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

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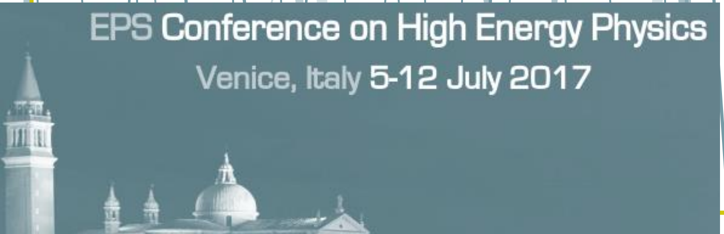
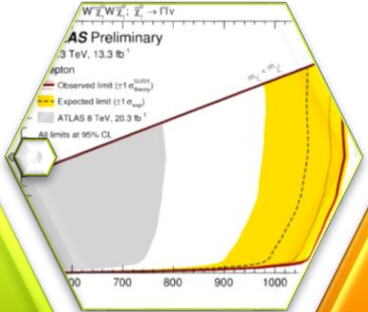
on behalf of the ATLAS collaboration

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

ATLAS EXPERIMENT

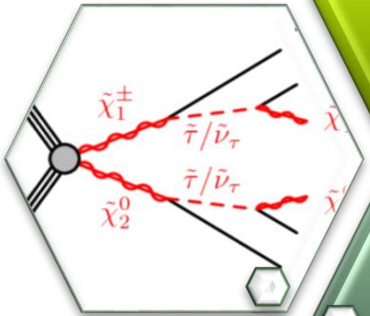


Outline

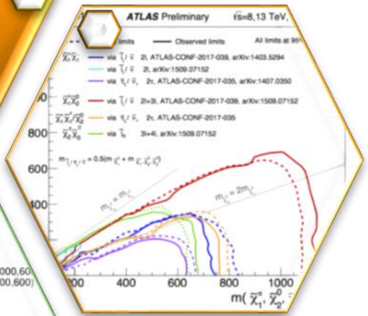


Events with 4 charged leptons

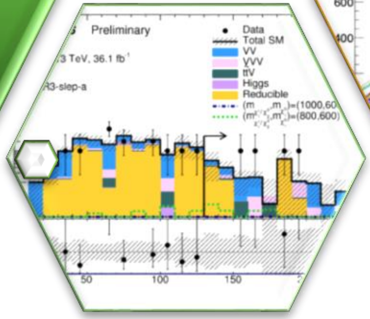
Electroweak production of SUSY particles
charginos, neutralinos & sleptons



Events with 2 or 3 charged leptons



Events with tau hadronic decays



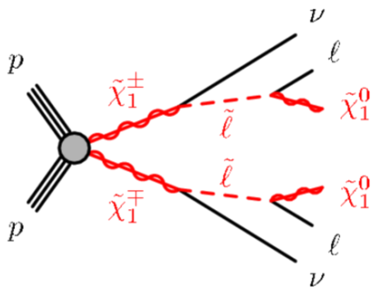
2-lepton searches

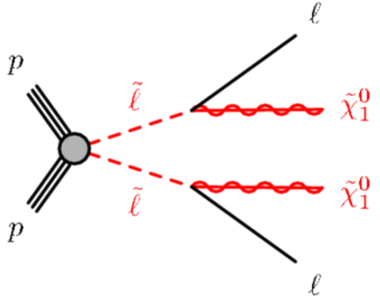
2ℓ+0jets: targets direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{l}\tilde{l}$ pair production

- Several 1D or 2D binned regions
- Same-flavor: m_{ll} vs m_{T2}
- Different-flavor: m_{T2}

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

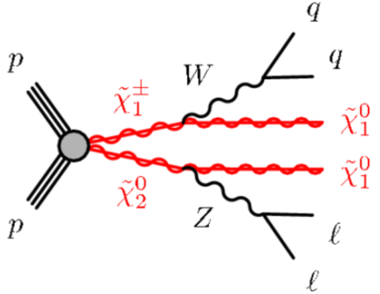
$$m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}, \mathbf{q}_{\mathrm{T}}) = \sqrt{2(p_{\mathrm{T}}q_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}} \cdot \mathbf{q}_{\mathrm{T}})}$$





2ℓ+jets: targets $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ associated production via gauge bosons

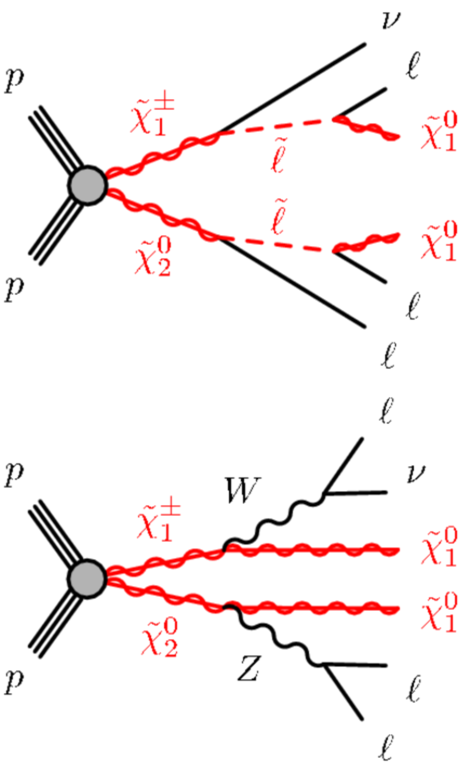
- Several binned regions targeting low and high $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}$-$\tilde{\chi}_1^{0}$ mass splitting



3-lepton searches

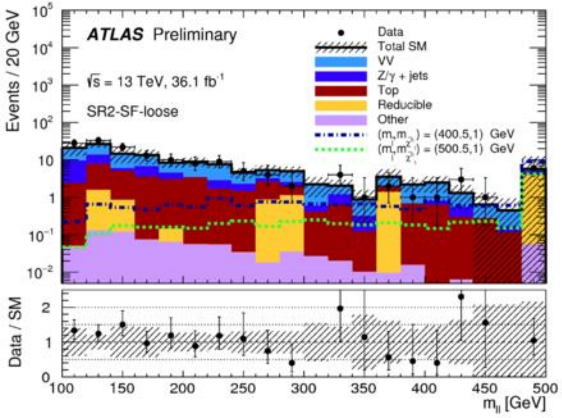
3ℓ+jets: targets $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ associated production

- Same-flavor lepton pairs
- E_T^{miss} and m_T^{min}
  - lepton pairing yielding the minimum m_T
- Binned signal regions optimized for the $\tilde{l}$-mediated and gauge-boson-mediated decays
- Defined using E_T^{miss}, m_T^{min}, m_{ll} and p_T^{l3}

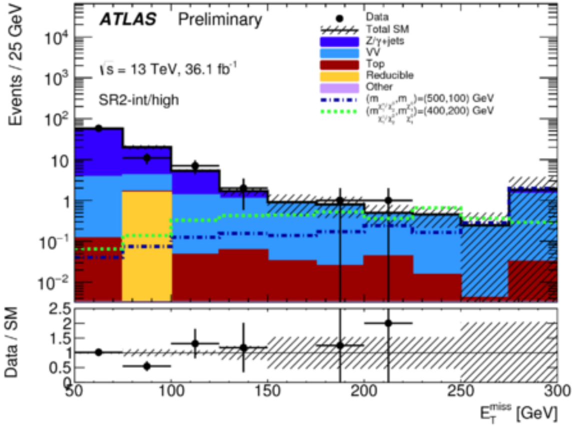


$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$: pure Wino
$\tilde{\chi}_1^0$: pure Bino

