SUSY Multileptons at ATLAS

RHUL seminar

30th May 2012

Tina Potter, University of Sussex
ATLAS and the LHC

In 2011 ATLAS recorded 5.25 fb⁻¹ data

This talk will focus on the (public) 2011 data results

In 2012 ATLAS has already recorded over 3 fb⁻¹ data at 8 TeV

Updates to searches this summer!
SUSY Motivation

SUSY offers a rich array of signatures!

Long decay chains through gluinos, squarks, gauginos and sleptons.

ATLAS aims to search for SUSY in a model-independent way

e.g. in R-Parity conserving models...

The lightest SUSY particle (LSP) is stable and escapes detection
→ Missing Transverse Energy

Decaying colored sparticles produce jets

Decaying sleptons and gauginos can produces leptons

3rd generation may be kinematically favoured
→ b-jet, tau signatures
Multilepton SUSY searches from the competition

Past results

**LEP-SUSY Working Group**
- Chargino m > 104 GeV
- Slepton (e, mu) m > ~100 GeV
- Stau m > 80 GeV

**Tevatron**
- Direct chargino-neutralino production and decay to 3 leptons “golden channel”
- No excess seen

**Newer results**

**CMS**
- Very recent update to 3L and 4L searches with full 2011 dataset (EX0-11-045, SUS-11-013, CMS-PAS-SUS-11-016)
- Generic many-signal region searches, (over 100 channels!) including tau multiplicity
- No excess seen

Interpretation in RPC and RPV SUSY
Three lepton searches

Focus on the “golden” channel: weakly produced sparticle pairs

$\tilde{\chi}^\pm_1 \tilde{\chi}^0_2$

CERN-PH-EP-2012-098
Accepted by Physical Review Letters

Four lepton searches

Focus is on multilepton-rich RPV models

$\tilde{\tau}$ LSP

ATLAS-CONF-2012-001
ATLAS-CONF-2012-035

Considering electrons and muons as leptons
Hadronic tau decays not yet considered
### Data
Periods B-K of 2011 data – integrated luminosity of 2.06 fb\(^{-1}\)
Triggered using lowest un-prescaled single electron or muon triggers

### Standard Model MC
- **MC@NLO**  
  Ttbar and single top
- **Alpgen**  
  Z/W+LFjets, Z/W+HFjets, low-mass Z+LFjets
- **Herwig**  
  ZZ, WZ, WW
- **Madgraph**  
  ttbar+Z/W/WW, same-sign WW, Z/W+gamma

### MC Signal Samples
- **Herwig**  
  pMSSM Direct Gaugino
- **Herwig++**  
  Simplified Model Direct Gaugino, RPV

### Trigger
**Egamma Stream**
- EF\(_{e20}\)\(_{medium}\) (B-J), EF\(_{e22}\)\(_{medium}\) (K)
  - Trigger element matches signal electron with pT>25 GeV and ΔR<0.15

**Muons Stream**
- EF\(_{mu18}\) (B-I), EF\(_{mu18}\)\(_{medium}\) (J-K)
  - Trigger element matches signal muon with pT>20 GeV and ΔR<0.15
  - To avoid double counting, must have failed Egamma Stream trigger

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MC is weighted for the trigger efficiency measured in data
Physics Motivation: RPC Weak SUSY

Current limits on gluino and squark masses are ~1 TeV (for mSUGRA/CMSSM scenarios)

If squarks and gluinos are heavy, searches for weak SUSY production become very important

(Neutralinos, Charginos, Sleptons and Sneutrinos)

\[ \tilde{\chi}_{1,2,3,4}^0 \quad \tilde{\chi}_{1,2}^\pm \quad \tilde{l} \quad \tilde{\nu} \]

Direct gaugino production may be the dominant SUSY cross-section at the LHC

“Golden” channel to search for weak SUSY

\[ \begin{align*}
\tilde{q} & \rightarrow \tilde{l} \tilde{l} \tilde{\nu} \\
W^{\pm*} & \rightarrow \tilde{l} l \tilde{\nu} \\
Z^* & \rightarrow \tilde{l} \ell^\pm \tilde{\nu}
\end{align*} \]

Striking signature

Large lepton multiplicities from the gaugino decays (via sleptons or real/virtual gauge bosons)

