Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

Huajie Cheng [IHEP, CAS]
On behalf of the ATLAS Collaboration

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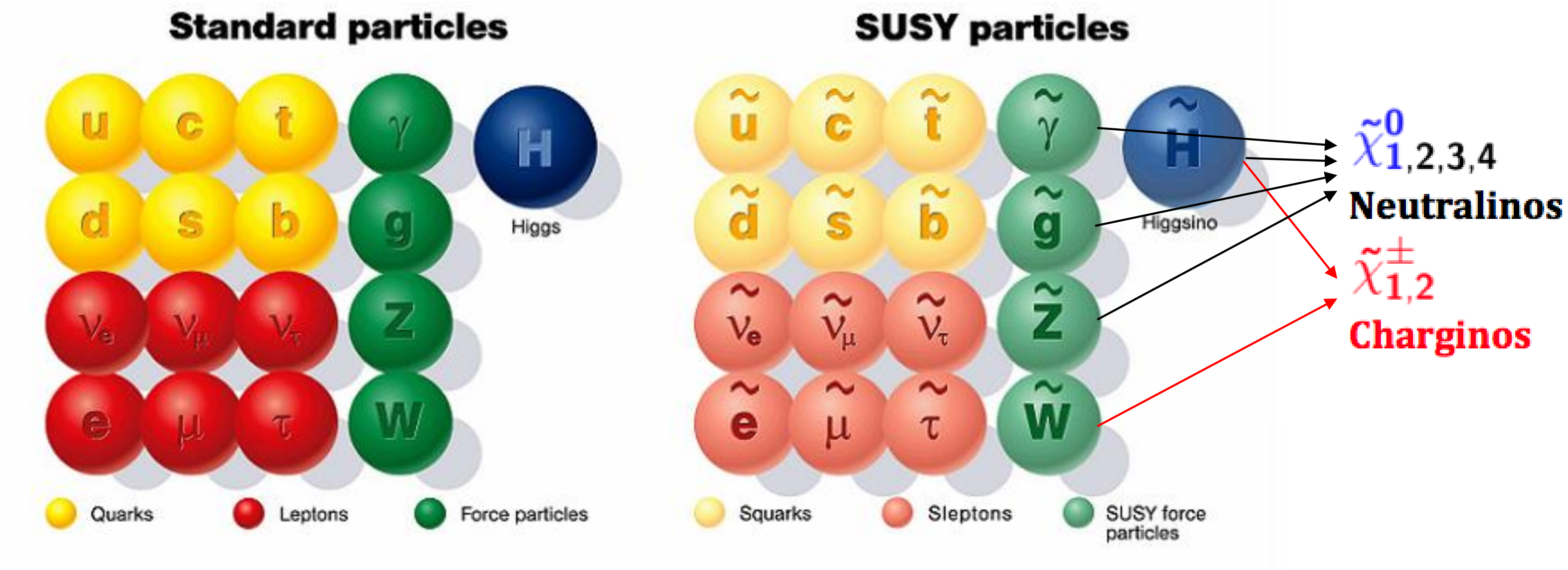
Yaroslavl, Russia

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

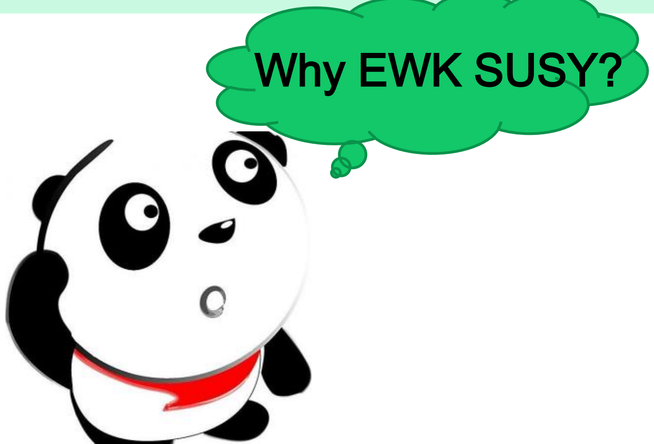
Introduction

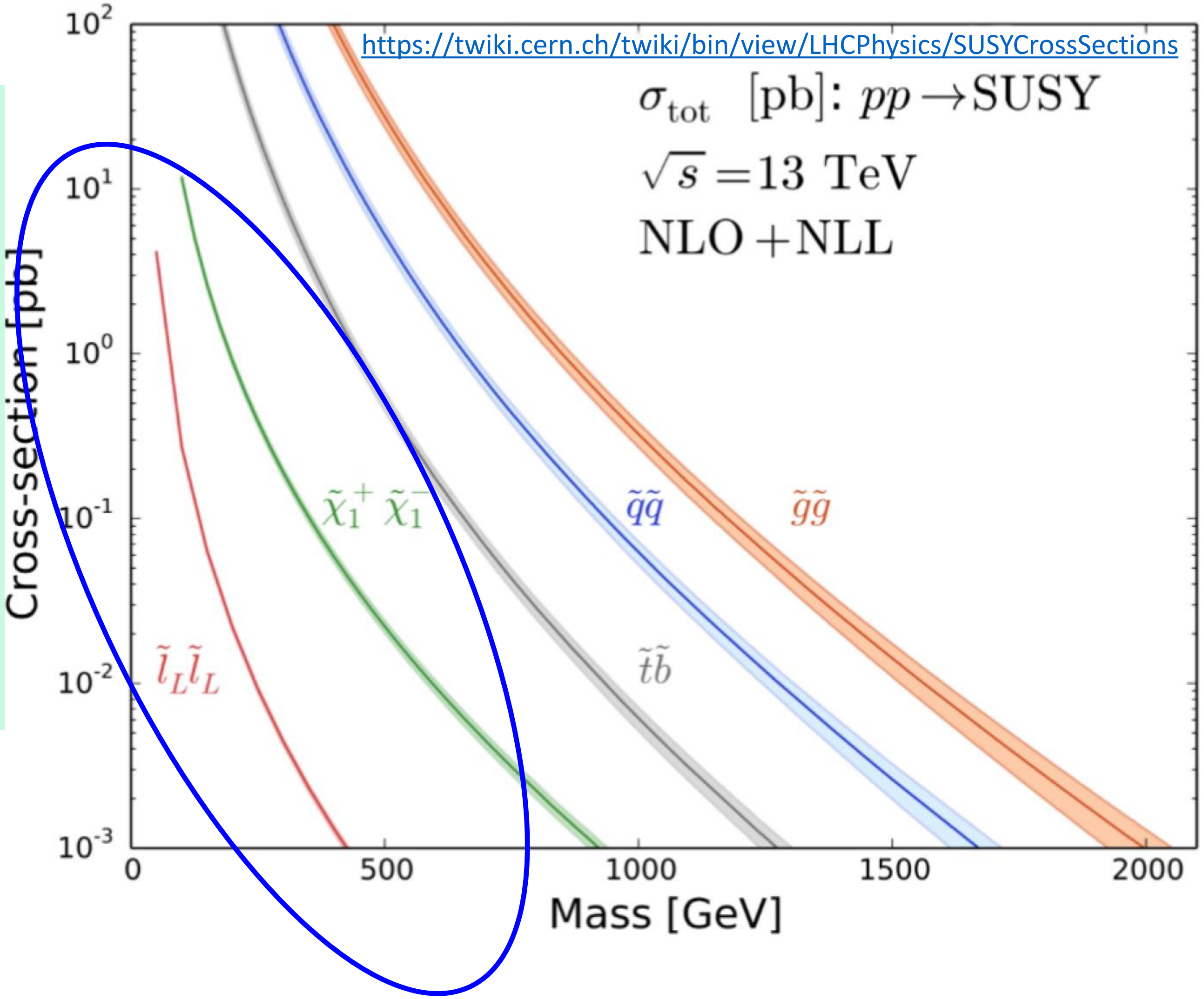


- The SUper-SYmmetry is a well motivated and favored extension of the Stand Model (SM):
  - solves hierarchy problem, grand unification issue, dark matter candidate…
- This talk will focus on the electroweak SUSY searches performed by ATLAS @13TeV.

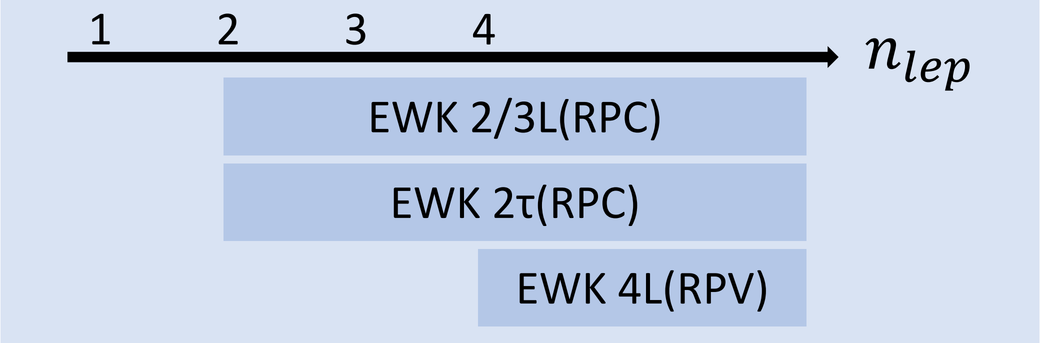
Motivation

- If the coloured sparticles are too heavy for LHC, electroweak productions will be dominant.
- Smaller cross sections, limits are less stringent, and motivated by naturalness.
- Multi lepton final states make it easier to suppress the SM background.





