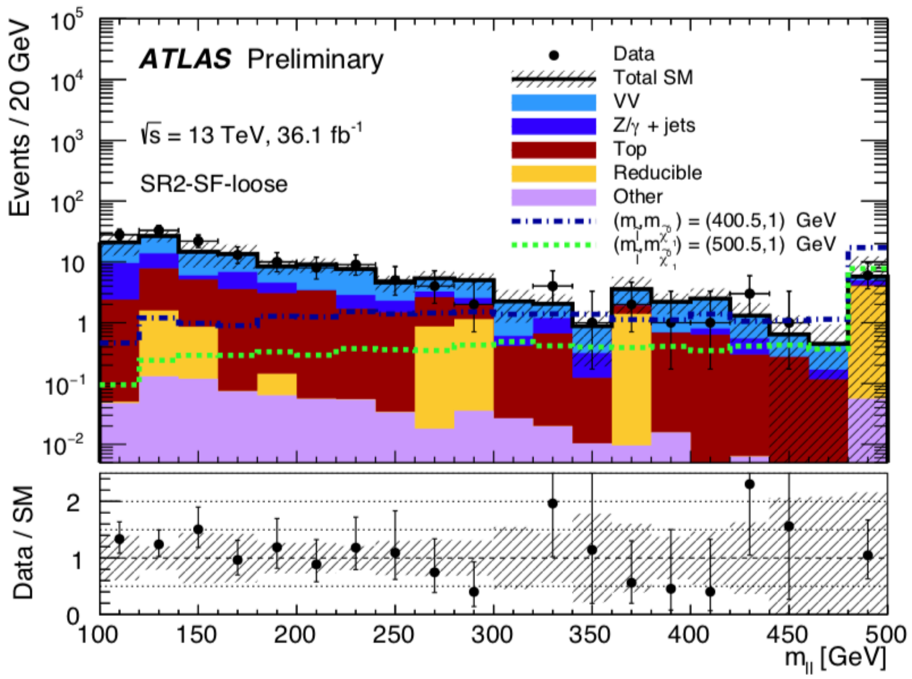


2ℓ+0jets binned signal region definitions			
m_{T2}[GeV]	$m_{\ell\ell}$ [GeV]	SF bin	DF bin
100-150	111-150	SR2-SF-a	SR2-DF-a
	150-200	SR2-SF-b	
	200-300	SR2-SF-c	
	> 300	SR2-SF-d	
150-200	111-150	SR2-SF-e	SR2-DF-b
	150-200	SR2-SF-f	
	200-300	SR2-SF-g	
	> 300	SR2-SF-h	
200-300	111-150	SR2-SF-i	SR2-DF-c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

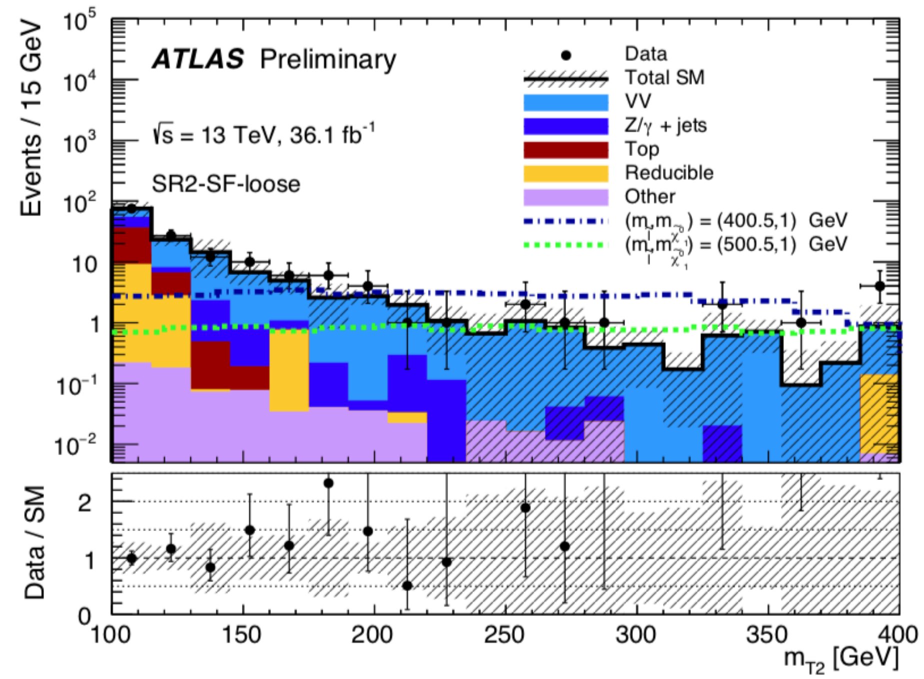
$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