Missing transverse energy from the two escaping LSPs

Hadronically quiet – no hadronic activity from the hard process

Low SM background

16/01/12 Tina Potter - Sussex
Phenomenological MSSM (pMSSM)

RPC MSSM contains 105 parameters

In pMSSM, reduce free parameters to 19 by the following assumptions:
- CP conservation (removes all phases)
- Minimal flavour violation (removes off-diagonal terms in mass matrices)
- Negligible trilinear couplings for 1\textsuperscript{st} and 2\textsuperscript{nd} generation
- Degenerate 1\textsuperscript{st} and 2\textsuperscript{nd} generation sfermion masses

For these models, heavy squarks, gluinos and left-handed sleptons, \( \tan \beta = 6 \), \( m_A = 500 \text{GeV} \)

Right-handed sleptons masses:

\[
m_{\tilde{\nu}_R} = \left( m_{\tilde{\chi}_2^0} + m_{\tilde{\chi}_1^0} \right) / 2
\]

Free parameters remain: \( M_1, M_2, \mu \)

Direct gaugino production is dominant in these models
Simplified Models

Phenomenological model

Mass degenerate Chargino1 and Neutralino2 – wino-like

Neutralino1 (LSP) bino-like

BR into sleptons 50%, sneutrinos 50%

Other particles set at the TeV scale

\[ m_{\tilde{\nu}} = m_{\tilde{l}_L} = \left( m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm} \right)/2 \]

SUSY inspired model, chargino1-neutralino2 direct production
Object Selection

- **Electrons**
  - **Tagged**
    - **isEM medium**
    - **ET > 10 GeV** *(15 GeV in crack)*
    - **|eta| < 2.47**
    - **Author = 1 or 3**
    - **isGoodOQ**
    - **Energy smeared in MC**
    - **Energy scaled in data**
    - **Pass overlap removal**
  - **Signal**
    - **ptcone20/pt < 0.1**

- **Muons**
  - **Tagged**
    - **STACO Loose**
    - **Combined or segment tag**
    - **pT > 10 GeV**
    - **|eta| < 2.4**
    - **Inner detector hit requirements**
    - **ID and MS smeared in MC**
    - **Pass overlap removal**
  - **Signal**
    - **ptcone20 < 1.8 GeV**

- **Jets**
  - **AntiKt4 topo with EM+JES**
  - **ET > 20 GeV**
  - **|eta| < 2.4**
  - **Inner detector hit requirements**
  - **ID and MS smeared in MC**
  - **Pass overlap removal**
  - **Signal**
    - **ptcone20 < 1.8 GeV**

- **Overlap removal**
  - Discard softer electron if dR(e1, e2) < 0.1
  - Discard jet if dR(e, jet) < 0.2
  - Discard electron if dR(e, jet) < 0.4
  - Discard muon if dR(μ, jet) < 0.4
  - Discard electron and muon if dR(e, μ) < 0.1
  - Discard SFOS pair with Mll < 20 GeV

- **MET**
  - E = Eele + Emuon + Ejet + Ecell
  - MET_RefFinal_Simplified20 terms except Muons from Baseline
  - RefFinal regions (barel + endcap + forward)
  - SUSYTools prescription for MET correction
Event Selection

Preselection
GRL + trigger
Primary vertex with at least 5 tracks
Veto if larError!=0
Veto events with badly reconstructed jets
Veto events with tagged electron or jet above 40 GeV x corr in LAr hole
Veto tagged muon with |z₀| > 1 mm or |d₀| > 0.2 mm
Reject events with badly measure muons

Baseline
Exactly 3 leptons
At least 1 SFOS pair
MET > 50 GeV

SR1 aims at selecting leptonic gaugino decays through sleptons or off-shell bosons
SR2 aims at selecting leptonic gaugino decays through on-shell bosons

SR1: Z depleted
Veto Z
Veto b-jets (JetFitterCombNN>2)

SR2: Z-rich
Require Z

Z identified with |M_{SFOS} − M_Z| < 10 GeV
Expected Background

As estimated from MC (uncertainties are statistical only)

- WZ 45% (84%) in SR1 (SR2)
- ttbar 40% (5%) in SR1 (SR2)