Common strategy



- Analyses target final states with **different lepton multiplicities**.
- Interpretation is usually performed with simplified SUSY models.
- An analysis can probe several models.
- Scenarios with R-parity-conserving (RPC) and R-parity-violating (RPV) decays are both being examined.

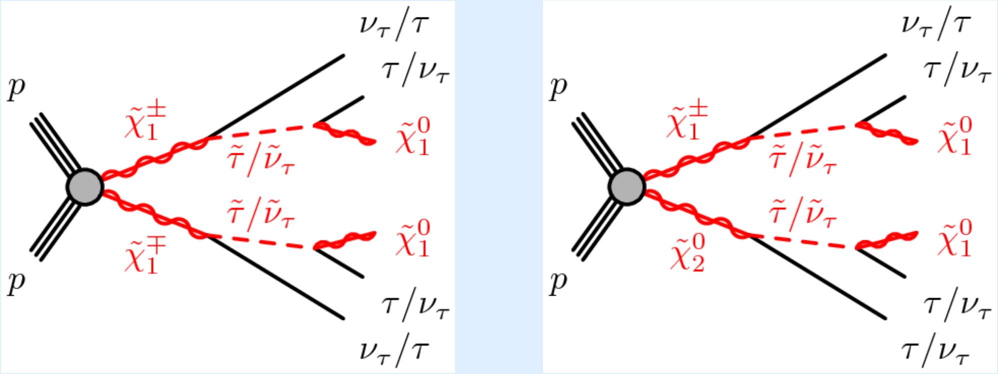
$$R_P = (-1)^{3(B-L)+2S}$$

- SUSY searches rely on accurate modelling of the Standard Model backgrounds
  - Control/validation regions (CR/VR) are defined to study the background modeling
- Discriminating variables are used to separate signals from backgrounds:

complexity ↓

- Object counting, momenta, energies
  - e.g. $N_{jet,bjet,l,r}$, p_T
- Scale variables, event-wise variables
  - e.g. $H_T = \Sigma P_T$, E_T^{miss}, $m_{eff} = \Sigma P_T + E_T^{miss}$
- Angular variables
  - e.g. $\Delta\varphi(jet, E_T^{miss})$, $\Delta R(l,l)$
- Mass variables
  - e.g. m_{ll}, $\mathrm{m_T}(\mathrm{l}, E_T^{miss})$
- Hypothesis based event variables
  - e.g. m_{T2}

Signal Processes



2τ (RPC)

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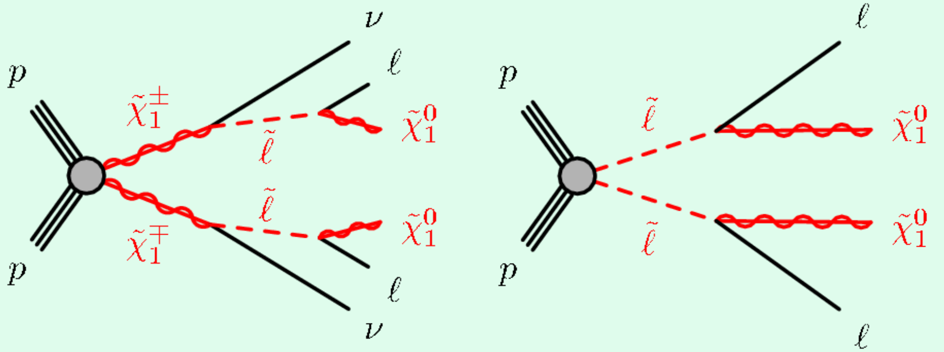
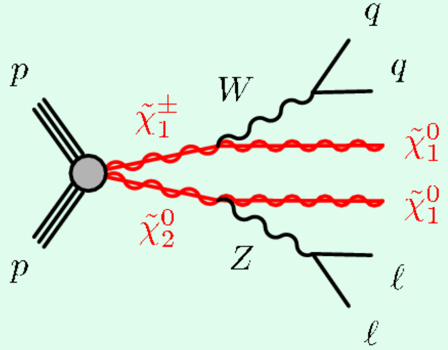
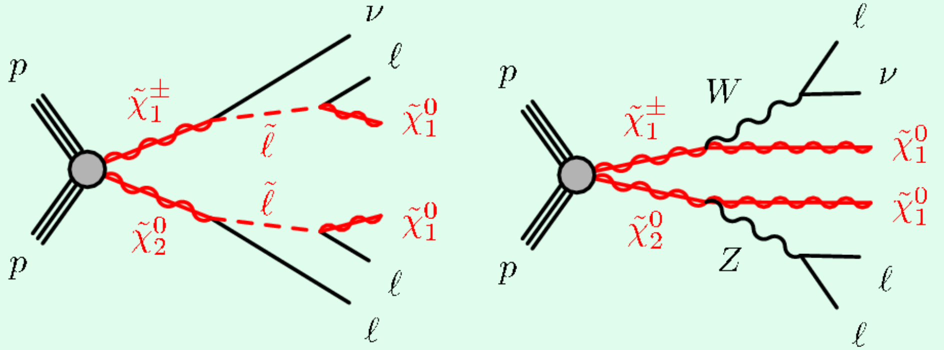
2l + 0jets



2l + jets



3l



2/3l (RPC)

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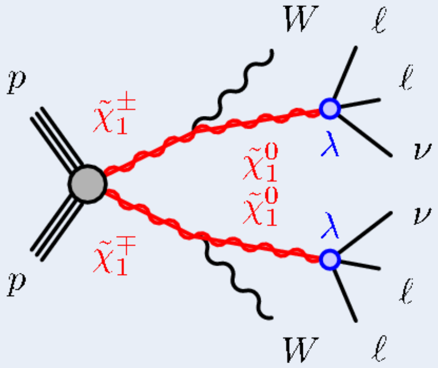
Simplified model

BR=100% for the targeted decay

$\tilde{\chi}_1^{\pm}$ (C1)/$\tilde{\chi}_2^0$ (N2) and $\tilde{\chi}_1^0$ (N1) masses as free parameters

$m_{\tilde{l}_L/\tilde{\tau}_L/\tilde{\nu}} = 0.5(m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0, \tilde{\chi}_3^0})$



4l (RPV)

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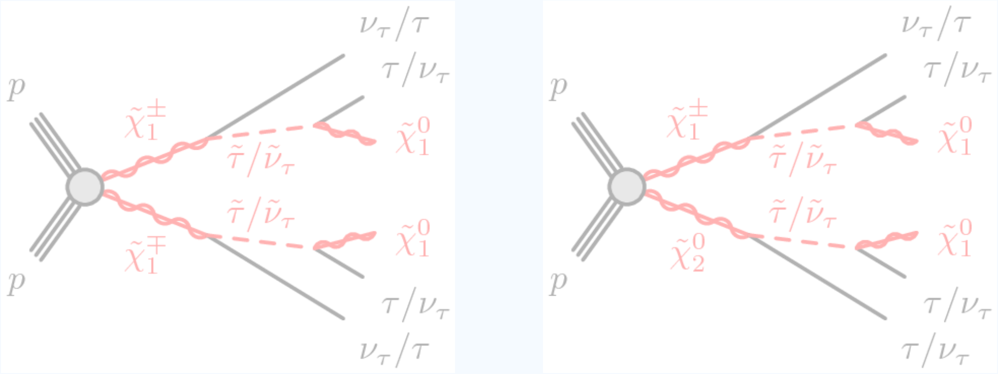
Signal Processes



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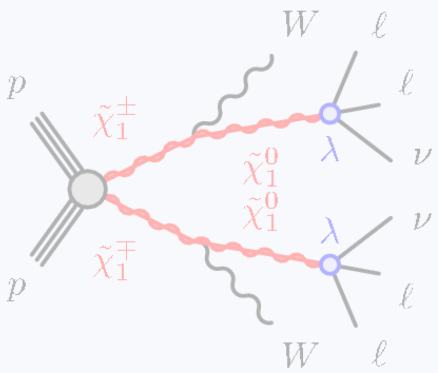