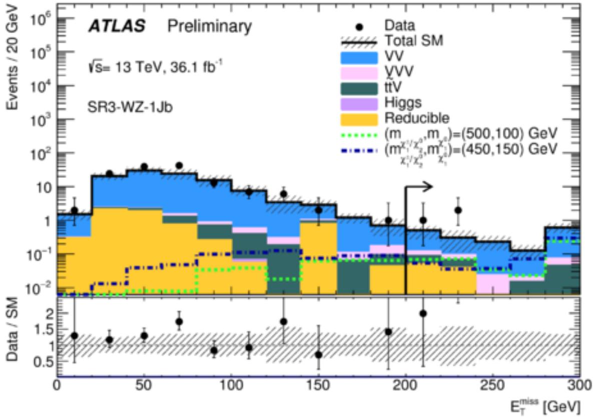
Signal region distributions



2ℓ+0jets: inclusive signal region with loose m_{ll} and m_{T2} cuts



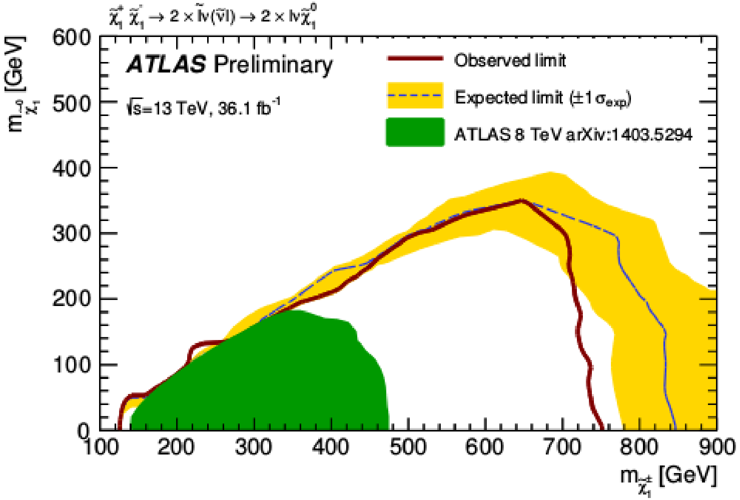
2ℓ+jets: inclusive signal regions targeting intermediate and high $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ - $\tilde{\chi}_1^0$ mass splitting



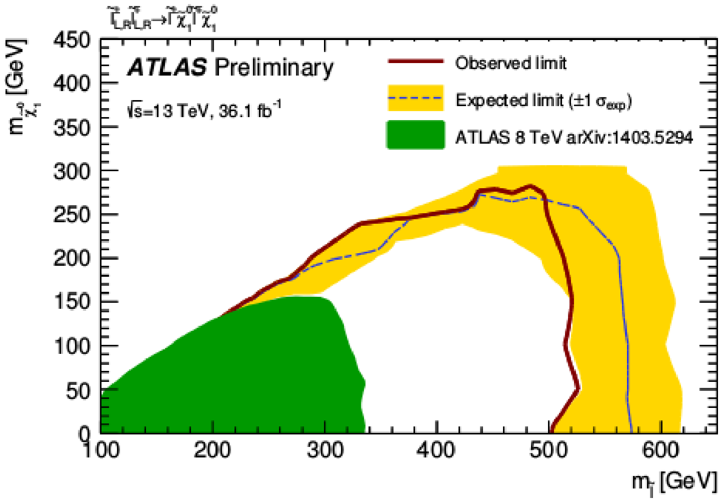
3ℓ: signal region targeting WZ-mediated decays with m_{ll} consistent to m_Z

Dominant backgrounds: Z+jets (data-driven estimate using γ+jets) & **di-bosons** (MC for shape, Data for normalization)

Exclusion limits: **2l+0jets signal regions**



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

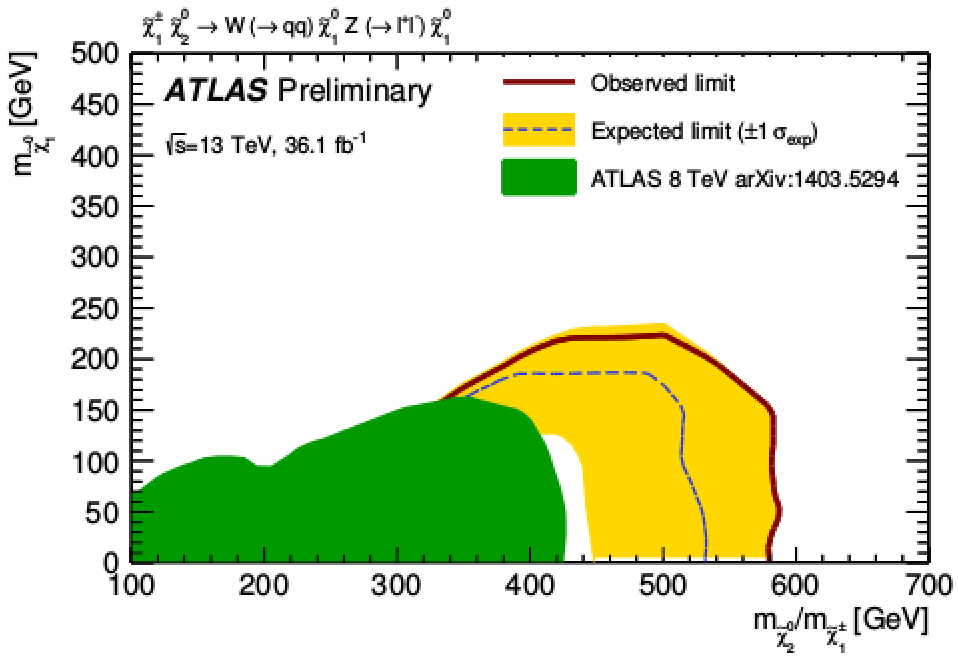


(b) Direct $\tilde{\ell}$ pair production (combined left-handed, $\tilde{\ell}_L$, and right-handed sleptons, $\tilde{\ell}_R$)

NLPS masses excluded up to 750 GeV for massless $\tilde{\chi}_1^0$

Slepton masses excluded up to 500 GeV for massless $\tilde{\chi}_1^0$ and mass-degenerate left-/right-handed $\tilde{l}$

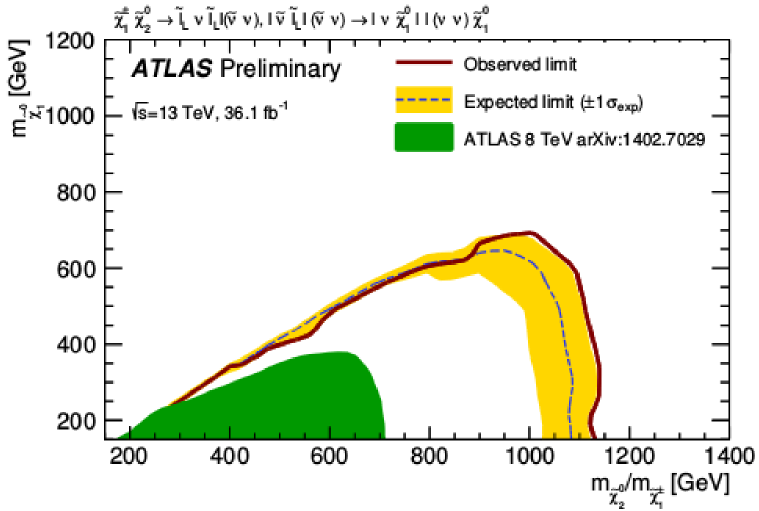
Exclusion limits: **2l+jets signal regions**



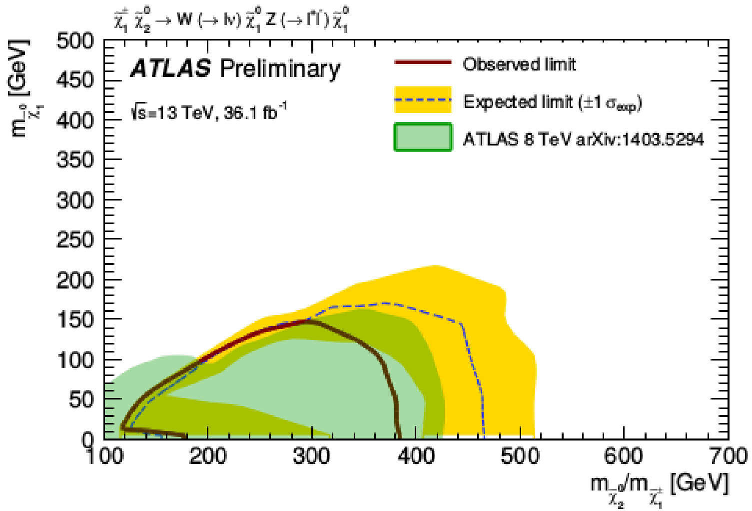
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production with decays via gauge bosons

