Searches for electroweak production of SUSY particles involving the Higgs boson and the higgsino with ATLAS

Francisco Alonso
on behalf of the ATLAS Collaboration

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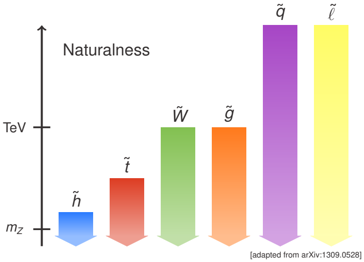
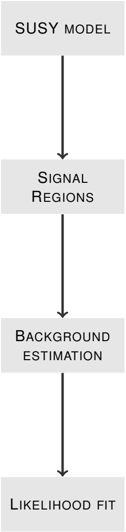
Introduction

- SUSY explains some of the SM problems, but it must be broken and the **sparticles mass scale is undetermined**
- **"Natural" SUSY**
  - Fine-tuning arguments suggest the mass of the SUSY partner of the Higgs boson, the higgsino, is not too far from the weak scale
- Search of higgsinos is an **experimental challenge due to the soft decay products** (and the low production cross section)
  - But it can also be the dominant mechanism at LHC if gluinos/squarks are heavier than a few TeV

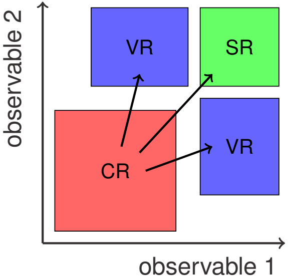


→ This talk presents **recent ATLAS results** of analyses explicitly targeting the **higgsino**, as well as searches for **electroweak production** of SUSY particles in final states involving the **Higgs boson**

Analyses strategy



- **Signal Regions** (SR) motivated by a SUSY model and optimised to have a good signal over background significance
- **Background estimation**
  - Data-driven techniques used for fake backgrounds
  - MC normalised in dedicated Control Regions (CR)
    - High background purity and small signal contamination

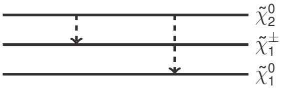


- **Simultaneous likelihood fit**
  - Background-only fit:
    - Validation Regions (VR) to cross-check CR→SR extrapolation before SR unblinding
    - Expected/observed events comparison in the SRs
  - Discovery fit to quantify the excess (and provide "model-independent" limits)
  - Exclusion fit to set exclusion limits in the considered model cross-section and SUSY particles masses

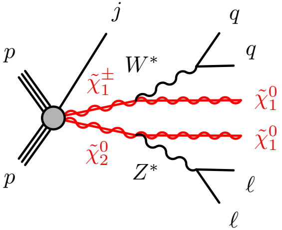
Search for compressed mass spectra

ATLAS-CONF-2019-014

- Lightest SUSY partners ($\tilde{\chi}_1^0, \tilde{\chi}_1^\pm, \tilde{\chi}_2^0$) assumed to be a triplet of Higgsino-like states



$\Delta m \sim$ a few GeV

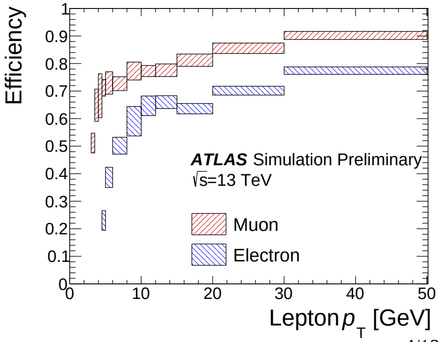


- Where $\tilde{\chi}_2^0$ can decay to a dilepton pair via off-shell Z boson ($m_{\ell\ell}$ is kinematically restricted to smaller values than Δm)

- Search for events with **two same-flavour opposite-charge leptons**, **large E_T^{miss}** and **hadronic activity** (+ ISR jet)

- Due the small mass splitting very soft leptons are required ($p_T^e > 4.5$ GeV and $p_T^\mu > 3$ GeV)

- Additional 1 lepton + 1 track SR improves efficiency of very small mass splitting ($p_T^{track} > 500$ MeV)



Search for compressed mass spectra

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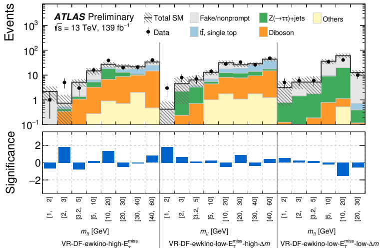
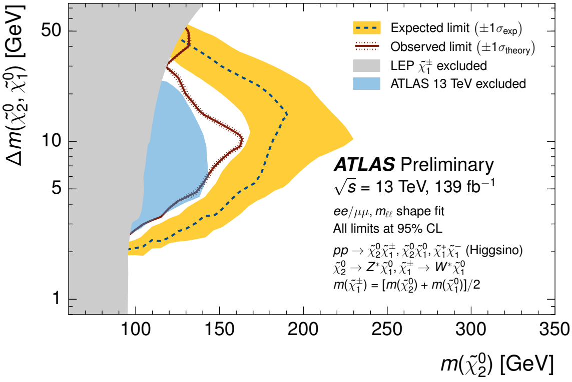
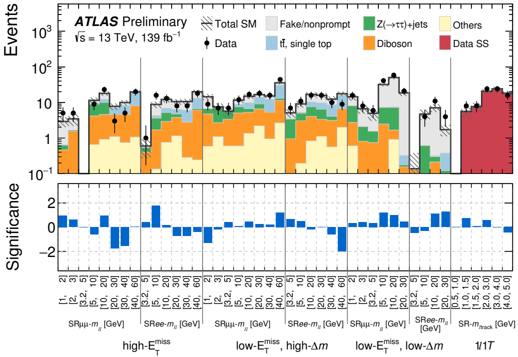
- Good agreement in all the validation regions
- No significant excess observed, but some deviations weaken the observed limit
- For $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^\pm) \sim 10$ GeV, exclusion up to 162 GeV
- Other interpretations in the previous talk by Sarah



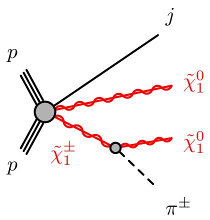


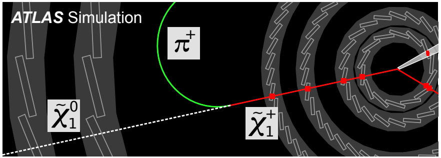


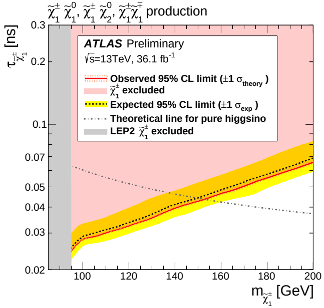
Disappearing track search

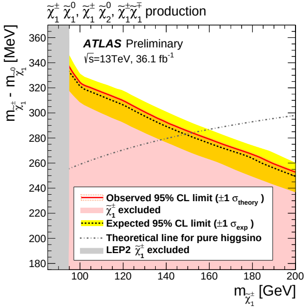
[ATL-PHYS-PUB-2017-019]

