Inclusive searches for squarks and gluinos in final states with leptons with the ATLAS detector

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Introduction

• Leptons can appear in SUSY decay chains involving W/Z or sleptons
  ○ Also in the decays of neutralinos in some RPV models: \( \tilde{\chi}_1^0 \rightarrow \ell^+ \ell^- \nu \)
• Typically lower signal branching ratios than 0-lepton analyses, but not so affected by QCD multi-jet background

Also providing some additional experimental handles:
  ○ Leptonically decaying Z boson
  ○ Kinematic edges in dilepton invariant mass (can also be used to measure particle masses)
  ○ Same-sign dileptons (gluino production or long decay chains)

Searches for squarks/gluinos included in this talk:
  ○ [NEW] 1\( \ell \) (36.1 fb\(^{-1}\)): SUSY-2016-12, to appear
  ○ 2\( \ell \) opposite-sign (14.7 fb\(^{-1}\)): Eur. Phys. J. C 77 (2017) 144
  ○ 2\( \ell \) same-sign/3\( \ell \) (36.1 fb\(^{-1}\)): arXiv:1706.03731, submitted to JHEP
Search with $1\ell$: Motivation & Strategy

- Targeting SUSY models with $W/Z$ bosons, with either short/long decay chains

- Models probed with signal regions (SRs) with $1\ell$, large $E_T^{\text{miss}}$ ($> 200$ GeV), and either $\geq 2$ jets, $\geq 4$ jets (several $\tilde{q}/\tilde{g}$, $\tilde{\chi}^\pm$ and $\tilde{\chi}_1^0$ mass differences), $\geq 6$ jets or $\geq 9$ jets

- Sensitivity enhanced using transverse mass ($m_T$), aplanarity or effective mass ($m_{\text{eff}}$)

- Control regions (CRs):
  - $b$-veto: $W+$jets
  - $\geq 1b$-jet: $t\bar{t}+Wt$

- For $\geq 2$-6 jets:
  - CRs at low $E_T^{\text{miss}}$, $m_T$, aplanarity
  - For each $m_{\text{eff}}$ bin, with same $N_{\text{jet}}$ requirements as SRs
  - Using MC CR$\rightarrow$SR transfer factor

- For $\geq 9$ jets:
  - Estimated using data at low $N_{\text{jet}}$ and $m_T$
Search with 1\ell: Results

- Validation regions defined at intermediate values of $E_T^{\text{miss}}, m_T$ → Good agreement with the background estimates
- No significant excess observed in the SRs (mild excess in 2-jet $b$-veto)
Search with 1ℓ: Interpretations

- Excluding gluino(squarks) masses of 2.1(1.2) TeV in $\tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$ and $\tilde{q} \rightarrow qW\tilde{\chi}_1^0$ simplified models
- Limits also computed for varying $(\tilde{g}/\tilde{q}, \tilde{\chi}_1^±, \tilde{\chi}_1^0)$ mass hierarchies
- In $\tilde{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$ simplified models, limits reach 1.7 TeV in gluino mass
Search with $2\ell OS$: Motivation & Strategy

- Two different searches in $2\ell OS+jets+E_{T}^{\text{miss}}$:
  - $Z \rightarrow \ell\ell$ produced in the decay chain of $\tilde{g}/\tilde{q} \Rightarrow$ Excess at $m_{\ell\ell} \sim m_{Z}$
  - Excess with triangular shape expected in cascade decays like $\tilde{\chi}_{2}^{0} \rightarrow \ell \tilde{\chi}_{1} \rightarrow \ell\ell \tilde{\chi}_{1}^{0} \Rightarrow$ “edge” on $m_{\ell\ell}$ depending on the sparticle masses

- $3\sigma$ excess in Run-1 $\rightarrow$ on-sell $Z$ SR essentially unchanged since then
- Edge search: SRs for low/medium/high $H_{T}$, divided in 24 $m_{\ell\ell}$ windows

**Backgrounds:**
- Flavor symmetric ($t\bar{t}$, $WW$): estimated from $e\mu$ data
- $Z$+jets ($E_{T}^{\text{miss}}$ from jet mismeasurements): estimated by smearing $\gamma$+jets data
- Fake/non-prompt leptons: data-driven
- Rest (diboson, etc.): from MC

**Dedicated VRs for the main backgrounds**
Search with 2ℓOS: On-shell Z results

- No excess observed in the on-shell Z search
- Data in agreement with expected background kinematic distributions

- Excluding gluino masses up to 1.3 TeV and squark masses up to 1 TeV in simplified models featuring \( \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0 \) decays (\( m_{\tilde{\chi}_1^0} = 1 \) GeV, similar to GGM models)
Search with $2\ell OS$: Edge results

- No significant excess across the bins of the edge search
  - Largest excess of $1.7\sigma$ local significance in SR at high $H_T$ and $12 < m_{\ell\ell} < 101$ GeV