NLPS masses excluded up to ~580 GeV for massless $\tilde{\chi}_1^0$

Exclusion limits: **3l signal regions**



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



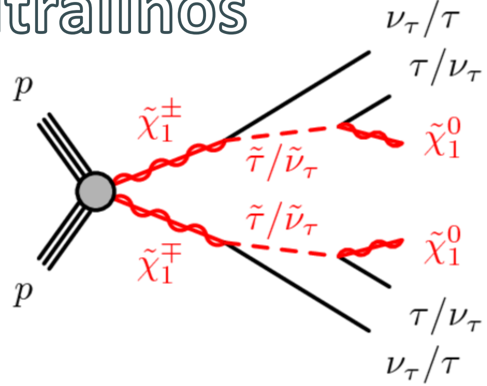
(b) Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ pair production with WZ-mediated decays

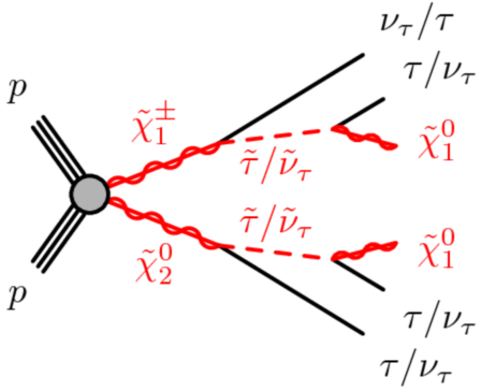
NLPS masses excluded up to 1150 GeV for m($\tilde{\chi}_1^0$) = 200 GeV

NLPS masses excluded up to 380 GeV for massless $\tilde{\chi}_1^0$

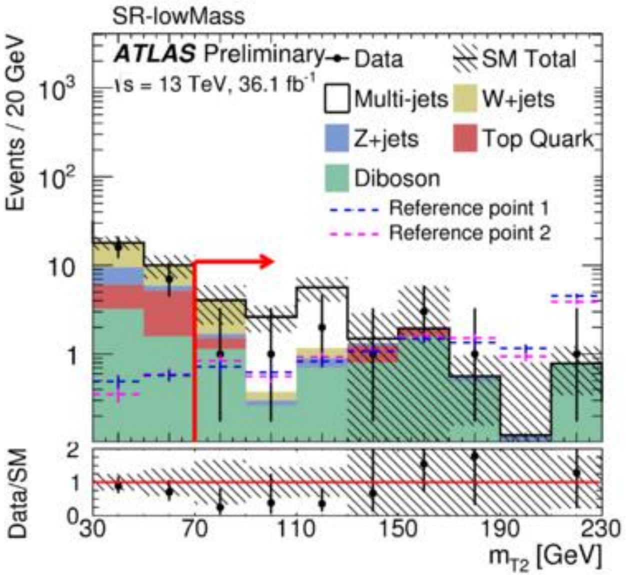
Direct production of charginos and neutralinos

- Well motivated scenarios:
  - Models with light staus can lead to DM relic density consistent with cosmological observations
  - Light sleptons could play role in co-annihilation of neutralinos ($m \sim \mathcal{O}(100)$ *GeV*)
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production with $\tilde{\chi}_1^{0}$ being a pure Bino and $\tilde{\tau}_1$a pure $\tilde{\tau}_{\mathrm{L}}$
- 2 signal regions based on m_{T2} and E_T^{miss}
- Cover regions with $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^{0}) \gtrsim 200$ GeV
- Target events with all-hadronic τ decays

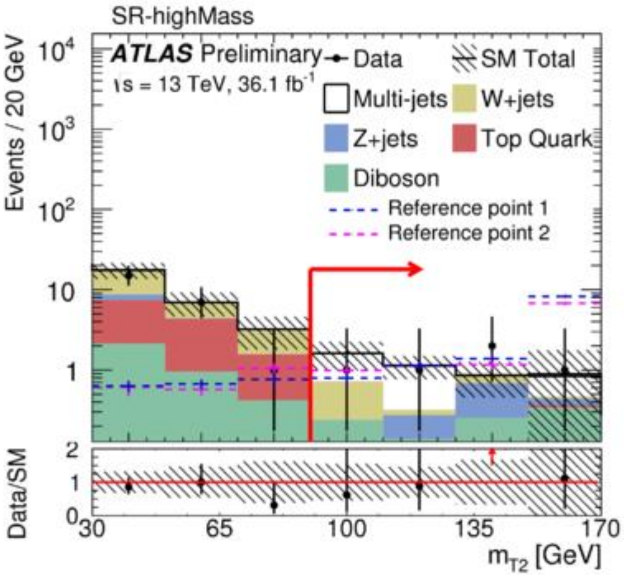




Distributions in signal regions



m_{T2} in the “low-mass” signal region



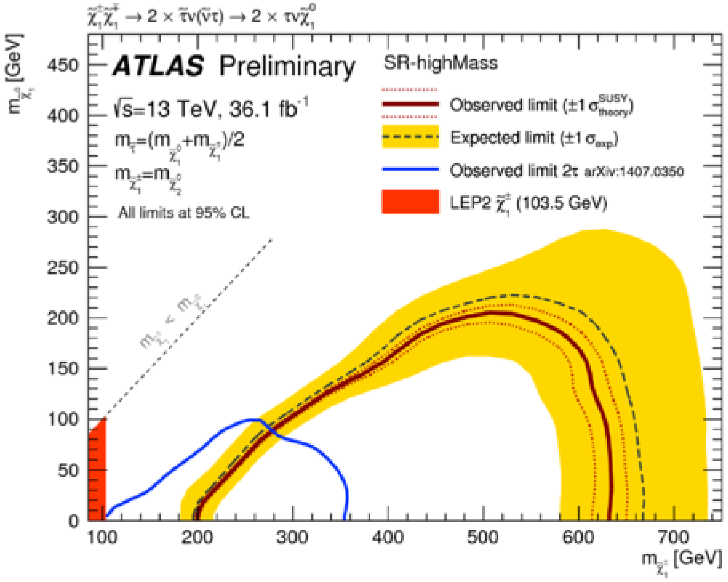
m_{T2} in the “high-mass” signal region

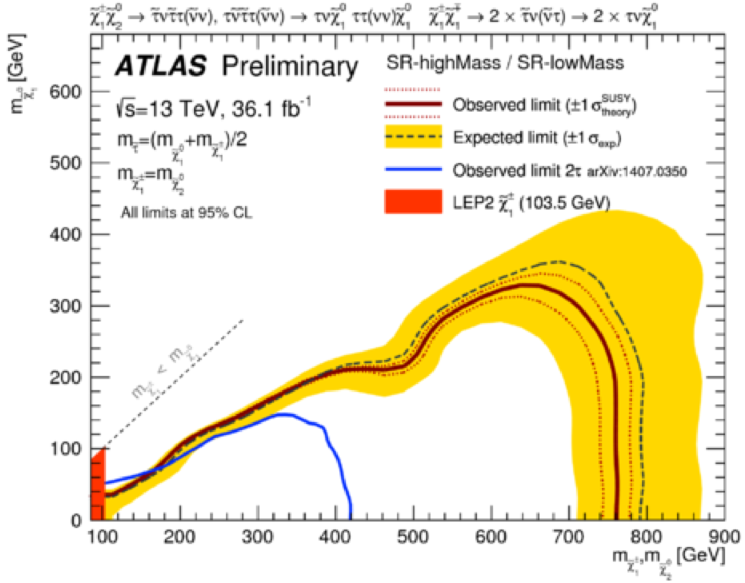
---- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production with m(C1, N2) = 600 GeV

---- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ production with m(C1) = 600 GeV

$\tilde{\chi}_1^{0}$ is massless

Exclusion Contours





Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ search:

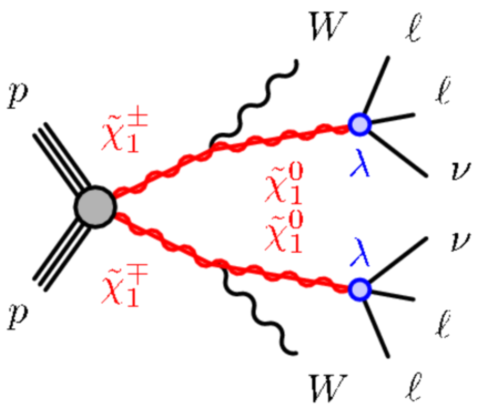
$\tilde{\chi}_1^{\pm}$ masses excluded up to 630 GeV for massless $\tilde{\chi}_1^0$