- When $\tilde{\chi}_1^0$ LSP is almost pure-wino or higgsino $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim 100$ MeV and $\tilde{\chi}_1^\pm$ is long-lived.
- In the pure-higgsino case, the lifetime of the chargino is ~ 0.05ns
  $\rightarrow$ may reach the detector before decaying to the LSP and a soft pion (BR $\sim 95\%$)
- Soft pion ($p_{\mathrm{T}} \sim 300$ MeV) can be identified as a "disappearing" track
- Re-interpretation of the pure-wino analysis [1712.02118] in the pure-higgsino case







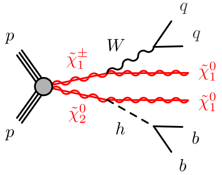


Comprehensive *Wh* search with 36.1 fb^{-1}

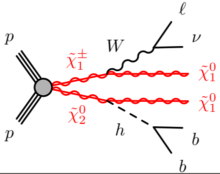
[1812.09432]
SUSY-2017-01

- Comprehensive search of chargino/neutralino production promptly decaying as $\tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$, assuming mass-degenerated and wino-like $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$, and a bino-like $\tilde{\chi}_1^0$
- Four signatures are explored for the different decays of the *W* and Higgs boson

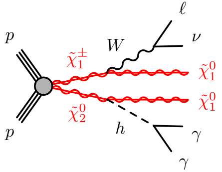
Fully hadronic signature ($0\ell bb$)



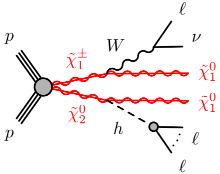
Single lepton + 2 *b*-jets signature ($1\ell bb$)



Single lepton + diphoton signature ($1\ell\gamma\gamma$)



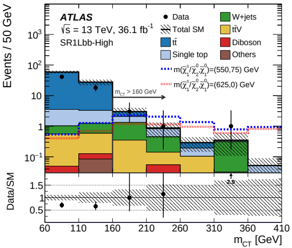
Same-sign dilepton ($\ell^\pm\ell^\pm$) and 3 lepton signatures (3ℓ)

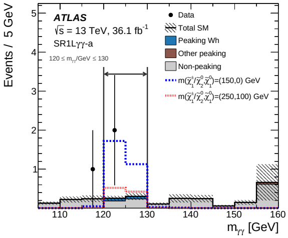


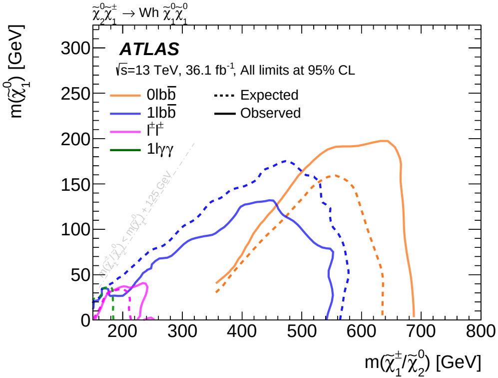
Comprehensive *Wh* search with 36.1 fb^{-1}

[1812.09432]
SUSY-2017-01

- No significant excess was found in any of the channels
- Mild excess in the $h \to \gamma\gamma$ SRs not allowing exclusion limit even combining both SR
- Masses of $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ smaller than 680 GeV are excluded for a massless $\tilde{\chi}_1^0$
  - Unprecedented sensitivity to high-mass region by the signatures with *b*-jets ($0\ell bb$ and $1\ell bb$)
  - Multilepton signature provides sensitivity in the region of low masses



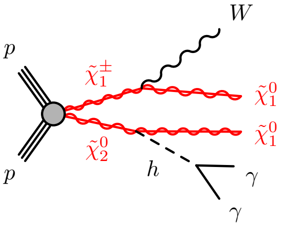


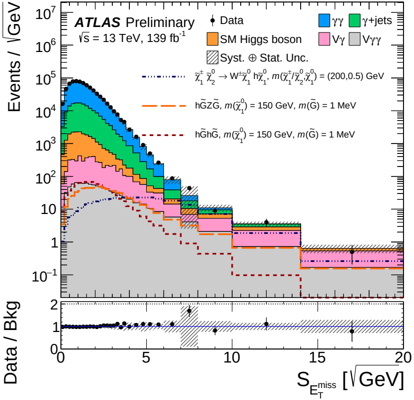


$Wh(\to \gamma\gamma)$ analysis with 139 fb^{-1}

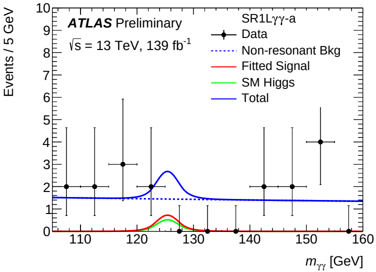
ATLAS-CONF-2019-019

- Analysis updated with the full Run 2 data
- Using the full (leptonic and hadronic) W decays
- Twelve orthogonal event categories using the number of leptons/jets, dijet mass and $S_{E_T^{\text{miss}}}$





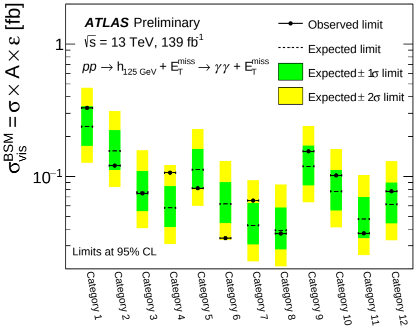
→ No excess observed in the "follow-up" analysis with the full Run 2 data

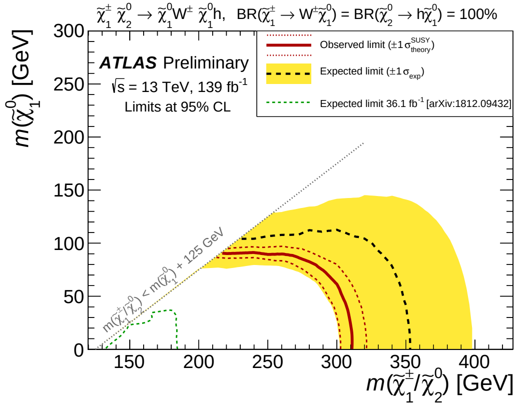


$Wh(\to \gamma\gamma)$ analysis with 139 fb^{-1}

ATLAS-CONF-2019-019

- Good agreement in all the individual categories and in the combined fit to data
- First observed sensitivity to $Wh(\to \gamma\gamma)$ in ATLAS with Run 2 data