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

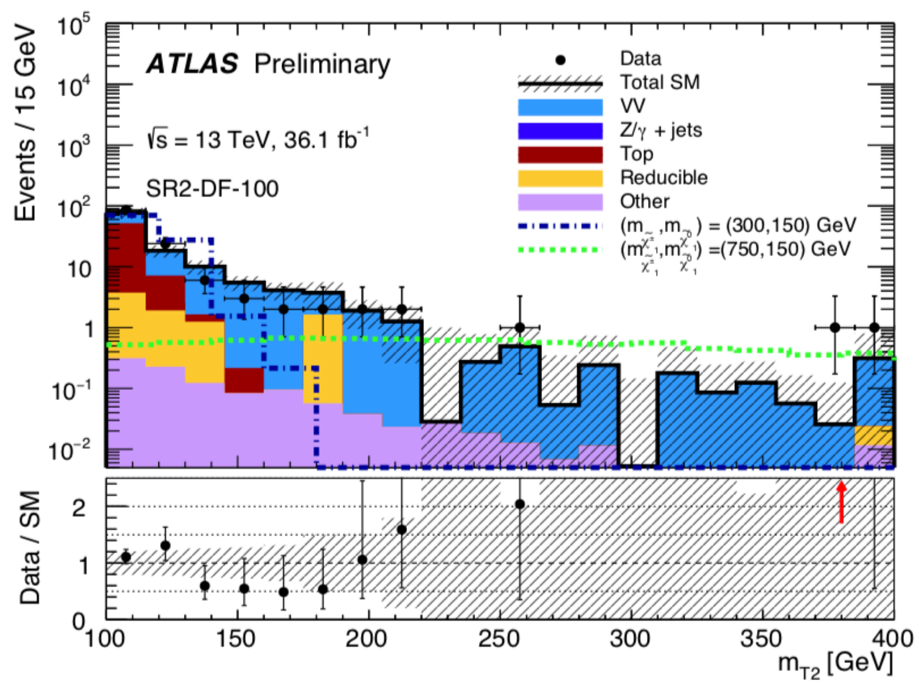
Final states with 2L+0jets



(a) $m_{\ell\ell}$ distribution in SR2-SF-loose



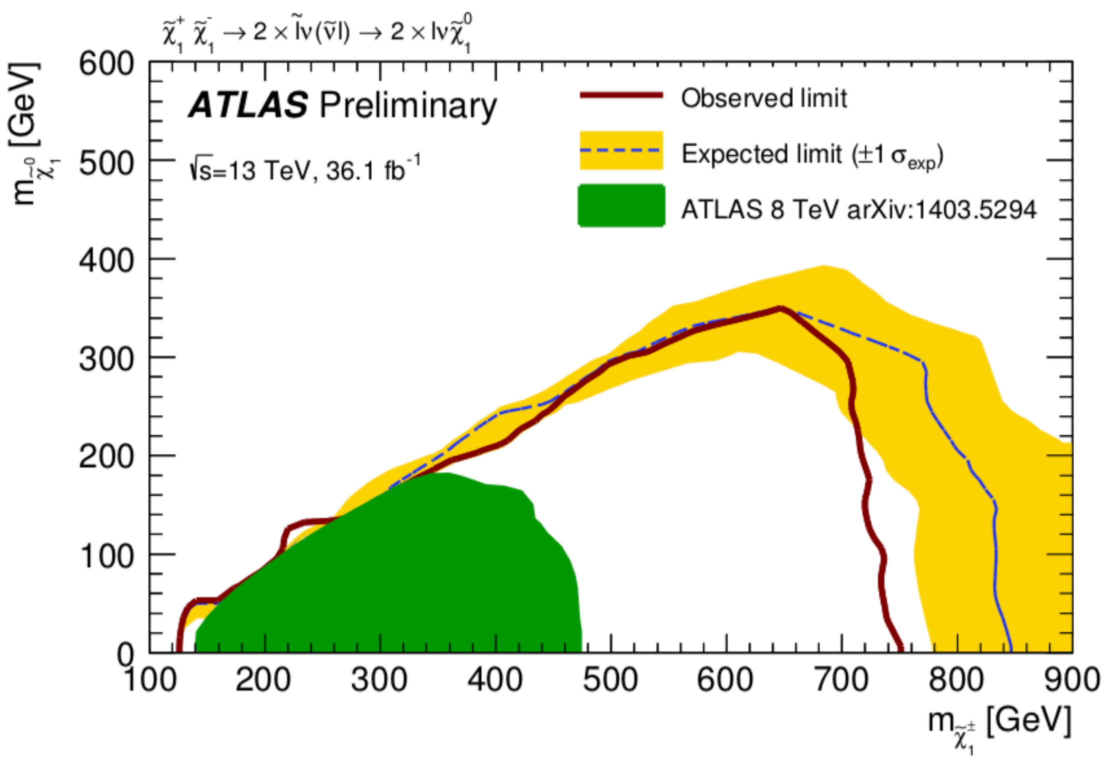
(b) m_{T2} distribution in SR2-SF-loose



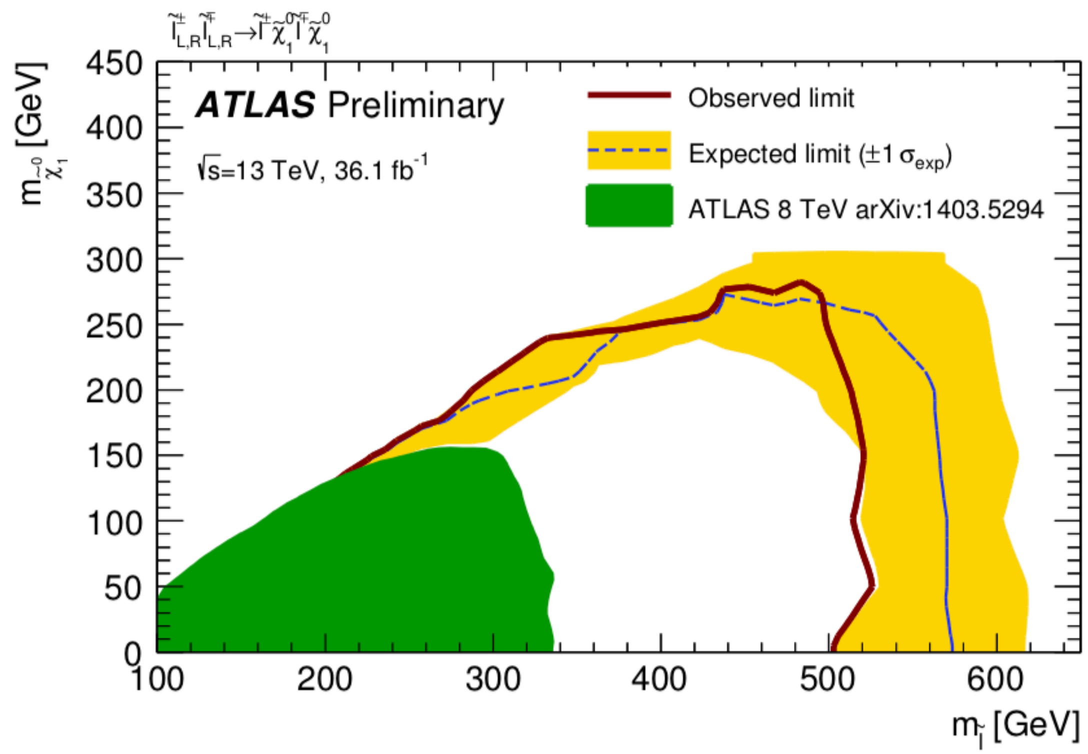
(c) m_{T2} distribution in SR2-DF-100

Final states with 2L+0jets

- No significant deviations from the SM
- Set lower limits on sparticle masses at 95 % CL:
  - C1 masses < 750 GeV excluded for massless LSP
  - Slepton masses < 500 GeV excluded for masses LSP



(a) Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ pair production with $\tilde{\ell}$-mediated decays



