Searches for the electroweak production of supersymmetric particles with the ATLAS detector

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on behalf of the ATLAS collaboration

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– virtual conference

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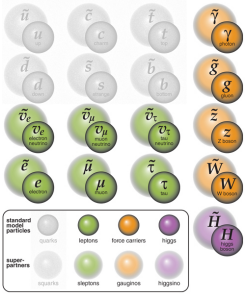
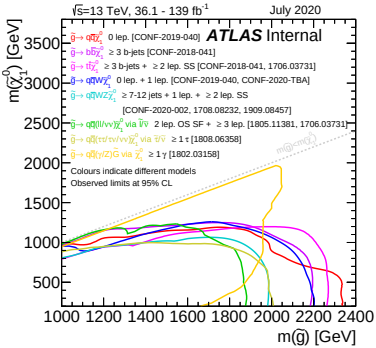
Motivation for *electroweak* supersymmetry

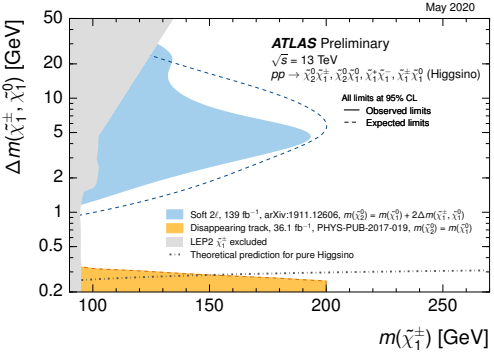
- Limits on **strong SUSY production** reaching beyond the TeV scale, while constraints on **electroweak SUSY production** are weaker
  - natural SUSY under pressure given broad exclusion

  → Electroweak sector important in continuing searches at LHC

- **Using the full Run 2 dataset**:
  - keep pushing the limits, but also make sure to *cover gaps in challenging regions*
  - consider wide range of *interpretations*: production mode, LSP, mass hierarchy, ...







ATLAS searches for electroweak supersymmetry

- Considering various **production modes**, *intermediate states*, and final states
- Simplified model interpretations and model independent results

Electroweakino pair production

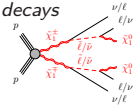
intermediate boson decays

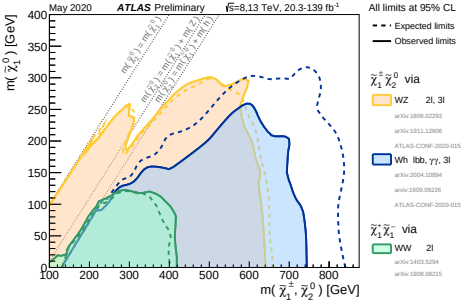
$\geq 4\ell$ NEW, 3ℓ RECENT,

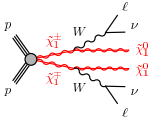
soft 2ℓ, $2\ell 0j$, Wh $\gamma\gamma$ and $1\ell b\bar{b}$

slepton decays

$2\ell 0j$

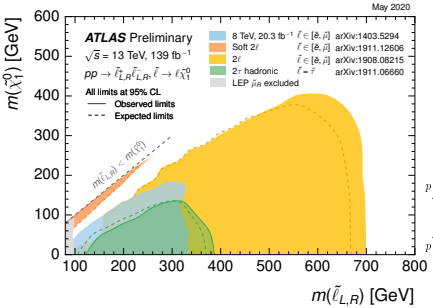


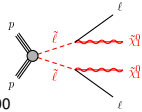




Direct slepton production

soft 2ℓ, $2\ell 0j$, scalar taus





RPV scenarios

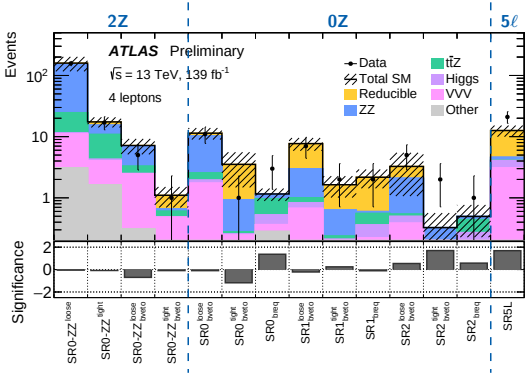
$\geq 4\ell$ NEW – $\tilde{\chi}_1^0 \to \ell\ell\nu$ decays

3ℓ RECENT – RPV decays of $\tilde{\chi}_1^\pm/\tilde{\chi}_1^0$ via intermediate bosons

$\geq 4\ell$ NEW

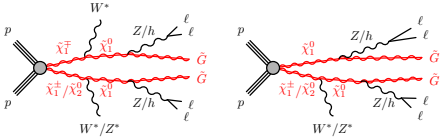
search considering final states with $\geq$4 leptons ($\leq$2 hadronic τ_h)

- RPC & RPV interpretations
- high lepton multiplicity, E_T^{miss} & m_{eff} provide good handles for background rejection
  - irreducible background: **ZZ** and **$t\bar{t}Z$**
  - reducible background: **fake leptons** w/ dedicated fake measurement region per region
- signal regions separated by
  - presence/absence of Z bosons (2Z/0Z)
  - τ_h & b-jet multiplicity
  - E_T^{miss} or m_{eff}



GGM

- light mass degenerate higgsino triplet
- nearly massless gravitino LSP

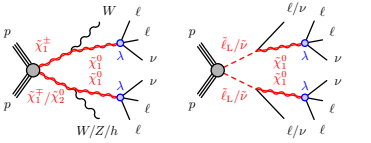


$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}$ *production* $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}/\tilde{\chi}_1^{0}\tilde{\chi}_2^{0}$ *production*

RPV

(see also talk by J. Junggeburth, 28/July)

