Recent ATLAS results on searches for electroweak produced supersymmetric particles

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Supersymmetry (SUSY)

- A set of theories predicting (boson/fermionic) partners for Standard Model (SM) particles (fermionic/boson), differing by 1/2 in spin
- In $R = (-1)^{3(B-L)+2S}$-parity conserving scenarios, the Lightest Supersymmetric Particle (LSP) is stable $\rightarrow$ possible dark matter candidate
- Higgs boson mass stable, potentially allowing unification of inverse gauge couplings

Due to electroweak symmetry breaking, the higgsinos and electroweakinos mix to form:
- Neutralinos $\tilde{\chi}_i^{0} = 1,...,4$ $\leftrightarrow$ Neutral higgsinos and electroweak (EWK) gauginos
- Charginos $\tilde{\chi}_{j}^{\pm} = 1,2$ $\leftrightarrow$ Charged higgsinos and electroweak gauginos
All Hadronic: Outline

Three physics scenarios considered:

- baseline Minimal Supersymmetric Standard Model (MSSM), with bino ($\tilde{B}$), wino ($\tilde{W}$) and higgsino ($\tilde{H}$) considered as $\tilde{\chi}_{\text{heavy}}$ or $\tilde{\chi}_{\text{light}}$, in 4 mass hierarchies:

- General Gauge Mediation (GGM) / naturalness-driven gravitino LSP model ($\tilde{H}$, $\tilde{G}$)

- Naturalness-driven axino LSP model ($\tilde{H}$, $\tilde{a}$)

Hadronic decay modes of $W$, $Z$ and $h$ bosons to take advantage of the larger Branching Ratios (BR).

Dedicated analysis for the $b\bar{b}b\bar{b}b\bar{b}$ final state.
All Hadronic: Analysis Strategy

The analysis strongly relies on large-radius (large-$R$) reconstructed jets

**Signal Regions (SRs)**

- Two main selections according to the presence of two $b$-tagged jets
- Multiple SRs defined to target different physics processes
- $V_{qq}$ boson tagging requirements
- Selected events with hard kinematics: effective mass of the two leading large-$R$ jets and Missing Transverse Energy (MET)
- Transverse mass $m_{T2}$ to suppress SM backgrounds, mainly $t\bar{t}$

**Background Estimation**

**Control and Validation Regions (CRs, VRs)**

- Main backgrounds: $Z(\rightarrow \nu\nu) + jets$, $W(\rightarrow \ell\nu) + jets$, $VV$ and $t\bar{t}$, $Wt$ and $tt + X$ for regions with 2 $b$-jets.
- Irreducible, $VVV$ and $tt + X$: estimated using Monte Carlo (MC) simulation
- Reducible: a partly data-driven method used (CRs/VRs)
- Topology with initial-state radiation jet (ISR) and 1 lepton/photon events
All Hadronic: Results

No significant excess is found in any of the SRs. Exclusion limits are set:

- Exclusion limits on $(\tilde{W}, \tilde{B})$ specific simplified models: $\tilde{\chi}_1^\pm \tilde{\chi}_1'^\mp$ - $WW$, $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ - $WZ/Wh$

- $(\tilde{H}, \tilde{G})$ complements sensitivity achieved by ATLAS searches $ZZ \to 4\ell$ and multi-$b$

- $(\tilde{H}, \tilde{B})$ limits interpreted for the $Z/h$-funnel Dark Matter model
2\ell + 2J: Outline

Common final state signature: 2 Opposite Sign (OS), Same-Flavor (SF) leptons and jets

- Mainly motivated by the 2.0\sigma and 1.4\sigma excesses using previous 36 fb\(^{-1}\) search
- Two SRs, using recursive-jigsaw reconstruction (RJR) variables (not optimized for full Run 2 dataset)
  + New analysis strategy for the same topology, optimized for full Run 2 dataset
- New search inspired by gauge-mediated SUSY breaking (GMSB), targeting the pair production of higgsino next-to-lightest SUSY particles (NLSPs) decaying into a ZZ or Zh pair and gravitino LSPs
- Similar methodology as for the previous 36 fb\(^{-1}\) search, but optimized for the full Run 2 and with a new region targeting off-shell Z boson decays

For completeness: this analysis also considers the strong production of gluino or squark pairs, see Ben’s talk in the morning!
$2\ell + 2J$: Analysis Strategy

**RJR search**
- Selection kept the same as the previous search
- SRs designated to target $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \sim 100$ GeV