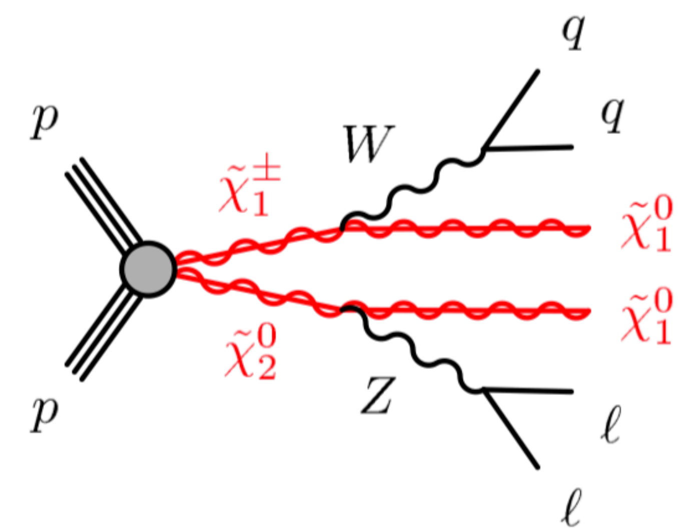
(b) Direct $\tilde{\ell}$ pair production (combined left-handed, $\tilde{\ell}_{\mathrm{L}}$, and right-handed sleptons, $\tilde{\ell}_{\mathrm{R}}$)

Final states with 2L+jets

- Targets pair production of C1 and N2 (next-to-lightest neutralino) decaying via SM gauge bosons
  - Z -> 2 SFOS leptons
  - W -> 2 jets

- Require at least 2 jets

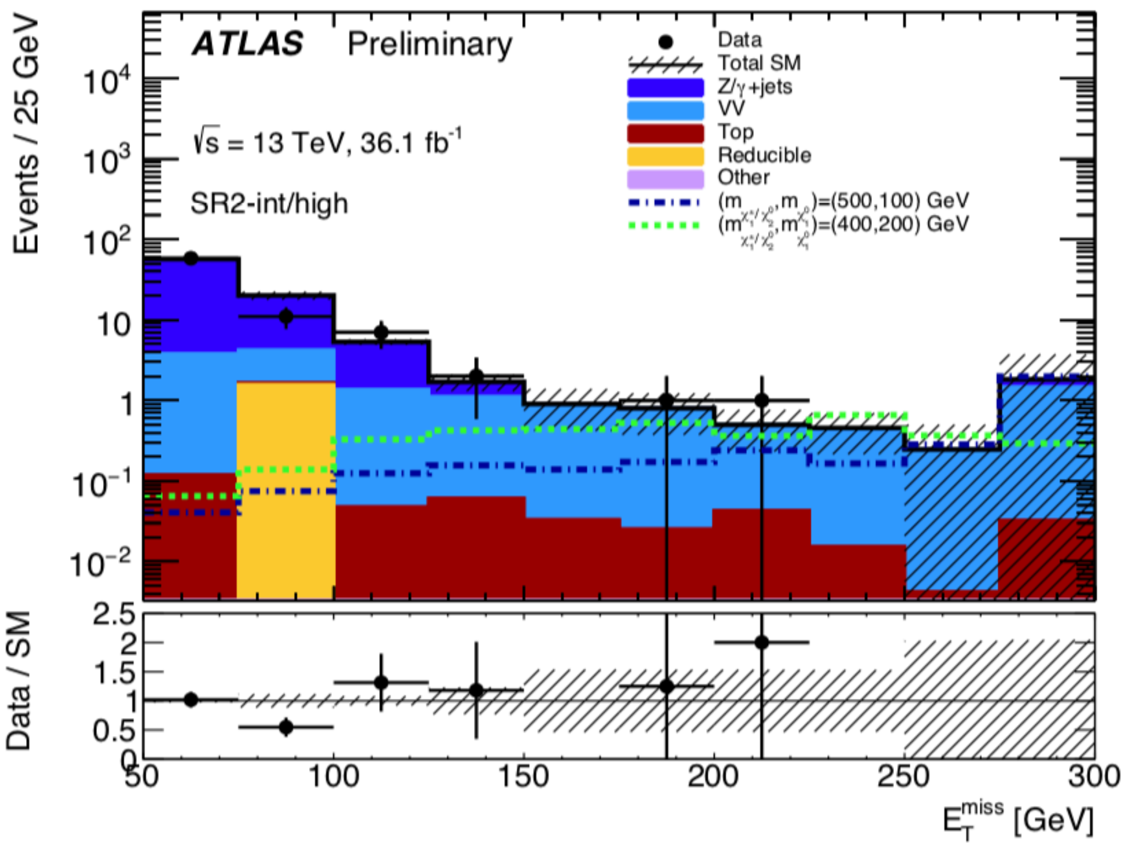
- Signal regions target different mass splittings Δm between the pair produced sparticles and the LSP
  - High Δm: MET > 150 GeV
  - Intermediate Δm: MET > 250 GeV
  - Low Δm: MET > 100 GeV – 2 SRs: w/ and w/o ISR



