Searches for Squarks and Gluinos with ATLAS

Marc Hohlfeld
Universität Mainz

on behalf of the ATLAS Collaborations

PANIC 2011
● Introduction
● Collider and detector
● Search for Supersymmetry
  ▲ 0 lepton analysis
  ▲ Analysis with b–jets
  ▲ 1 lepton analysis
  ▲ GMSB search
  ▲ Search for R–hadrons
● Conclusion

Results presented today
\[ \int Ldt \text{ up to } 1.04 \text{ fb}^{-1} \]
Going Beyond the Standard Model

- The Standard Model is very successful...
  - ...but it cannot answer all questions and has some caveats
    ⇒ Many ways and attempts to extend the Standard Model

- Supersymmetry
  - Extension of the Poincare group
    - Supersymmetric partner for every SM particle
    - Squarks, Gluinos, Charginos, Neutralinos,...

- Why Supersymmetry?
  - Cancellation of radiative corrections for the Higgs mass
  - Unification of the couplings
  - Provides a dark matter candidate
What Are We Looking For?

- Squark and Gluino production
  - Cross section basically determined by masses of squarks/gluinos
- Decay chains
What Are We Looking For?

- Squark and Gluino production
  - Cross section basically determined by masses of squarks/gluinos
- Decay chains
What Are We Looking For?

- Squark and Gluino production
  - Cross section basically determined by masses of squarks/gluinos
- Decay chains
What Are We Looking For?

- Squark and Gluino production
  ▲ Cross section basically determined by masses of squarks/gluinos
- Decay chains
What Are We Looking For?

- Squark and Gluino production
  ▲ Cross section basically determined by masses of squarks/gluinos
- Decay chains

![Diagram with squarks, gluinos, and W boson interactions]
What Are We Looking For?

- Squark and Gluino production
  - Cross section basically determined by masses of squarks/gluinos
- Decay chains

```
\begin{align*}
\tilde{g} & \rightarrow \tilde{q} \tilde{\chi}_1^0 \\
\tilde{q} & \rightarrow q \tilde{\chi}_1^0 \nu
\end{align*}
```
What Are We Looking For?

- Squark and Gluino production
  - Cross section basically determined by masses of squarks/gluinos
- Decay chains

```
\begin{align*}
\tilde{g} & \Rightarrow \tilde{q} \quad \tilde{q} \quad \tilde{\chi}_1 \quad \tilde{\chi}_1^0 \\
q & \quad q
\end{align*}
```

- Final state consists of
  - $k$ leptons + $n$ jets + missing transverse energy $\not{E}_T$
  - Dedicated analyses for third generation particles
- Searches in different final states considered here
  - GMSB models $\Rightarrow \gamma\gamma + \not{E}_T + X$
  - R–hadrons $\Rightarrow$ Slow moving particles

$(k = 0–3$, $n = 2–4)$
$(b$–jets, $\tau$ leptons)
Proton–proton collisions at $\sqrt{s} = 7 \text{ TeV}$
Already more than $\int \mathcal{L} dt = 1.4 \: \text{fb}^{-1}$ delivered
ATLAS Detector

- Emphasis on
  - Very good particle identification
  - Very good jet, $E_T$ resolution
  - Large coverage and hermiticity
ATLAS Detector

- Emphasis on
  ▲ Very good particle identification
  ▲ Very good jet, $\Sigma E_T$ resolution
  ▲ Large coverage and hermiticity

ATLAS Preliminary
Data 2010 $\sqrt{s} = 7$ TeV
$\int L dt = 36 \text{ pb}^{-1}$

$E_{\text{miss}}^x, E_{\text{miss}}^y$ Resolution [GeV]

MinBias: fit 0.45 $\sqrt{\Sigma E_T}$
$Z \rightarrow \text{ee}: 0.42 \sqrt{\Sigma E_T}$
$Z \rightarrow \mu\mu$: fit 0.44 $\sqrt{\Sigma E_T}$
MC MinBias: fit 0.48 $\sqrt{\Sigma E_T}$
MC $Z \rightarrow \text{ee}$: fit 0.42 $\sqrt{\Sigma E_T}$

$\Sigma E_T$(event) [GeV]

LAr hadronic end-cap and forward calorimeters
Tile calorimeters
Pixel detector
LAr electromagnetic calorimeters
Transition radiation tracker
Conductor tracker