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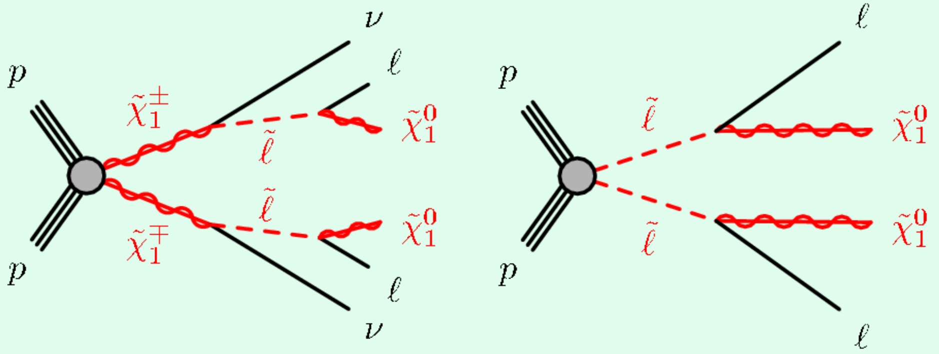
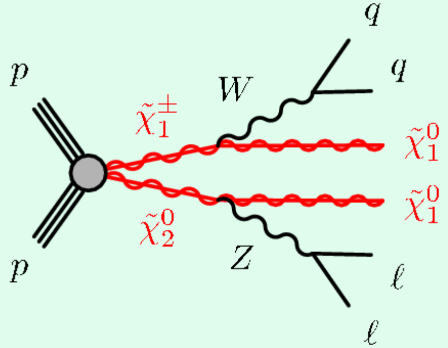
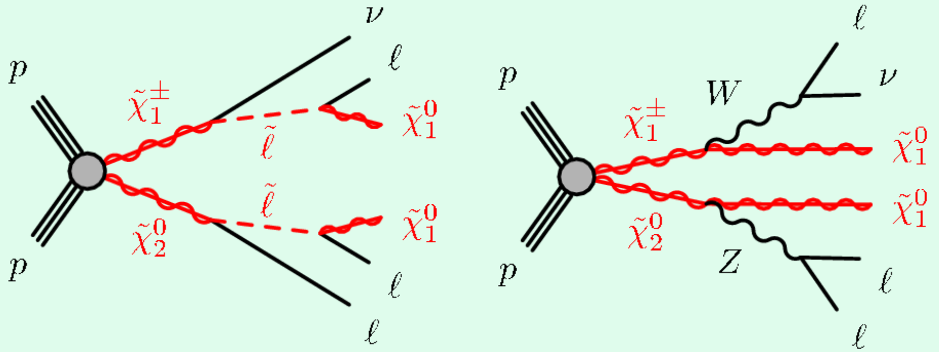
2l + 0jets



2l + jets



3l



2/3l (RPC)

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2/3L: Signal Regions 2l+0jets

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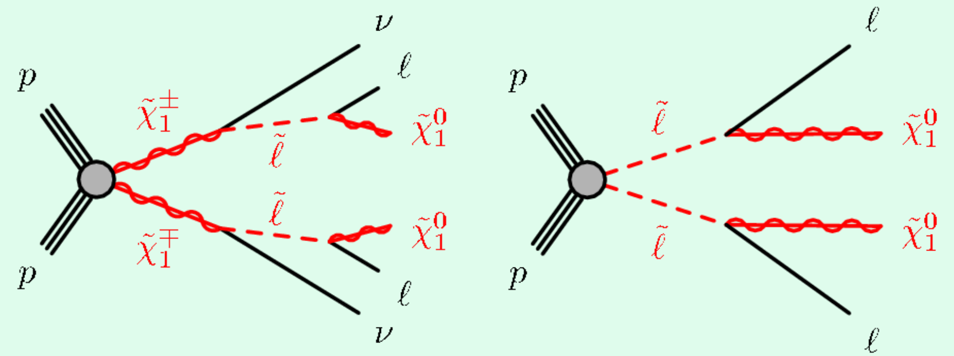
m_{T2} [GeV]	$m_{\ell\ell}$ [GeV]	SF bin	DF bin
2ℓ+0jets binned signal region definitions			
100-150	111-150	SR2-SF-a	SR2-DF-a
	150-200	SR2-SF-b	
	200-300	SR2-SF-c	
	> 300	SR2-SF-d	
150-200	111-150	SR2-SF-e	SR2-DF-b
	150-200	SR2-SF-f	
	200-300	SR2-SF-g	
	> 300	SR2-SF-h	
200-300	111-150	SR2-SF-i	SR2-DF-c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

m_{T2} binned

2l + 0jets



C1C1 → slep → 2l

slep → 2l

- Signature: 2 opposite-sign (OS) leptons, 0 jet, large E_T^{miss}.
- SRs defined for same-flavor (**SF**) and different-flavor (**DF**) separately, further binned in stransverse mass (**m_{T2}**) and invariant mass (**m_{ll}, only for SF**) after preselection on m_{ll} and a jet veto.

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

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

2/3L: Signal Regions 2l+jets

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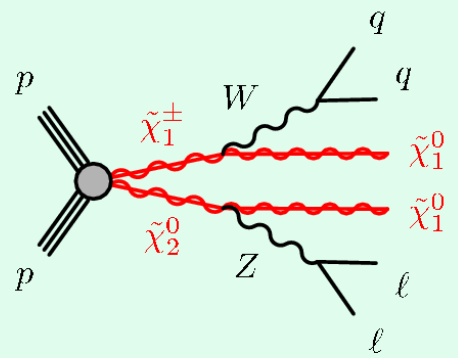
	Main selections
SR2-int	≥ 2 jets, $E_T^{miss} > 150GeV$
SR2-high	≥ 2 jets, $E_T^{miss} > 250GeV$
SR2-low-2J	2 jets, $E_T^{miss} > 100GeV$, W recoiling against the Z+E_T^{miss} system
SR2-low-3J	3-5 jets, $E_T^{miss} > 100GeV$, ISR jets recoiling against the Z+W+E_T^{miss} system

- Signature: 2 SFOS leptons, ≥ 2 non-b-tagged jets, large E_T^{miss}.
- Select events with 2 leptons from an on-sell Z boson and 2 jets from W boson.

2l + jets



C1N2 → WZ → 2l+2j

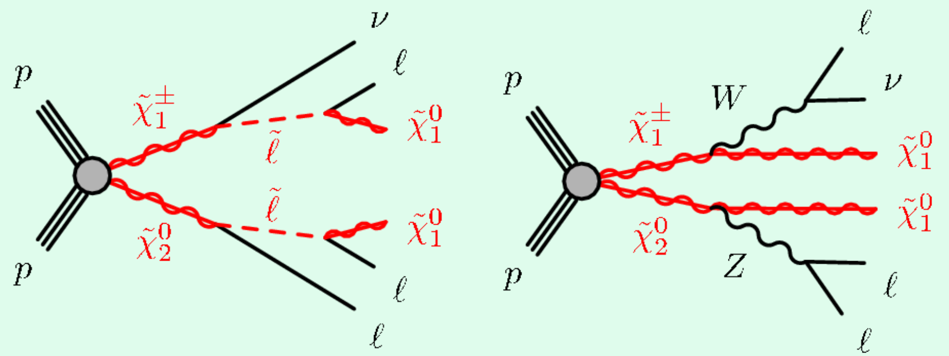
- Two inclusive SRs targeting **intermediate** / **large** mass splittings between C1/N2 and N1.
- Two orthogonal SRs for low mass splitting:
  - SR2-low-2J: assume 2 jets from **W boson**
  - SR2-low-3J: assume C1N2 recoils against **ISR jets**

2/3L: Signal Regions 3l

3l SR definitions		
SRs for slepton mediated	$\lvert m_{SFOS} - m_Z \rvert > 10\text{GeV}$	binned in p_T^{l3}
SRs for gauge-boson mediated	$\lvert m_{SFOS} - m_Z \rvert < 10\text{GeV}$	binned in E_T^{miss}, p_T^{l3}, n_{jet} and m_T^{min}

- Signature: Exactly 3 leptons (2 SFOS leptons), 0 b-tagged jets, large E_T^{miss}.
- Two sets of SRs defined by m_{ll} to target **slepton** and **gauge-boson** mediated decays, further binned in E_T^{miss}, p_T^{l3}, n_{jet} and m_T^{min}.