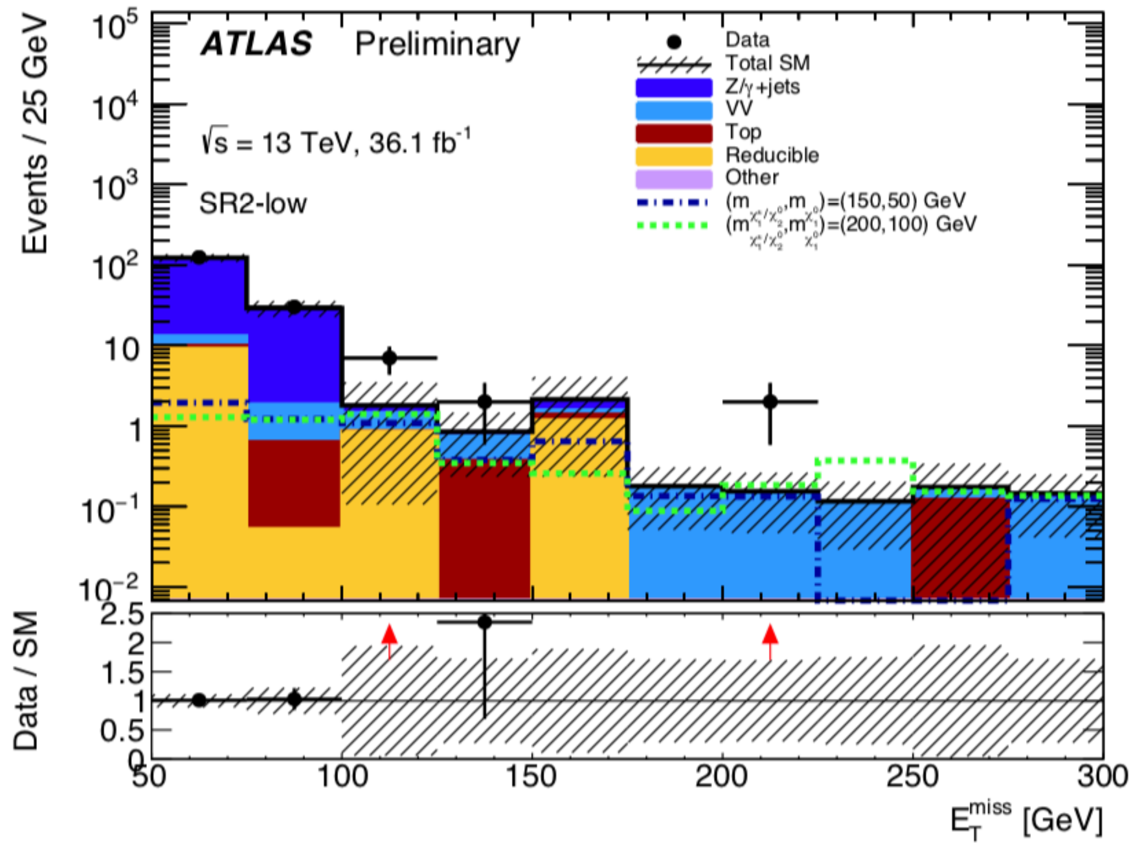
2ℓ+jets signal region definitions

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

Final states with 2L+jets



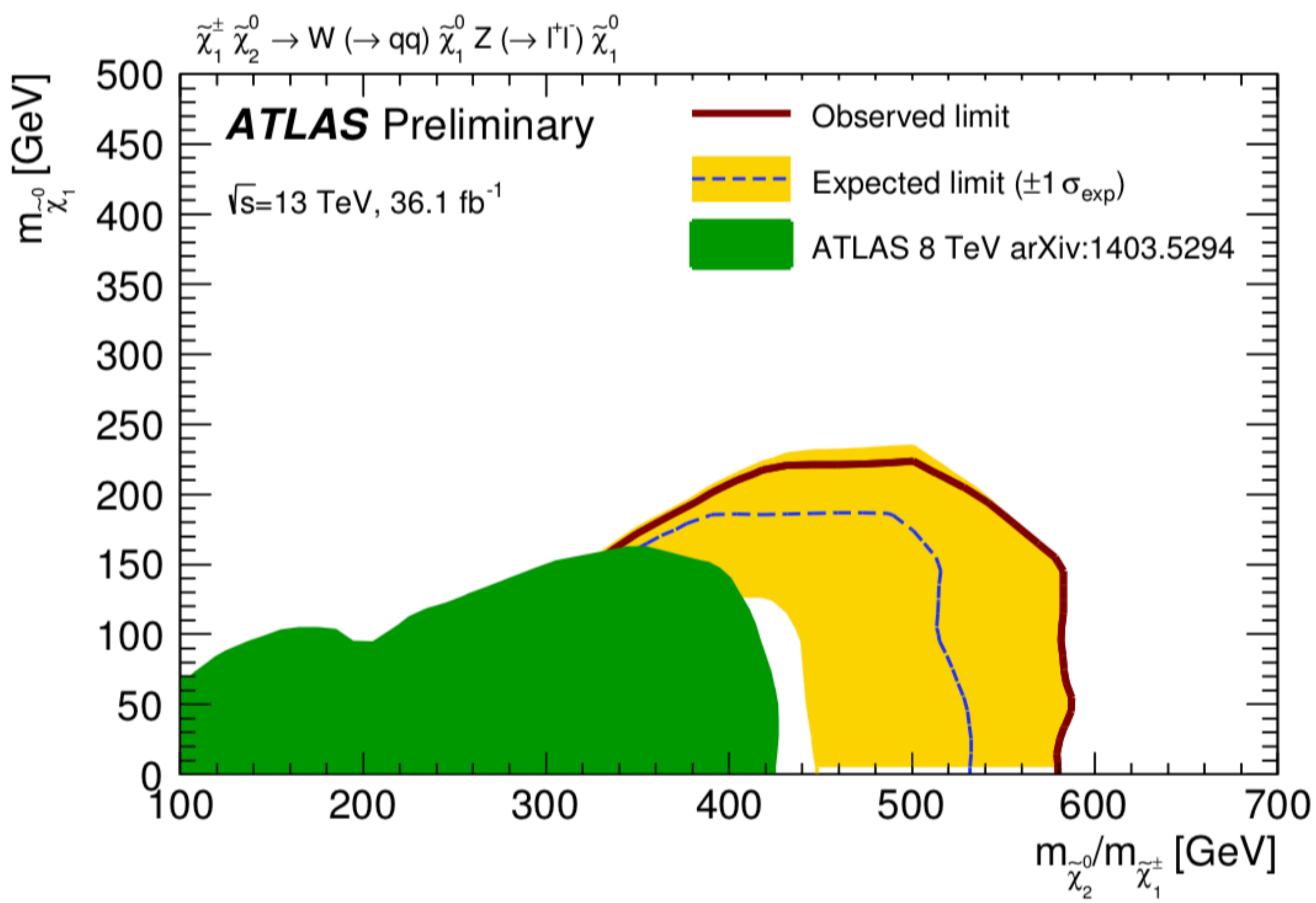
(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR2-int/high



(b) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR2-low

Final states with 2L+jets