Marc Hohlfeld
PANIC 2011
JULY 25

ATLAS
0 Lepton Channel

- 0 lepton channel is most sensitive one due to highest BR
  ▲ Main backgrounds are $Z \rightarrow \nu\nu + \text{jets}$ and $W \rightarrow \tau\nu + \text{jets}$

- Five signal regions (SR) to cover different decay topologies
  ▲ $\tilde{q}\tilde{q} \rightarrow jj + \not{E}_T$: di-jet analysis
  ▲ $\tilde{q}\tilde{q} \rightarrow jjj + \not{E}_T$: three jet selection
  ▲ $\tilde{q}\tilde{g} \rightarrow jjj + \not{E}_T$: four jet requirement

- Main discriminating variable is effective mass
  ▲ $M_{\text{eff}} = \sum_{j=1}^{N_{\text{jet}}^{\text{sel}}} p_T^{\text{jet}_j} + \not{E}_T$

- Five control regions (CR) for every SR to estimate backgrounds
  ▲ $Z \rightarrow \nu\nu$: Estimate from $\gamma + j$ and $Z \rightarrow ee/Z \rightarrow \mu\mu$
  ▲ Multijets: Select events where jet and $\not{E}_T$ are aligned
  ▲ $W \rightarrow \tau\nu$: Select $W \rightarrow e/\mu\nu$ ($M_T$ cut) and anti b-tag
  ▲ $tt$: Same as $W$ but with b-tag

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>≥ 2 jets</th>
<th>≥ 3 jets</th>
<th>≥ 4 jets</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
</tr>
<tr>
<td>Leading jet $p_T$</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
<td>&gt; 130</td>
</tr>
<tr>
<td>Second jet $p_T$</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Third jet $p_T$</td>
<td>–</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Fourth jet $p_T$</td>
<td>–</td>
<td>–</td>
<td>&gt; 40</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>$\Delta\phi(\text{jet}, E_T^{\text{miss}})$</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
<td>&gt; 0.4</td>
</tr>
<tr>
<td>$E_T^{\text{miss}} / m_{\text{eff}}$</td>
<td>&gt; 0.3</td>
<td>&gt; 0.25</td>
<td>&gt; 0.25</td>
<td>&gt; 0.2</td>
</tr>
<tr>
<td>$m_{\text{eff}}$ [GeV]</td>
<td>&gt; 1000</td>
<td>&gt; 1000</td>
<td>&gt; 500/1000</td>
<td>&gt; 1100</td>
</tr>
</tbody>
</table>

Entries / 100 GeV

Data 2011 (\sqrt{s} = 7 \text{ TeV})

- ATLAS Preliminary
0 Lepton Channel

- 0 lepton channel is most sensitive one due to highest BR
  ▶ Main backgrounds are $Z \to \nu \nu + \text{jets}$ and $W \to \tau \nu + \text{jets}$
- Five signal regions (SR) to cover different decay topologies
  ▶ $\tilde{q}\tilde{q} \to jj + \not{E}_T$: di-jet analysis
  ▶ $\tilde{q}\tilde{q} \to j jj + \not{E}_T$: three jet selection
  ▶ $\tilde{g}\tilde{g} \to j j j j + \not{E}_T$: four jet requirement
- Main discriminating variable is effective mass
  ▶ $M_{\text{eff}} = \sum_{j=1}^{N_{\text{jet}}} p_{Tj} + \not{E}_T$
- Five control regions (CR) for every SR to estimate backgrounds
  ▶ $Z \to \nu \nu$: Estimate from $\gamma + j$ and $Z \to ee/Z \to \mu \mu$
  ▶ Multijets: Select events where jet and $\not{E}_T$ are aligned
  ▶ $W \to \tau \nu$: Select $W \to e/\mu \nu$ ($M_T$ cut) and anti b-tag
  ▶ $tt$: Same as $W$ but with b-tag


<table>
<thead>
<tr>
<th>Signal Region</th>
<th>$\geq 2$ jets</th>
<th>$\geq 3$ jets</th>
<th>$\geq 4$ jets</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
</tr>
<tr>
<td>Leading jet $p_T$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
</tr>
<tr>
<td>Second jet $p_T$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>Third jet $p_T$</td>
<td>$-$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>Fourth jet $p_T$</td>
<td>$-$</td>
<td>$-$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>$\Delta \phi(\text{jet}, E_T^{\text{miss}})_{\text{min}}$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}/m_{\text{eff}}$</td>
<td>$&gt; 0.3$</td>
<td>$&gt; 0.25$</td>
<td>$&gt; 0.25$</td>
<td>$&gt; 0.2$</td>
</tr>
<tr>
<td>$m_{\text{eff}} [\text{GeV}]$</td>
<td>$&gt; 1000$</td>
<td>$&gt; 1000$</td>
<td>$&gt; 500/1000$</td>
<td>$&gt; 1100$</td>
</tr>
</tbody>
</table>