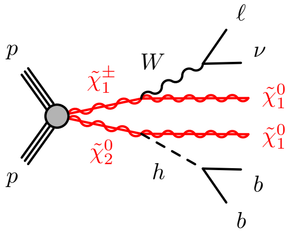


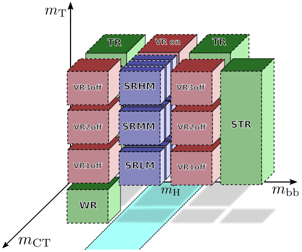
- Large gain when compared to 36 fb^{-1} due mainly to the use of all W boson decay channels

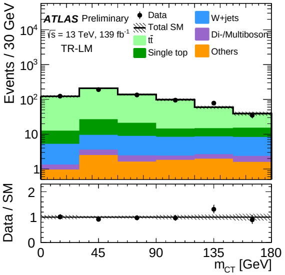
$Wh(1\ell bb)$ analysis with 139 fb^{-1}

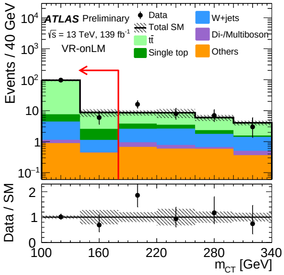
ATLAS-CONF-2019-031

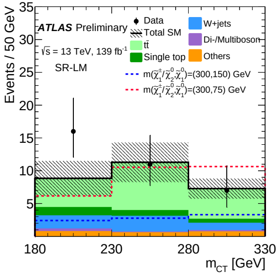
- Analysis updated with the full Run 2 data and a improved and powerful strategy
- The three signal regions (low, medium and high Δm) have been re-optimised and now are binned in m_{T} and m_{CT}
- Similar background estimation strategy but using a binned $t\bar{t}$ control region







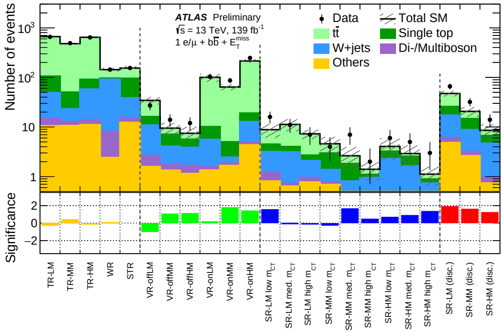


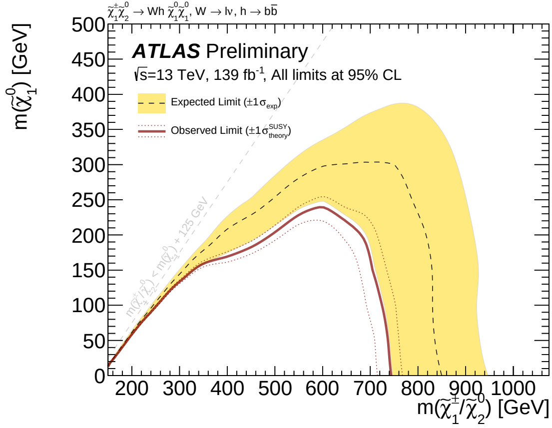


$Wh(1\ell bb)$ analysis with 139 fb^{-1}

ATLAS-CONF-2019-031

- No significant excess is observed in data over the SM prediction
- Significant sensitivity improvement with respect to previous publication (simultaneous fit to all the multi-bin SRs is used for exclusion)
- The masses of $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ up to 730 GeV are excluded for a massless $\tilde{\chi}_1^0$

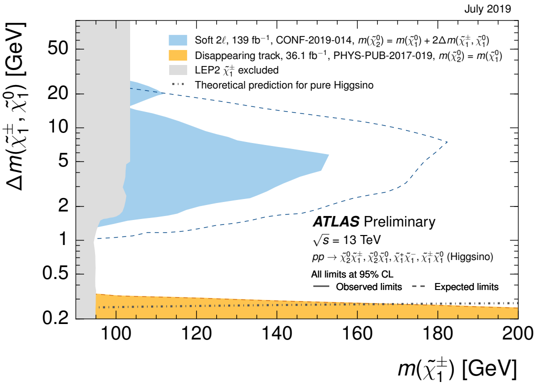


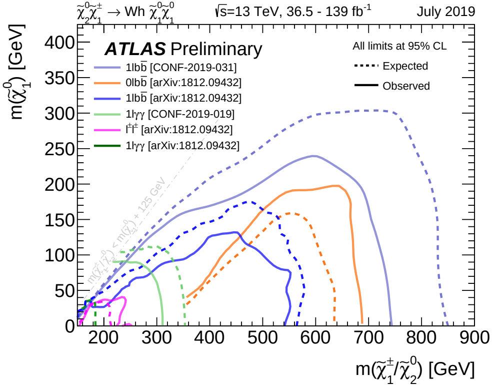


Summary and conclusions

[SUSY Public results]

- Comprehensive electroweak search program in ATLAS involving higgsinos and the Higgs boson
- Unfortunately no SUSY yet, but:
  - Probing very difficult signatures in compressed scenarios
  - Significant sensitivity gains in the last updates due to luminosity and analysis improvements
- New searches and updates with the full data are still to come

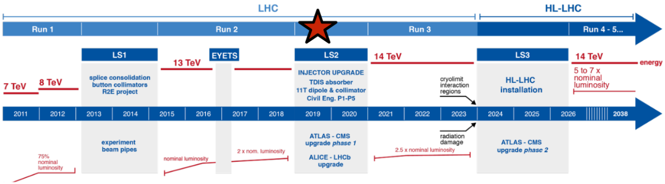


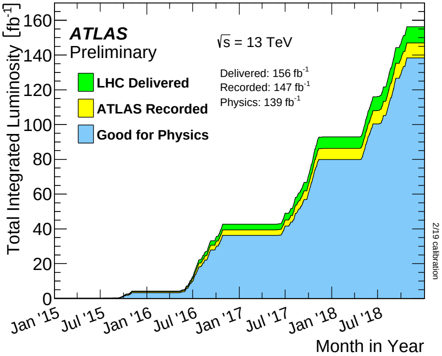


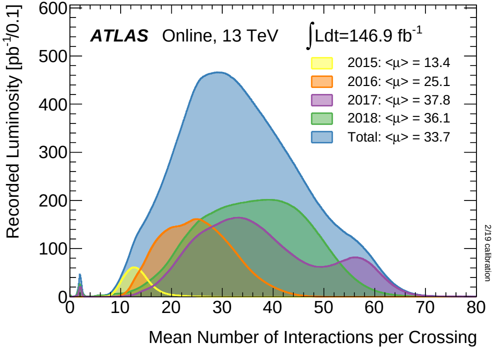
Backup

ATLAS Run-2 data

- Run-2 ATLAS data-taking successfully finished!
- Recorded 139 fb^{-1} "good for physics" between 2015-2018 (with 1.7% uncertainty)