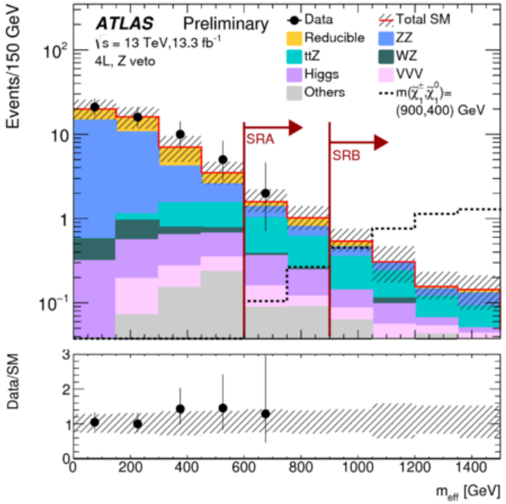
Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ combined:

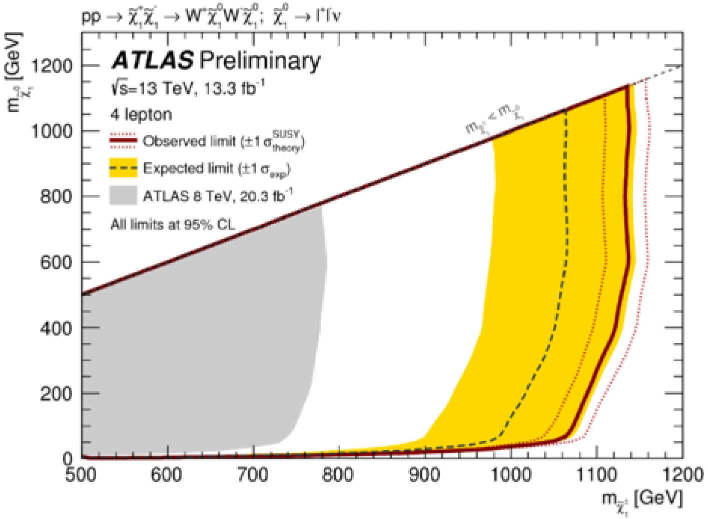
$\tilde{\chi}_1^{\pm}$ /$\tilde{\chi}_2^0$ masses excluded up to 760 GeV for massless $\tilde{\chi}_1^0$

→Limits significantly extend previous LEP, ATLAS and CMS results in the high $\tilde{\chi}_1^{\pm}$ mass region

4 leptons







Wino-like chargino production with indirect R-parity violation decays

$$\tilde{\chi}_1^0 \rightarrow \ell_k^{\pm} \ell_{i/j}^{\mp} \nu_{j/i}$$

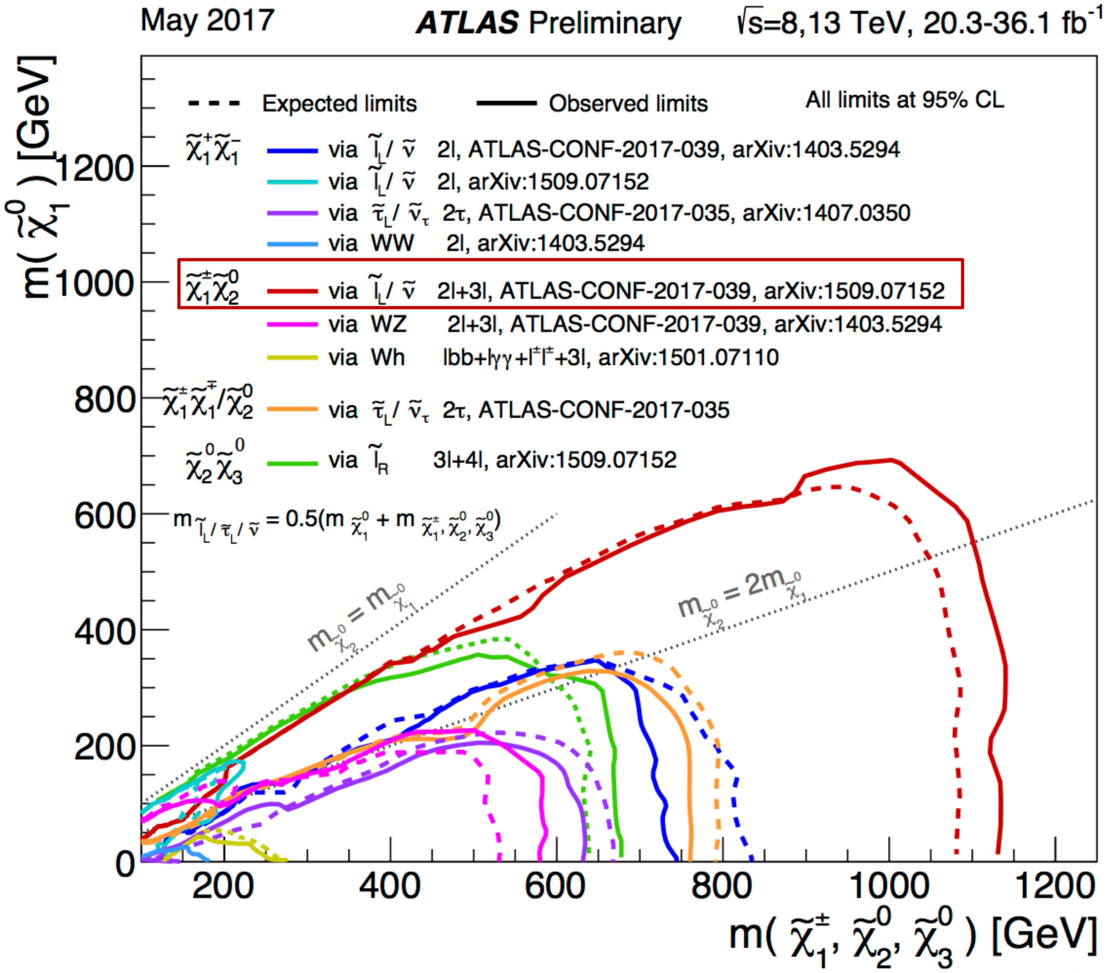
m_{eff} distribution

$m_{eff} = \Sigma\ pT(l) + \Sigma\ pT(jets) + E_T^{miss}$

$\tilde{\chi}_1^{\pm}$ masses excluded up to ~1.1 TeV at 95% CL

Exclusions Landscape

- 95% CL exclusion limits on $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, and $\tilde{\chi}_2^{0}\tilde{\chi}_3^{0}$ production with either SM-boson-mediated or slepton-mediated decays
- As a function of the $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^{0}$, $\tilde{\chi}_3^{0}$ and $\tilde{\chi}_1^{0}$ masses
- The production cross-section is for *pure wino* $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, and *pure higgsino* $\tilde{\chi}_2^{0}\tilde{\chi}_3^{0}$
- ---, --- : analyses involving $\tilde{\tau}$'s



Synopsis

- Searches for the electroweak production of neutralinos, charginos and sleptons decaying into final states with SM leptons, E_T^{miss} and jets are performed
- Absence of significant excess over the SM background expectations $\Rightarrow$ results used to set exclusion limits on several simplified SUSY scenarios
- Gaugino masses are excluded up to ~1.05 TeV assuming massless LSP $\tilde{\chi}_1^0$
- ATLAS aims to use even more advance techniques and analyze the new LHC data, in order maximize sensitivity in the quest of SUSY!