- $\tilde{\chi}_1^0 \to \ell^{\pm}\ell^{\mp}\nu$ decays, wino/slepton/gluino NLSP
- considering τ multiplicity extremes of LL$\bar{\text{E}}$ coupling: λ_{12k} and λ_{i33}



wino NLSP *slepton NSLP* *gluino NLSP*

$\geq 4\ell$ NEW – GGM targetting regions

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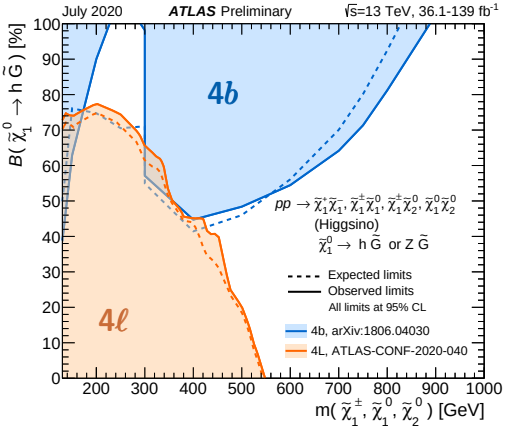
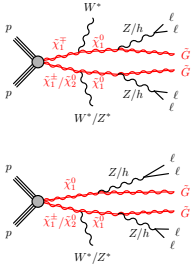
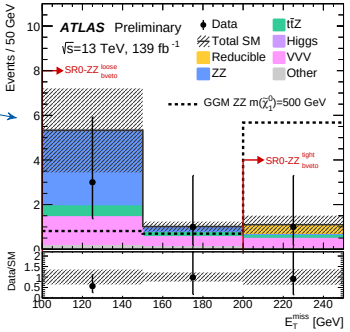
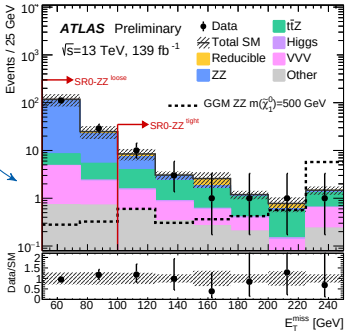
- **4L0T regions**: 2Z boson selection, E_T^{miss} thresholds, and b-veto
- follow-up on excess from PhysRevD.98.032009 regions without b-veto
- dominant backgrounds: **ZZ**, **ttZ** and **VVV**, as well as **(two) fake leptons**
- due to relatively high $Z \to \ell\ell$ branching ratio, better sensitivity to $\mathcal{B}(\tilde{\chi}_1^0 \to Z + \tilde{G})$ than to $\mathcal{B}(\tilde{\chi}_1^0 \to h + \tilde{G})$



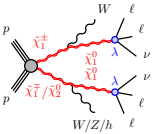




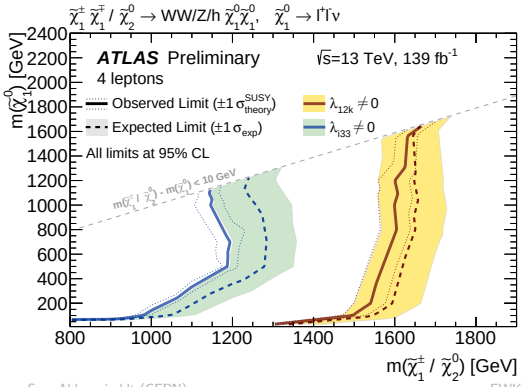


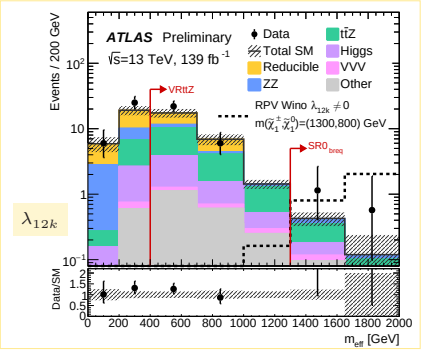
$\geq 4\ell$ NEW – RPV targetting regions

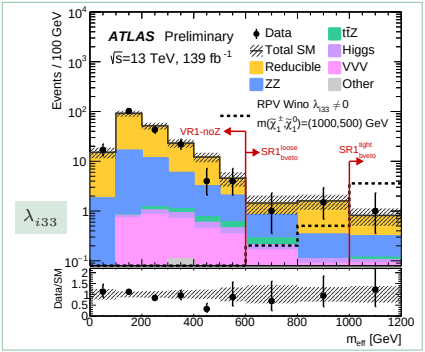
- **4L0T** (λ_{12k} (k=1,2)) and **3L1T/2L2T** (λ_{i33} (i=1,2)) regions
- selection using **Z-veto** and separating by **b-multiplicity**
  - general SRs & VRs with moderate m_{eff} threshold
  - specific λ_{ijk} targetting SRs at very high m_{eff}
- dominant backgrounds: **ZZ** and **$t\bar{t}Z$**, as well as **fake leptons**



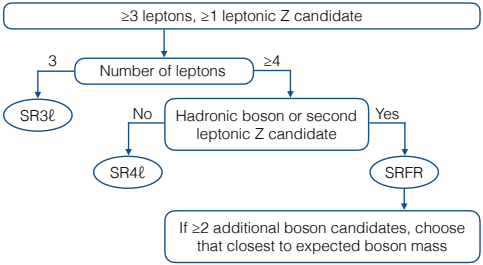
- considering $\mathcal{B}(\tilde{\chi}_1^0 \to \ell\ell\nu) = 100\%$
- showing **wino NSLP scenario**
- *slepton or gluino scenarios in backup:*
  excluding masses up to 1.23 TeV (slepton) and 2.58 TeV (gluino)

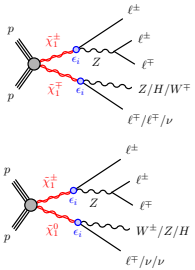


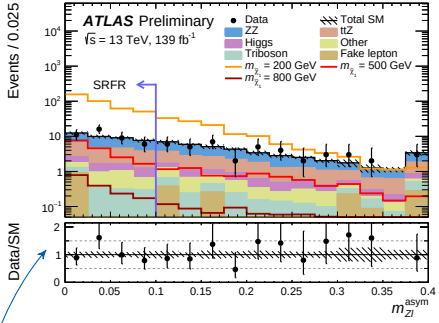


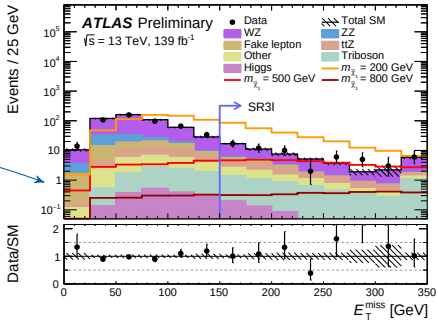


RPV chargino $\rightarrow 3\ell$ RECENT





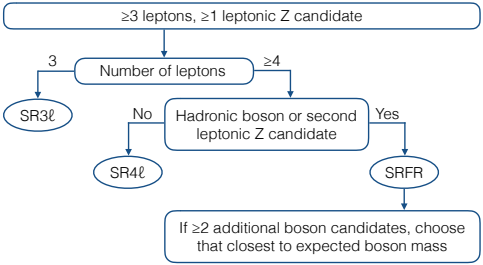


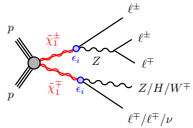


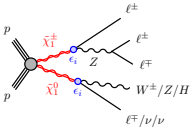
resonance search in trilepton invariant mass $m_{Z\ell}$ (one leg)