**Main electroweak search**
- 13 orthogonal SRs designed to cover different regions of the $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ and GMSB models’ parameter spaces
- Extended phase space targeted up to $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) = 1$ GeV and up to 500 GeV for $m(\tilde{\chi}_1^0)$ in GMSB models
- Main variables: lepton/jet multiplicities, dijet mass and $\Delta R$, MET Significance, $m_{T2}$
- Dominant backgrounds: $WZ$, $ZZ$ (1 normalization factor), $t\bar{t}$ production. Additionally $Z/\gamma^* + jets$ for off-shell regions (2 factors, due to Drell-Yan kinematics)
No more excess in the 2 RJR-search SRs

No excess in the EWK and GMSB topologies

Excluded $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0)$ up to 820 GeV for a massless LSP and $m(\tilde{\chi}_1^0)$ up to 900 GeV for the higgsino NLSP

Extended limits on EWK particles in multiple and different regions of parameter space!
2\ell + 0J: Outline

- Targeting compressed mass spectra not excluded by previous iteration, focused on $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \gtrsim 100$ GeV, with related unfolding effort. Now $\Delta m(\tilde{\chi}_1^\pm/\tilde{\ell}, \tilde{\chi}_1^0) \lesssim 100$ GeV

- Signature: 2 OS leptons and MET

- Two dedicated and different strategies for chargino (machine learning approach) and slepton (flavor subtraction) searches

- $\tilde{\ell} = \tilde{\ell}/\tilde{\mu}$. Smuons particularly interesting as possible explanation for the observed muon $g-2$ anomaly
2\ell + 0J: Analysis Strategy

Slepton search
- Flavor asymmetric channel: 2 SF OS leptons as signal signature
- New semi data-driven procedure to extrapolate SF background starting from DF events, to improve the moderately compressed limits.
- Multi-bin fit in $m_{T2}^{100}$ (assuming $m(\tilde{\chi}_1^0) = 100$ GeV) for 0-jet and 1-jet events, potentially accounting ISR jet

Chargino search
- Exploited machine learning technique, based on *Boosted Decision Tree* (BDT) with *Gradient* boosting, to get sensitivity to low-mass compressed phase space
- 4 classification categories: Signal, VV, top-quark ($t\bar{t}$, $Wt$), Others
- Multi-bin fit in BDT variables, with DF/SF split, in the 0-jet channel only
- Main backgrounds: VV and top-quark
Chargino masses up to 135 GeV are excluded for $\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) = 100$ GeV

Slepton masses up to 150 GeV are excluded for $\Delta m(\tilde{\ell}, \tilde{\chi}_1^0) = 50$ GeV
Based on the EWK $2\ell + 0J$ first iteration, the same starting point as previous analysis

$WW$ background as the main background process $\rightarrow$ Dedicated normalization factor

The idea is to make the reverse process: differences from unity of scaling factors suggest mismodelling in the phase space targeted by the search and producing "unfolded" particle-level measurements

Measured $WW$ production in a SUSY-inspired phase space, helping to improve future searches and complementary to existing ATLAS 13 TeV measurements of $WW$ production in 0-jet events and in $\geq 1$-jet events
From $WW$ CR/VR definitions in $2\ell + 0J$ paper: $\mu_{WW}^{2\ell+0j} = 1.25 \pm 0.11$

<table>
<thead>
<tr>
<th>Region</th>
<th>$2\ell + 0J$ defs.</th>
<th>Unfolding</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR-WW</td>
<td>DF $n_{jets} = 0$</td>
<td>DF $m_{T2} \in [60, 65]$</td>
</tr>
<tr>
<td>VR-WW</td>
<td>$E_T^{miss} &gt; 60$</td>
<td>$E_T^{miss} \in [60, 100]$</td>
</tr>
<tr>
<td></td>
<td>$E_{miss}^{significance} &gt; 5$</td>
<td>$E_{miss}^{significance} \in [60, 80]$</td>
</tr>
<tr>
<td></td>
<td>$m_{e\mu} &gt; 100$</td>
<td>$m_{e\mu} &gt; 100$</td>
</tr>
</tbody>
</table>

$$\sigma_{WW} = \frac{N_{obs} - N_{bkg}}{C \cdot L}$$

with: $N_{obs}$ observed data-events in the fiducial region, $N_{bkg}$ predicted number of background events, $L$ the integrated luminosity, $C = 0.55 \pm 0.08$ correction factor of the observation due to limited acceptances and detector inefficiencies.
**2\ell + 0\ell** Unfolding: Results

Differential cross-section calculated using the *Iterative Bayesian Unfolding* technique

\[
\sigma_{WW \rightarrow e^\pm \nu \mu^\mp \nu} = 19.2 \pm 0.3 \, \text{(stat)} \pm 2.5 \, \text{(syst)} \pm 0.4 \, \text{(lumi)} \, \text{fb} = 19.2 \pm 2.6 \, \text{(total)} \, \text{fb}
\]