![Di-jet Channel](image)
0 Lepton Channel

- 0 lepton channel is most sensitive one due to highest BR
  ▲ Main backgrounds are $Z \rightarrow \nu \nu + \text{jets}$ and $W \rightarrow \tau \nu + \text{jets}$

- Five signal regions (SR) to cover different decay topologies
  ▲ $\tilde{q} \tilde{q} \rightarrow jj + \slashed{E}_T$: di-jet analysis
  ▲ $\tilde{q} \tilde{q} \rightarrow j jj + \slashed{E}_T$: three jet selection
  ▲ $\tilde{g} \tilde{g} \rightarrow j jjj + \slashed{E}_T$: four jet requirement

- Main discriminating variable is effective mass
  ▲ $M_{\text{eff}} = \sum_{j=1}^{N_{\text{jet}}} p_T^{\text{jet}_j} + \slashed{E}_T$

- Five control regions (CR) for every SR to estimate backgrounds
  ▲ $Z \rightarrow \nu \nu$: Estimate from $\gamma + j$ and $Z \rightarrow ee/Z \rightarrow \mu \mu$
  ▲ Multijets: Select events where jet and $\slashed{E}_T$ are aligned
  ▲ $W \rightarrow \tau \nu$: Select $W \rightarrow e/\mu \nu$ ($M_T$ cut) and anti b-tag
  ▲ $t\bar{t}$: Same as $W$ but with b-tag

<table>
<thead>
<tr>
<th>Signal Region</th>
<th>$\geq 2$ jets</th>
<th>$\geq 3$ jets</th>
<th>$\geq 4$ jets</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{\text{miss}}$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
</tr>
<tr>
<td>Leading jet $p_T$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
<td>$&gt; 130$</td>
</tr>
<tr>
<td>Second jet $p_T$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>Third jet $p_T$</td>
<td>$-$</td>
<td>$&gt; 40$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>Fourth jet $p_T$</td>
<td>$-$</td>
<td>$-$</td>
<td>$&gt; 40$</td>
<td>$&gt; 80$</td>
</tr>
<tr>
<td>$\Delta \phi(\text{jet}, E_T^{\text{miss}})_{\text{min}}$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
<td>$&gt; 0.4$</td>
</tr>
<tr>
<td>$E_T^{\text{miss}} / m_{\text{eff}}$</td>
<td>$&gt; 0.3$</td>
<td>$&gt; 0.25$</td>
<td>$&gt; 0.25$</td>
<td>$&gt; 0.2$</td>
</tr>
<tr>
<td>$m_{\text{eff}}$ [GeV]</td>
<td>$&gt; 1000$</td>
<td>$&gt; 1000$</td>
<td>$&gt; 500/1000$</td>
<td>$&gt; 1100$</td>
</tr>
</tbody>
</table>
0 Lepton Channel

- Expected and observed events for $\int L dt = 1.04 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>Dominant bkg</th>
<th>$\geq 2$ jets</th>
<th>$\geq 3$ jets</th>
<th>$\geq 4$ jets</th>
<th>$\geq 4$ jets</th>
<th>High mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z/\gamma + j$</td>
<td>$Z/\gamma + j, W + j$</td>
<td>$tt, W + j$</td>
<td>$Z/\gamma + j, W + j$</td>
<td>$tt\bar{t}$</td>
<td></td>
</tr>
<tr>
<td>Total bkg</td>
<td>$62.3 \pm 4.3 \pm 9.2$</td>
<td>$55.0 \pm 3.8 \pm 7.3$</td>
<td>$984 \pm 39 \pm 145$</td>
<td>$33.4 \pm 2.9 \pm 6.3$</td>
<td>$13.2 \pm 1.9 \pm 2.6$</td>
</tr>
<tr>
<td>Data</td>
<td>58</td>
<td>59</td>
<td>1118</td>
<td>40</td>
<td>18</td>
</tr>
</tbody>
</table>

$\int L dt \sim 1.04 \text{ fb}^{-1}$
Squark-Gluino model ($m_{\tilde{\chi}^0_1} = 0$, $m_{\text{non } \tilde{q}, \tilde{g}} = 5 \text{ TeV}$)