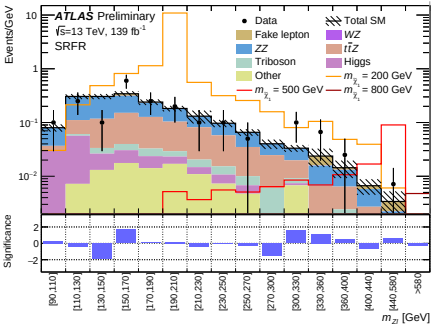
- $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ and $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ pair production and $\tilde{\chi}_1 \rightarrow Z/h/W + \ell/\nu$ decays
- **event assignment** into SR3ℓ, SR4ℓ & SRFR
- making use of mass asymmetry in two leg region: $m_{Z\ell}^{asym} = \frac{|m_{Z\ell} - m_{\tilde{\chi},2}|}{m_{Z\ell} - m_{\tilde{\chi},2}}$
- S/B discrimination in transverse mass m_T and E_T^{miss} variables
- dedicated CRs for **ZZ**, **WZ**, and **ttZ** + data-driven **fake lepton** background estimation
- simultaneous fit over all SRs and $m_{Z\ell}$ bins
- *Physics Briefing: Fantastic decays and where to find them*

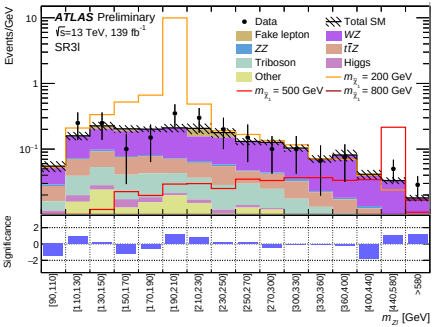
RPV chargino $\rightarrow 3\ell$ RECENT









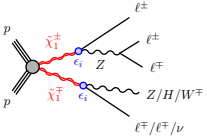


resonance search in trilepton invariant mass $m_{Z\ell}$ (one leg)

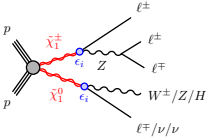
- $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ and $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ pair production and $\tilde{\chi}_1 \rightarrow$ Z/h/W + ℓ/ν decays
- **event assignment** into SR3ℓ, SR4ℓ & SRFR
- making use of mass asymmetry in two leg region: $m_{Z\ell}^{asym} = \frac{|m_{Z\ell} - m_{\tilde{\chi},2}|}{m_{Z\ell} - m_{\tilde{\chi},2}}$
- S/B discrimination in transverse mass m_T and E_T^{miss} variables
- dedicated CRs for **ZZ**, **WZ**, and **ttZ** + data-driven **fake lepton** background estimation
- **simultaneous fit over all SRs and $m_{Z\ell}$ bins**
- *Physics Briefing: Fantastic decays and where to find them*

RPV chargino $\rightarrow 3\ell$ RECENT

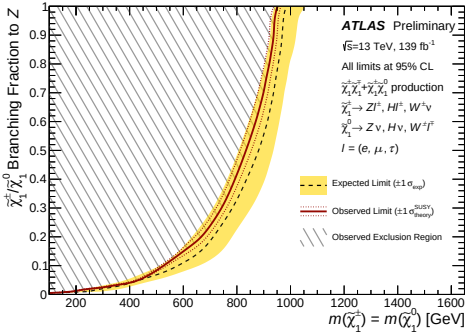
interpretation in terms of branching fraction to bosons and leptons

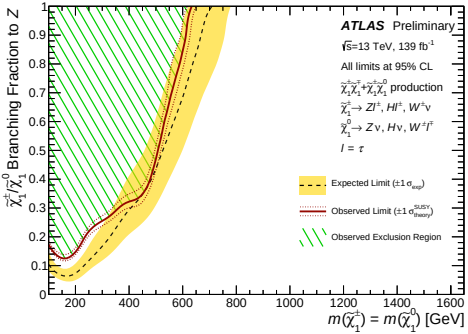


- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}$ pair production treated together, with $\mathcal{B}(\tilde{\chi}_1^{\pm})/\mathcal{B}(\tilde{\chi}_1^{0})$ fully correlated
- considering 4 scenarios for the lepton branching fraction:
  equal $\mathcal{B}(\rightarrow e, \mu, \tau)$ or 100% $\mathcal{B}(\rightarrow \ell)$ for each one individually
- results presented as a **scan of the branching fraction to bosons**



- sensitivity is dominated by $\mathcal{B}(\rightarrow Z)$, which produces the target 3ℓ resonance, and drops for $\mathcal{B}(\rightarrow Z) < 20\%$
- excluding gaugino masses up to ~1 TeV at large $\mathcal{B}(\rightarrow Z)$, for the e & μ channels
- exclusion slightly weaker for the inclusive or τ channels





3ℓ RECENT

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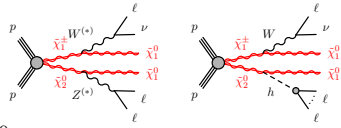
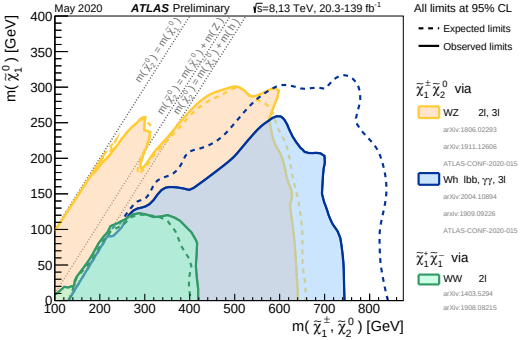
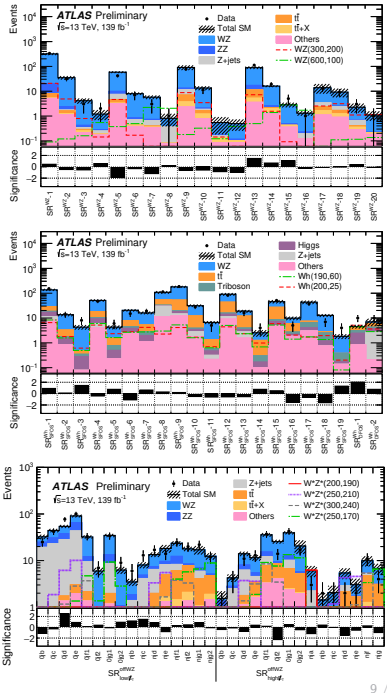
search for $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production, targetting decays with intermediate bosons and $3\ell + E_T^{miss}$ final states



