Searches for supersymmetry in events with photons or tau leptons and missing transverse momentum with the ATLAS detector

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for the ATLAS collaboration

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Gauge Mediated Supersymmetry Breaking (GMSB) is one possible theory to introduce SUSY breaking

- Breaking happens at a high scale in a hidden sector. It is communicated to the weak scale MSSM by messenger fields
- Messengers couple to SM fields via standard gauge interactions
- In minimal version: six free parameters (two for Higgs sector)
  - In the searches presented here $\Lambda$ - setting the sparticle mass scale - and $\tan \beta$ - Higgs VEV ratio - are varied
  - Other parameters fixed to ensure one particular signature
• \( \tilde{G} \) (Gravitino) is always lightest SUSY particle (LSP)
• \( \tilde{G} \) has eV mass, is collider-stable and non-interacting \( \Rightarrow \not\! E_T \)
• NLSP\( \rightarrow \tilde{G} \) decay at the end of every decay chain

• NLSP determines search signatures
• Only short lived NLSP considered here
• Two NLSP possibilities studied:
  • \( \tilde{\chi}^0 \rightarrow \gamma \tilde{G} \), one photon in every decay chain
  • \( \tilde{\tau} \rightarrow \tau \tilde{G} \), one tau in every decay chain

• Production modes depend on squark and gluino masses
• Strong production for lower, electroweak production for higher values of \( \Lambda \)
• Two searches based on 2.05 fb$^{-1}$ of data recorded in 2011
• Target intermediate scale GMSB model with $\tilde{\tau}$ NLSP and production of colored sparticles
• Trigger on one hard jet (130 GeV) and large missing transverse energy $E_T$ (130 GeV)
• Select events with either one or two reconstructed taus with $p_T > 20$ GeV and no light leptons
• Separation between direction of jets and $E_T$ used to suppress missing energy due to instrumental effects
• Use $m_{\text{eff}} = \left( \sum_{\text{selected taus/jets}} p_T + E_T \right)$, $E_T/m_{\text{eff}}$ and transverse mass $m_T^\tau$ as main discriminating variables
• Background estimates based on extrapolations from control regions into signal region
• Separate hadronic tau decays from jets using multivariate techniques
• Generally smaller track multiplicity and stronger collimation than QCD jets
• Require $\geq 1$ “tight” tau for single tau and $\geq 2$ “loose” taus for di tau selection

• Individual cuts to suppress single background channels
• Main selection cut on $m_{\text{eff}}$ at 600 GeV (700 GeV) for the one tau (di tau) selection
• Multijet background estimated by measuring probability of jets to fake taus in control region

• True tau background evaluated from control region with $m_\tau^T < 70 \text{ GeV}$

• ...separating top from W using a multivariate discriminant

• Additional influence of fake taus studied in control region with $70 \text{ GeV} < m_\tau^T < 110 \text{ GeV}$ or $m_{\text{eff}} < 600 \text{ GeV}$

• Extrapolate to signal region with $110 \text{ GeV} < m_\tau^T$

• Dominant uncertainties from jet energy uncertainties (besides extrapolation, normalization and signal cross section)

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>$W + \text{jets}$</th>
<th>$Z + \text{jets}$</th>
<th>Multijet</th>
<th>$\sum \text{SM}$</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$5.6 \pm 1.4$</td>
<td>$4.7 \pm 1.5$</td>
<td>$2.4 \pm 0.7$</td>
<td>$0.5 \pm 0.6$</td>
<td>$13.2 \pm 4.2$</td>
<td>$11$</td>
</tr>
</tbody>
</table>
- Multijet background expected to contribute < 0.01 events by extrapolating estimate in sidebands to control region
- Contribution from $Z \rightarrow \tau \tau$ background estimated from simulation
- $W$ and $t$ estimated by extrapolating from dedicated control region to signal region
- Similar uncertainties as in the one tau search