- Largest syst. contribution from experimental jet uncertainty: 12% on measured \(\sigma_{WW}\)
- Compatible with Powheg and Sherpa nominal predictions: 17.8 and 17.1 fb (Uncertainties not considered in theory predictions)

\[
\mu_{WW}^{Unf.} \times f_{NLO}^\sigma(= 1.13) = 1.22 \leftarrow \mu_{WW}^{2\ell+0j} = 1.25 \pm 0.11
\]
Conclusions

- Exciting analyses recently published, pushing exclusion limits on SUSY particle masses to always higher values
- New results and physics confirmation, now starting to interconnect SUSY $\leftrightarrow$ SM with dedicated techniques
- Machine Learning tools can make the difference when looking at compressed mass spectra phase space
- Take advantage of preservation, reinterpretation and combination of analyses to expand coverage, hopefully soon
- LHC Run 3 is about to start: new strategies, new data, new perspectives...

Stay Tuned!
Backup
### Table 1: Summary of the production modes, final states, and signal regions (SRs) used for the hypothesis tests, and the branching ratio assumptions for the signal models targeted in the search. The notation and definition of the simplified models are considered in the interpretation. The SRs are described in Section 7.

<table>
<thead>
<tr>
<th>Model</th>
<th>Production</th>
<th>Final states</th>
<th>SRs simultaneously fitted</th>
<th>Branching ratio</th>
</tr>
</thead>
</table>
| $(\tilde{W}, \tilde{B})$ | $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{\mp}_{1}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{2}$ | $WW, WZ, Wh$ | 4Q-VV, 2B2Q-WZ, 2B2Q-Wh | $\mathcal{B}(\tilde{\chi}^{\pm}_{1} \rightarrow W\tilde{\chi}^{0}_{1}) = 1$
$\mathcal{B}(\tilde{\chi}^{0}_{2} \rightarrow Z\tilde{\chi}^{0}_{1})$ scanned |
| $(\tilde{H}, \tilde{B})$ | $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{\mp}_{1}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{2}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{3}, \tilde{\chi}^{0}_{2}\tilde{\chi}^{0}_{3}$ | $WW, WZ, Wh, ZZ, Zh, hh$ | 4Q-VV, 2B2Q-VZ, 2B2Q-Vh | $\mathcal{B}(\tilde{\chi}^{\pm}_{1} \rightarrow W\tilde{\chi}^{0}_{1}) = 1$
$\mathcal{B}(\tilde{\chi}^{0}_{2} \rightarrow Z\tilde{\chi}^{0}_{1})$ scanned
$\mathcal{B}(\tilde{\chi}^{0}_{3} \rightarrow Z\tilde{\chi}^{0}_{1}) = 1 - \mathcal{B}(\tilde{\chi}^{0}_{2} \rightarrow Z\tilde{\chi}^{0}_{1})$ |
| $(\tilde{W}, \tilde{H})$ | $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{\mp}_{2}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{3}$ | $WW, WZ, Wh, ZZ, Zh, hh$ | 4Q-VV, 2B2Q-VZ, 2B2Q-Vh | Determined from $(M_{2}, \mu, \tan \beta)$ |
| $(\tilde{H}, \tilde{W})$ | $\tilde{\chi}^{\pm}_{2}\tilde{\chi}^{\mp}_{2}, \tilde{\chi}^{\pm}_{2}\tilde{\chi}^{0}_{3}, \tilde{\chi}^{0}_{2}\tilde{\chi}^{0}_{3}$ | $WW, WZ, Wh, ZZ, Zh, hh$ | 4Q-VV, 2B2Q-VZ, 2B2Q-Vh | Determined from $(M_{2}, \mu, \tan \beta)$ |
| $(\tilde{H}, \tilde{G})$ | $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{\mp}_{1}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{1}, \tilde{\chi}^{0}_{1}\tilde{\chi}^{0}_{1}$ | $ZZ, Zh, hh$ | 4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh | $\mathcal{B}(\tilde{\chi}^{0}_{1} \rightarrow Z\tilde{\chi}
\tilde{\chi}
\tilde{\chi})$ scanned |
| $(\tilde{H}, \tilde{a})$ | $\tilde{\chi}^{\pm}_{1}\tilde{\chi}^{\mp}_{1}, \tilde{\chi}^{\pm}_{1}\tilde{\chi}^{0}_{1}, \tilde{\chi}^{0}_{1}\tilde{\chi}^{0}_{1}$ | $ZZ, Zh, hh$ | 4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh | $\mathcal{B}(\tilde{\chi}^{0}_{1} \rightarrow Z\tilde{\chi}
\tilde{\chi}
\tilde{\chi})$ scanned |