<table>
<thead>
<tr>
<th>SUSY ref. point</th>
<th>SR1</th>
<th>SR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tilde{t}\tilde{t}$</td>
<td>122±5</td>
<td>55.4±3.5</td>
</tr>
<tr>
<td>Single $t$</td>
<td>9.4±0.7</td>
<td>3.3±0.4</td>
</tr>
<tr>
<td>$t\bar{t}V$</td>
<td>1.5±0.4</td>
<td>0.26±0.15</td>
</tr>
<tr>
<td>ZZ</td>
<td>0.38±0.05</td>
<td>2.72±0.13</td>
</tr>
<tr>
<td>$WZ$</td>
<td>0.70±0.15</td>
<td>3.37±0.30</td>
</tr>
<tr>
<td>$WW$</td>
<td>10.6±1.2</td>
<td>58.4±2.7</td>
</tr>
<tr>
<td>$V\gamma$</td>
<td>0±1.3</td>
<td>0±1.3</td>
</tr>
<tr>
<td>$Z+\text{LFjets}$</td>
<td>0.9±0.7</td>
<td>0.4±0.4</td>
</tr>
<tr>
<td>$Z+\text{HFjets}$</td>
<td>0.12±0.12</td>
<td>0.8±0.4</td>
</tr>
<tr>
<td>$W+\text{LFjets}$</td>
<td>0±0.30</td>
<td>0±0.30</td>
</tr>
<tr>
<td>$W+\text{HFjets}$</td>
<td>0±1.4</td>
<td>0±1.4</td>
</tr>
<tr>
<td>DY</td>
<td>0±0.09</td>
<td>0±0.09</td>
</tr>
<tr>
<td>$\Sigma\text{SM}$</td>
<td>23.7±2.5</td>
<td>69.3±3.4</td>
</tr>
</tbody>
</table>

SUSY reference point: Simplified model with $m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}}$, $m_{\tilde{\chi}_1^0} = 150, 150, 100, 50$ GeV.
Background Modelling

Irreducible background: processes with at least 3 real leptons
WZ, ZZ, ttbarW, ttbarWW, ttbarZ

**Modelled using MC**

Reducible background: processes with at least 1 fake lepton
Single top and top pair production, Z+jets, W+jets, WW

**Modelled using the matrix method**

**Internal conversion muons estimated separately**

Fake leptons come mostly from heavy flavour decays
Conversion electrons are also important
Matrix Method – Fake Estimate

Set of linear equations relating kinematic properties of the leptons to the real and fake composition

Normally, a 8x8 matrix is needed for a 3-lepton system
In this analysis, **leading lepton is real 99% of the time**
Use a **4x4 matrix** using the 2 sub-leading leptons

\[
\begin{pmatrix}
N_{TT} \\
N_{TL'} \\
N_{LT} \\
N_{L'L'}
\end{pmatrix} = \begin{pmatrix}
\epsilon_1 \epsilon_2 & \epsilon_1 f_2 & f_1 \epsilon_2 & f_1 f_2 \\
\epsilon_1 (1 - \epsilon_2) & \epsilon_1 (1 - f_2) & f_1 (1 - \epsilon_2) & f_1 (1 - f_2) \\
(1 - \epsilon_1) \epsilon_2 & (1 - \epsilon_1) f_2 & (1 - f_1) \epsilon_2 & (1 - f_1) f_2 \\
(1 - \epsilon_1) (1 - \epsilon_2) & (1 - \epsilon_1) (1 - f_2) & (1 - f_1) (1 - \epsilon_2) & (1 - f_1) (1 - f_2)
\end{pmatrix} \begin{pmatrix}
N_{RR} \\
N_{RF} \\
N_{FR} \\
N_{FF}
\end{pmatrix}
\]

Loose lepton (\(L\)): tagged lepton
Tight lepton (\(T\)): signal lepton
Loose' lepton (\(L'\)): loose lepton that is not tight

Fake rate (\(f\)): probability of a loose fake lepton passing tight requirements
Real efficiency (\(\epsilon\)): probability of a loose real lepton passing tight requirements

Use control regions to measure \(f\) and \(\epsilon\) in data and MC

Tagged leptons are those without isolation or isEM tight applied
Signal leptons are those with isolation or isEM tight applied
Matrix Method – Fake Rate Measurement

Use control regions to measure fake rates in data and MC
Obtain scale factors to correct the MC fake rate
Assume uniformity of scale factors across background processes and event selection

We use the MC rates and scale factors to estimate a weighted average fake rate relevant for each signal and validation region

\[ f^\ell_{XR} = \sum_{i,j} (sf^i \times R^{ij}_{XR} \times f^{ij}) \]