- Squark-gluino-neutralino model ($m_{\text{LSP}} = 0 \text{ GeV}$)

**ATLAS Preliminary**
- 0 lepton 2011 combined
- $CL_s$ observed 95% C.L. limit
- $CL_s$ median expected limit
- exp. limit 68%, 99% CL
- 2010 data PCL 95% C.L. limit

**ATLAS Preliminary**
- $L^{\text{int}} = 1.04 \text{ fb}^{-1}$, $\sqrt{s} = 7 \text{ TeV}$
- $\sigma_{\text{SUSY}} = 0.01 \text{ pb}$
- $\sigma_{\text{SUSY}} = 0.1 \text{ pb}$
- $\sigma_{\text{SUSY}} = 1 \text{ pb}$
- $\sigma_{\text{SUSY}} = 10 \text{ pb}$

**mSUGRA ($\tan \beta = 10$)**

- MSUGRA/CMSSM: $\tan \beta = 10$, $A_0 = 0$, $\mu > 0$

**ATLAS Preliminary**
- $L^{\text{int}} = 1.04 \text{ fb}^{-1}$, $\sqrt{s} = 7 \text{ TeV}$
- LEP2 $\tilde{\chi}^0_1$
- $\text{D0 } \tilde{g}, \tilde{q}, \tan \beta = 3, \mu < 0, 2.1 \text{ fb}^{-1}$
- $\text{CDF } \tilde{g}, \tilde{q}, \tan \beta = 5, \mu < 0, 2 \text{ fb}^{-1}$
- Theoretically excluded

**0 lepton 2011 combined**
- $CL_s$ observed 95% C.L. limit
- $CL_s$ median expected limit
- exp. limit 68%, 99% CL
- Reference point
- 2010 data PCL 95% C.L. limit

- Limits on non SM cross section from 5 SR: $\sigma \cdot A \cdot \varepsilon < 24, 30, 477, 32$ and 17 fb
- Limits on masses: $m_{\tilde{q}} > 800 \text{ GeV}$, $m_{\tilde{g}} > 850 \text{ GeV}$
  $m_{\tilde{q}/\tilde{g}} > 1075 \text{ GeV}$ for $m_{\tilde{q}} = m_{\tilde{g}}$
B–Jets Channel (0 Leptons)

- Mixing leads to very light $\tilde{t}_1$ and $\tilde{b}_1$ mass eigenstates
  ▲ Increased production $\Rightarrow$ b–jets in final state
- Require $\geq 1$ b–jet among the selected jets
  ▲ Main backgrounds are $t\bar{t}$ and $W$ +jets
- Constrain $t\bar{t}$ and W background in CR
  ▲ Similar procedure as in 0/1 lepton analysis
- Define four signal regions
  ▲ Based on number of b–tags (1 or 2) and $M_{eff}$ requirement ($> 500/700$ GeV)

<table>
<thead>
<tr>
<th>b–tags</th>
<th>1</th>
<th>1</th>
<th>2</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_{eff}$ (GeV)</td>
<td>500</td>
<td>700</td>
<td>500</td>
<td>700</td>
</tr>
<tr>
<td>dominant bkg</td>
<td>$t\bar{t}$</td>
<td>$t\bar{t}$, $W$ +jets</td>
<td>$t\bar{t}$</td>
<td>$t\bar{t}$, $W$ +jets</td>
</tr>
<tr>
<td>Total bkg</td>
<td>$356^{+103}_{-92}$</td>
<td>$70^{+24}_{-22}$</td>
<td>$79^{+28}_{-25}$</td>
<td>$13.0^{+5.6}_{-5.2}$</td>
</tr>
<tr>
<td>Data</td>
<td>361</td>
<td>63</td>
<td>76</td>
<td>12</td>
</tr>
</tbody>
</table>

\[ \int Ldt = 833 \text{ pb}^{-1} \]
Exclusive $\tilde{b}_1 \rightarrow b + \tilde{\chi}_1^0$ decays

- **Mass limit** $m_{\tilde{\chi}_1^0} > 280$ GeV (for $m_{\tilde{g}} < 680$ GeV and $m_{\tilde{g}} - m_{\tilde{\chi}_1^0} > 100$ GeV)
- **Limits in SO(10) models**
  - ▲ $m_{\tilde{g}} > 570$ GeV D–term splitting model
  - ▲ $m_{\tilde{g}} > 450$ GeV Higgs splitting model
1 Lepton Channel