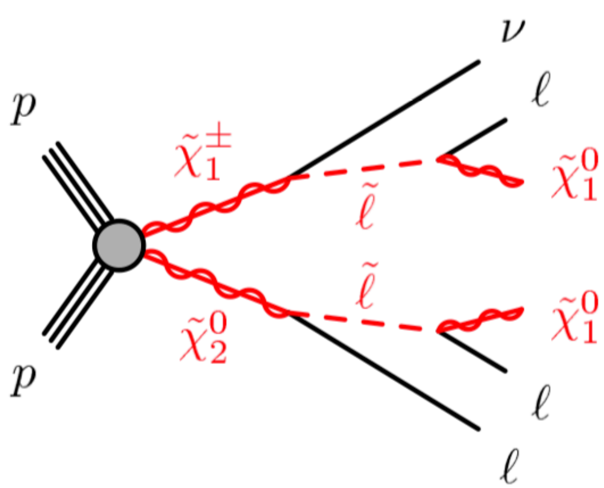
- No significant deviations from the SM
- Set lower limits on sparticle masses at 95 % CL:
  - C1/N2 masses < 580 GeV excluded for massless LSP

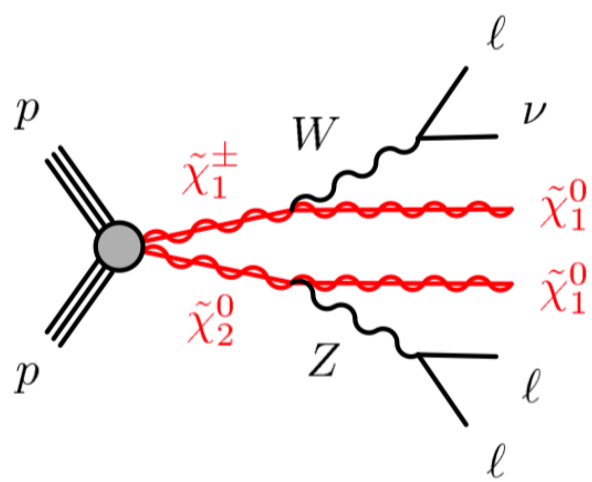


Final states with 3L

- Targets pair production of C1 and N2, decaying via sleptons or SM gauge bosons to 3 leptons