<table>
<thead>
<tr>
<th>$\sum \text{SM}$</th>
<th>Data</th>
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</thead>
<tbody>
<tr>
<td>$5.3 \pm 1.3\text{(stat)} \pm 2.2\text{(syst)}$</td>
<td>3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Top</th>
<th>$W + \text{jets}$</th>
<th>$Z + \text{jets}$</th>
<th>DiBosons</th>
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</thead>
<tbody>
<tr>
<td>$1.57 \pm 0.42 \pm 0.75$</td>
<td>$2.5 \pm 1.0 \pm 1.2$</td>
<td>$1.08 \pm 0.70 \pm 0.63$</td>
<td>$0.14 \pm 0.05 \pm 0.03$</td>
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</tbody>
</table>
Upper limits on non-SM events of 8.5 (7) are set at 95% CL by single (di) tau search

Limit interpreted as exclusion contour in $(\Lambda, \tan \beta)$ plane

Translates into limit on gluino mass of $m_{\tilde{g}} > 920(990)$ GeV for $\tan \beta > 20$
• Search uses 4.8 $fb^{-1}$ of data recorded in 2011
• Target two classes of GMSB models
  • High-scale colored sparticle production with bino NLSP
  • Intermediate-scale gaugino production with bino-like NLSP
• Use diphoton trigger to select events with two photon candidates
• Require two 50 GeV photons and $E_T$
• Special care taken to reduce the amount of photons faked by electrons
• Use $E_T$, $H_T := \sum_{\text{photons/jets/leptons}} p_T$ and the isolation between $E_T$ and photons $\Delta \phi_{\text{min}}(\gamma, E_T)$ as main signal selection variables
Photon Searches

Photons

- Identification by shower shape in calorimeter, exploiting the high granularity of the ATLAS electromagnetic calorimeter
- ATLAS TRT capability allows reconstructing converted photons very efficiently
- Photon selection depends on conversion type (0/1/2 tracks)
  - Large suppression of fakes by requiring one-track conversions to have no hits in the Pixel detector
  - Reconstructed electrons always precede overlapping photons
  - Strongly improved suppression of electron fakes offers optimized control over backgrounds compared to former analyses
• Three different signal regions (SR) constructed
• SR A and B for colored production, SR C for electroweak production

<table>
<thead>
<tr>
<th></th>
<th>SR A</th>
<th>SR B</th>
<th>SR C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T &gt;$</td>
<td>200 GeV</td>
<td>100 GeV</td>
<td>125 GeV</td>
</tr>
<tr>
<td>$H_T &gt;$</td>
<td>600 GeV</td>
<td>1100 GeV</td>
<td>-</td>
</tr>
<tr>
<td>$\Delta \phi_{min}(\gamma, E_T^\text{miss}) &gt;$</td>
<td>0.5</td>
<td>-</td>
<td>0.5</td>
</tr>
</tbody>
</table>
• Three classes of backgrounds

  QCD containing all backgrounds with jets being reconstructed as photons and fake $\not{E}_T$

  Electroweak containing all backgrounds with true $\not{E}_T$ from neutrinos and fake photons from electrons or jets

  Irreducible containing two true photons and $\not{E}_T$ from neutrinos, dominantly $W(\rightarrow \ell \nu) + \gamma \gamma$ and $Z(\rightarrow \bar{\nu} \nu) + \gamma \gamma$

• QCD estimated by constructing three templates from events that pass “loose” identification but fail “tight” and applying $H_T$ and $\Delta \phi$ cuts according to each signal region

• Expected number of events obtained by normalizing templates to data in region $\not{E}_T < 20 \text{ GeV}$
• Electroweak background estimated from events containing one photon and one electron passing signal cuts
• Prediction has to be scaled by electron to photon fake probability measured in $Z \rightarrow ee$ events
• Irreducible background estimated from Monte Carlo simulation