References

- Summary plots from the ATLAS Supersymmetry physics group, Webpage
- Search for electroweak production of supersymmetric particles in the two and three lepton final state at √=13TeV with the ATLAS detector, ATLAS-CONF-2017-039
- Search for the direct production of charginos and neutralinos in final states with tau leptons in s√= 13 TeV pp collisions with the ATLAS detector, ATLAS-CONF-2017-035
- Search for supersymmetry in events with four or more leptons in s√=13TeV pp collisions using 13.3fb−1 of ATLAS data, ATLAS-CONF-2016-075

Backup

The Venetian Walls of Nicosia, Cyprus

Built: 1567–1570
Architect: Giulio Savorgnano
Republic of Venice

2/3 Leptons

Definitions of the binned and inclusive signal regions for the 2 +0jets channel

2ℓ+0jets binned signal region definitions			
m_{T2}[GeV]	$m_{\ell\ell}$ [GeV]	SF bin	DF bin
100-150	111-150	SR2-SF-a	SR2-DF-a
	150-200	SR2-SF-b	
	200-300	SR2-SF-c	
	> 300	SR2-SF-d	
150-200	111-150	SR2-SF-e	SR2-DF-b
	150-200	SR2-SF-f	
	200-300	SR2-SF-g	
	> 300	SR2-SF-h	
200-300	111-150	SR2-SF-i	SR2-DF-c
	150-200	SR2-SF-j	
	200-300	SR2-SF-k	
	> 300	SR2-SF-l	
> 300	> 111	SR2-SF-m	SR2-DF-d
2ℓ+0jets inclusive signal region definitions			
> 100	> 111	SR2-SF-loose	-
> 130	> 300	SR2-SF-tight	-
> 100	-	-	SR2-DF-100
> 150	-	-	SR2-DF-150
> 200	-	-	SR2-DF-200
> 300	-	-	SR2-DF-300

Binned signal regions are used to maximize exclusion sensitivity across the C1C1 pair production and direct slepton pair production grids.

In the SF regions a two-dimensional binning in m_{T2} and m is used as this provides strong rejection against the Z/γ+jets background

In the DF regions, where the Z/γ+jets background is negligible a one-dimensional binning in m_{T2} is sufficient.

Signal region definitions used for the 2 +jets channel

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

* SR2-int and SR2-high (inclusive) are used to target intermediate and large mass splittings between the C1N2 and the LSP.

* SR2-low is defined to target lower mass splittings (in particular, the region of parameter space around {m(C1)=m(C2), m(N1)} = {200,100} GeV)

* SR2-low-2J requires exactly two jets which are both assumed to originate from the W boson

* SR2-low-3J requires 3–5 signal jets and assumes the C1N2 system recoils against initial-state-radiation (ISR) jets - The two jets originating from the W boson are selected to be those closest to the Z (→) + E T miss system that have a mass mjj consistent with the mass of the W boson.

* SR2-low: a W boson recoiling against the Z+MET system for SR2-low-2J and a W +Z+MET system recoiling against ISR jets in SR2-low-3J

Binned signal regions used in the 3 channel

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

To resolve ambiguities when multiple SFOS pairings are present, the transverse mass value of the unpaired lepton is calculated for each possible SFOS pairing and the lepton that yields the minimum transverse mass is assigned to the W boson

Background Estimate

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		

Control region and validation region definitions for the 2 +0jets channel

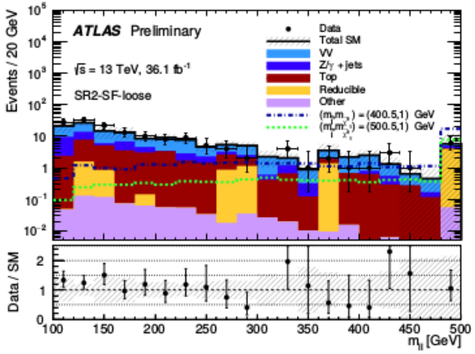
2ℓ+0jets control and validation region definitions					
Region	CR2-VV-DF	CR2-VV-SF	CR2-Top	VR2-VV-SF/DF	VR2-Top
lepton flavour	SF	DF	DF	SF (DF)	DF
$n_{\text{central non}-b-\text{tagged jets}}$	0	0	0	0	0
$n_{\text{central } b-\text{tagged jets}}$	0	0	≥ 1	0	≥ 1
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]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

- Central non-b-tagged jets: $p_{\mathrm{T}} > 60$ GeV, $|\eta| < 2.4$ and not b-tagged.
- Central b-tagged jets: $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.4$ and b-tagged.

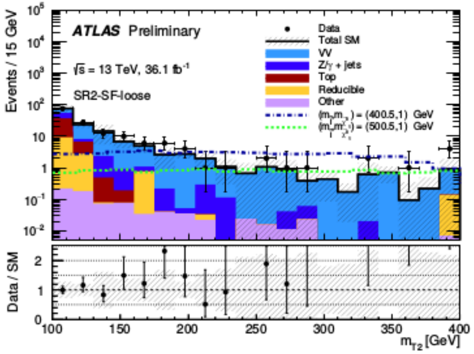
Validation region definitions used for the 2 +jets channel