3l



C1N2 → slep → 3l

C1N2 → WZ → 3l

2/3L: Background Estimation

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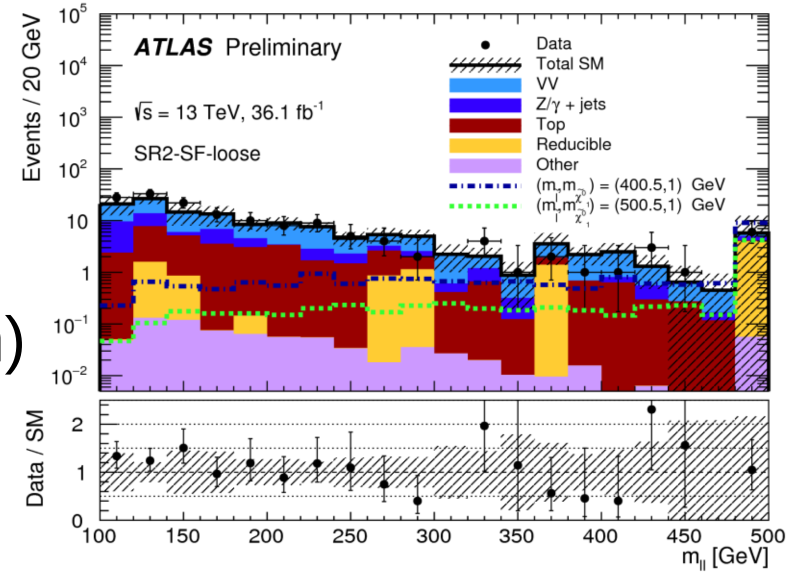
Background estimation summary			
Channel	2ℓ+0jets	2ℓ+jets	3ℓ
Fake leptons	Matrix method (MM)		Fake factor method (FF)
$t\bar{t}+Wt$ VV Z/γ+jets	CR CR MC	MC MC γ+jet template	FF CR (WZ-only) FF
Higgs/ VVV/ top+V	MC		

- **Irreducible backgrounds:** (prompt and real leptons)
  - VV, Z/γ+jets, $t\bar{t}$ dominant in 2l channels; small contributions from Higgs, VVV, top+V
  - In general estimated from MC simulation, dominant backgrounds are normalized in dedicated CRs
- **Reducible backgrounds:** (≥1 fake or non-prompt lepton)
  - Multi-jet, W+jets, single top for 2l channels
  - Besides, Z+jets, $t\bar{t}$, WW are also reducible for 3l channel
  - Estimated from data using “fake factor method”.



2/3L: Results

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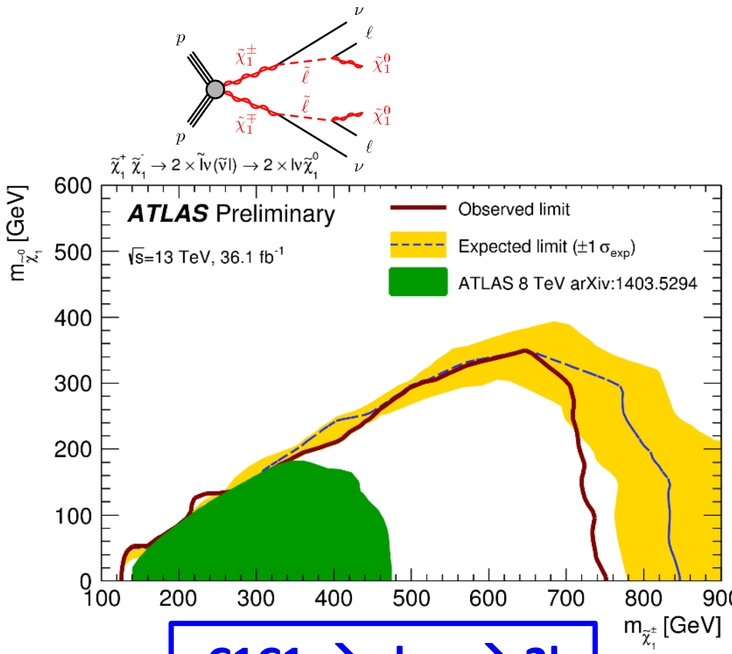
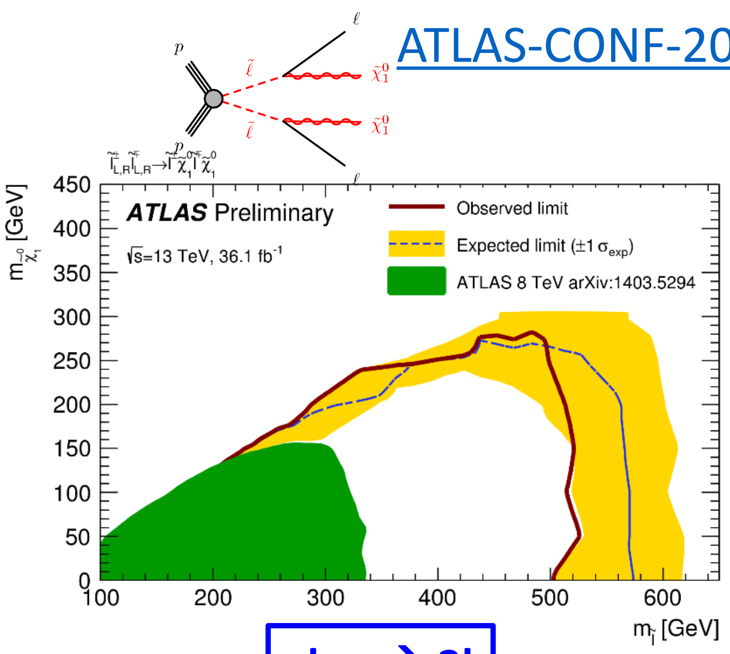
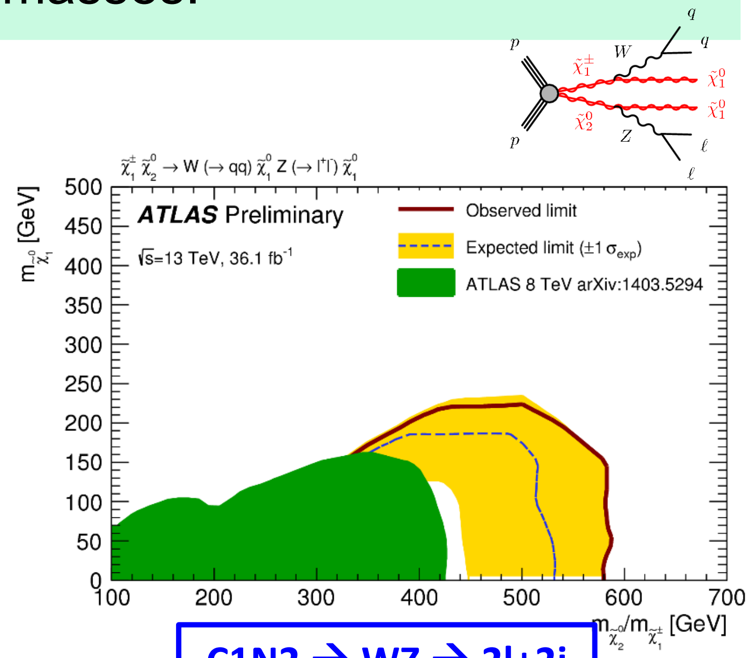
- No significant excess above SM predictions in any SRs.
- Extended the exclusion limit to higher C1/N2 and slepton masses.