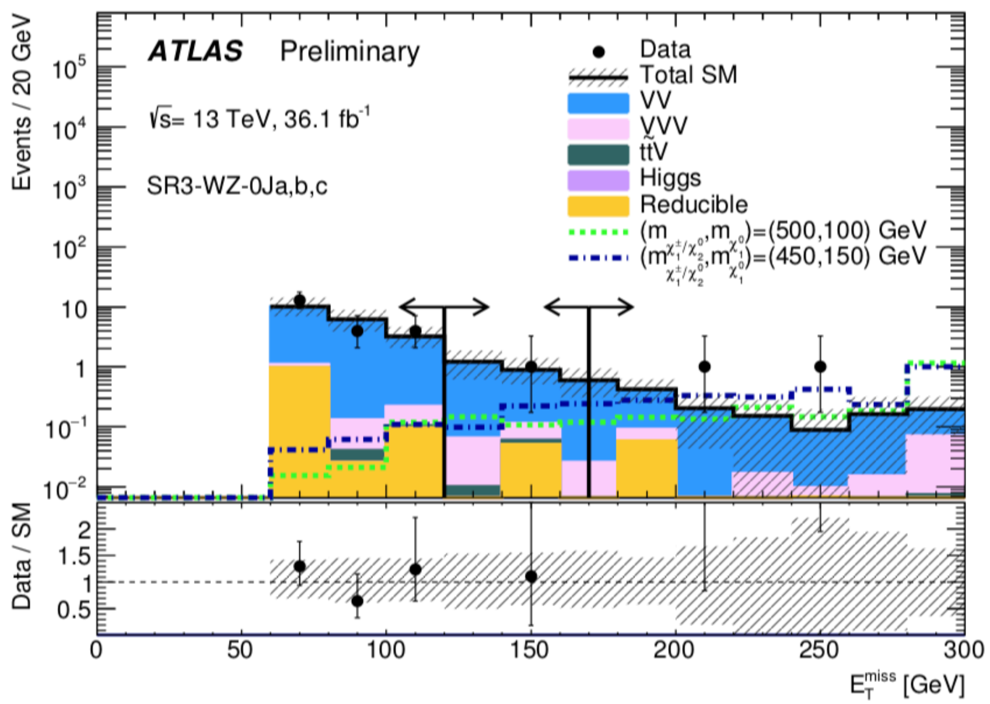
- Binned signal regions
  - Slepton mediated decays: no m_{ll} resonance, binned in 3rd lepton p_T
  - WZ mediated decays: on-shell Z, binned in MET and m_T^{min}



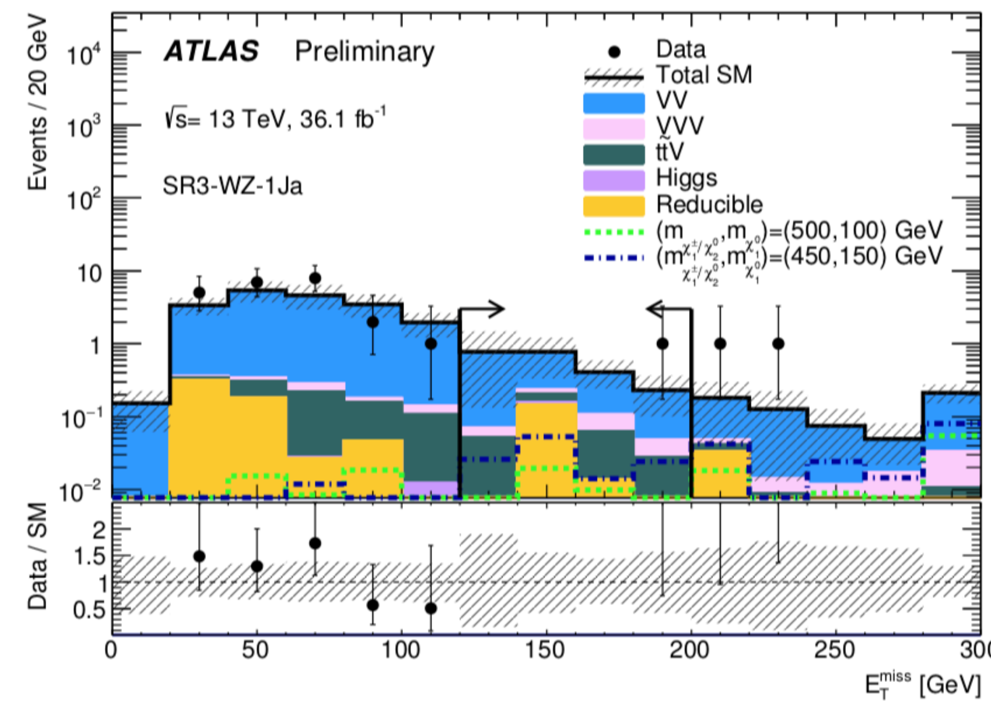


3ℓ binned signal region definitions							
m_{SFOS} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$p_{\mathrm{T}}^{\ell_3}$ [GeV]	$n_{\mathrm{non}-b-\mathrm{tagged\ jets}}$	$m_{\mathrm{T}}^{\mathrm{min}}$ [GeV]	$p_{\mathrm{T}}^{\ell\ell\ell}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{jet1}}$ [GeV]	Bins
<81.2	> 130	20-30 > 30		> 110			SR3-slep-a SR3-slep-b
>101.2	> 130	20-50 50-80 > 80		> 110			SR3-slep-c SR3-slep-d SR3-slep-e
81.2-101.2	60-120 120-170 > 170		0	> 110			SR3-WZ-0Ja SR3-WZ-0Jb SR3-WZ-0Jc
81.2-101.2	120-200 > 200	> 35	≥ 1	> 110 110-160 > 160	< 120	> 70	SR3-WZ-1Ja SR3-WZ-1Jb SR3-WZ-1Jc