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

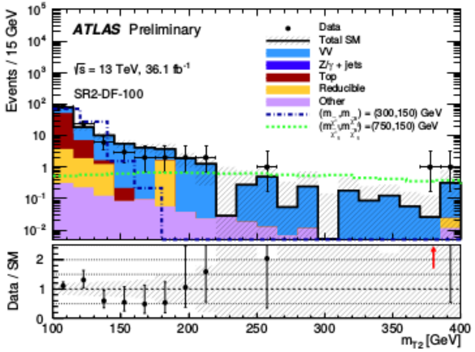
2 +0jets channel



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

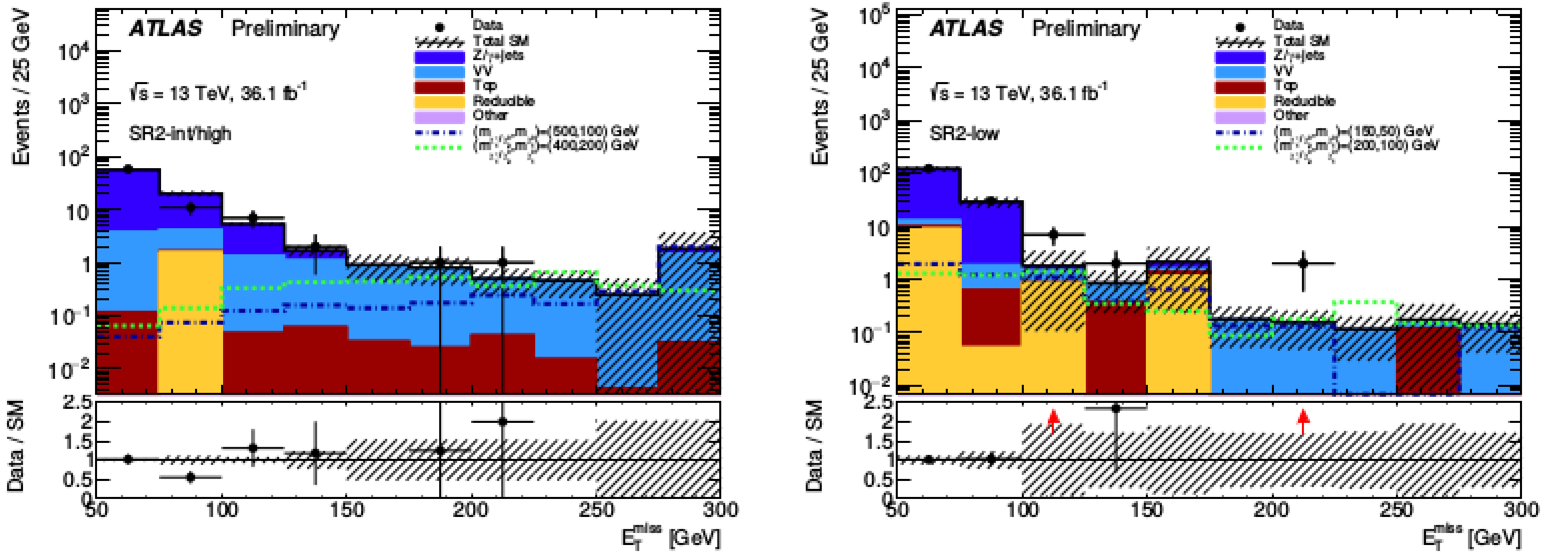


(b) m_{T2} distribution in SR2-SF-loose



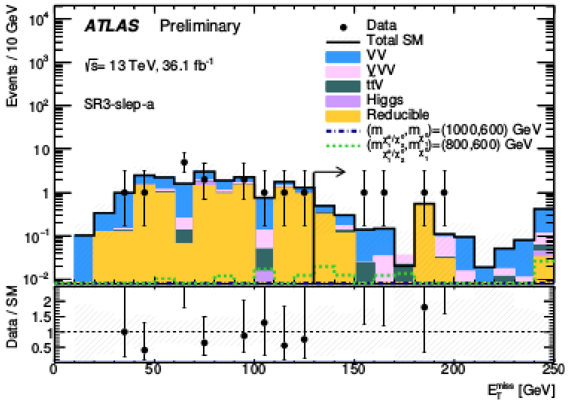
(c) m_{T2} distribution in SR2-DF-100

2l+jets

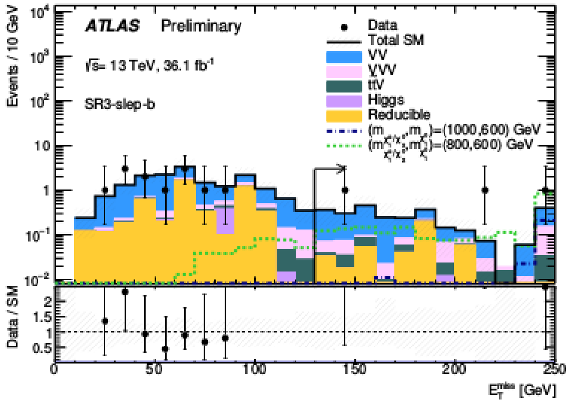


(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR2-int/high (b) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR2-low

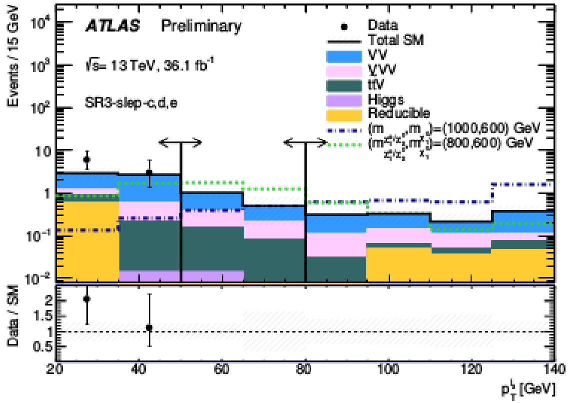
3l channel



(a) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR3-slep-a

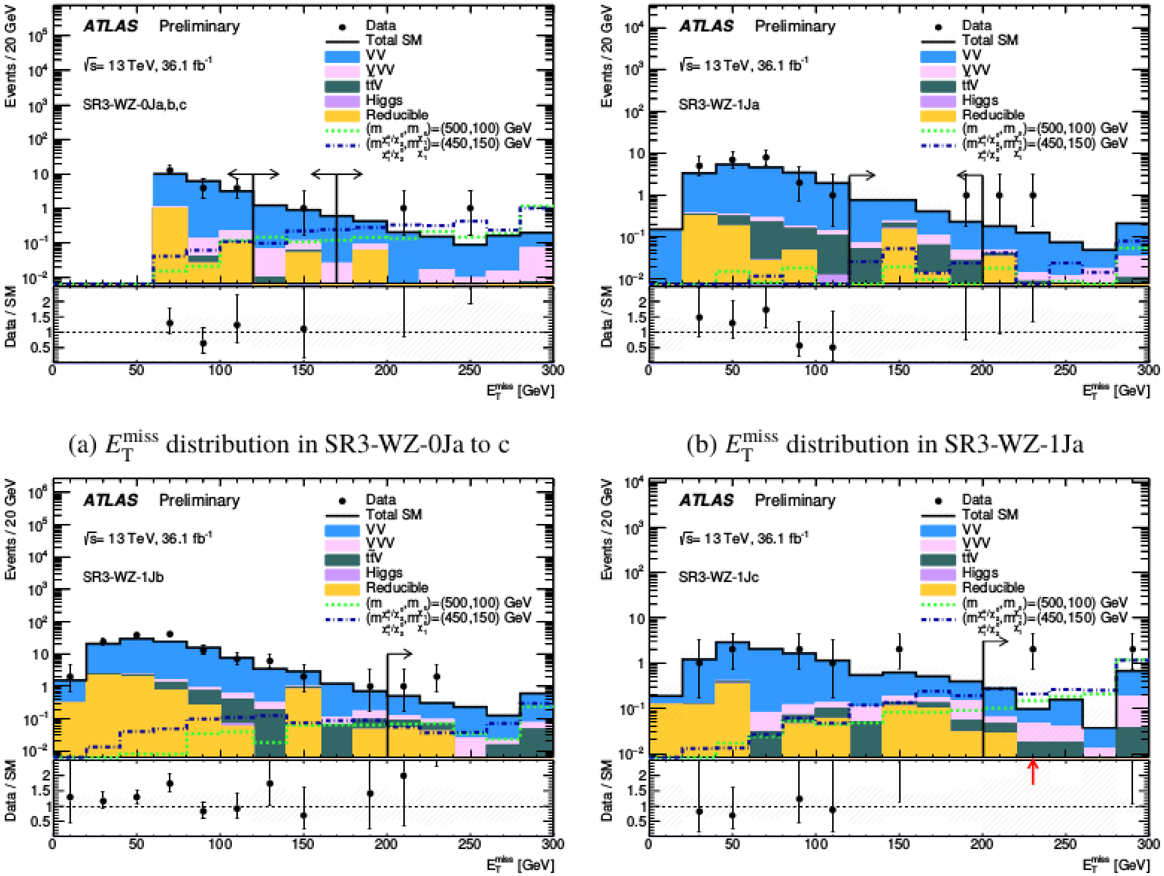


(b) $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution in SR3-slep-b



(c) Distribution of third leading lepton p_{T} in SR3-slep-c to e

3l channel



(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

staus

Stau searches

→ Mass of lightest 3rd-generation sparticles, $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$ should be ~$\mathcal{O}$(100 GeV)

- arguments suggested by Naturalness to protect m_H from quadratically divergent quantum corrections

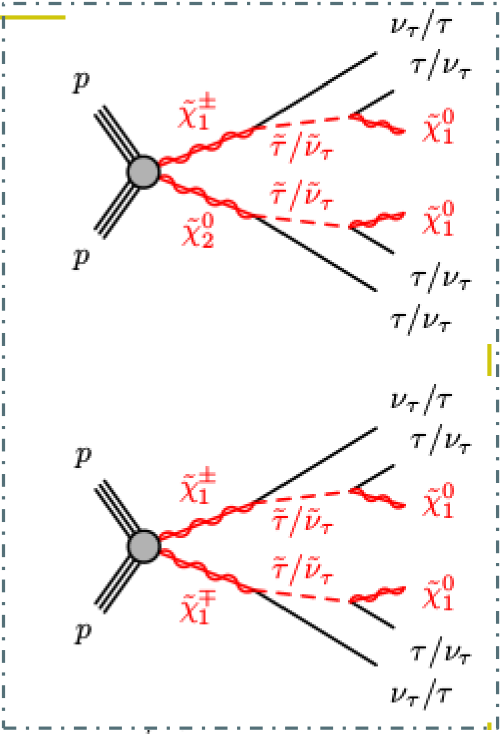
→ Models with light $\tilde{\tau}$ are consistent with current matter data from cosmological observations

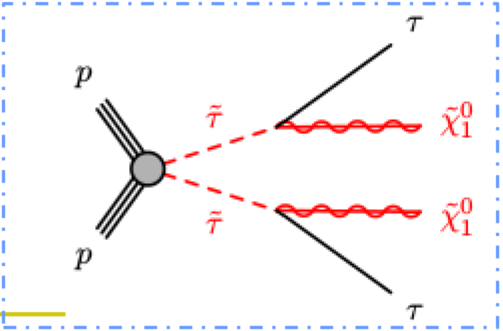
→ In the context of pMSSM, EW production of direct $\tilde{\tau}$'s becomes dominant if $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$ are heavy ($\tilde{\chi}_1^0$ is bino-like):

$$\begin{aligned} \sigma(\tilde{\tau}_L) &\sim 270 \rightarrow 0.5 \text{ fb} \\ \sigma(\tilde{\tau}_R) &\sim 97 \rightarrow 0.2 \text{ fb} \\ m_{\tilde{\tau}} &\sim 100 \rightarrow 500 \text{ GeV} \end{aligned}$$