### (\tilde{W}, \tilde{B}) simplified models: (\tilde{W}, \tilde{B})-SIM

<table>
<thead>
<tr>
<th>Model</th>
<th>Production</th>
<th>Final states</th>
<th>SRs simultaneously fitted</th>
<th>Branching ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1C1-WW</td>
<td>$\tilde{\chi}^{\pm}<em>{1}\tilde{\chi}^{\mp}</em>{1}$</td>
<td>$WW$</td>
<td>4Q-WW</td>
<td>$\mathcal{B}(\tilde{\chi}^{\pm}<em>{1} \rightarrow W\tilde{\chi}^{0}</em>{1}) = 1$</td>
</tr>
<tr>
<td>C1N2-WZ</td>
<td>$\tilde{\chi}^{\pm}<em>{1}\tilde{\chi}^{0}</em>{2}$</td>
<td>$WZ$</td>
<td>4Q-WZ, 2B2Q-WZ</td>
<td>$\mathcal{B}(\tilde{\chi}^{\pm}<em>{1} \rightarrow W\tilde{\chi}^{0}</em>{1}) = \mathcal{B}(\tilde{\chi}^{0}<em>{2} \rightarrow Z\tilde{\chi}^{0}</em>{1}) = 1$</td>
</tr>
<tr>
<td>C1N2-Wh</td>
<td>$\tilde{\chi}^{\pm}<em>{1}\tilde{\chi}^{0}</em>{2}$</td>
<td>$Wh$</td>
<td>2B2Q-Wh</td>
<td>$\mathcal{B}(\tilde{\chi}^{\pm}<em>{1} \rightarrow W\tilde{\chi}^{0}</em>{1}) = \mathcal{B}(\tilde{\chi}^{0}<em>{2} \rightarrow h\tilde{\chi}^{0}</em>{1}) = 1$</td>
</tr>
</tbody>
</table>
### All Hadronic: SRs, CRs, VRs

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<table>
<thead>
<tr>
<th></th>
<th>SR(CR0L)</th>
<th>VR(CR)1L</th>
<th>VR(CR)1Y</th>
<th>VRTTX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4Q 2B2Q</td>
<td>4Q 2B2Q</td>
<td>4Q 2B2Q</td>
<td></td>
</tr>
<tr>
<td><strong>n_{Large-R jets}</strong></td>
<td>≥ 2</td>
<td>≥ 2</td>
<td>≥ 2</td>
<td>= 1</td>
</tr>
<tr>
<td><strong>n_{lepton}</strong></td>
<td>= 0</td>
<td>= 1</td>
<td>= 0</td>
<td>= 3</td>
</tr>
<tr>
<td><strong>p_T(\ell_1) [GeV]</strong></td>
<td>-</td>
<td>&gt; 30</td>
<td>-</td>
<td>&gt; 30</td>
</tr>
<tr>
<td><strong>n_{photon}</strong></td>
<td>-</td>
<td>-</td>
<td>= 1</td>
<td>-</td>
</tr>
<tr>
<td><strong>n(V_{qq})</strong></td>
<td>= 2 (= 1)</td>
<td>= 1 (= 0)</td>
<td>= 2 (= 1)</td>
<td>-</td>
</tr>
<tr>
<td><strong>n(!V_{qq})</strong></td>
<td>= 0 (= 1)</td>
<td>= 0 (= 1)</td>
<td>= 0 (= 1)</td>
<td>-</td>
</tr>
<tr>
<td><strong>n(J_{bb})</strong></td>
<td>= 0</td>
<td>= 1</td>
<td>= 0</td>
<td>= 1</td>
</tr>
<tr>
<td><strong>m(J_{bb}) [GeV]</strong></td>
<td>- ∈ [70, 135 (150)]</td>
<td>- ∈ [70, 150]</td>
<td>- ∈ [70, 150]</td>
<td>-</td>
</tr>
<tr>
<td><strong>n_{unmatched b-jet}</strong></td>
<td>= 0</td>
<td>= 0</td>
<td>= 0</td>
<td>-</td>
</tr>
<tr>
<td><strong>n_{b-jet}</strong></td>
<td>≤ 1</td>
<td>= 0</td>
<td>≤ 1</td>
<td>-</td>
</tr>
<tr>
<td><strong>E_T^{miss} [GeV]</strong></td>
<td>&gt; 300</td>
<td>&gt; 200</td>
<td>&gt; 50</td>
<td>&lt; 200</td>
</tr>
<tr>
<td><strong>p_T(W) [GeV]</strong></td>
<td>-</td>
<td>&gt; 200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>p_T(γ) [GeV]</strong></td>
<td>-</td>
<td>-</td>
<td>&gt; 200</td>
<td>-</td>
</tr>
<tr>
<td><strong>m_{eff} [GeV]</strong></td>
<td>&gt; 1300</td>
<td>&gt; 1000 (&gt; 900)</td>
<td>&gt; 1000</td>
<td>&gt; 900</td>
</tr>
<tr>
<td><strong>min Δφ(E_T^{miss}, j)</strong></td>
<td>&gt; 1.0</td>
<td>&gt; 1.0</td>
<td>&gt; 1.0</td>
<td>-</td>
</tr>
<tr>
<td><strong>m_{T2} [GeV]</strong></td>
<td>-</td>
<td>&gt; 250</td>
<td>-</td>
<td>&gt; 250</td>
</tr>
</tbody>
</table>