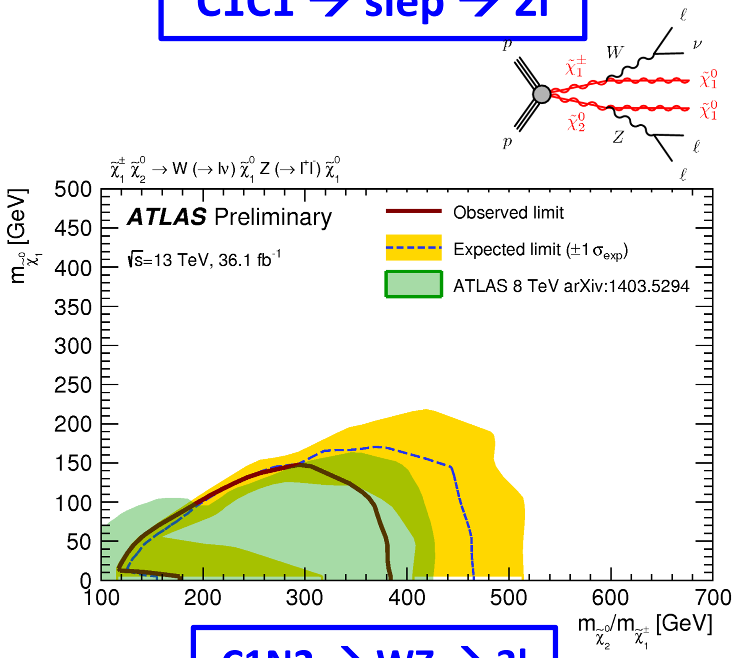
C1C1 → slep → 2l



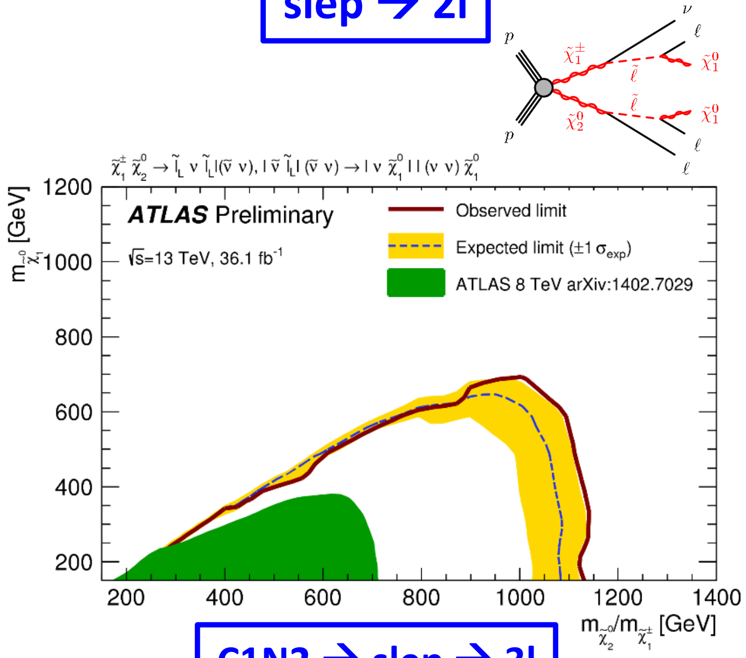
slep → 2l



C1N2 → WZ → 2l+2j

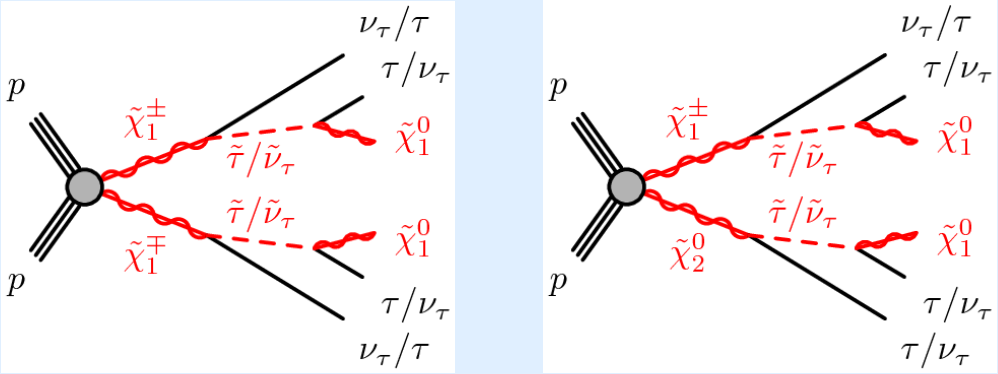


C1N2 → WZ → 3l



C1N2 → slep → 3l

Signal Processes



2τ (RPC)

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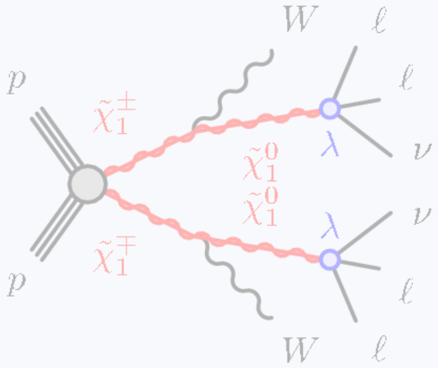
Simplified model

BR=100% for the targeted decay

$\tilde{\chi}_1^\pm$ (C1)/$\tilde{\chi}_2^0$ (N2) and $\tilde{\chi}_1^0$ (N1) masses as free parameters

$m_{\tilde{l}_L/\tilde{\tau}_L/\tilde{\nu}} = 0.5(m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm, \tilde{\chi}_2^0, \tilde{\chi}_3^0})$



4l (RPV)

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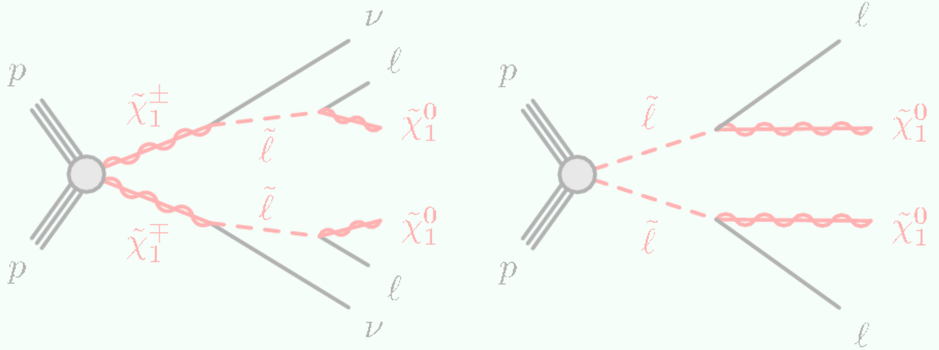
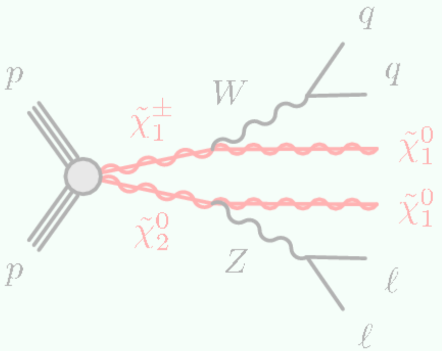
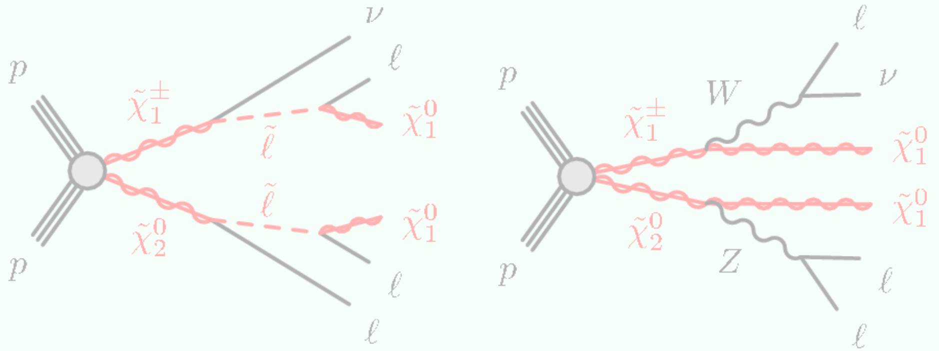
2l + 0jets



2l + jets



3l



2/3l (RPC)

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2τ: Signal Regions

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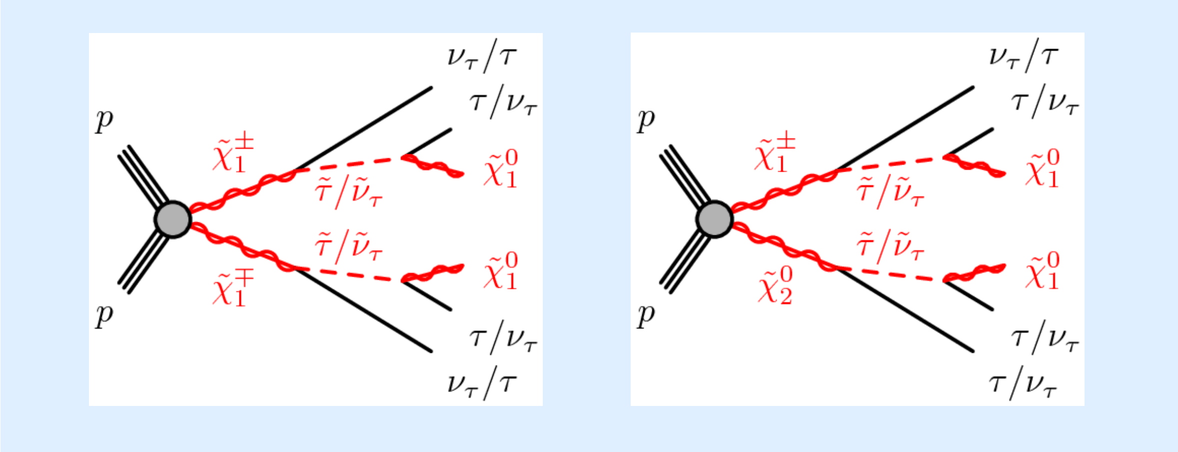
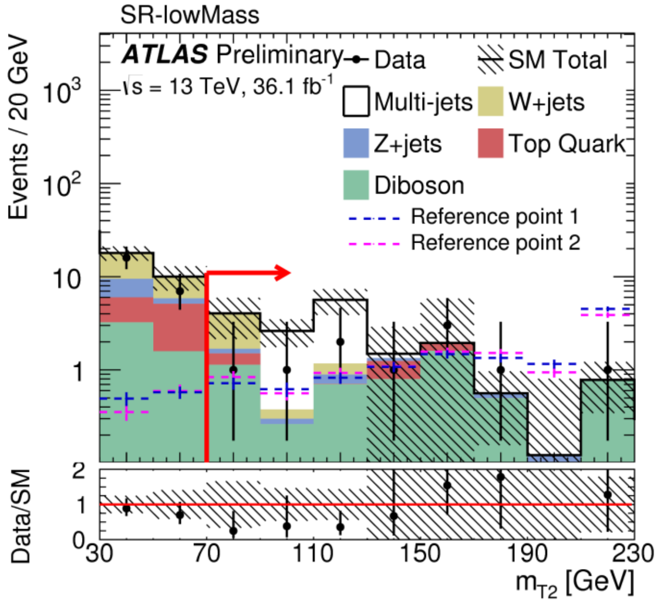
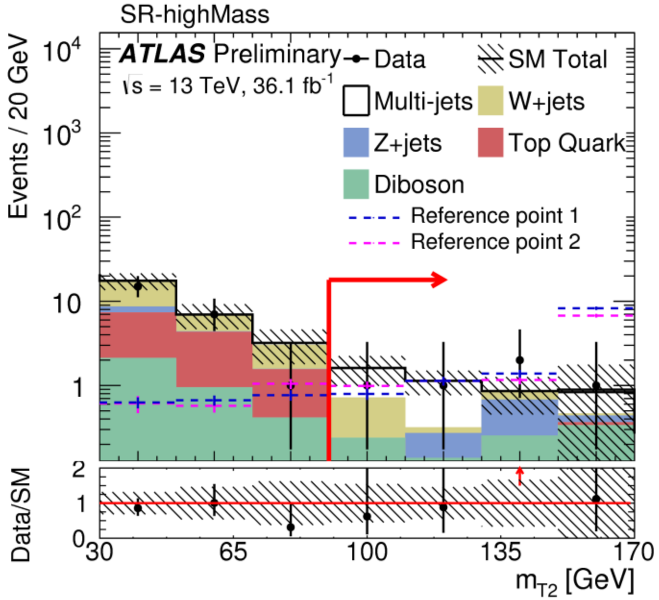