Simplified model with stau mixing

$$\tilde{\tau}_1 = \tilde{\tau}_R,\ \tilde{\tau}_2 = \tilde{\tau}_L$$





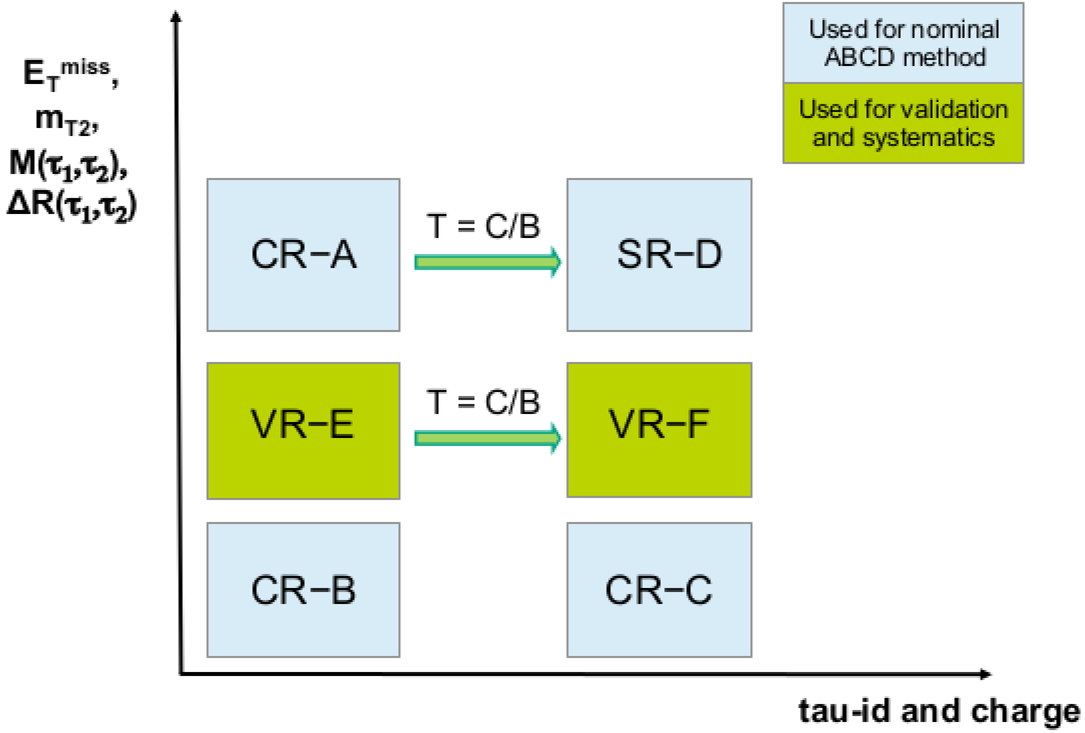
Signal Regions

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	
$m_{T2} > 70$ GeV	$m_{T2} > 90$ GeV	
di-tau+E_T^{miss} trigger	di-tau+E_T^{miss} trigger	asymmetric di-tau trigger
$E_T^{miss} > 150$ GeV	$E_T^{miss} > 150$ GeV	$E_T^{miss} > 110$ GeV
$p_{T,\tau_1} > 50$ GeV	$p_{T,\tau_1} > 80$ GeV	$p_{T,\tau_1} > 95$ GeV
$p_{T,\tau_2} > 40$ GeV	$p_{T,\tau_2} > 40$ GeV	$p_{T,\tau_2} > 65$ GeV

- SR-lowMass (SR-highMass) to cover signal models where the mass difference between the C1/N1 is smaller (larger) than 200 GeV.
- In SR-lowMass, only the di-tau+E T miss trigger is used
- In SR-highMass events are selected with the di-tau+E T miss trigger or by the asymmetric di-tau trigger

Background estimate

- CR-B and CR-C, events are recorded using a di-tau trigger
- multi-jet events in the control and validation regions is estimated from data after subtraction
- of other SM contributions estimated from MC simulation
- CR-B and VR-E more than 86 % of the events come from multi-jet production
- CR-A and CR-C the multi-jet purity is larger than 47 % and 68 %, respectively
- The signal contamination in CR-A for both SRs ranges from a few percent to 30–50 % for a few signal models, and it is taken into account in the simultaneous fit



ABCD Definitions

CR-A	SR-D (SR-lowMass)
di-tau+E_T^{miss} trigger	
≥ 2 loose tau leptons (SS) $m(\tau_1, \tau_2) < 250$ GeV $\Delta R(\tau_1, \tau_2) > 1.5$ $E_T^{miss} > 150$ GeV $m_{T2} > 70$ GeV	≥ 2 medium tau leptons (OS) $E_T^{miss} > 150$ GeV $m_{T2} > 70$ GeV
VR-E	**VR-F**
di-tau trigger	
≥ 2 loose tau leptons (SS) $m(\tau_1, \tau_2) < 250$ GeV $\Delta R(\tau_1, \tau_2) > 1.5$ $E_T^{miss} > 40$ GeV $50 < m_{T2} < 70$ GeV	≥ 2 medium tau leptons (OS) $E_T^{miss} > 40$ GeV $50 < m_{T2} < 70$ GeV
CR-B	**CR-C**
di-tau trigger	
≥ 2 loose tau leptons (SS) $m(\tau_1, \tau_2) < 250$ GeV $\Delta R(\tau_1, \tau_2) > 1.5$ $E_T^{miss} > 40$ GeV $20 < m_{T2} < 50$ GeV	≥ 2 medium tau leptons (OS) $E_T^{miss} > 40$ GeV $20 < m_{T2} < 50$ GeV

CR-A	SR-D (SR-highMass)
di-tau+E_T^{miss} or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS) < 1 medium 1 tight tau leptons $\Delta R(\tau_1, \tau_2) > 1.8$ $E_T^{miss} > 110$ GeV $m_{T2} > 90$ GeV	≥ 2 medium tau leptons (OS) ≥ 1 tight tau lepton $E_T^{miss} > 110$ GeV $m_{T2} > 90$ GeV
VR-E	**VR-F**
di-tau or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS) < 1 medium 1 tight tau leptons $\Delta R(\tau_1, \tau_2) > 1.8$ $E_T^{miss} > 40$ GeV $60 < m_{T2} < 90$ GeV	≥ 2 medium tau leptons (OS) ≥ 1 tight tau lepton $E_T^{miss} > 40$ GeV $60 < m_{T2} < 90$ GeV
CR-B	**CR-C**
di-tau or asymmetric di-tau trigger	
≥ 2 loose tau leptons (OS) < 1 medium 1 tight tau leptons $\Delta R(\tau_1, \tau_2) > 1.8$ $E_T^{miss} > 40$ GeV $10 < m_{T2} < 60$ GeV	≥ 2 medium tau leptons (OS) ≥ 1 tight tau $E_T^{miss} > 40$ GeV $10 < m_{T2} < 60$ GeV