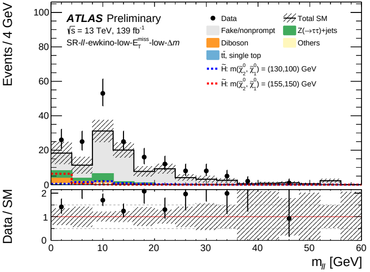


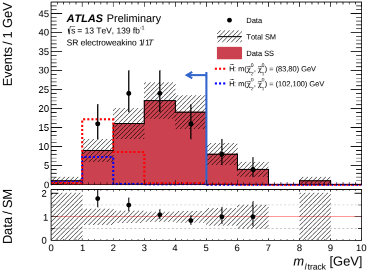


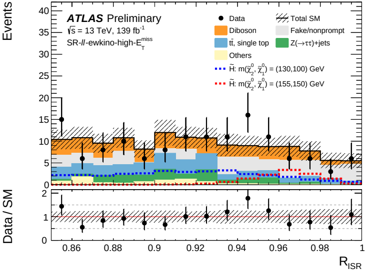
Search for compressed mass spectra

ATLAS-CONF-2019-014

- Different SRs for low/high $E_{\mathrm{T}}^{\mathrm{miss}}$ and low/high Δm defined using additional variables and binned in $m_{\ell\ell}$
  - R_{ISR} compares $E_{\mathrm{T}}^{\mathrm{miss}}$ and ISR hemisphere momentum using recursive jigsaw reconstruction
- Dominant backgrounds are estimated using in-situ techniques or normalised in a CR in the simultaneous fit
  - Reducible: fake or non-prompt leptons $\rightarrow$ data-driven fake factor method
  - Irreducible: 2 prompt leptons ($t\bar{t}/tW$, WW/WZ and $Z^*/\gamma^*(\rightarrow\tau\tau)$ + jets) $\rightarrow$ MC normalised in CRs







Search for compressed mass spectra

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- Control and validation regions

Region	SR orthogonality	Lepton Flavor	Additional requirements
CR-top-ewkino-high-$E_{\mathrm{T}}^{\mathrm{miss}}$ CR-top-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-high-$\Delta m$	$N_{b-\mathrm{jet}}^{20} \geq 1$	$ee+\mu\mu+e\mu+\mu e$	$R_{\mathrm{ISR}} \in [0.7, 1.0]$, $m_{\mathrm{T}}^{\ell_1}$ removed $E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$ and $m_{\mathrm{T}}^{\ell_1}$ removed
CR-tau-ewkino-high-$E_{\mathrm{T}}^{\mathrm{miss}}$ CR-tau-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-high-$\Delta m$ VR-tau-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-low-$\Delta m$	$m_{\tau\tau} \in [60, 120]$ GeV	$ee+\mu\mu+e\mu+\mu e$	$R_{\mathrm{ISR}} \in [0.7, 1.0]$, $m_{\mathrm{T}}^{\ell_1}$ removed $R_{\mathrm{ISR}} \in [0.6, 1.0]$, $m_{\mathrm{T}}^{\ell_1}$ removed –
CR-VV-ewkino-high-$E_{\mathrm{T}}^{\mathrm{miss}}$ CR-VV-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-high-$\Delta m$	$R_{\mathrm{ISR}} \in [0.7, 0.85]$ $R_{\mathrm{ISR}} \in [0.6, 0.8]$	$ee+\mu\mu+e\mu+\mu e$	$m_{\mathrm{T}}^{\ell_1}$ removed $m_{\mathrm{T}}^{\ell_1} > 30$ GeV, $N_{\mathrm{jets}} = 1$, $E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$ removed
VR-SS-ewkino-high-$E_{\mathrm{T}}^{\mathrm{miss}}$ VR-SS-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-high-$\Delta m$ VR-SS-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-low-$\Delta m$	Same sign $\ell^{\pm}\ell^{\pm}$	$ee+\mu e$, $\mu\mu+e\mu$	$R_{\mathrm{ISR}} \in [0.7, 1.0]$, $m_{\mathrm{T}}^{\ell_1}$ and $p_{\mathrm{T}}^{\ell_2}$ removed $E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$, $m_{\mathrm{T}}^{\ell_1}$ and $p_{\mathrm{T}}^{\ell_2}$ removed –
VR-DF-ewkino-high-$E_{\mathrm{T}}^{\mathrm{miss}}$ VR-DF-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-high-$\Delta m$ VR-DF-ewkino-low-$E_{\mathrm{T}}^{\mathrm{miss}}$-low-$\Delta m$	$e\mu+\mu e$	$e\mu+\mu e$	– – –

Control Region		Normalization Parameters electroweakino	slepton
CR-top	high-$E_{\mathrm{T}}^{\mathrm{miss}}$	1.07 ± 0.04	1.03 ± 0.05
	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	1.01 ± 0.02	1.00 ± 0.02
CR-tau	high-$E_{\mathrm{T}}^{\mathrm{miss}}$	0.95 ± 0.09	0.80 ± 0.13
	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	0.99 ± 0.05	1.02 ± 0.06
CR-VV	high-$E_{\mathrm{T}}^{\mathrm{miss}}$	0.88 ± 0.19	0.83 ± 0.23
	low-$E_{\mathrm{T}}^{\mathrm{miss}}$	0.75 ± 0.14	0.72 ± 0.15

Search for compressed mass spectra

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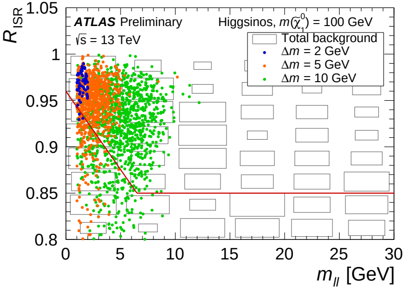
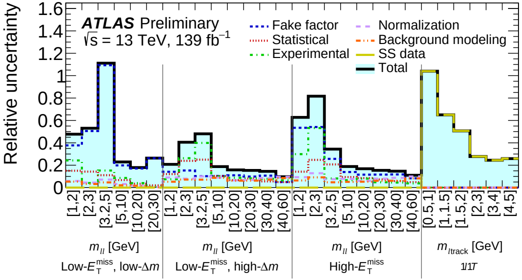
- Preselection and signal regions definition