Also, the following criteria are applied:

- n_{Large-R jets} ≥ 2
- n_{lepton} = 0
- p_T(\ell_1) > 30 GeV
- n_{photon} = 1
- n(V_{qq}) = 2
- n(!V_{qq}) = 0
- n(J_{bb}) = 1
- m(J_{bb}) ∈ [70, 150] GeV
- n_{unmatched b-jet} = 0
- n_{b-jet} ≤ 1
- E_T^{miss} > 300 GeV
- p_T(W) > 200 GeV
- p_T(γ) > 200 GeV
- m_{eff} > 1300 GeV
- min Δφ(E_T^{miss}, j) > 1.0
- m_{T2} > 250 GeV
**All Hadronic: Systematics**

**ATLAS, \( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)**

- Total
- Theory
- CR statistical
- Reducible BG composition
- Boson tagging
- Experimental
- MC statistical

\[ \text{Relative uncertainty} \]

- Boson tagging
- Theory
- Experimental
- MC statistical

- **Reducible BG composition**

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All Hadronic: $Z/h$-funnel

\begin{align*}
m(\tilde{\chi}_1^0) &= m_Z/2 \ (Z\text{-funnel}) \\
m(\tilde{\chi}_1^0) &= m_h/2 \ (h\text{-funnel})
\end{align*}
All Hadronic: \((\tilde{W}, \tilde{B})\) simplified models

\[(\tilde{W}, \tilde{B})\text{-SIM (C1C1-WW)} \chi_{1/2}^{\pm0} \rightarrow WW \chi_{0/0}^{0}
\]

\[\chi \sim m(0, 50, 100, 150, 200, 250, 300, 350, 400, 450) \text{ [GeV]} \]

\[m(\tilde{\chi}_i^0) \text{ [GeV]} \]

\[\chi \sim \frac{1}{\pm} \chi \sim \text{Expected limit (±1} \sigma_{\text{exp}}\text{)}
\]

\[\text{Observed limit (±1} \sigma_{\text{SUSY}}\text{)}
\]

\[\text{Observed 95% CL}
\]

\[\text{arXiv:2105.01676 (3L, 139fb)}\]

\[\text{All limits at 95% CL}
\]