- Signature: 2 OS hadronically decaying τ leptons, 0 b-tagged jet, large E_T^{miss}.
- Two SRs defined targeting **low** and **high** mass splittings between C1/N2 and N1.
- m_{T2} is the most powerful discriminating variable.

SR-lowMass	SR-highMass
≥ 2 medium τ	≥ 1 medium τ and 1 tight τ
$E_T^{miss} > 150GeV,\ P_T^{\tau 1} > 50GeV$	$E_T^{miss} > 110GeV,\ P_T^{\tau 1} > 80GeV$
$m_{T2} > 70GeV$	$m_{T2} > 90GeV$





2τ: Background Estimation

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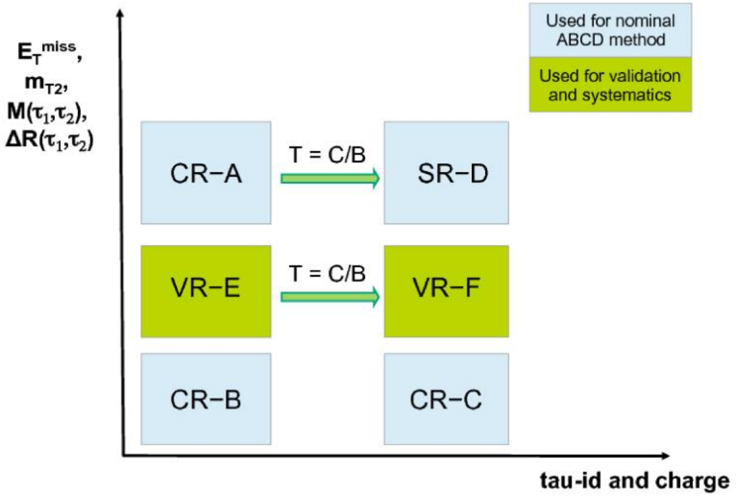
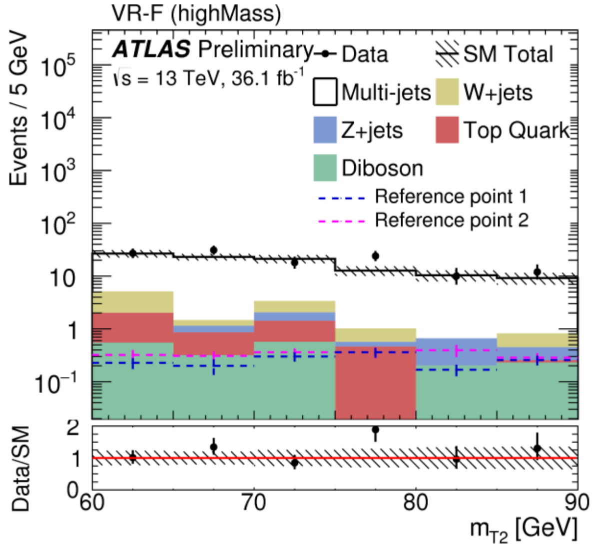
- **Irreducible backgrounds:**
  - VV, Z+jets, top ($t\bar{t}$, single top, $t\bar{t}V$).
  - Estimated from MC simulation.
- **Reducible backgrounds:**
  - 1 fake τ: W+jets, estimated from MC + normalization factor from data.
  - 2 fake τ: multi-jet, estimated from data using "ABCD method".
- **Validation:**
  - A dedicated VR is designed for each background to validate the estimation from data.





2τ: Results

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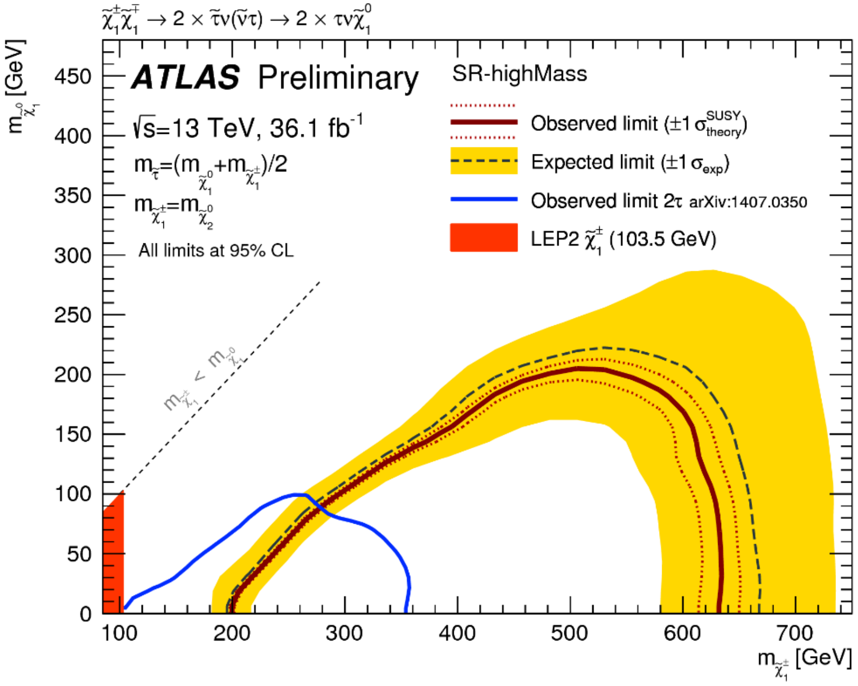
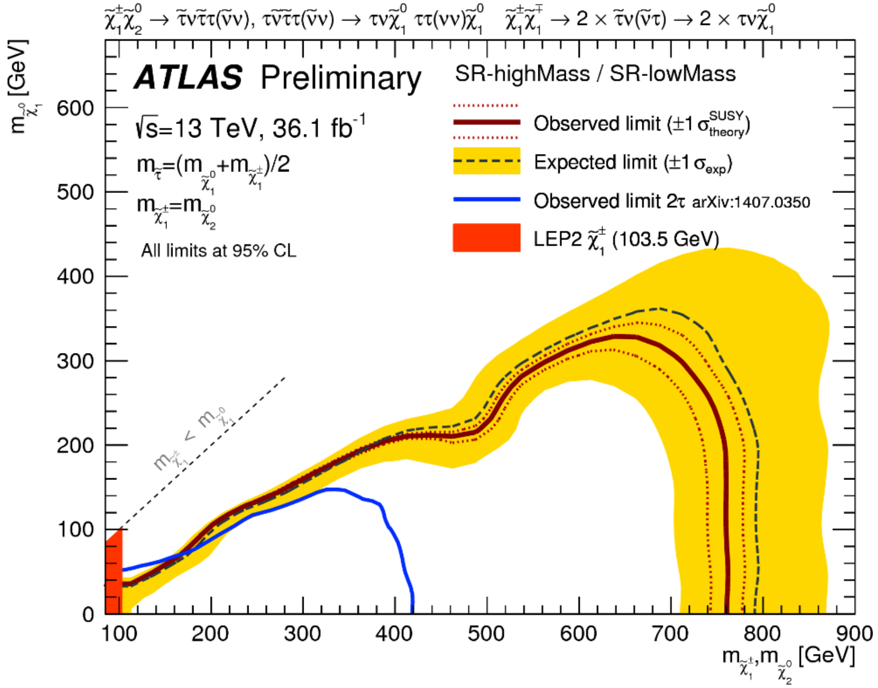
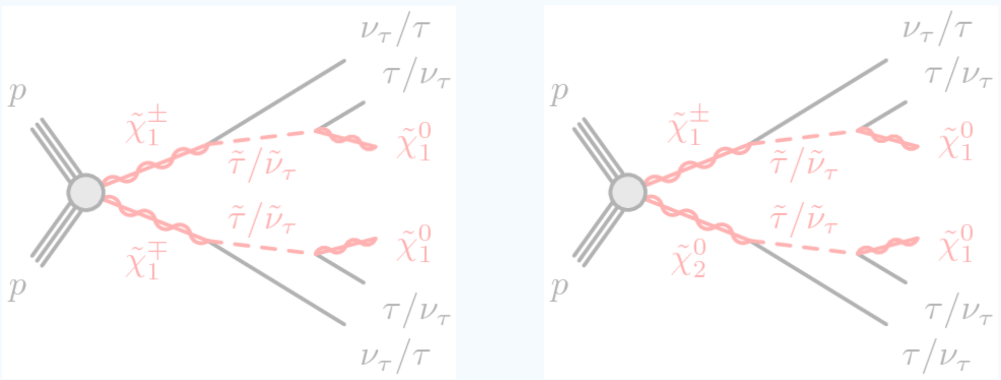
- No significant excess above SM predictions in any SRs.
- Extended the exclusion limit to higher C1/N2 and slepton masses.
- Limits on cross-section set for re-interpretation.