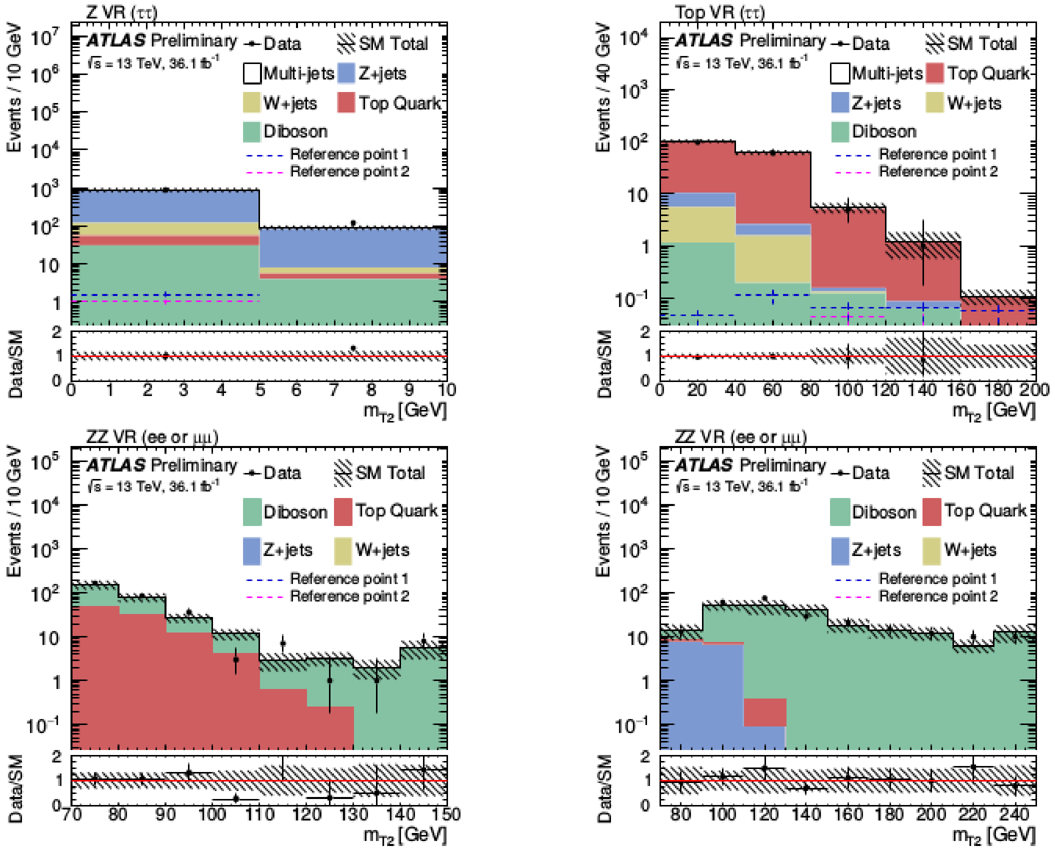
Z and Top Validation Regions

Z-VR	Top-VR
at least one opposite sign tau lepton pair	
tau $p_T > 50, 40$ GeV	
$E_T^{miss} > 60$ GeV	
at least two medium tau leptons	at least one medium and one loose tau lepton
b-jet veto	at least 1 b-jet
$m_{T2} < 10$ GeV	$m_{T2} > 10$ GeV
	m_{CT} top-tagged

WW and ZZ Validation regions

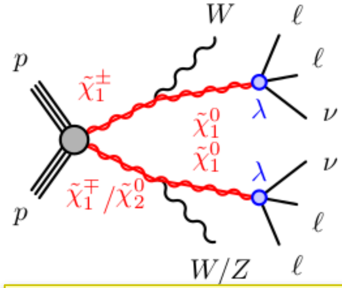
WW-VR	ZZ-VR
one opposite sign lepton pair	
$\mu\ p_{\mathrm{T}}$ >30 GeV, $e\ p_{\mathrm{T}}$ > 40 GeV	
jet veto	
$m_{\ell\ell}$ > 50 GeV	
$E_{\mathrm{T}}^{\mathrm{miss}}$ >50 GeV	
$m_{T\mu}$ > 100 GeV	
m_{T2} > 70 GeV	
two isolated leptons (e or μ) with different flavor	two isolated leptons (e or μ) with same flavor
m_{CT} top tag veto	$\Delta R(\ell,\ell) < 1.5$
	$\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV

VR Distributions

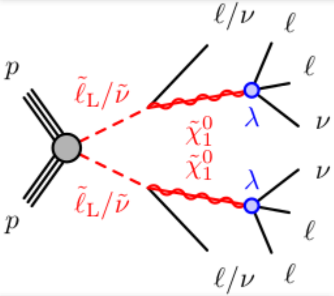


4L RPV

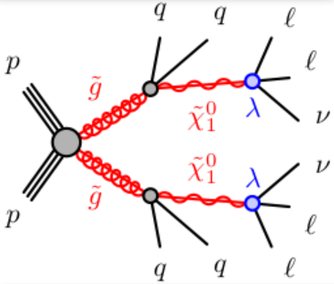
RPV Scenarios



m-degenerate wino-like NLSP



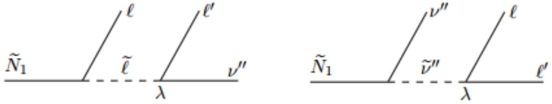
m-degenerate $\tilde{\ell}_L, \tilde{\nu}$



gluino pair-produced NLSP

- Simplified models of with RPC cascade & RPV decay scenarios where the LSP is a bino-like $\tilde{\chi}_1^0$ & prompt $10 \leq m_{LSP} \leq m_{NLSP} - 10$ *GeV*

- The RPV LSP decay is mediated by the lepton-number-violating super-potential term:



$$W_{LL\bar{E}} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k$$

Yukawa coupling

Lepton SU(2)-doublet super-field

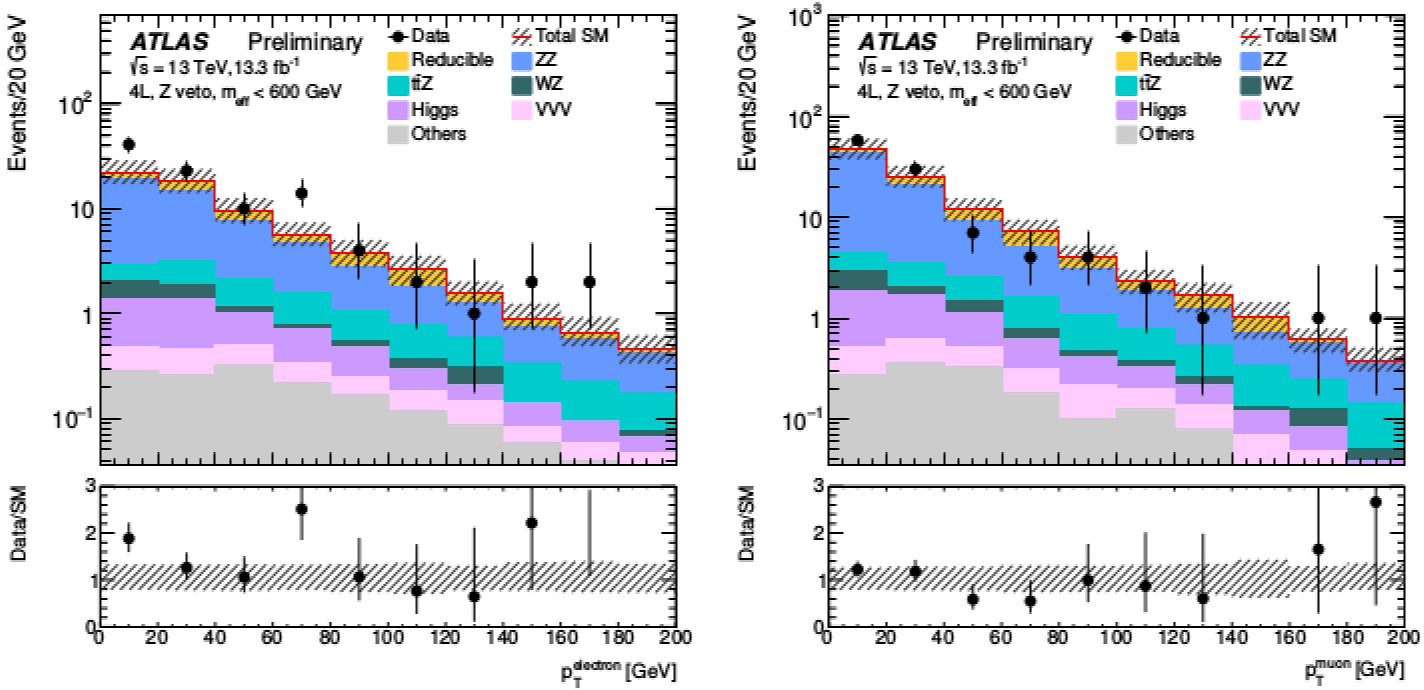
Lepton singlet super-field

- Two extreme scenarios of the λ_{ijk} RPV couplings are considered with different sensitivity
  - **LLE12k:** e,μ - enriched
  - **LLEi33:** τ-favored

Regions

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

VR Distributions



FF method

To account correctly for the relative abundances of fake lepton types and production processes, a weighted average Fw of fake factors is computed in each CR, as:

$$F_w = \sum_i \left(R^i \times F^i\right)$$

Number of reducible backgrounds

$$N_{\text{red}}^{\text{SR}} = [N_{\text{data}}^{\text{CR}} - N_{\text{irr,1-fake}}^{\text{CR}}] \times F_{w,1} \times F_{w,2}.$$