\[\sqrt{s} = 13 \text{ TeV, 139 fb}^{-1}
\]
## $2\ell + 2J$: SRs, CRs, VRs

<table>
<thead>
<tr>
<th>Region</th>
<th>$n_{\text{jets}}$</th>
<th>$n_{b\text{-tag jets}}$</th>
<th>$S(E_{\text{T}}^{\text{miss}})$</th>
<th>$m_{\ell\ell}$</th>
<th>$m_X$</th>
<th>$m_{T2}$</th>
<th>$\Delta R_X$</th>
<th>$p_{j1}^{T}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-High-EWK</td>
<td>$\geq 2$</td>
<td>$\leq 1$</td>
<td>(18, 21, $\infty$)</td>
<td>71–111</td>
<td>$60 &lt; m_{jj} &lt; 110$</td>
<td>$&gt; 80$</td>
<td>$\Delta R_{jj} \in (0, 0.8, 1.6)$</td>
<td>$-$</td>
</tr>
<tr>
<td>VR-High-Sideband-EWK</td>
<td>$\geq 2$</td>
<td>$\leq 1$</td>
<td>$&gt; 18$</td>
<td>71–111</td>
<td><em>20</em> $&lt; m_{jj} &lt; 60 \cup m_{jj} &gt; 110$</td>
<td>$&gt; 80$</td>
<td>$\Delta R_{jj} &lt; 1.6$</td>
<td>$-$</td>
</tr>
<tr>
<td>VR-High-R-EWK</td>
<td>$\geq 2$</td>
<td>$\leq 1$</td>
<td>$&gt; 18$</td>
<td>71–111</td>
<td>$m_{jj} &gt; 20$</td>
<td>$&gt; 80$</td>
<td>$\Delta R_{jj} &gt; 1.6$</td>
<td>$-$</td>
</tr>
<tr>
<td>SR-1J-High-EWK</td>
<td>1</td>
<td>$\leq 1$</td>
<td>$&gt; 12$</td>
<td>71–111</td>
<td>$60 &lt; m_{jj} &lt; 110$</td>
<td>$&gt; 80$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>VR-1J-High-Sideband-EWK</td>
<td>1</td>
<td>$\leq 1$</td>
<td>$&gt; 12$</td>
<td>71–111</td>
<td><em>20</em> $&lt; m_{j1} &lt; 60 \cup m_{j1} &gt; 110$</td>
<td>$&gt; 80$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>SR-$\ell\ell bb$-EWK</td>
<td>$\geq 2$</td>
<td>$\geq 2$</td>
<td>$&gt; 18$</td>
<td>71–111</td>
<td>$60 &lt; m_{bb} &lt; 150$</td>
<td>$&gt; 80$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
<tr>
<td>VR-$\ell\ell bb$-EWK</td>
<td>$\geq 2$</td>
<td>$\geq 2$</td>
<td>12–18</td>
<td>81–101</td>
<td>$60 &lt; m_{bb} &lt; 150$</td>
<td>$&gt; 80$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>$n_{\text{jets}}$</th>
<th>$n_{b\text{-tag jets}}$</th>
<th>$S(E_{\text{T}}^{\text{miss}})$</th>
<th>$m_{\ell\ell}$</th>
<th>$m_X$</th>
<th>$m_{T2}$</th>
<th>$\Delta R_X$</th>
<th>$\Delta@\phi(p_{\ell\ell}^{T}, p_{\text{miss}}^{T})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-Low-EWK</td>
<td>2</td>
<td>0</td>
<td>(6, 9, 12)</td>
<td>81–101</td>
<td>$60 &lt; m_{jj} &lt; 110$</td>
<td>$&gt; 80$</td>
<td>$\Delta R_{\ell\ell} &lt; 1$</td>
<td>$-$</td>
</tr>
<tr>
<td>VR-Low-EWK</td>
<td>2</td>
<td>0</td>
<td>6–12</td>
<td>81–101</td>
<td>$60 &lt; m_{jj} &lt; 110$</td>
<td>$&gt; 80$</td>
<td>$1 &lt; \Delta R_{\ell\ell} &lt; 1.4$</td>
<td>$-$</td>
</tr>
<tr>
<td>SR-Low-2-EWK</td>
<td>2</td>
<td>0</td>
<td>6–9</td>
<td>81–101</td>
<td>$60 &lt; m_{jj} &lt; 110$</td>
<td>$&lt; 80$</td>
<td>$\Delta R_{\ell\ell} &lt; 1.6$</td>
<td>$&lt; 0.6$</td>
</tr>
<tr>
<td>VR-Low-2-EWK</td>
<td>2</td>
<td>0</td>
<td>6–9</td>
<td>81–101</td>
<td><em>20</em> $&lt; m_{jj} &lt; 60 \cup m_{jj} &gt; 110$</td>
<td>$&lt; 80$</td>
<td>$\Delta R_{\ell\ell} &lt; 1.6$</td>
<td>$&lt; 0.6$</td>
</tr>
<tr>
<td>CR-Z-EWK</td>
<td>2</td>
<td>0</td>
<td>6–9</td>
<td>81–101</td>
<td><em>20</em> $&lt; m_{jj} &lt; 60 \cup m_{jj} &gt; 110$</td>
<td>$&gt; 80$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>$n_{\text{jets}}$</th>
<th>$n_{b\text{-tag jets}}$</th>
<th>$S(E_{\text{T}}^{\text{miss}})$</th>
<th>$m_{\ell\ell}$</th>
<th>$m_{T2}$</th>
<th>$p_{j1}^{T}$</th>
<th>$\Delta@\phi(p_{j1}^{T}, p_{\text{miss}}^{T})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-OffShell-EWK</td>
<td>$\geq 2$</td>
<td>0</td>
<td>$&gt; 9$</td>
<td>(12, 40, 71)</td>
<td>$&gt; 100$</td>
<td>$&gt; 100$</td>
<td>$&gt; 2$</td>
</tr>
<tr>
<td>VR-OffShell-EWK</td>
<td>$\geq 2$</td>
<td>0</td>
<td>$&gt; 9$</td>
<td>12–71</td>
<td>80–100</td>
<td>$&gt; 100$</td>
<td>$&gt; 2$</td>
</tr>
<tr>
<td>CR-DY-EWK</td>
<td>$\geq 2$</td>
<td>0</td>
<td>6–9</td>
<td>12–71</td>
<td>$&gt; 100$</td>
<td>$-$</td>
<td>$-$</td>
</tr>
</tbody>
</table>
$2\ell + 2J$: EWK Pull Plot