- wino NLSP interpretation, $m(\tilde{\chi}_1^0)\times m(\tilde{\chi}_2^0) > 0$
- separate selections focussing on
  - $\Delta m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0 - \tilde{\chi}_1^0)$ near or above m_Z → *on-shell WZ selection & Wh selection*
  - the low Δm compressed region → *off-shell WZ selection*
- dominant background contributions from **WZ**, **$t\bar{t}$**, and **fake leptons**





3ℓ RECENT

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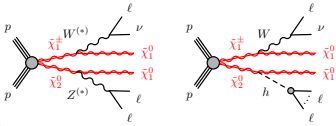

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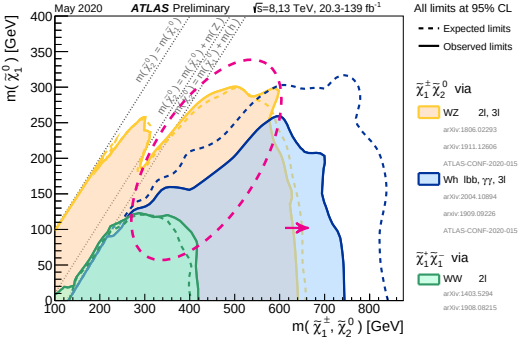

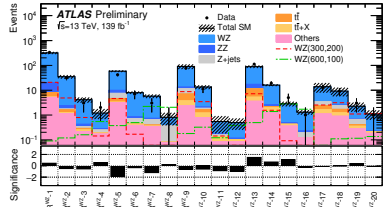

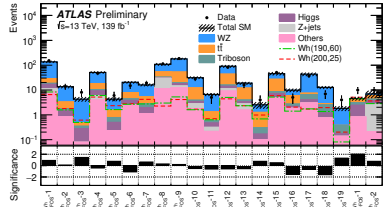

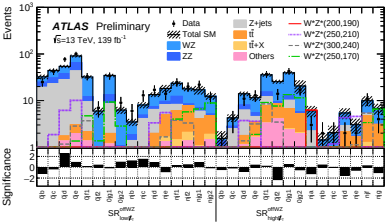

3ℓ RECENT

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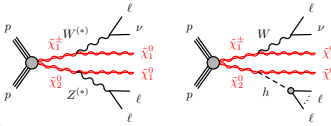
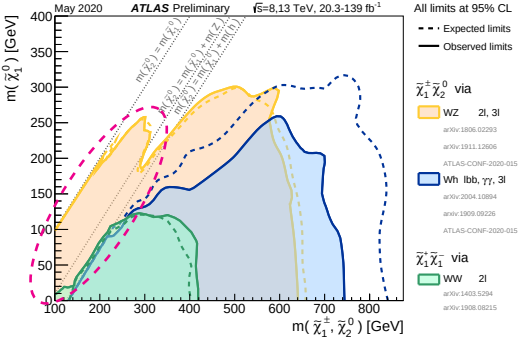
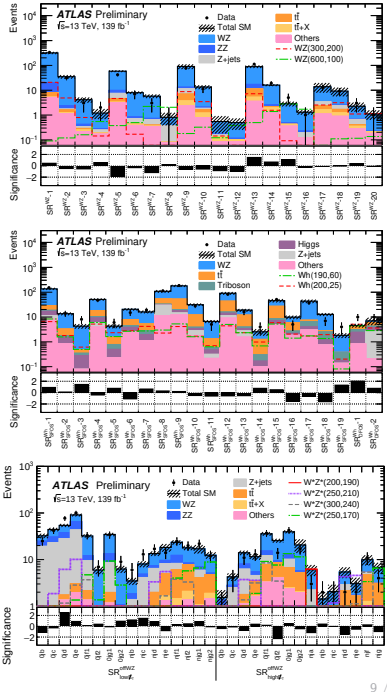
ATL-PHYS-PUB-2020-020

search for $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ pair production, targetting decays with intermediate bosons and $3\ell + E_T^{miss}$ final states

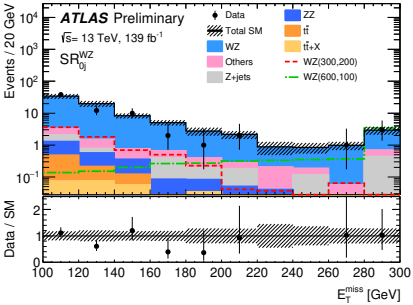


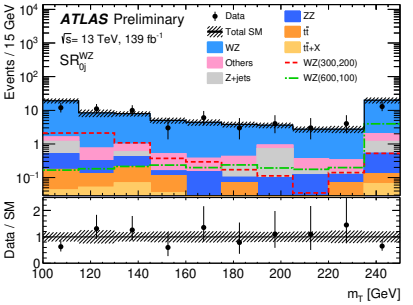
- wino NLSP interpretation, $m(\tilde{\chi}_1^0)\times m(\tilde{\chi}_2^0) > 0$
- separate selections focussing on
  - $\Delta m(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0 - \tilde{\chi}_1^0)$ near or above m_Z → *on-shell WZ selection & Wh selection*
  - the low Δm compressed region → ***off-shell WZ selection***
- dominant background contributions from **WZ**, **$t\bar{t}$**, and **fake leptons**





3ℓ RECENT – on-shell WZ & Wh selections

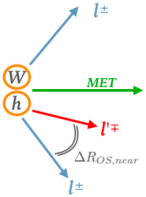


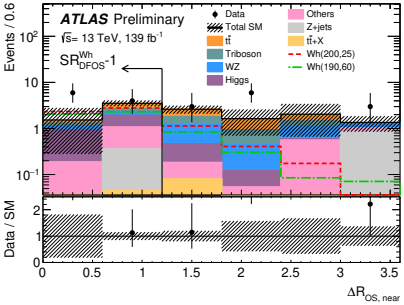


- separating events with SFOS lepton pair into three $m_{\ell\ell}$ regions:
  - one **on-shell WZ** ($\in$ [75, 105] GeV) region
  - two **Wh** ($<$75 / $>$105 GeV) regions
- target various signal Δm via
  - E_T^{miss} & m_T binnings
  - [0j/nj low H_T/nj high H_T] categories