**XR**: signal or validation region
**i**: fake type (heavy flavour or conversion)
**j**: process (top or gauge boson)
**sf^i**: scale factor for fake type i
**R^{ij}_{XR}**: fraction of fake type i and process j in region XR
**f^{ij}**: fake rate of type i and process j (no MET or SFOS cuts applied)
  parametrised by ET and eta for electrons, and pT for muons
Systematics

Irreducible background

MC statistics (10%)
Cross-section (7%)
PDF Acceptance (14%)

Others (<5%)
- Jet energy scale/resolution
- Electron energy scale/resolution
- Muon momentum resolution
- Lepton id efficiency
- B-tagging efficiency
- Pileup
- LAr hole veto

Reducible background

MC Fake Rate
- MET dependence (20%)

Data/MC Scale Factors
- Conversions (30-50%)
- HF Pythia vs Herwig (10%)
- HF pT vs eta (10%)

MC Process fractions
- Muons (10%)
- Electrons (30%)
A virtual photon radiated from a final state lepton can produce muons. If asymmetric it can give just one extra lepton.

This contribution is estimated using a data-driven approach. Measure the probability that a signal lepton will emit a virtual photon which gives a signal muon.

In MET < 50 GeV region

\[
\text{probability} = \frac{\mu\mu\mu \text{ events in } Z \text{ mass window } [81.2,101.2] \text{ GeV}}{\mu\mu \text{ events in } Z \text{ mass window } [81.2,101.2] \text{ GeV}}
\]

Apply this probability to dilepton events in signal region. Assign 100% uncertainty as radiation may also come from initial state quarks.

Small component of background in SR1 (0.5±0.5) and SR2 (0.7±0.7)
### Background Model Validation

**VR1**  
Z-rich validation region, 3 leptons, MET 30-50 GeV

**VR2**  
Ttbar-rich validation region, 3 leptons, no SFOS, MET>50 GeV

<table>
<thead>
<tr>
<th>Selection</th>
<th>VR1</th>
<th>VR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}W^{(<em>)}/Z^{(</em>)}$</td>
<td>1.4±1.1</td>
<td>0.7±0.6</td>
</tr>
<tr>
<td>$ZZ^{(*)}$</td>
<td>6.7±1.5</td>
<td>0.03±0.04</td>
</tr>
<tr>
<td>$WZ^{(*)}$</td>
<td>61±11</td>
<td>0.4±0.2</td>
</tr>
<tr>
<td>Reducible Bkg.</td>
<td>56±35</td>
<td>14±9</td>
</tr>
<tr>
<td>Total Bkg.</td>
<td>125±37</td>
<td>15±9</td>
</tr>
<tr>
<td>Data</td>
<td>122</td>
<td>12</td>
</tr>
</tbody>
</table>

Agreement within uncertainties
### Signal Region Results

<table>
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<tr>
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<th>SR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}W^(<em>)/Z^(</em>)$</td>
<td>0.4±0.3</td>
<td>2.7±2.1</td>
</tr>
<tr>
<td>$ZZ^(*)$</td>
<td>0.7±0.2</td>
<td>3.4±0.8</td>
</tr>
<tr>
<td>$WZ^(*)$</td>
<td>11±2</td>
<td>58±11</td>
</tr>
<tr>
<td>Reducible Bkg.</td>
<td>14±4</td>
<td>7.5±3.9</td>
</tr>
<tr>
<td>Total Bkg.</td>
<td>26±5</td>
<td>72±12</td>
</tr>
<tr>
<td>Data</td>
<td>32</td>
<td>95</td>
</tr>
</tbody>
</table>

**SR1** Z-depleted signal region

**SR2** Z-rich signal region

Consistency with Standard Model

**SR1**: $p_0$-value=0.19 (0.9σ)

**SR2**: $p_0$-value=0.06 (1.6σ)

No significant excess is observed

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**3L analysis**

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SR1 leptons

3L analysis

\( p_T \) distributions of the three leptons in SR1
SR2 leptons

$p_T$ distributions of the three leptons in SR2

ATLAS

Events / 20 GeV

$\sqrt{s} = 7$ TeV $\int L \, dt = 2.06 \, fb^{-1}$

Data 2011
Total SM
Reduc.bkgd
WZ
ZZ
tW$^\nu$/Z$^\nu$
The agreement between observation and expectation is assessed via a pure frequentist approach

\[ L(n_S | \mu, b, \theta) = P(n_S | \lambda_S (\mu, b, \theta)) \times P_{\text{Syst}}(\theta^0, \theta) \]

The six dominant systematic uncertainties are treated separately, each with its own nuisance parameter.