Variable	Preselection requirements: 2ℓ	$1\ell 1T$
Number of leptons (tracks)	$= 2$ leptons	$= 1$ lepton and ≥ 1 track
Lepton p_{T} [GeV]	$p_{\mathrm{T}}^{\ell_1} > 5$	$p_{\mathrm{T}}^{\ell} < 10$
$\Delta R_{\ell\ell}$	$\Delta R_{ee} > 0.30$, $\Delta R_{\mu\mu} > 0.05$, $\Delta R_{e\mu} > 0.2$	$0.05 < \Delta R_{\ell \mathrm{track}} < 1.5$
Lepton (track) charge and flavor	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$	$e^{\pm}e^{\mp}$ or $\mu^{\pm}\mu^{\mp}$
Lepton (track) invariant mass [GeV]	$3 < m_{ee} < 60$, $1 < m_{\mu\mu} < 60$	$0.5 < m_{\ell \mathrm{track}} < 5$
J/ψ invariant mass [GeV]	veto $3 < m_{\ell\ell} < 3.2$	veto $3 < m_{\ell \mathrm{track}} < 3.2$
$m_{\tau\tau}$ [GeV]	< 0 or > 160	no requirement
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 120	> 120
Number of jets	≥ 1	≥ 1
Number of b-tagged jets	$= 0$	no requirement
Leading jet p_{T} [GeV]	≥ 100	≥ 100
$\min(\Delta\phi(\text{any jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}))$	> 0.4	> 0.4
$\Delta\phi(j_1, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	≥ 2.0	≥ 2.0

Variable	Electroweakino SR Requirements: Low-$E_{\mathrm{T}}^{\mathrm{miss}}$, low-$\Delta m$	Low-$E_{\mathrm{T}}^{\mathrm{miss}}$, high-$\Delta m$	High-$E_{\mathrm{T}}^{\mathrm{miss}}$	$1\ell 1T$
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	[120, 200]	[120, 200]	> 200	> 200
$E_{\mathrm{T}}^{\mathrm{miss}}/H_{\mathrm{T}}^{\mathrm{lep}}$	> 10	< 10	–	> 30
$\Delta\phi(\mathrm{lep}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}})$	–	–	–	< 1.0
Lepton or track p_{T} [GeV]	–	$p_{\mathrm{T}}^{\ell_2} > 5 + m_{\ell\ell}/4$	$p_{\mathrm{T}}^{\ell_2} > \min(10, 2 + m_{\ell\ell}/3)$	$p_{\mathrm{T}}^{\mathrm{track}} < 5$
$M_{\mathrm{T}}^{\mathrm{S}}$ [GeV]	< 50	–	–	–
$m_{\mathrm{T}}^{\ell_1}$ [GeV]	–	[10, 60]	< 60	–
R_{ISR}	–	[0.8, 1.0]	$[\max(0.85, 0.98 - 0.02 \times m_{\ell\ell}),\ 1.0]$	–





Dissapearing track search

ATL-PHYS-PUB-2017-019

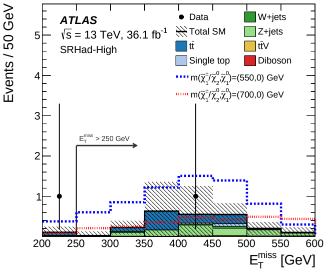
Number of observed events		
	9	
Number of expected events		
Hadron+electron background	6.1	$\pm$ 0.6
Muon background	0.15	$\pm$ 0.09
Fake background	5.5	$\pm$ 3.3
Total background	11.8	$\pm$ 3.1
Number of expected signal events for the higgsino LSP model with $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = $ **(160 GeV, 0.05 ns)**		
	10.3	$\pm$ 2.1
Number of expected signal events for the wino LSP model with $(m_{\tilde{\chi}_1^\pm}, \tau_{\tilde{\chi}_1^\pm}) = $ **(400 GeV, 0.2 ns)**		
	13.5	$\pm$ 2.1

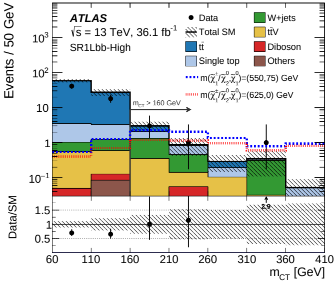
Number of observed events and predicted background events, together with the yield of expected signal for a benchmark point $(m_{\tilde{\chi}_1^\pm}, \tau\tilde{\chi}_1^\pm)$ = (160 GeV, 0.05 ns) in the signal region with a requirement of pixel-tracklet $p_{\mathrm{T}} > 100$ GeV. The observed and expected background yields, but not the signal yield, are taken from Ref. [1712.02118]. For a comparison, the number of expected signal events for the pure wino LSP model with $(m_{\tilde{\chi}_1^\pm}, \tau\tilde{\chi}_1^\pm)$ = (400,GeV, 0.2 ns) is also shown.

Comprehensive Wh search with 36.1 fb^{-1}

[1812.09432]
SUSY-2017-01

- Fully hadronic signature ($0\ell bb$)
  - E_T^{miss} trigger, lepton veto, large m_{eff}
  - Two SRs for low/high masses using m_{bb}, m_{eff}, m_{CT}, $m_T^{b,min}$
- Single lepton plus di b-jet signature ($1\ell bb$):
  - E_T^{miss} trigger, one e/μ and 2/3 jets (2 b-tagged)
  - Three SRs (different bins in m_T) for different NLSP Δm
- Single lepton + diphoton signature ($1\ell\gamma\gamma$)
  - Diphoton trigger, one lepton and exactly two photons, $120 < m_{\gamma\gamma} < 130$ GeV
  - Non peaking background estimated using $m_{\gamma\gamma}$ side-band and Higgs background from MC
- Same-sign dilepton ($\ell^\pm\ell^\pm$) and 3 lepton signatures (3ℓ)
  - Single/Dilepton trigger, two analyses requiring exactly 2 same-sign leptons or 3 leptons
  - Data-driven estimation for fake/non-prompt lepton background





Some variables used in the *Wh* analyses

[1812.09432]
SUSY-2017-01

- m_{T} is the transverse mass formed by the $E_{\mathrm{T}}^{\mathrm{miss}}$ and the leading lepton in the event:

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right)}$$

- $m_{\mathrm{T}}^{b,\mathrm{min}}$ is the minimum transverse mass formed by $E_{\mathrm{T}}^{\mathrm{miss}}$ and up to two of the highest-p_{T} b-jets in the event, defined as:

$$m_{\mathrm{T}}^{b,\mathrm{min}} = \min_{i \leq 2} \left(\sqrt{2 p_{\mathrm{T}}^{b\text{-jet}_i} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{b\text{-jet}_i})\right)} \right)$$

- The lepton–$E_{\mathrm{T}}^{\mathrm{miss}}$–$\gamma$ transverse mass $m_{\mathrm{T}}^{W\gamma_i}$ is calculated with respect to the i^{th} photon γ_i, ordered in terms of decreasing E_{T}, the $E_{\mathrm{T}}^{\mathrm{miss}}$, and the identified lepton ℓ:

$$\begin{aligned}
\left(m_{\mathrm{T}}^{W\gamma_i}\right)^2 = {} & 2 E_{\mathrm{T}}^{\gamma_i} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\gamma_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right) \\
& + 2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right) \\
& + 2 E_{\mathrm{T}}^{\gamma_i} p_{\mathrm{T}}^{\ell} \left(1 - \cos \Delta\phi(\gamma_i, \ell)\right)
\end{aligned}$$