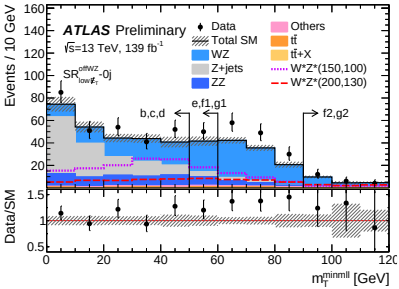
  $\rightarrow$ 20+19 SRs total
- extensive validation of dominant **WZ** background

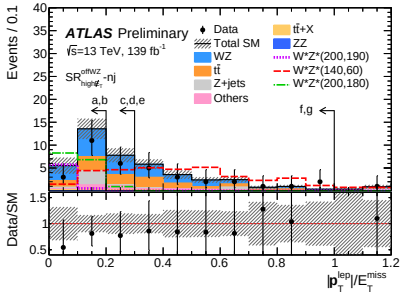
two additional DFOS lepton pair SRs for Wh selection

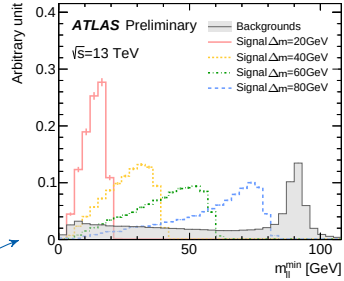




3ℓ RECENT – off-shell WZ selection

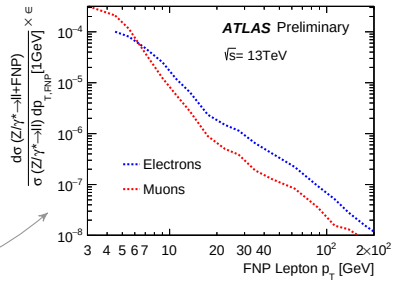






- separating events with SFOS lepton pair in **off-shell WZ** range ($m_{\ell\ell}^{min} < 75$ GeV) into four regions by low/high E_T^{miss} and 0j/nj
- slicing each region into $m_{\ell\ell}^{min}$ bins (→ 31 SRs), targetting various signal Δm and making use of signal **kinematic end points in stransverse mass $m_{T,2}^{100}$ and $m_{\ell\ell}^{min}$**
- further S/B discrimination with m_T^{mllmin} and p_T^{lep}/E_T^{miss} selection optimised per region

- improve **soft lepton** acceptance for the compressed high E_T^{miss} region using E_T^{miss} triggers (lepton triggers used elsewhere)
- **BDT-based isolation** applied on 3rd lepton, aimed to reduce **fake lepton background** (see also talk by S. Chen , 31/July)

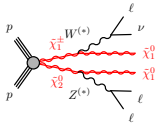


3ℓ RECENT

Improving the exclusion for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ **pair-production with** ***intermediate WZ*** in various regions

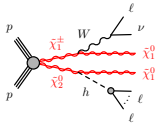
- extending to higher $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ mass and closing the gap between compressed and bulk regions, around $\Delta m = m_Z$
- covering (intermediate) compressed region, down to $\Delta m = 7$ GeV

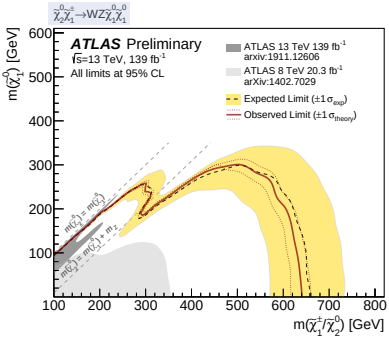
Showing **observed relic density** interpretation following PRD 98 (2018) 015010

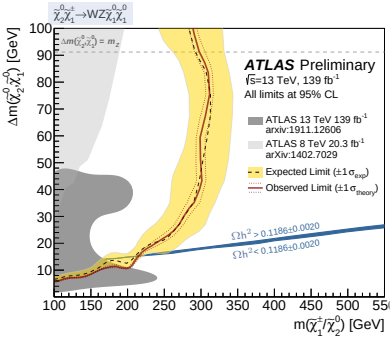


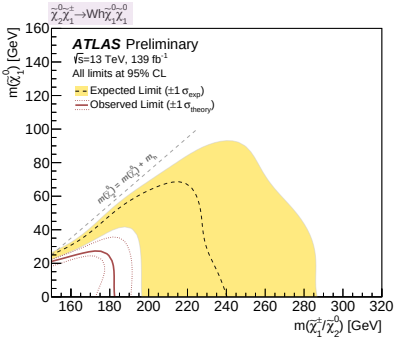
Also showing exclusion for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ **pair-production with** ***intermediate Wh***

- slightly weaker observed limit than expected due to mild excess in DFOS SRs









Summary

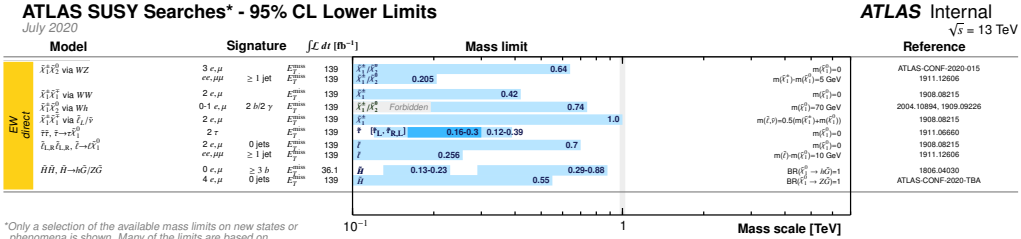
Several new/recent results from the electroweak side using the full Run 2 dataset

- 4ℓ NEW – ATLAS-CONF-2020-040
- 3ℓ RPV RECENT – ATLAS-CONF-2020-009
- 3ℓ RECENT – ATLAS-CONF-2020-015

Don't forget other still recent results

- $2\ell 0$j – Eur. Phys. J. C 80 (2020) 123
- direct staus – Phys. Rev. D 101 (2020) 032009
- soft 2ℓ – Phys. Rev. D 101 (2020) 052005
- $1\ell b\bar{b}$ – arXiv:1909.09226, acc. EPJC
- $\gamma\gamma$ – arXiv:2004.10894, sub. JHEP

Not finished analysing Run 2 data and well underway preparing Run 3, stay tuned for more results!