Combination package used to set limits (https://svnweb.cern.ch/trac/atlasgrp/browser/Physics/SUSY/Analyses/Combination)

**Observed (Expected) visible cross-section limits**

- **SR1:** 9.9 (7.1) fb
- **SR2:** 23.8 (14.1) fb
SR1 results used to set limits

\[ \int L \, dt = 2.06 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \]
\[ M_{\chi} = 100 \text{ GeV}, \tan \beta = 6 \]

- Observed \( \geq 95\% \) CL<sub>S</sub>
- Expected 95\% CL<sub>S</sub>
- Expected ±1\sigma
- LEP2 \( \tilde{\chi}_1^\pm \) (103.5 GeV)

\( \tilde{\chi}_2^0 \) Higgsino component
large (reduced leptonic BR)
Degenerate $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ masses are excluded up to 300 GeV for $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$ up to 250 GeV.
R-parity is introduced to SUSY to avoid rapid proton decay ---→ RPC leads to a stable LSP.

But other symmetries may be just as well motivated and prevent proton decay – allowing some lepton/baryon number violation (Phys.Rev.**D75**, 035002 (2007))

These scenarios are known as R-parity violating (RPV) ---→ LSP is unstable and decays to SM

\[ \tilde{\tau}_1 \rightarrow \tilde{\chi}_1^0 + \tilde{e}_R^{\pm} + \ell^- + \nu \]

**Striking signature**

Four leptons + two taus from the stau decays – via off-shell SUSY particles

Missing transverse energy from the many neutrinos in the event

RPV scenarios (mSUGRA/CMSSM): stau is the LSP (Phys.Rev.**D83**, 015013 (2011))

Classic mSUGRA RPV scenario with stau LSP ("BC1" point)

\[ m_{1/2}=400 \text{ GeV}, \tan\beta=13, m_0=A_0=0, \mu>0, \lambda_{121}=0.032 \text{ at } m_{\text{GUT}} \]

The RPV coupling is small enough so that SUSY pair production dominates, but large enough so that stau LSP decays promptly

Staus may be produced in pairs, or from higher mass SUSY decays
Inspired by BC1-point classic mSUGRA RPV scenario with stau LSP

\[ m_0 = A_0 = 0, \mu > 0, \lambda_{121} = 0.032 \text{ at } m_{\text{GUT}} \]

Scan \[ m_{1/2} = 100-1300 \text{ GeV} \]
\[ \tan\beta = 3-60 \]

Choice in \( \lambda_{121} \) affects sparticle spectrum and stau lifetime. Effect is low below upper limit of \( \lambda_{121} = 0.1 \) from neutrino mass constraints.

Stau decay is 4-body for most of the parameter space
2-body at high \( \tan\beta \)
  → lower lepton multiplicity

Stau lifetime larger at high \( \tan\beta \)
  → reduced reconstruction efficiency
Object Selection

- **Muons**
  - Tagged
    - STACO Loose
    - Combined or segment tag
  - *pT > 10 GeV*
  - |eta| < 2.4
  - Inner detector hit requirements
  - ID and MS smeared in MC
  - Pass overlap removal
  - **Signal**
    - ptcone20 < 1.8 GeV and etcone30<4 GeV

- **Electrons**
  - Tagged
    - *isEM medium*
    - ET > 10 GeV (15 GeV in crack)
    - |eta| < 2.47
    - Author = 1 or 3
    - isGoodOQ
    - Energy smeared in MC
    - Energy scaled in data
    - Pass overlap removal
  - **Signal**
    - isEM-tight
    - ptcone20/pt < 0.1

- **Jets**
  - AntiKt4 topo with EM+JES
  - ET > 20 GeV
  - |eta| < 2.4
  - Inner detector hit requirements
  - ID and MS smeared in MC
  - Pass overlap removal
  - **Signal**
    - ptcone20 < 1.8 GeV and etcone30<4 GeV

- **MET**
  - E = Eele + Emuon + Ejet + Ecell
  - MET_RefFinal_Simplified20 terms except Muons from Baseline
  - RefFinal regions (barel + endcap + forward)
  - SUSYTools prescription for MET correction