• Systematic uncertainties from alternative background estimate

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<th>SR B</th>
<th>SR C</th>
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<tbody>
<tr>
<td>QCD</td>
<td>$0.07 \pm 0.00 \pm 0.07$</td>
<td>$0.27 \pm 0.00 \pm 0.27$</td>
<td>$0.85 \pm 0.30 \pm 0.71$</td>
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<tr>
<td>EW</td>
<td>$0.03 \pm 0.03 \pm 0.01$</td>
<td>$0.09 \pm 0.05 \pm 0.02$</td>
<td>$0.80 \pm 0.16 \pm 0.22$</td>
</tr>
<tr>
<td>$W(\rightarrow \ell\nu) + \gamma\gamma$</td>
<td>0.0</td>
<td>0.0</td>
<td>$0.18 \pm 0.13 \pm 0.18$</td>
</tr>
<tr>
<td>$Z(\rightarrow \bar{\nu}\nu) + \gamma\gamma$</td>
<td>0.0</td>
<td>0.0</td>
<td>$0.27 \pm 0.09 \pm 0.04$</td>
</tr>
<tr>
<td>Total</td>
<td>$0.10 \pm 0.03 \pm 0.07$</td>
<td>$0.36 \pm 0.05 \pm 0.27$</td>
<td>$2.11 \pm 0.37 \pm 0.77$</td>
</tr>
<tr>
<td>Observed</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
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• Minimal GMSB scenario “SPS8” with full particle spectrum
• $\Lambda$ is the only free parameter determining mass scales
• A lower limit of $203 \, \text{TeV}$ is set on the SPS8 breaking scale $\Lambda$
• \ldots using signal region C
• In studied range of $\Lambda$ dominantly direct EW gaugino production
• Corresponding limits on $m_{\tilde{\chi}_0^\pm} \gtrsim 290 \, \text{GeV}$ and $m_{\tilde{\chi}_1^\pm} \gtrsim 560 \, \text{GeV}$. 

ATLAS Preliminary

SPS8: $M_{\text{mess}}=2\Lambda$, $N=1$, $\tan\beta=15$, $c\tau_{\text{NLO}}<0.1\,\text{mm}$

$\int Ldt = 4.8 \, \text{fb}^{-1}$, $\sqrt{s} = 7 \, \text{TeV}$
GGM (General Gauge Mediation) simplified model with Bino like $\tilde{\chi}_0^1$

- Only gluino production
- $m_\tilde{g}$ and $m_\tilde{\chi}_0^1$ as free parameters
- All other masses decoupled

A lower limit on $m_\tilde{g}$ of 1.07 TeV is determined for $m_\tilde{\chi}_0^1 > 50$ GeV

... using signal regions A and B depending on the neutralino masses
Summary

- Gauge mediation is an attractive theory of SUSY breaking
- Special properties lead to particular interesting signatures
- Photons and taus can exploit GMSB signatures for sensitive low background searches for SUSY
- Stringent limits on gauge mediated SUSY production set

References

One tau search arXiv:1204.3852, accepted for publication by PLB
Two tau search arXiv:1203.6580, accepted for publication by PLB
Diphoton search ATLAS-CONF-2012-072
Back Up
\( p_T^{\tau_1} = 66 \text{ GeV} \)
\( p_T^{\tau_2} = 48 \text{ GeV} \)
\( p_T^{\text{jet}_1} = 214 \text{ GeV} \)
\( p_T^{\text{jet}_2} = 177 \text{ GeV} \)
\( E_T = 203 \text{ GeV} \)
1 tau Selection

- $\geq 1$ “tight” tau
- $\frac{E_T}{m_{\text{eff}}} > 0.25$
- $m_T > 110$ GeV
- $m_{\text{eff}} > 600$ GeV

2 tau Selection

- $\geq 2$ “loose” taus
- $m_T^1 + m_T^2 > 80$ GeV
- $m_{\text{eff}} > 700$ GeV
• Identification by shower shape in calorimeter, exploiting the high granularity of the ATLAS electromagnetic calorimeter
• ATLAS TRT capabilities to reconstruct and identify photon conversions leads to three classes of photons
  • Unconverted photons that have no tracks pointing to the photon cluster
  • Single track conversions that have one electron track that does not have hits in the innermost pixel detector
  • Two tracks conversions that have two electron tracks and a conversion vertex consistent with the decay of a zero mass particle
• Reconstructed electrons always precede overlapping photons
• Overall achieve 55% fake rejection at 70% signal efficiency
• Strongly improved suppression of electron fakes offers optimized control over backgrounds
- $\tan \beta = 2$ and $c\tau_{NLSP} < 0.1 \text{ mm}$
- $m_{\tilde{q}}$ and $m_{\tilde{\chi}^0}$ as free parameters
- All $\tilde{d}$ and $\tilde{u}_L$ masses degenerate, $\tilde{u}_R$ decoupled
- All other masses decoupled
- A lower limit on $m_{\tilde{q}}$ of 0.91 TeV is determined for $m_{\tilde{\chi}^0} > 50 \text{ GeV}$