SM process	SR-lowMass	SR-highMass
diboson	5.9 ± 2.2	1.0 ± 0.8
W+jets	1.8 ± 1.1	0.7 ± 0.5
Top quark	1.2 ± 1.0	$0.03^{+0.26}_{-0.03}$
Z+jets	$0.6^{+0.7}_{-0.6}$	0.6 ± 0.5
multi-jet	4.3 ± 4.0	1.3 ± 1.1
SM total	14 ± 6	3.7 ± 1.4
Observed	10	5
Reference point 1	11.6 ± 2.6	11.8 ± 2.8
Reference point 2	10.0 ± 2.1	11.4 ± 2.6
p_0	0.5	0.3
Expected $\sigma_{\rm vis}^{95}$ [fb]	$0.31^{+0.12}_{-0.08}$	$0.17^{+0.08}_{-0.05}$
Observed $\sigma_{\rm vis}^{95}$ [fb]	0.26	0.20





Signal Processes



2τ (RPC)

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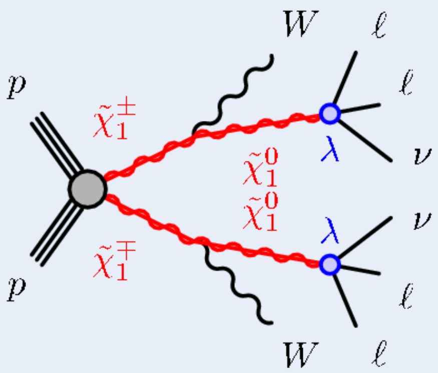

4l (RPV)

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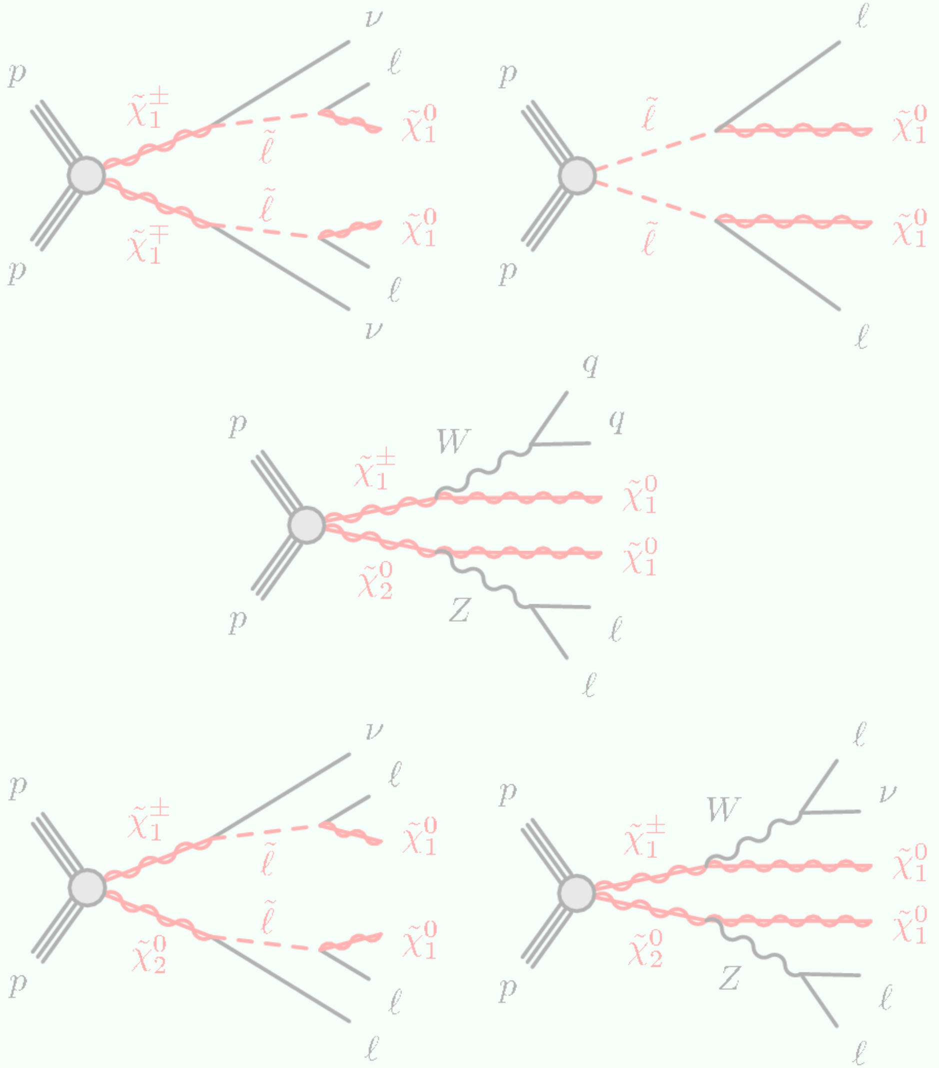
2l + 0jets

2l + jets

3l



2/3l (RPC)

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4L: SRs & Background Estimation

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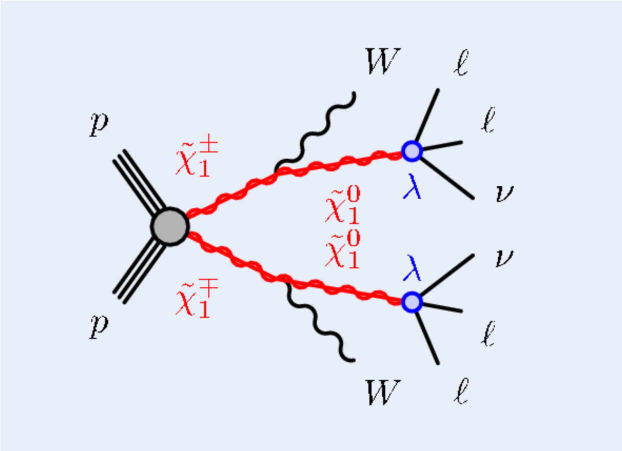
- Signature: ≥ 4 leptons.
- SR defined based on m_{eff} after vetoing leptons from Z boson.

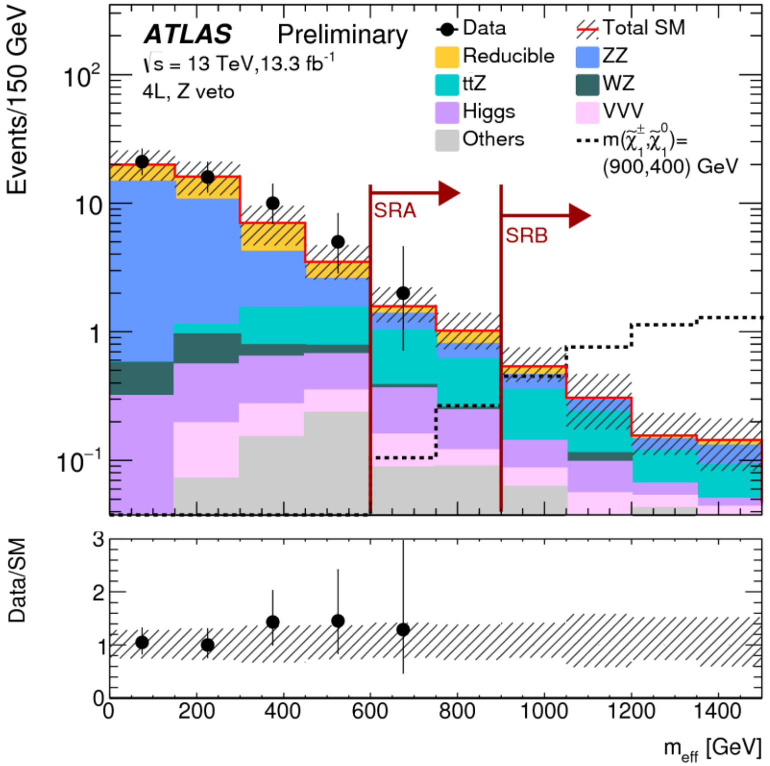
$$m_{eff} = E_T^{miss} + \sum_l p_T(l) + \sum_J [p_T(J)]_{>40GeV}$$

SRA	SRB
N (e,μ) ≥ 4	N (e,μ) ≥ 4
Z boson veto	Z boson veto
$m_{eff} > 600GeV$	$m_{eff} > 900GeV$



Assume $\frac{1}{2}\lambda_{ijk}L_iL_j\overline{E_k}$ term violate
→ multi-lepton final states.