**ATLAS** Preliminary

$\sqrt{s}=13$ TeV, 139 fb$^{-1}$

- Data
- Standard Model
  - Diboson
  - Other
  - $Z/\gamma^* + \text{jets}$
  - Top

Events

Significance

- CR-DY-EWK
- CR-Z-EWK
- CR-tt-EWK
- CR-VZ-EWK
- VR-OffShell-EWK
- VR-Low-EWK
- VR-Low-2-EWK
- VR-Int-EWK
- VR-High-R-EWK
- VR-High-Sideband-EWK
- VR-1J-High-Sideband-EWK
- SR-OffShell_a-EWK
- SR-OffShell_b-EWK
- SR-Low_a-EWK
- SR-Low_b-EWK
- SR-Low-2-EWK
- SR-Int_a-EWK
- SR-Int_b-EWK
- SR-High_16a-EWK
- SR-High_16b-EWK
- SR-High_8a-EWK
- SR-High_8b-EWK
- SR-1J-High-EWK

Backup
### Slepton search

<table>
<thead>
<tr>
<th>Signal region (SR)</th>
<th>SR-0J</th>
<th>SR-1J</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n_{\text{b-tagged jets}})</td>
<td>(= 0)</td>
<td>(= 0)</td>
</tr>
<tr>
<td>(E_T^{\text{miss}}) significance</td>
<td>(&gt; 7)</td>
<td>(&gt; 7)</td>
</tr>
<tr>
<td>(n_{\text{non-b-tagged jets}})</td>
<td>(= 0)</td>
<td>(= 1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>SR-0J</th>
<th>SR-1J</th>
</tr>
</thead>
<tbody>
<tr>
<td>(p_T^{\ell_1}) [GeV]</td>
<td>(&gt; 140)</td>
<td>(&gt; 100)</td>
</tr>
<tr>
<td>(p_T^{\ell_2}) [GeV]</td>
<td>(&gt; 20)</td>
<td>(&gt; 50)</td>
</tr>
<tr>
<td>(m_{\ell_1\ell_2}) [GeV]</td>
<td>(&gt; 11)</td>
<td>(&gt; 60)</td>
</tr>
<tr>
<td>(p_T^{\text{miss}}) [GeV]</td>
<td>(&lt; 5)</td>
<td>-</td>
</tr>
<tr>
<td>[cos (\theta_{\ell})]</td>
<td>(&lt; 0.2)</td>
<td>(&lt; 0.1)</td>
</tr>
<tr>
<td>(\Delta\phi_{\ell_1,\ell_2})</td>
<td>(&gt; 2.2)</td>
<td>(&gt; 2.8)</td>
</tr>
<tr>
<td>(\Delta\phi_{\ell_1,\ell_2})</td>
<td>(&gt; 2.2)</td>
<td>-</td>
</tr>
</tbody>
</table>

### Chargino search

#### Binned SRs

- \(m_{T_2}^{100}\) [GeV]
  - \(\epsilon\{100,105\}\)
  - \(\epsilon\{105,110\}\)
  - \(\epsilon\{110,115\}\)
  - \(\epsilon\{115,120\}\)
  - \(\epsilon\{120,125\}\)
  - \(\epsilon\{125,130\}\)
  - \(\epsilon\{130,140\}\)
  - \(\epsilon\{140,\infty\}\)

#### Inclusive SRs

<table>
<thead>
<tr>
<th>(m_{T_2}^{100}) [GeV]</th>
<th>SR-DF-81-SF-77</th>
<th>SR-DF-81-SF-78</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\epsilon{100,\infty})</td>
<td>(\epsilon{0.81,1})</td>
<td>(\epsilon{0.77,1})</td>
</tr>
<tr>
<td>(\epsilon{110,\infty})</td>
<td>(\epsilon{0.81,1})</td>
<td>(\epsilon{0.77,1})</td>
</tr>
<tr>
<td>(\epsilon{120,\infty})</td>
<td>(\epsilon{0.81,1})</td>
<td>(\epsilon{0.77,1})</td>
</tr>
<tr>
<td>(\epsilon{130,\infty})</td>
<td>(\epsilon{0.81,1})</td>
<td>(\epsilon{0.77,1})</td>
</tr>
<tr>
<td>(\epsilon{140,\infty})</td>
<td>(\epsilon{0.81,1})</td>
<td>(\epsilon{0.77,1})</td>
</tr>
</tbody>
</table>
**2\(\ell + 0J\): Background estimation for sleptons**