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Backup

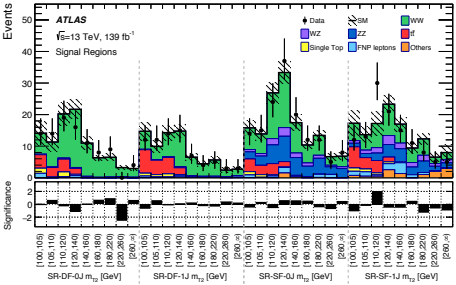
(Direct) slepton production

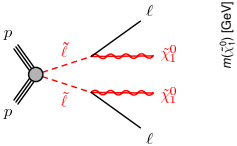
$2\ell 0j$

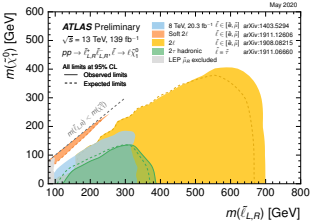
Eur. Phys. J. C 80 (2020) 123

- S/B discrimination using E_T^{miss}, E_T^{miss} signif. and $m_{T,2}$
- looking at the $m_{T,2}$ distribution in 4 regions separated by lepton flavor (SF/DF) and 0 or 1 jets
- diboson (**WW**, **WZ**, **ZZ**) & **$t\bar{t}$** dominant backgrounds
- **direct slepton** production exclusion for massless $\tilde{\chi}_1^0$ up to $m(\tilde{\chi}_1^{\pm}) = 700$ GeV

  and for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ **production with intermediate bosons (sleptons)**, up to $m(\tilde{\chi}_1^{\pm}) = 420$ (1000) GeV, for massless $\tilde{\chi}_1^0$



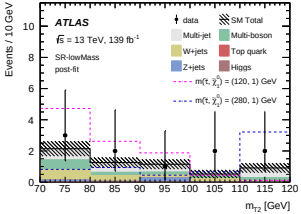


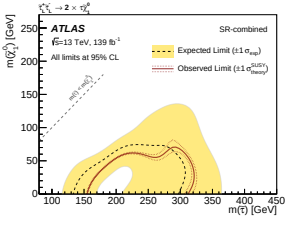


Direct scalar tau production

Phys. Rev. D 101 (2020) 032009

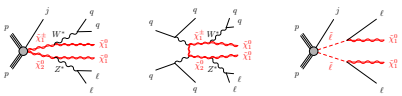
- SRs relying on $m_{T,2}$ and low/high mass separation
- challenging **fake tau background from multijet production**
  → ABCD method + tau promotion
- higher production cross-section for $\tilde{\tau}_L$, but higher efficiency for $\tilde{\tau}_R$
- exclusions for massless $\tilde{\chi}_1^0$ between $m(\tilde{\tau}) = 120$ and 390 GeV ($\tilde{\tau}_{R,L}$), and between $m(\tilde{\tau}) = 155$ and 310 GeV ($\tilde{\tau}_L$)

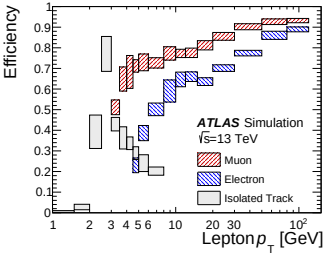




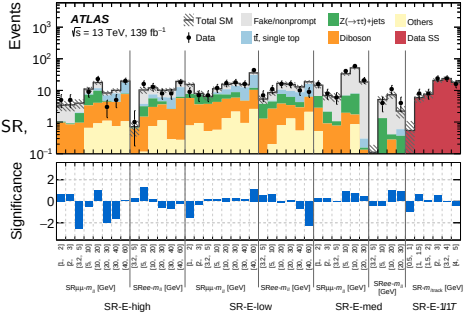
Phys. Rev. D 101 (2020) 052005

soft 2ℓ



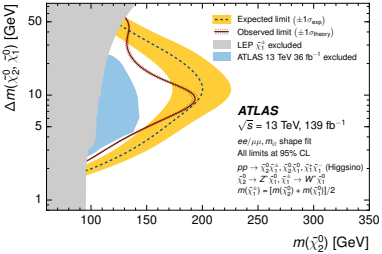


- very soft leptons: $p_T > 4.5(3.0)$ GeV for e (μ)
- final state: 2ℓ (opposite-sign) or 1ℓ+1 track + ISR
  - signal regions targetting ewkinos+ISR, VBF ewkinos & sleptons+ISR
  - binned fit in $m_{\ell\ell}$
  - dominant fake lepton background

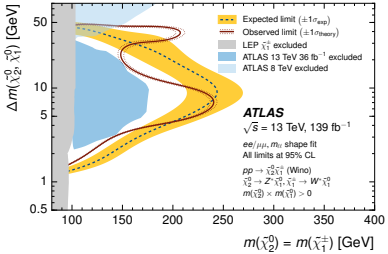


- multiple model interpretations

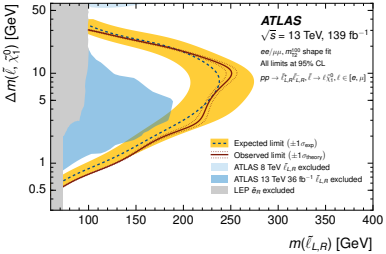
$\tilde{\chi}\tilde{\chi}$ production higgsino interpretation