Some variables used in the *Wh* analyses

- m_{CT} is the contransverse mass variable and is defined for the $b\bar{b}$ system as:

$$m_{\mathrm{CT}} = \sqrt{2 p_{\mathrm{T}}^{b_1} p_{\mathrm{T}}^{b_2} \left(1 + \cos \Delta\phi_{bb}\right)}$$

- m_{T2} is referred to as the stransverse mass and is closely related to m_{T}. It is used to bound the masses of particles produced in pairs and each decaying into one particle that is detected and another particle that contributes to the missing transverse momentum. In the case of a dilepton final state, it is defined by:

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

where $\vec{q}_{\mathrm{T}}$ is the transverse vector that minimizes the larger of the two transverse masses m_{T}, and $\vec{p}_{\mathrm{T}}^{\,\ell,1}$ and $\vec{p}_{\mathrm{T}}^{\,\ell,2}$ are the leading and subleading transverse momenta of the two leptons in the pair.

Wh: Full hadronic signature ($0\ell bb$)

[1812.09432]
SUSY-2017-01

Variable	SRHad-High	SRHad-Low
N_{lepton}	$= 0$	$= 0$
N_{jet} ($p_{\text{T}} > 30$ GeV)	$\in [4,\ 5]$	$\in [4,\ 5]$
$N_{b\text{-jet}}$	$= 2$	$= 2$
$\Delta\phi^{4j}_{\text{min}}$	> 0.4	> 0.4
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 250	> 200
m_{eff} [GeV]	> 900	> 700
$m_{b\bar{b}}$ [GeV]	$\in [105, 135]$	$\in [105, 135]$
$m_{q\bar{q}}$ [GeV]	$\in [75, 90]$	$\in [75, 90]$
m_{CT} [GeV]	> 140	> 190
$m_{\text{T}}^{b,\text{min}}$ [GeV]	> 160	> 180

CR channels	CRHad-TT(HM)	CRHad-ST(HM)	CRHad-Zj(HM)	CRHad-TT(LM)	CRHad-ST(LM)	CRHad-Zj(LM)
Observed events	102	17	39	695	23	78
Fitted bkg events	102 ± 10	17 ± 4	39 ± 6	695 ± 26	23 ± 5	78 ± 9
$t\bar{t}$	97 ± 11	3.7 ± 2.0	2.9 ± 2.4	659 ± 34	4.7 ± 2.3	10^{+12}_{-10}
Single top	$2.7^{+3.5}_{-2.7}$	10 ± 5	$0.8^{+0.9}_{-0.8}$	19 ± 19	15 ± 6	1.0 ± 0.9
$W+$jets	$0.5^{+0.6}_{-0.5}$	2.2 ± 1.1	0.0059 ± 0.0025	3.9 ± 3.1	2.8 ± 1.2	0.0059 ± 0.0026
$Z+$jets	1.1 ± 0.6	0.08 ± 0.07	32 ± 7	9.5 ± 3.2	0.09 ± 0.04	63 ± 17
$t\bar{t}+V$	0.63 ± 0.14	0.62 ± 0.16	2.0 ± 0.4	3.1 ± 0.5	0.80 ± 0.17	3.7 ± 0.6
Diboson	$0.08^{+0.14}_{-0.08}$	< 0.07	0.8 ± 0.8	1.16 ± 0.34	< 0.07	0.8 ± 0.5

SR channels	SRHad-High	SRHad-Low
Observed events	1	7
Fitted bkg events	2.5 ± 1.3	8 ± 4
$t\bar{t}$	1.1 ± 0.9	4 ± 4
Single top (Wt)	$0.15^{+0.16}_{-0.15}$	0.44 ± 0.33
$W+$jets	$0.1^{+0.3}_{-0.1}$	1.0 ± 0.7
$Z+$jets	1.0 ± 0.7	1.7 ± 1.0
$t\bar{t}+V$	0.09 ± 0.03	0.40 ± 0.08
Diboson	< 0.01	$0.3^{+0.4}_{-0.3}$

Wh: Single lepton + 2 *b*-jets signature ($1\ell bb$)

[1812.09432]
SUSY-2017-01

Variable	SR1Lbb-Low	SR1Lbb-Medium	SR1Lbb-High
N_{lepton}		$= 1$	
p_{T}^{ℓ} [GeV]		> 27	
N_{jet} ($p_{\text{T}} > 25$ GeV)		$= 2$ or 3	
$N_{b\text{-jet}}$		$= 2$	
$E_{\text{T}}^{\text{miss}}$ [GeV]		> 200	
m_{CT} [GeV]		> 160	
m_{T} [GeV]	$\in [100, 140]$	$\in [140, 200]$	> 200
$m_{b\bar{b}}$ [GeV]		$\in [105, 135]$	

CR channels	CR1Lbb-TT(LM)	CR1Lbb-TT(MM)	CR1Lbb-TT(HM)	CR1Lbb-Wj	CR1Lbb-ST
Observed events	192	359	1115	72	65
Fitted bkg events	192 ± 14	359 ± 19	1115 ± 34	72 ± 9	65 ± 8
$t\bar{t}$	147 ± 33	325 ± 32	1020 ± 90	15 ± 14	20^{+23}_{-20}
Single top	28 ± 25	22^{+24}_{-22}	60^{+70}_{-60}	4^{+6}_{-4}	33 ± 25
W+jets	16 ± 7	7.3 ± 2.7	25 ± 11	51 ± 17	8 ± 4
$t\bar{t} + V$	1.16 ± 0.20	2.8 ± 0.4	6.9 ± 1.1	0.079 ± 0.022	3.2 ± 0.6
Diboson	0.57 ± 0.24	0.92 ± 0.29	1.3 ± 0.4	2.1 ± 1.1	0.84 ± 0.28
Others	0.125 ± 0.032	0.20 ± 0.06	1.9 ± 0.5	0.24 ± 0.17	0.10 ± 0.04

SR channels	SR1Lbb-Low	SR1Lbb-Medium	SR1Lbb-High
Observed events	6	7	5
Fitted bkg events	5.7 ± 2.3	2.8 ± 1.0	4.6 ± 1.2
$t\bar{t}$	3.4 ± 2.9	1.4 ± 1.0	1.1 ± 0.6
Single top (Wt)	$1.4^{+1.4}_{-1.4}$	$0.8^{+0.9}_{-0.8}$	1.2 ± 1.1
W+jets	0.6 ± 0.4	0.20 ± 0.11	1.6 ± 0.6
$t\bar{t} + V$	0.10 ± 0.04	0.32 ± 0.09	0.54 ± 0.14
Diboson	$0.12^{+0.15}_{-0.12}$	0.05 ± 0.03	0.08 ± 0.02
Others	0.10 ± 0.05	0.03 ± 0.01	0.04 ± 0.02