- Require exactly one lepton + ≥ 3 jets + $E_T$
  - Main backgrounds are $t\bar{t}$ and $W \rightarrow \ell\nu + jets$

- Main cuts for background suppression
  - $m_T = \sqrt{2 \cdot p_T^\ell \cdot E_T \cdot (1 - \cos \Delta \phi(\ell, E_T))} > 100 \text{ GeV}$
  - $M_{\text{eff}} = p_T^\ell + \sum_{j=1}^{N_{\text{jet}}^{\text{sel}}} p_T^{\text{jet}_j} + E_T > 500 \text{ GeV}$
  - $E_T / M_{\text{eff}} > 0.25$

- Constrain $t\bar{t}$ and $W$ background in CR
  - $30 \text{ GeV} < E_T < 80 \text{ GeV}, 40 \text{ GeV} < m_T < 80 \text{ GeV}$

<table>
<thead>
<tr>
<th>Muon channel</th>
<th>Signal region</th>
<th>Top region</th>
<th>$W$ region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>12</td>
<td>504</td>
<td>1650</td>
</tr>
<tr>
<td>Fitted $t\bar{t}$</td>
<td>$7.2 \pm 2.7 \ (5.7)$</td>
<td>$416 \pm 29 \ (327)$</td>
<td>$247 \pm 17 \ (195)$</td>
</tr>
<tr>
<td>Fitted $W/Z$</td>
<td>$5.0 \pm 2.6 \ (5.0)$</td>
<td>$66 \pm 16 \ (66)$</td>
<td>$1335 \pm 48 \ (1336)$</td>
</tr>
<tr>
<td>Fitted QCD</td>
<td>$0.00^{+0.13}_{-0.00}$</td>
<td>$22.8 \pm 6.1$</td>
<td>$68 \pm 16$</td>
</tr>
<tr>
<td>Fitted sum</td>
<td>$12.2 \pm 3.8$</td>
<td>$504 \pm 22$</td>
<td>$1650 \pm 41$</td>
</tr>
</tbody>
</table>
## 1 Lepton Channel

![Graph showing ATLAS limits on supersymmetric particles](image)

### MSUGRA/CMSSM: \( \tan\beta = 10, A_0 = 0, \mu > 0 \)

L\(^{\text{int}}\) = 165 pb\(^{-1}\), \(\sqrt{s} = 7\) TeV

**ATLAS** Preliminary

1 lepton, \(\geq 3\) jets

<table>
<thead>
<tr>
<th>(\langle\sigma V\rangle_{95}^{\text{obs}}) [fb]</th>
<th>(S_{95}^{\text{obs}})</th>
<th>(S_{95}^{\text{exp}})</th>
<th>(CL_B)</th>
<th>(p(s = 0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron channel</td>
<td>41</td>
<td>6.8</td>
<td>10.6(^{+6.6}_{-4.7})</td>
<td>0.24</td>
</tr>
<tr>
<td>Muon channel</td>
<td>53</td>
<td>8.8</td>
<td>8.8(^{+5.7}_{-3.8})</td>
<td>0.50</td>
</tr>
</tbody>
</table>
In GMSB the NLSP decays mostly to $\gamma + \tilde{G}$

- Final state consists of $\gamma\gamma + E_T + X$
- Main backgrounds are QCD ($\gamma\gamma, \gamma j, jj$) events
  - $\gamma\gamma$ modelled with $Z \rightarrow ee + 0$ jet events
  - For $\gamma j$ use events with failed photon ID cuts
- Additional background from $W$ and $t\bar{t}$ events (with misidentified electrons and/or fake $\gamma$)
  - Select $e + \gamma$ events
  - Apply $e \rightarrow \gamma$ probability measured in $Z \rightarrow ee$
- Normalize at low $E_T$ (below 20 GeV)

<table>
<thead>
<tr>
<th>$E_T$ (GeV)</th>
<th>20–75</th>
<th>75–125</th>
<th>&gt; 125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>0.59±0.05</td>
<td>0.96±0.06</td>
<td>4.66±0.14</td>
</tr>
<tr>
<td>Total bkg</td>
<td>61.4±2.3</td>
<td>0.38±0.08</td>
<td>0.10±0.04</td>
</tr>
<tr>
<td>Data</td>
<td>63</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ \int L\,dt = 36 \text{ pb}^{-1} \]
Bino–like $\tilde{\chi}_1^0$, $\tan \beta = 2$, $m_{\text{others}} = 1.5$ TeV