$\tilde{\chi}\tilde{\chi}$ production bino/wino interpretation



direct slepton production

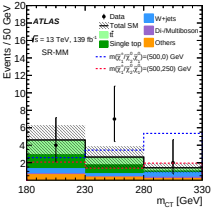


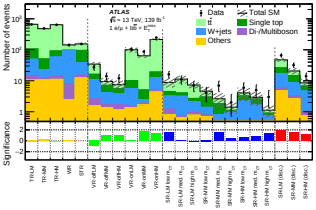
Intermediate Wh

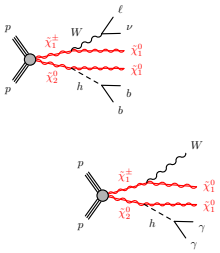
$1\ell b\bar{b}$

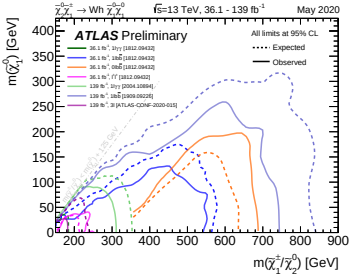
arXiv:1909.09226, acc. EPJC

- targetting final states with 1ℓ and $2b + E_T^{miss}$
- S/B discrimination using $m_{b\bar{b}}$, $m_{b\ell}$, m_T, and contransverse mass m_{CT}
- event separation into three classes targetting low, medium and higher $\Delta m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0 - \tilde{\chi}_1^0)$
- dominant $t\bar{t}$ and single-t backgrounds
- wino NLSP interpretation
- excluding $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses up to 740 GeV, for massless $\tilde{\chi}_1^0$





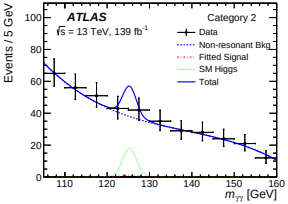


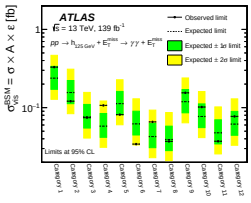


$\gamma\gamma$

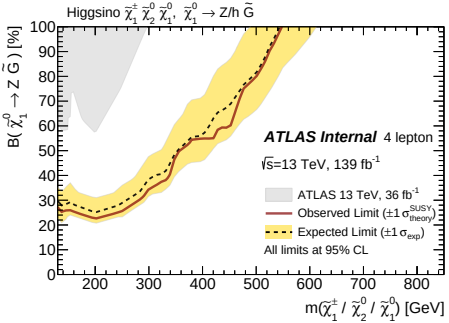
arXiv:2004.10894, sub. JHEP

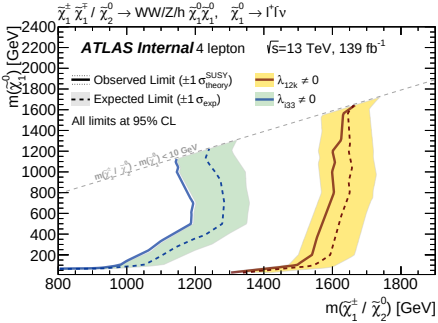
- targetting final states with two photons + E_T^{miss}, and variable lepton/jet multiplicities
- event categorisation by leptonic / hadronic / mixed final states, and in m_{jj} and E_T^{miss} signif.
- simultaneous fit of the $m_{\gamma\gamma}$ distributions
- excluding $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ masses up to 310 GeV, for massless $\tilde{\chi}_1^0$
- model-independent upper limits on the cross section / category

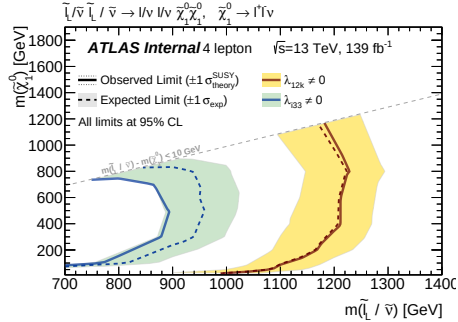


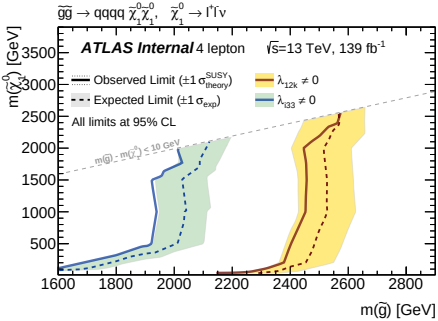


4ℓ NEW

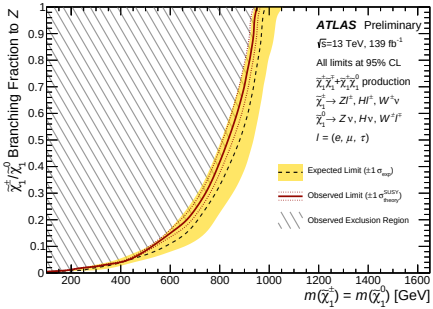

Higgsino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to Z/h\,\tilde{G}$
$B(\tilde{\chi}_1^0 \to Z\,\tilde{G})$ [%]
ATLAS Internal 4 lepton
$\sqrt{s}$=13 TeV, 139 fb^{-1}
ATLAS 13 TeV, 36 fb^{-1}
Observed Limit ($\pm 1\,\sigma^{SUSY}_{theory}$)
Expected Limit ($\pm 1\,\sigma_{exp}$)
All limits at 95% CL
$m(\tilde{\chi}_1^\pm / \tilde{\chi}_2^0 / \tilde{\chi}_1^0)$ [GeV]

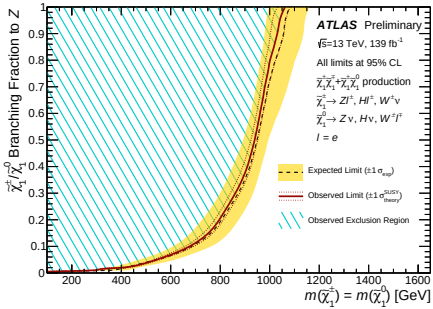

$\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp / \tilde{\chi}_2^0 \to WW/Z/h\,\tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to l^+l^-\nu$
ATLAS Internal 4 lepton
$\sqrt{s}$=13 TeV, 139 fb^{-1}
Observed Limit ($\pm 1\,\sigma^{SUSY}_{theory}$)
Expected Limit ($\pm 1\,\sigma_{exp}$)
$\lambda_{12k} \neq 0$
$\lambda_{i33} \neq 0$
All limits at 95% CL
$m(\tilde{\chi}_1^\pm / \tilde{\chi}_2^0) - m(\tilde{\chi}_1^0) < 10$ GeV
$m(\tilde{\chi}_2^0)$ [GeV]
$m(\tilde{\chi}_1^\pm / \tilde{\chi}_2^0)$ [GeV]