Wh: Single lepton + diphoton signature ($1\ell\gamma\gamma$)

[1812.09432]
SUSY-2017-01

Variable	SR1L$\gamma\gamma$-a	SR1L$\gamma\gamma$-b
N_{γ}	$= 2$	$= 2$
p_{T}^{γ} [GeV]	$> (40, 31)$	$> (40, 31)$
N_{lepton}	$= 1$	$= 1$
p_{T}^{ℓ} [GeV]	> 25	> 25
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 40	> 40
$\Delta\phi_{W,h}$	> 2.25	> 2.25
$m_{\gamma\gamma}$ [GeV]	$\in [120, 130]$	$\in [120, 130]$
$N_{b\text{-jet}}$ ($p_{\mathrm{T}} > 30\ GeV$)	$= 0$	$= 0$
$m_{\mathrm{T}}^{W\gamma_1}$ [GeV]	≥ 150	≥ 150
$m_{\mathrm{T}}^{W\gamma_2}$ [GeV]	> 140	$\in [80, 140]$
m_{T} [GeV]	> 110	< 110

SR channels	SR1L$\gamma\gamma$-a	SR1L$\gamma\gamma$-b
Observed events	2	9
Total bkg events	0.37 ± 0.22	5.3 ± 1.0
Wh background	0.09 ± 0.01	1.8 ± 0.3
Other peaking backgrounds	0.04 ± 0.01	0.19 ± 0.02
Non-peaking background	0.22 ± 0.22	3.3 ± 0.9

Wh: Same-sign dilepton ($\ell^{\pm}\ell^{\pm}$)

[1812.09432]
SUSY-2017-01

Variable	SRSS-j1	SRSS-j23
$\Delta\eta_{\ell\ell}$	< 1.5	-
N_{jet} ($p_{\text{T}} > 20$ GeV)	$= 1$	$= 2$ or 3
$N_{b\text{-jet}}$	$= 0$	$= 0$
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 100	> 100
m_{T} [GeV]	> 140	> 120
m_{eff} [GeV]	> 260	> 240
$m_{\ell j(j)}$ [GeV]	< 180	< 130
m_{T2} [GeV]	> 80	> 70

SR channels	SRSS-j1	SRSS-j23
Observed events	2	8
Fitted bkg events	6.7 ± 2.2	5.3 ± 1.6
FNP events	3.3 ± 2.1	1.8 ± 1.5
WZ	2.2 ± 0.5	1.9 ± 0.6
Rare	0.44 ± 0.13	0.73 ± 0.17
$t\bar{t} + V$	0.12 ± 0.05	0.14 ± 0.05
WW	0.17 ± 0.03	0.51 ± 0.07
ZZ	0.06 ± 0.03	0.07 ± 0.04
Charge-flip events	0.47 ± 0.07	0.27 ± 0.03

Wh: 3 lepton signatures (3ℓ)

[1812.09432]
SUSY-2017-01

Variable	SR3L-DFOS-0J	SR3L-DFOS-1Ja	SR3L-DFOS-1Jb
N_{jet} ($p_{\text{T}} > 20$ GeV)	$= 0$	> 0	> 0
$N_{b\text{-jet}}$	$= 0$	$= 0$	$= 0$
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 60	$\in [30, 100]$	> 100
$m_{\ell_{\text{DFOS}}+\ell_{\text{near}}}$ [GeV]	< 90	< 60	< 70
$\Delta R_{\text{OS,near}}$	-	< 1.4	< 1.4
$\Delta\phi_{\text{SS}}$	-	-	< 2.8

Variable	SR3L-SFOS-0Ja	SR3L-SFOS-0Jb	SR3L-SFOS-1J
N_{jet} ($p_{\text{T}} > 20$ GeV)	$= 0$	$= 0$	> 0
$N_{b\text{-jet}}$	$= 0$	$= 0$	$= 0$
$E_{\text{T}}^{\text{miss}}$ [GeV]	$\in [80, 120]$	> 120	> 110
$m_{\text{T}}^{\text{min}}$ [GeV]	> 110	> 110	> 110
$m_{\text{SFOS}}^{\text{min}}$	> 20 $GeV, \notin [81.2, 101.2]$	> 20 $GeV, \notin [81.2, 101.2]$	> 20 $GeV, \notin [81.2, 101.2]$

SR channels	SR3L-SFOS-0Ja	SR3L-SFOS-0Jb	SR3L-SFOS-1J
Observed events	0	3	11
Fitted bkg events	3.8 ± 1.7	2.4 ± 1.0	11.5 ± 2.6
WZ	2.5 ± 1.2	2.0 ± 0.9	7.4 ± 2.3
ZZ	0.10 ± 0.04	0.07 ± 0.02	0.29 ± 0.09
$t\bar{t} + V$	0.09 ± 0.03	0.02 ± 0.01	1.9 ± 0.5
Tribosons	0.57 ± 0.29	0.16 ± 0.08	1.4 ± 0.4
Higgs SM	$0.24^{+0.25}_{-0.24}$	0.07 ± 0.07	0.07 ± 0.04
FNP events	$0.27^{+0.31}_{-0.27}$	$0.11^{+0.20}_{-0.11}$	$0.4^{+0.5}_{-0.4}$

SR channels	SR3L-DFOS-0J	SR3L-DFOS-1Ja	SR3L-DFOS-1Jb
Observed events	0	7	1
Fitted bkg events	2.1 ± 1.0	8.3 ± 3.8	1.7 ± 0.7
WZ	0.18 ± 0.13	1.01 ± 0.27	0.54 ± 0.16
ZZ	0.0017 ± 0.0012	0.06 ± 0.02	0.03 ± 0.01
$t\bar{t} + V$	0.0013 ± 0.0013	0.79 ± 0.29	0.43 ± 0.16
Tribosons	0.52 ± 0.28	0.66 ± 0.22	0.23 ± 0.08
Higgs SM	0.39 ± 0.15	$0.1^{+0.5}_{-0.1}$	0.05 ± 0.04
FNP	1.0 ± 0.9	5.6 ± 3.8	$0.4^{+0.6}_{-0.4}$