- **Overlap removal**
  - Discard softer electron if dR(e1, e2) < 0.1
  - Discard jet if dR(e, jet) < 0.2
  - Discard electron if dR(e, jet) < 0.4
  - Discard muon if dR(μ, jet) < 0.4
  - Discard electron and muon if dR(e, μ) < 0.1
  - Discard SFOS pair with Mll < 20 GeV
**Event Selection**

**Preselection**
- GRL + trigger
- Primary vertex with at least 5 tracks
- Veto if larError!=0
- Veto events with badly reconstructed jets
- Veto events with tagged electron or jet above 40 GeV x corr in LAr hole
- Veto tagged muon with $|z_0| > 1$ mm or $|d_0| > 0.2$ mm
- Reject events with badly measure muons

**Baseline**
- At least 4 leptons

**SR1**
- MET $> 50$ GeV

**SR2: Z-depleted**
- Veto Z

$Z$ identified with $|M_{SFOS} - M_Z| < 10$ GeV

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Also sensitive to $\tilde{\chi}_2^0 \tilde{\chi}_2^0$ production
However the cross-sections for such processes are very low --- explore with 2012 dataset III
Process fractions in SR2 in the RPV grid

4L analysis
Background Estimation

MC used for all SM backgrounds

Cross-checks performed for ttbar, ZZ and internal conversions

<table>
<thead>
<tr>
<th></th>
<th>4L</th>
<th>SR1</th>
<th>SR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>0.22±0.15</td>
<td>0.17±0.14</td>
<td>0.13±0.11</td>
</tr>
<tr>
<td>Single $t$</td>
<td>0±0.04</td>
<td>0±0.04</td>
<td>0±0.04</td>
</tr>
<tr>
<td>$t\bar{t}V$</td>
<td>0.59±0.26</td>
<td>0.48±0.21</td>
<td>0.07±0.04</td>
</tr>
<tr>
<td>ZZ</td>
<td>19±5</td>
<td>0.44±0.19</td>
<td>0.019±0.020</td>
</tr>
<tr>
<td>WZ</td>
<td>0.54±0.17</td>
<td>0.25±0.10</td>
<td>0.09±0.05</td>
</tr>
<tr>
<td>WW</td>
<td>0±0.015</td>
<td>0±0.015</td>
<td>0±0.015</td>
</tr>
<tr>
<td>$Z\gamma$</td>
<td>0±0.5</td>
<td>0±0.5</td>
<td>0±0.5</td>
</tr>
<tr>
<td>$Z+(u,d,s \text{ jets})$</td>
<td>3.8±1.6</td>
<td>0.33±0.67</td>
<td>0.33±0.67</td>
</tr>
<tr>
<td>$Z+(c,b \text{ jets})$</td>
<td>0.26±0.28</td>
<td>0.024±0.035</td>
<td>0.024±0.035</td>
</tr>
<tr>
<td>Drell-Yan</td>
<td>0±0.29</td>
<td>0±0.05</td>
<td>0±0.05</td>
</tr>
<tr>
<td>$\Sigma\text{ SM}$</td>
<td>25±5</td>
<td>1.7±0.9</td>
<td>0.7±0.8</td>
</tr>
</tbody>
</table>

**Leading systematics**

- MC statistics
- Jet energy scale/resolution
- Cross-sections

**SR1**  4L, MET>50

**SR2**  Z-depleted SR
Results

|  | 4L       | SR1       | SR2       |
|----------------|----------|----------|
| $\bar{t}t$     | 0.22±0.15| 0.17±0.14| 0.13±0.11 |
| Single $t$     | 0±0.04   | 0±0.04   | 0±0.04   |
| $t\bar{t}V$    | 0.59±0.26| 0.48±0.21| 0.07±0.04|
| ZZ             | 19±5     | 0.44±0.19| 0.019±0.020|
| WZ             | 0.54±0.17| 0.25±0.10| 0.09±0.05|
| WW             | 0±0.015  | 0±0.015  | 0±0.015  |
| Z$\gamma$     | 0±0.5    | 0±0.5    | 0±0.5    |
| $Z+(u,d,s\text{ jets})$ | 3.8±1.6 | 0.33±0.67| 0.33±0.67|
| $Z+(c,b\text{ jets})$ | 0.26±0.28| 0.024±0.035| 0.024±0.035|
| Drell-Yan     | 0±0.29   | 0±0.05   | 0±0.05   |
| $\Sigma \text{ SM}$ | 25±5     | 1.7±0.9  | 0.7±0.8  |
| Data          | 24       | 4        | 0        |