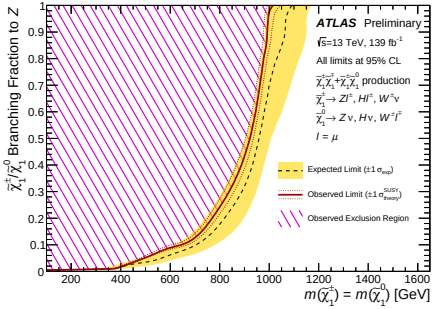

$\tilde{l}_L/\tilde{\nu}\ \tilde{l}_L / \tilde{\nu} \to l/\nu\ l/\nu\ \tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to l^+l^-\nu$
ATLAS Internal 4 lepton
$\sqrt{s}$=13 TeV, 139 fb^{-1}
Observed Limit ($\pm 1\,\sigma^{SUSY}_{theory}$)
Expected Limit ($\pm 1\,\sigma_{exp}$)
$\lambda_{12k} \neq 0$
$\lambda_{i33} \neq 0$
All limits at 95% CL
$m(\tilde{l}_L / \tilde{\nu}) - m(\tilde{\chi}_1^0) < 10$ GeV
$m(\tilde{\chi}_1^0)$ [GeV]
$m(\tilde{l}_L / \tilde{\nu})$ [GeV]

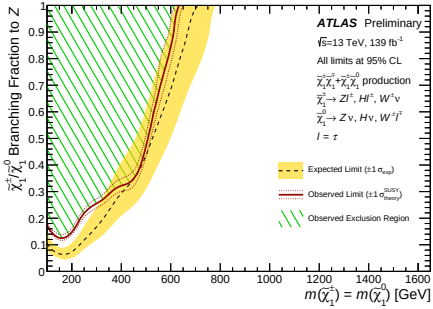

$\tilde{g}\tilde{g} \to qqqq\ \tilde{\chi}_1^0\tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \to l^+l^-\nu$
ATLAS Internal 4 lepton
$\sqrt{s}$=13 TeV, 139 fb^{-1}
Observed Limit ($\pm 1\,\sigma^{SUSY}_{theory}$)
Expected Limit ($\pm 1\,\sigma_{exp}$)
$\lambda_{12k} \neq 0$
$\lambda_{i33} \neq 0$
All limits at 95% CL
$m(\tilde{g}) - m(\tilde{\chi}_1^0) < 10$ GeV
$m(\tilde{\chi}_1^0)$ [GeV]
$m(\tilde{g})$ [GeV]

RPV chargino $\rightarrow 3\ell$ RECENT

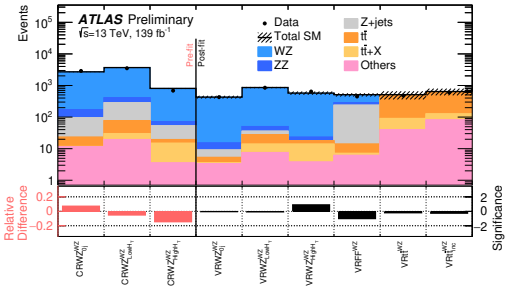


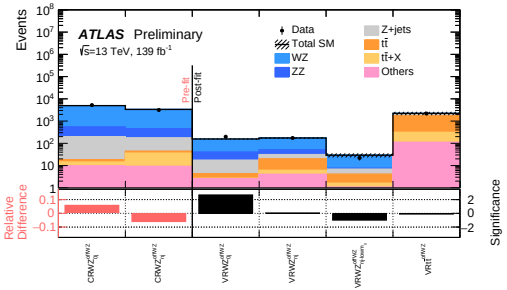




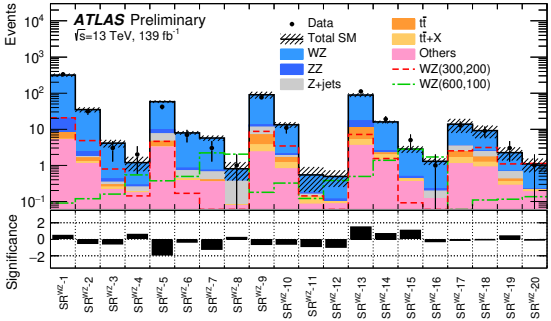


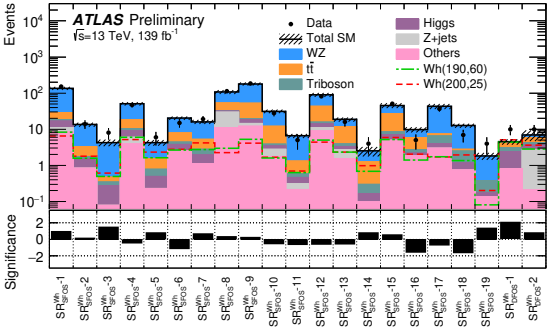
3ℓ RECENT

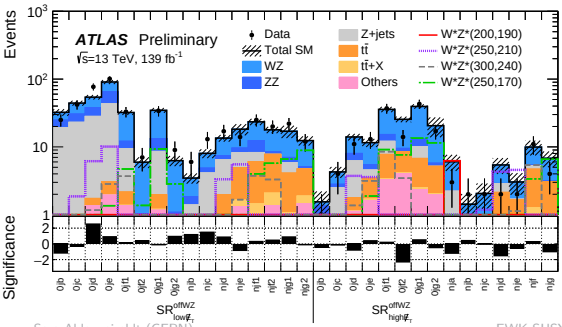

ATLAS Preliminary
√s=13 TeV, 139 fb-1
Data
Total SM
WZ
ZZ
Z+jets
tt̄
tt̄+X
Others
Pre-fit
Post-fit
Events
Relative Difference
Significance


ATLAS Preliminary
√s=13 TeV, 139 fb-1
Data
Total SM
WZ
ZZ
Z+jets
tt̄
tt̄+X
Others
Pre-fit
Post-fit
Events
Relative Difference
Significance

3ℓ RECENT


ATLAS Preliminary
√s=13 TeV, 139 fb-1
Data
Total SM
WZ
ZZ
Z+jets
tt̄
tt̄+X
Others
WZ(300,200)
WZ(600,100)
Events
Significance


ATLAS Preliminary
√s=13 TeV, 139 fb-1
Data
Total SM
WZ
tt̄
Triboson
Higgs
Z+jets
Others
Wh(190,60)
Wh(200,25)
Events
Significance


ATLAS Preliminary
√s=13 TeV, 139 fb-1
Data
Total SM
WZ
ZZ
Z+jets
tt̄
tt̄+X
Others
W*Z*(200,190)
W*Z*(250,210)
W*Z*(300,240)
W*Z*(250,170)
Events
Significance