- **Irreducible backgrounds:**
  - ZZ, $t\bar{t}Z$, $t\bar{t}WZ$, VVZ, Higgs, $t\bar{t}t\bar{t}$, $t\bar{t}tW$.
  - Estimated from MC simulation.
- **Reducible backgrounds:**
  - 1 fake lepton: WZ, WWW, $t\bar{t}W$: estimated from MC
  - 2 fake leptons: $t\bar{t}$, Z+jets: estimated from data using "fake factor method"



4L: Results

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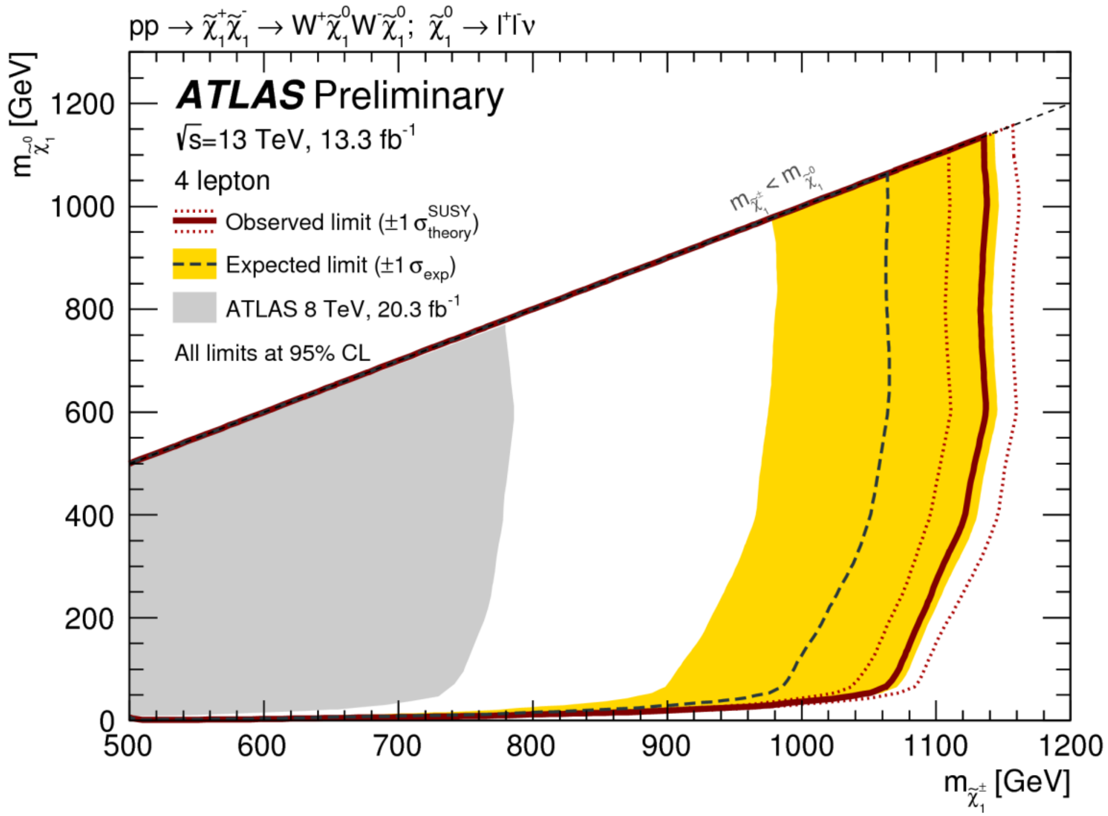
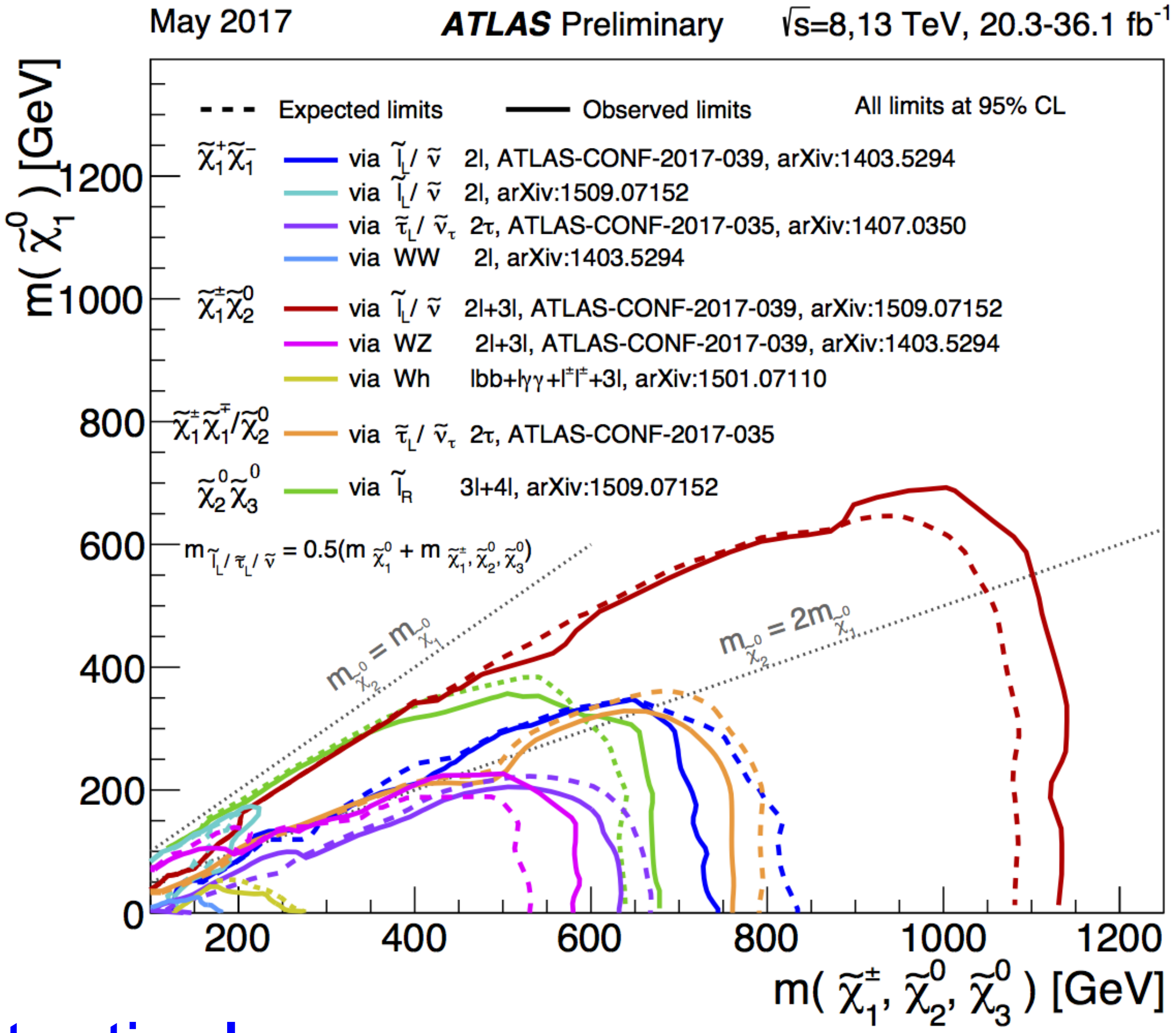
Sample	VR	SRA	SRB
Irreducible			
ZZ	29 ± 5	0.6 ± 0.4	0.20 ± 0.19
$t\bar{t}Z$	2.05 ± 0.24	1.43 ± 0.23	0.47 ± 0.09
Higgs	1.7 ± 1.4	0.4 ± 0.4	0.11 ± 0.11
VVZ	0.72 ± 0.14	0.31 ± 0.06	0.123 ± 0.027
Others	0.28 ± 0.07	0.32 ± 0.04	0.181 ± 0.022
1-fake ℓ reducible	1.14 ± 0.07	0.168 ± 0.018	0.069 ± 0.014
2-fake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



- No significant excess beyond SM expectations.
- Exclusion limits are extended to higher C1 mass as well as lower N1 mass.
- Model-independent cross-section limits are also derived.

Summary

- Three SUSY searches for electroweak productions using 13TeV datasets are presented.
- No discovery yet.
- Exclusion limits on gaugino/slepton masses have been largely extended.
- More studies with full 2015+2016 dataset and new results targeting compressed region are coming -- stay tuned!



Thank you for your attention!

Backup

SR definitions: 2/3L

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

2ℓ+jets signal region definitions

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

3ℓ binned signal region definitions

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

SR definitions: 2τ and 4L

2τ

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

4L

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