Consistency with Standard Model

SR1: $p_0$-value=0.10 (CL$_b$ = 0.07)
SR2: $p_0$-value >0.5 (CL$_b$ = 0.78)

Observed (Expected) visible cross-section limits

SR1: 3.5 (2.1) fb
SR2: 1.5 (1.5) fb

No significant excess is observed
Lepton $p_T$ in 4L events

$\sqrt{s} = 7$ TeV \hspace{1cm} \int L \, dt = 2.06 \text{ fb}^{-1}$

ATLAS Preliminary

Events / 10 GeV

$E_T(p_T^{\ell})$ leading lepton [GeV]

Events / 5 GeV

$E_T(p_T^{\ell})$ 3rd leading lepton [GeV]

Data 2011

Total SM

$t\bar{t}$

$t\bar{t} V$

WZ

$ZZ \rightarrow$ III

$ZZ \rightarrow$ other

$Z+$jets

SM + RPV

SM + DGwSL

Events / 10 GeV

$E_T(p_T^{\ell})$ 2nd leading lepton [GeV]

Events / 5 GeV

$E_T(p_T^{\ell})$ 4th leading lepton [GeV]

Data 2011

Total SM

$t\bar{t}$

$t\bar{t} V$

WZ

$ZZ \rightarrow$ III

$ZZ \rightarrow$ other

$Z+$jets

SM + RPV

SM + DGwSL
SR2 results used to set limits

mSUGRA/CMSSM, \( m_0 = A_0 = 0 \) GeV, \( \mu > 0 \), \( \lambda_{121} = 0.032 \) at \( M_{\text{GUT}} \), \( L^\text{int} = 2.06 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV} \)

\[
\begin{align*}
\text{ATLAS Preliminary} \\
n_{e\mu} \geq 4, E_T^{\text{miss}} > 50 \text{ GeV, Z Veto} \\
n_{\text{obs}} = 0, n_{\text{exp}} = 0.7 \pm 0.8
\end{align*}
\]

First limits from the LHC on stau LSP models

BC1-like model is excluded for \( m_{1/2} < 800 \) GeV and \( \tan \beta < 40 \)
Corresponding gluino mass limit of 1.77 TeV
Summary and conclusion

Searches for SUSY in 3 and 4 lepton final states
Targeting weak SUSY production and RPV stau LSP models

No significant excesses so far

Limits set in

pMSSM models: large areas of parameter space excluded

Simplified models: $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ masses excluded up to 300 GeV

RPV BC1-like models: excluded $m_{1/2} < 800$ GeV and $\tan\beta < 40$, $m(\text{gluino}) < 1.77$ TeV

Update with full 2011 dataset very soon

Will the much larger 2012 8 TeV dataset hold any surprises ??
Backup – The ATLAS detector

Magnets
- 5 tonne central solenoid: 2T in inner detector
- 4T Toroid system

Inner Detector
- $|\eta|<2.5$, $B=2T$
- Precise tracking and vertexing
- Silicon Pixels, Strips and TRT straws

Electromagnetic Calorimeter
- $|\eta|<3.2$
- Layers of lead and LAr

Hadronic Calorimeter
- $|\eta|<5$
- Central: iron/scintillator tiles
- Forward: copper/tungsten-LAr

Muon Spectrometer
- $|\eta|<2.7$
- Gas-based chambers
Theoretical systematic uncertainties on signal processes

Common approach adopted in ATLAS SUSY analyses

Vary CTEQ6.6 PDFs
Vary MSTW PDFs
Vary factorisation/renormalisation scales in PROSPINO with CTEQ6.6 central value PDF
Vary factorisation/renormalisation scales in PROSPINO with MSTW central value PDF
Vary strong coupling $\alpha_s$ using CTEQ6.6 PDFs

The maximum uncertainty between the CTEQ6.6 and MSTW sets is used

Total signal uncertainties 10-20 % (incl other syst.) for the models considered

Currently, error band in limit plots includes signal uncertainties – a common approach with CMS that separates these is being adopted for future limit plots