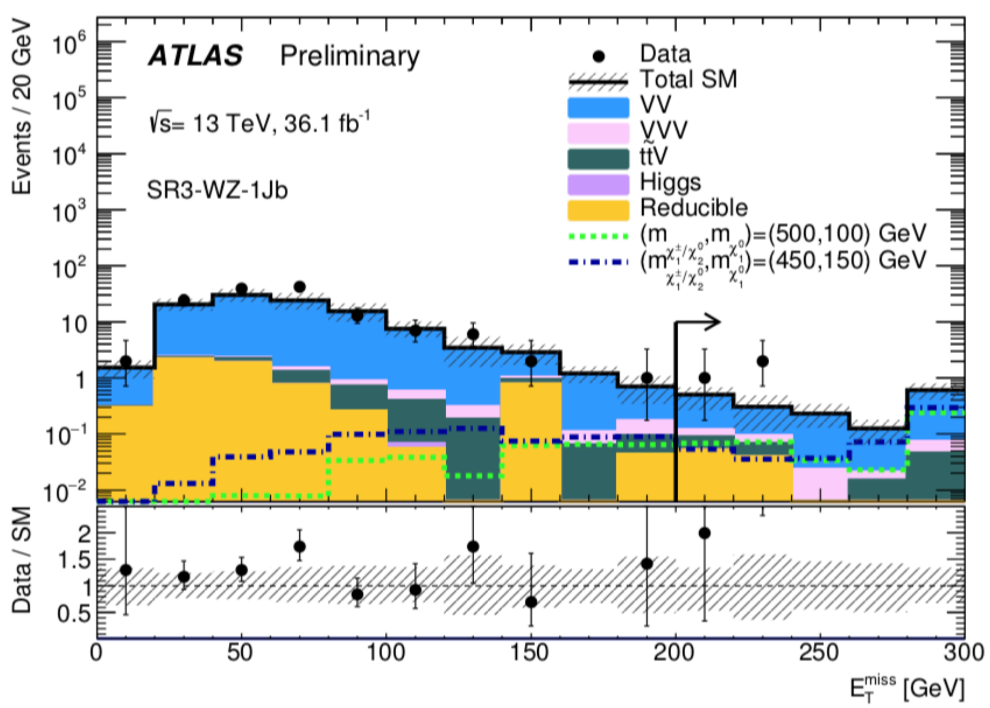
Final states with 3L



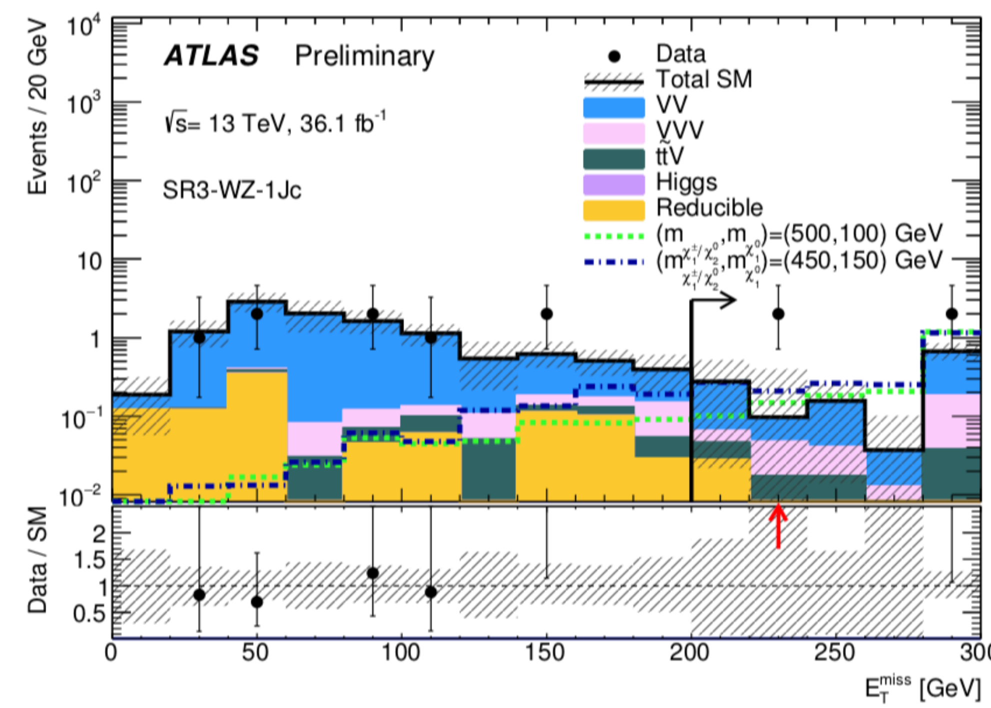
(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR3-WZ-0Ja to c