- Interpretation in simplified models with $\tilde{g} \rightarrow qq\tilde{\chi}_2^0$, $\tilde{\chi}_2^0 \rightarrow \ell\ell \rightarrow \ell\ell\tilde{\chi}_1^0$
- Excluding gluino masses up to 1.8 TeV and neutralino masses of up to 900 GeV
Search with $2\ell SS/3\ell$: Motivation & Strategy

- Signature: dilepton same-sign (SS) or three leptons + jets
- Broad sensitivity to many SUSY models with gluinos (Majorana particles) or involving $W/Z/\tilde{\ell}$, both in $R$-parity conserving/violating SUSY scenarios
- Analysis featuring looser kinematic requirements than other searches (SS requirement rejecting $t\bar{t}$) → Better sensitivity to compressed scenarios
- Only analysis exploring $\tilde{b} \rightarrow t\tilde{\chi}_1^\pm$ and $\tilde{d}_R$ production in RPV

- SRs defined with SS/3$\ell$, 3-6 jets, 0-2 $b$-jets, $E_T^{\text{miss}}$ (for RPC) and $m_{\text{eff}}$

- New signature: three same-sign leptons ($\ell^+\ell^+\ell^\pm$)
  - Model originally proposed by Low et al. (arXiv:1507.01601) to explain Run-1 same-sign excesses ($t\bar{t}H$, $t\bar{t}W$, etc.)
  - Very basic SR: $\geq 3\ell$ with the same charge, $\geq 1$ $b$-jet, veto on $81 < m_{e^+ e^-} < 101$ GeV
Search with $2\ell$SS/$3\ell$: Results

- **Background estimation:**
  - Electron charge mis-id: data-driven
    - Factor $\sim 10$ reduction with new BDT
  - Fake/non-prompt lepton: data-driven
    - Two different methods used and combined for final estimates
  - Others ($t\bar{t}V$, diboson, rare): from MC
- **No significant excess observed in the SRs**
Search with 2ℓSS/3ℓ: RPC Interpretations

- Significantly extending previous limits:
  - Excluding $\tilde{b}$ masses of 700 GeV in $\tilde{b} \rightarrow t\tilde{\chi}^\pm_1$
  - Excluding $\tilde{g}$ masses up to 1.6-1.8 TeV in some models
  - Very good improvement also for heavy $\tilde{\chi}^0_1$ (compressed scenarios), reaching $\tilde{\chi}^0_1$ masses of $\sim$900 GeV
- First limits of $m_{\tilde{t}} \approx 700$ GeV in the $\tilde{t}_1 \rightarrow t\tilde{\chi}_2^0 \rightarrow tW\tilde{\chi}_1^\pm \rightarrow tWW^*\tilde{\chi}_1^0$ model
Search with 2$\ell$SS/3$\ell$: RPV Interpretations

- Excluding gluino masses of 1.4-1.8 TeV in RPV models, with also very good coverage for compressed topologies
- Exclusion limits of around 500 GeV in models with $\tilde{d}_R$ pair production
Summary

• Signatures with leptons are a powerful and versatile strategy to search for squarks and gluinos at the LHC
  ○ Leptons are produced in decay chains with sleptons, gauge bosons or in RPV models
  ○ Great reduction of backgrounds

• Recent analyses using $1-3\ell + \text{jets} (+E_T^{\text{miss}})$ in ATLAS
  ○ No excess observed 😐
  ○ Exclusion limits reaching gluino masses of up to 2 TeV
  ○ Also good sensitivity at high neutralino masses and in compressed topologies

• Also new signatures being explored: $2\ell^{\pm}S\text{S}$ without $E_T^{\text{miss}}$ for RPV models or $\ell^{\pm}\ell^{\pm}\ell^{\pm}$
Backup Slides
Search with 1ℓ: alternative background estimation

- $m_T$ requirements in SR:
  - Dileptonic $t\bar{t}$ dominates in the SR
  - Semi-leptonic $t\bar{t}$ is more prominent in the CR (missing lepton, hadronically decaying tau)

- Alternative background estimation by object replacement method

- Consistent results with nominal estimation

Alternative estimation of dileptonic background
- Due to $m_T$ cut dileptonic background dominates SR
- Alternative estimation by replacement method
- Consistent results with nominal estimation

Yields $1 \times 10^7$ ATLAS Internal

$\sqrt{s} = 13$ TeV, 36.5 fb$^{-1}$, $\text{miss } p_T + \text{jets} + E_T^{\mu}$

Pull (Obj. Rep.-Nom.)

$2 \times 10^{-1}$

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Search with 2ℓOS: additional interpretations

\[ \tilde{g} \tilde{g} \rightarrow q\bar{q} \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow Z \tilde{\chi}_1^0; \ m(\tilde{\chi}_1^0) = m(\tilde{\chi}_2^0) + 100 \text{ GeV} \]

\[ \tilde{g} \tilde{g} \rightarrow q\bar{q} \tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_2^0; \ m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^0) + 100 \text{ GeV} \]

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