\[
N_{SF}^{\text{exp}} = N_{ee}^{\text{exp}} + N_{\mu\mu}^{\text{exp}} = \frac{1}{2} \cdot \left( \kappa + \frac{1}{\kappa} \right) \cdot \alpha \cdot N_{DF}
\]

\[
\kappa = \sqrt{\frac{N_{\mu^+\mu^-}}{N_{e^+e^-}}} \quad \alpha = \sqrt{\frac{\varepsilon_{ee}^{\text{trig.}} \cdot \varepsilon_{\mu\mu}^{\text{trig.}}}{\varepsilon_{e\mu}^{\text{trig.}}}}
\]

The \(\kappa\) and \(\alpha\) factors take into account, as event-by-event weights, the different reconstruction, isolation, identification, trigger efficiencies for \(e^\pm/\mu^\pm\)

- The factor \(\kappa\) is extracted from data in a control sample, obtained relaxing the cuts on \(p_T^{\ell_1}\) and parametrised as a function of that variable, MET-significance and inverting the cut on \(|\cos\theta_{\ell\ell}^*|\) to make it orthogonal to the SRs
- The factor \(\alpha\) is computed from the global efficiencies of the trigger selection applied in the analysis, evaluated on a control sample of data triggered with an independent selection
\(2\ell + 0J\): Pull plots

**ATLAS** Preliminary

- **Data**
- **SM**
- **m(\tilde{\chi}) = (100, 70) GeV**
- **m(\tilde{\chi}) = (150, 100) GeV**

**ATLAS** Preliminary

- **Data**
- **SM**
- **m(\tilde{\chi}) = (100, 10) GeV**
- **m(\tilde{\chi}) = (125, 25) GeV**
- **m(\tilde{\chi}) = (150, 50) GeV**
$2\ell + 0J$: Sleptons exclusion

![Graph showing slepton exclusions]
Iterative Bayesian Unfolding technique

- This technique corrects the detector-level distributions of data for migrations between bins introduced by the event reconstruction.

- It applies *fiducial* and *reconstruction efficiency* corrections:
  - Fiducial: events reconstructed in the signal region but originate outside the fiducial region at particle level.
  - Reconstruction efficiency: events lying in the fiducial region at particle level, but not entering the SR due to detector inefficiencies.

- Bins chosen for the differential measurements optimised to reduce the migration of events between particle-level and detector-level bins.

- Number of iterations also optimised, balancing statistical uncertainties (too many ones) and bias in the measurements towards the MC prediction (too few ones).

- Performed tests to estimate the bias introduced by using information from the nominal signal MC in the unfolding procedure: in all tests the expected particle-level distributions were accurately recovered.
2ℓ + 0J Unfolding: Results

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)

- Unfolded data
- Powheg-Box+Pythia8, k=1.13
- Sherpa 2.2.2, k=1.0
- Stat.
- Stat. + Syst.

*with Sherpa+OL gg → WW, k=1.7

Theory / Data

Uncertainty (%)

- B-tagging
- Jets
- Luminosity
- Lepton modelling
- Pile-up reweighting
- Top modelling
- Statistical uncertainties

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, 139 \text{ fb}^{-1} \)

- Stat.
- Stat. + Syst.

- \( m_{\text{ee}} \) [GeV]
- \( p_T^{\text{lead } \ell} \) [GeV]

- \( m_{\text{mu}} \) [GeV]
- \( p_T^{\text{lead } \ell} \) [GeV]
$2\ell + 0J$ Unfolding: Results

**ATLAS Preliminary**

- $\sqrt{s} = 13$ TeV, 139 fb$^{-1}$
- Theory / Data
- Data 2015+2016
- $\nu^\pm\mu^\pm e \rightarrow pp$

### Unfolded Data

- **$d\sigma/d\Delta\Phi_{\ell\ell}$ [fb]**
- **$d\sigma/d\cos\theta^*$ [fb]**

#### Theoretical Models

- Powheg-Box+Pythia8, $k=1.13$ *
- Sherpa 2.2.2, $k=1.0$ *
- Stat. ± Syst.

#### Uncertainty Sources

- Stat. ⊕ Syst.
- NLO (EW) ⊗ [NNLO (qq)+NLO (gg)]
- Powheg-Box+Pythia8, $k=1.13$ *
- Powheg-Box+Herwig++, $k=1.13$ *
- Sherpa 2.2.2, $k=1.0$ *

* comb. w. Sherpa+OL gg $\rightarrow$ WW, $k=1.7$