(b) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR3-WZ-1Ja



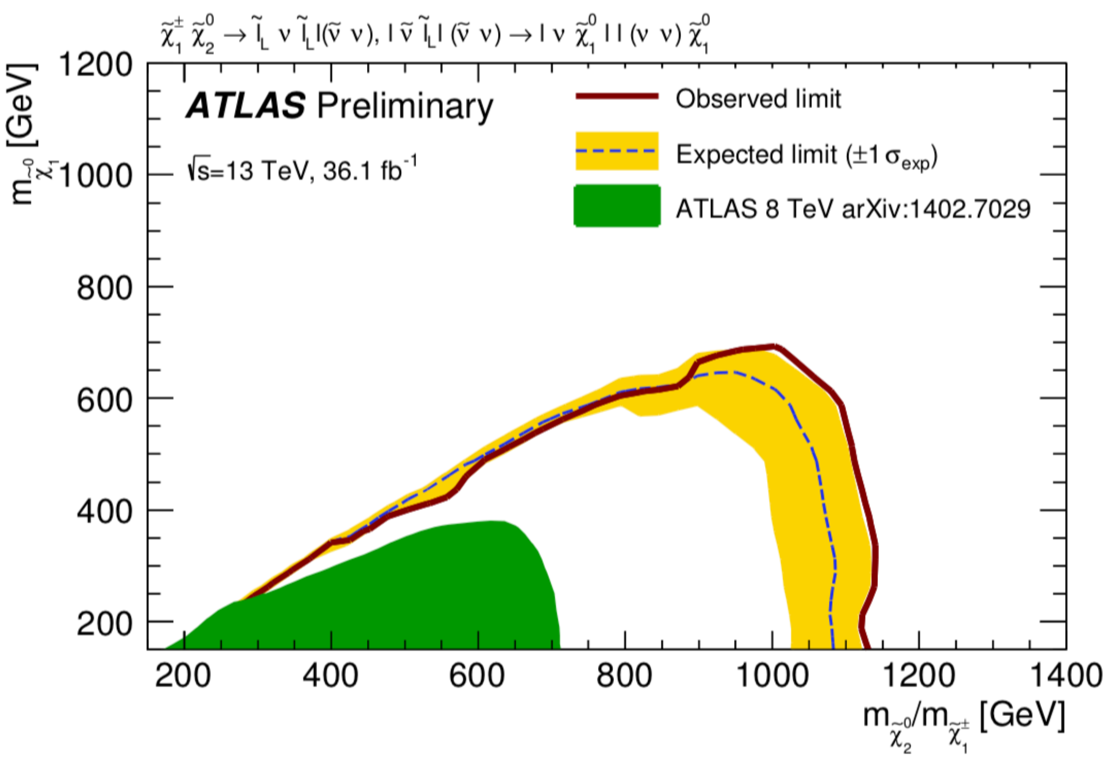
(c) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution SR3-WZ-1Jb



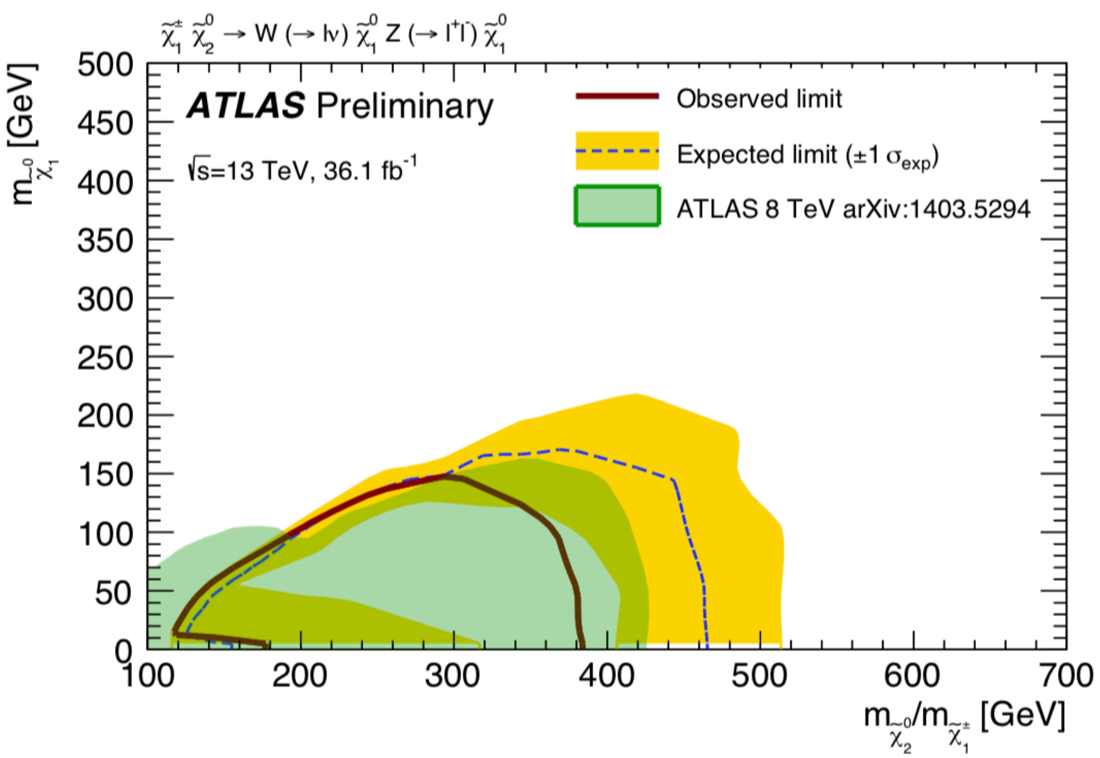
(d) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution SR3-WZ-1Jc

Final states with 2L+0jets

- No significant deviations from the SM
- Set lower limits on sparticle masses at 95 % CL:
  - WZ mediated decays: C1/N2 masses < 380 GeV excluded for massless LSP
  - Slepton mediated decays: C1/N2 masses < 1.1 TeV excluded for masses LSP



(a) Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production with $\tilde{\ell}$-mediated decays



(b) Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production with WZ-mediated decays

Conclusions and outlook

- We see no significant deviations from the SM in searches for sparticles produced in electroweak processes with two and three leptons in the final state
- Continue to exclude phase space past LHC Run 1 limits
- With strong limits on squarks and gluinos, electroweak production of charginos, neutralinos and sleptons are becoming increasingly relevant
- Efforts ongoing to target more compressed mass splitting scenarios