- Mass limit $m_{\tilde{g}} > 560$ GeV (for $m_{\tilde{\chi}_1^0} > 50$ GeV)
- Can also be used to set limits in UED models
R–Hadrons

- R–hadrons: heavy objects formed from $\tilde{q}$ or $\tilde{g}$ and light SM partons
  - Penetrating and moving relatively slowly
  - Specific ionisation energy loss $dE/dx_{\text{pixel}}$
  - Time–of–flight measurement $\beta_{\text{tile}}$

- Event selection
  - Trigger using $E_T$
  - High $p_T$ inner detector track matched to muon track or calorimeter cluster

- Calculate particle mass from $\beta\gamma$
  - Two mass measurements: $dE/dx$ (pixel detector) and $\beta$ (tile calorimeter)

\[ \int L dt = 34 \ \text{pb}^{-1} \]
### R–Hadrons

<table>
<thead>
<tr>
<th>Mass (GeV)</th>
<th>Signal $(\tilde{g})$</th>
<th>Background</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>13912</td>
<td>5.4</td>
<td>5</td>
</tr>
<tr>
<td>300</td>
<td>173</td>
<td>0.22</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>9.2</td>
<td>0.044</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>0.84</td>
<td>0.018</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Mass limits**
  - $m > 294$ GeV sbottom R–hadrons
  - $m > 309$ GeV stop R–hadrons
  - $m > 586$ GeV gluino R–hadrons

---

**ATLAS**

\[ \sqrt{s} = 7 \text{ TeV} \]

\[ \int L \, dt = 34 \text{ pb}^{-1} \]

R-hadron exclusion CLs 95% C.L. limit

$\Delta(m > 294 \text{ GeV})$ sbottom R–hadrons

$\Delta(m > 309 \text{ GeV})$ stop R–hadrons

$\Delta(m > 586 \text{ GeV})$ gluino R–hadrons
Other ATLAS SUSY Results

Many more results not shown in detail today

\[ \int \] = 0, \( \beta > 0 \), \( \mu > 0 \)

\( L = 34 \text{ pb} \), MSUGRA/CMSSM: \( \tan \beta = 7 \),\( TeVs \)

\[ \int \] = 0, \( \beta > 0 \).

Observed limit 95% CL SS

\[ \int \] = 7 TeVs

Observed limit 95% CL

ATLAS

\( L = 35 \text{ pb} \), \( \sqrt{s} = 7 \text{ TeV} \)

\[ \int \] = 35 pb, \( \sqrt{s} = 7 \text{ TeV} \)

ATLAS Preliminary

Observation limit 95% CL (Comp. spectrum)

\( L = 34 \text{ pb} \), \( \sqrt{s} = 7 \text{ TeV} \)

ATLAS

Median expected limit (Light neutralino)

2 leptons + \( E_T \) (OS)

0,1 lepton + b–jet + \( E_T \)

3 leptons

2 leptons + \( E_T \) (SF)

1 lepton + b–jet + \( E_T \)

2 leptons + \( E_T \) (SS)
LHC delivers large amounts of good data
LHC delivers large amounts of good data

The ATLAS detector is performing well and produced already many nice results
LHC delivers large amounts of good data

The ATLAS detector is performing well and produced already many nice results

There is still a large parameter space to be explored
BACKUP
SUSY Model

- The reference model for SUSY searches is mSUGRA
  - Characterized by five parameters ⇒ “easy”
    - Common scalar mass at GUT scale: $m_0$
    - Common Gaugino mass at GUT scale: $m_{1/2}$
    - Common trilinear coupling at GUT scale: $A_0$
    - Ratio of VEV of the neutral Higgs fields: $\tan \beta$
    - Sign of Higgs mass parameter: $\text{sign}(\mu)$
  - R–parity conservation ⇒ stable LSP (Neutralino)

- Attempt to be less model specific
  ⇒ Simplified models
    - Pick specific production and decay chain
    - Vary masses of the particles involved in the chain
    - Can easier be interpreted in different scenarios
    - Quote limits on cross section times efficiency

J. Wacker et al., hep-ph 1102.5338
Background Strategy

**W, Z, t¯t background**

- Semi–data driven approach
- Select events in control regions (CR)
  - ▲ Normalise MC to data
- Extrapolate to signal region using MC
  - ▲ Assume shape is described correctly

**QCD background**

- Fully–data driven approach
- Measure real and fake efficiencies in CRs
- Apply Matrix Method to get contribution in SR

---

**Extrapolation**

- Loose
- Tight

**ε_{real}**

**ε_{fake}**