Wh: Upper limits and *p*-values

[1812.09432]
SUSY-2017-01

	σ_{vis} [fb]	S^{95}_{obs}	S^{95}_{exp}	p_0-value
SRHad-Low	0.26	9.4	$9.5^{+3.3}_{-1.9}$	0.50
SRHad-High	0.10	3.6	$4.3^{+1.6}_{-1.0}$	0.50
SR1Lbb-Low	0.23	8.3	$8.0^{+3.3}_{-2.2}$	0.46
SR1Lbb-Medium	0.28	10.0	$5.6^{+2.9}_{-1.7}$	0.04
SR1Lbb-High	0.18	6.4	$6.1^{+3.1}_{-1.9}$	0.44
SR1L$\gamma\gamma$-a	0.15	5.5	$3.2^{+0.9}_{-0.1}$	0.03
SR1L$\gamma\gamma$-b	0.28	10.1	$6.4^{+2.6}_{-1.6}$	0.09
SRSS-j1	0.12	4.2	$6.1^{+2.7}_{-1.5}$	0.50
SRSS-j23	0.27	9.9	$6.6^{+3.4}_{-1.1}$	0.17
SR3L-SFOS-0Ja	0.08	3.0	$4.4^{+1.9}_{-1.3}$	0.47
SR3L-SFOS-0Jb	0.16	5.9	$5.0^{+2.0}_{-1.2}$	0.35
SR3L-SFOS-1J	0.26	9.2	$9.4^{+3.8}_{-2.5}$	0.50
SR3L-DFOS-0J	0.08	3.0	$3.8^{+1.4}_{-0.9}$	0.43
SR3L-DFOS-1Ja	0.25	9.0	$9.2^{+3.3}_{-2.0}$	0.50
SR3L-DFOS-1Jb	0.10	3.7	$4.0^{+1.6}_{-0.5}$	0.50

$Wh(\to \gamma\gamma)$ analysis with 139 fb^{-1}

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Channels	Names	Selection
Leptonic	Category 1	$0 < S_{E_T^{miss}} \leq 2,\ N_\ell \geq 1$
	Category 2	$2 < S_{E_T^{miss}} \leq 4,\ N_\ell \geq 1$
	Category 3	$4 < S_{E_T^{miss}} \leq 6,\ N_\ell \geq 1$
	Category 4	$S_{E_T^{miss}} > 6,\ N_\ell \geq 1$
Hadronic	Category 5	$5 < S_{E_T^{miss}} \leq 6,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]$ GeV
	Category 6	$6 < S_{E_T^{miss}} \leq 7,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]$ GeV
	Category 7	$7 < S_{E_T^{miss}} \leq 8,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]$ GeV
	Category 8	$S_{E_T^{miss}} > 8,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]$ GeV
Rest	Category 9	$6 < S_{E_T^{miss}} \leq 7,\ N_\ell = 0,\ N_j < 2$ or ($N_j \geq 2,\ M_{jj} \notin [40, 120]$ GeV)
	Category 10	$7 < S_{E_T^{miss}} \leq 8,\ N_\ell = 0,\ N_j < 2$ or ($N_j \geq 2,\ M_{jj} \notin [40, 120]$ GeV)
	Category 11	$8 < S_{E_T^{miss}} \leq 9,\ N_\ell = 0,\ N_j < 2$ or ($N_j \geq 2,\ M_{jj} \notin [40, 120]$ GeV)
	Category 12	$S_{E_T^{miss}} > 9,\ N_\ell = 0,\ N_j < 2$ or ($N_j \geq 2,\ M_{jj} \notin [40, 120]$ GeV)

Source	Signals [%]	Backgrounds [%]	
		SM Higgs boson	Non-resonant background
Experimental			
Luminosity	1.7		–
Jets (Scale, Resolution, JVT)	0.2–3.3	0.9–30.7	–
Electron/Photon (Scale, Resolution)	0.3–1.5	0.6–2.7	–
Photon (identification, isolation, trigger)	2.2–2.6	2.8–4.3	–
Electron (identification isolation)	0.0–0.5	0.0–0.6	–
Muon (identification, isolation, Scale, Resolution)	< 0.6	< 0.3	–
E_T^{miss} reconstruction (jets, soft term)	< 0.7	0.4–13.9	–
Pileup reweighting	0.3–1.8	1.3–15	–
Non-resonant background modelling		–	2–6
Theoretical			
Factorization and renormalization scale	< 1	3.7–5.9	–
PDF+α_S	< 6.6	2.1–2.9	–
Multiple parton-parton interactions	< 1		–
BR($H \to \gamma\gamma$)	1.73		–

Category	Data	Total bkg.	Non-resonant bkg.	SM Higgs boson	$W^\pm\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	$h\tilde{G}Z\tilde{G}$	$h\tilde{G}h\tilde{G}$
1	258	246 ± 7	230 ± 7	16.3 ± 1.4	2.8 ± 0.6	5 ± 6	5 ± 7
2	85	93 ± 4	77 ± 4	15.6 ± 1.3	6.6 ± 1.5	6 ± 7	4 ± 6
3	26	24.1 ± 2.0	17.1 ± 1.9	7.0 ± 0.6	6.9 ± 1.5	1.8 ± 2.2	1.8 ± 2.6
4	17	12.8 ± 1.4	8.4 ± 1.3	4.4 ± 0.4	10.7 ± 2.4	0.8 ± 0.8	0.9 ± 1.3
5	54	60 ± 4	57.9 ± 3.5	1.9 ± 0.6	7.2 ± 1.6	2.4 ± 2.8	0.8 ± 1.2
6	11	16.1 ± 1.8	15.4 ± 1.8	0.74 ± 0.26	6.0 ± 1.3	1.0 ± 1.2	0.4 ± 0.5
7	8	6.3 ± 1.1	5.9 ± 1.1	0.42 ± 0.10	4.3 ± 1.0	0.6 ± 0.8	0.18 ± 0.26
8	4	5.2 ± 1.0	4.4 ± 1.0	0.80 ± 0.11	5.3 ± 1.2	0.8 ± 1.0	0.20 ± 0.28
9	71	69 ± 4	65 ± 4	3.9 ± 0.8	9.1 ± 2.0	3 ± 4	1.1 ± 1.5
10	29	26.3 ± 2.2	24.2 ± 2.2	2.1 ± 0.4	6.9 ± 1.5	2.4 ± 2.8	0.5 ± 0.7
11	6	8.6 ± 1.2	7.2 ± 1.2	1.40 ± 0.22	4.6 ± 1.0	1.6 ± 2.0	0.3 ± 0.5
12	22	16.6 ± 1.7	13.4 ± 1.7	3.15 ± 0.33	7.9 ± 1.8	4 ± 5	0.5 ± 0.6

$Wh(\to \gamma\gamma)$ analysis with 139 fb^{-1}

ATLAS-CONF-2019-019

- Results are also interpreted in two GMSB scenarios with higgsino NLSP (the LSP is the gravitino)
- Cross-section upper-limits for higgsinos masses between 130 and 800 GeV:

  7.13-0.20 pb ($h\tilde{G}Z\tilde{G}$) and 17.3-0.19 pb ($h\tilde{G}h\tilde{G}$)