INCLUSIVE SUSY SEARCHES AT THE LHC USING THE CMS DETECTOR

Christian Autermann,
for the CMS collaboration

I. Phys. Inst. RWTH Aachen University,
Germany
Overview

Inclusive searches for supersymmetry

• 3-lepton and \( \geq 1 \) b-tag search, SUS-13-008

• Jets and missing transverse energy search, SUS-13-012

See also other new CMS results:

• Sezen Sekmen, Fri. 18:00 “Search for Natural SUSY with inclusive search strategies at CMS”

• Lesya Shchutska, Fri 18:30, “SUSY searches for EWK production of Gauginos and Sleptons at the LHC”

• Keith Ulmer, Sat. 12:30, “Search for Supersymmetry in the four W and multiple b-quark final state”
Inclusive search for SUSY with multi-leptons plus b

- Generic search, lepton requirement to suppress background
- Targeting possibly light third generation squarks (natural SUSY requires light 3rd generation)

Sensitivity to SUSY scenarios with at least
- Three light isolated leptons (e, µ),
- One b-tagged jet
- Missing transverse energy (MET)
- Hadronic activity

\( \sqrt{s} = 8 \text{ TeV}, \)  
19.5 fb\(^{-1}\) luminosity (full 2012)
Selection

- 3 leptons with $p_T > 20, 10, 10$ GeV
- $m(l^+l^-) > 12$ GeV
- $\geq 1$ b-tagged jet with $p_T > 30$ GeV
- No lepton with $\Delta R(l, b\text{-jet}) < 0.4$
- no jet with $\Delta R(l, \text{jet}) < 0.4$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Search Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sign/Flavor</td>
<td>3 $e/\mu$</td>
<td>On-Z</td>
</tr>
<tr>
<td>$N_{b\text{-jets}}$</td>
<td>$\geq 1$</td>
<td>1</td>
</tr>
<tr>
<td>$N_{jets}$</td>
<td>$\geq 2$</td>
<td>2–3</td>
</tr>
<tr>
<td>$H_T$ (GeV)</td>
<td>$\geq 60$</td>
<td>60–200</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ (GeV)</td>
<td>$\geq 50$</td>
<td>50–100</td>
</tr>
</tbody>
</table>

On-Z: Opposite-sign same-flavor di-lepton mass with $m(Z) \pm 15$ GeV

Off-Z: everything else

HT: scalar sum of jet $p_T$

$$H_T = \sum_i^{\text{jets}} \left| p_T, i \right|$$
Standard Model background

- Top – anti-top plus boson production: $ttW$, $ttZ$, $ttWZ$
- Single-top plus $Z$ production: $tbZ$
- Di-boson production: $WZ$, $ZZ$
- Triple-boson production, $WWW$, $WWZ$, $WZZ$
- Non-prompt lepton (e.g. from $b$-decays)

Monte Carlo simulation

Data side-band

CMS Preliminary $\sqrt{s} = 8$ TeV, $L_{\text{int}} = 19.5$ fb$^{-1}$

90 events

CMS Preliminary $\sqrt{s} = 8$ TeV, $L_{\text{int}} = 19.5$ fb$^{-1}$

73 events
Results

- Non-prompt lepton background dominant – this is extracted from data

- Simultaneous multi-bin fit to obtain final cross-section limits

- Lepton reconstruction and isolation efficiency uncertainties measured in data control sample on the Z peak

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>4.4</td>
</tr>
<tr>
<td>Modeling of lepton reconstruction, ID, $I_{\text{rel}}$ based on Z-events</td>
<td>12</td>
</tr>
<tr>
<td>Jet energy scale</td>
<td>5–15</td>
</tr>
<tr>
<td>Unclustered energy and lepton effects on $E_{\text{miss}}$</td>
<td>5</td>
</tr>
<tr>
<td>Modeling of b-jet multiplicity</td>
<td>5–20</td>
</tr>
<tr>
<td>Trigger</td>
<td>5</td>
</tr>
<tr>
<td>Total systematic uncertainty</td>
<td>15–30</td>
</tr>
</tbody>
</table>
Cross section limit and interpretation in simplified model spectra (SMS)

CMS Preliminary, 19.5 fb\(^{-1}\), \(\sqrt{s} = 8\) TeV

```
pp \to \tilde{g} \tilde{g}, \tilde{g} \to t \tilde{t} \tilde{\chi}_0^0 \ NLO+NLL\ exclusion

\text{Observed} \pm 1 \sigma_{\text{theory}}

\text{Expected} \pm 1 \sigma_{\text{experiment}}
```

95% C.L. upper limit on cross section (fb)

Off-shell stop

m(neutralino 1) = 50 GeV
Cross section limit and interpretation in SMS

\[ \frac{m(\chi^\pm)}{m(\chi^0)} = 0.5 \]

\[ M(\chi^\pm_1) = 300 \text{ GeV} \]

\[ M(\chi^0_2) - M(\chi^0_1) = 110 \text{ GeV} \]
Inclusive search for SUSY in the MET and jets final state

- Dominant squark and gluino pair/associated production
- Stable neutralino LSP

**Final state**
- MHT
  - Missing transverse Energy
  \[ H_T = \left| -\sum_{i} p_{T,i} \right| \]
- Jets
  - High multiplicity or
  - High $H_T$ (scalar sum jet $p_T$)

\[ \sqrt{s} = 8 \text{ TeV}, \]
\[ 19.5 \text{ fb}^{-1} \text{ luminosity} \]
(full 2012)

\[ \Rightarrow \text{Very little model assumptions} \]
Selection

- 3 jets \( p_T > 50 \) GeV, \( |\eta| < 2.5 \)
- \( \Delta \Phi(MHT, \text{jets}_{1,2,3}) > 0.5, 0.3, 0.3 \)
- Veto events with isolated e, \( \mu \) with \( p_T > 10 \) GeV

<table>
<thead>
<tr>
<th>Variable</th>
<th>baseline</th>
<th>36 signal search regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet-multiplicity</td>
<td>3 -</td>
<td>3 - 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 - 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 -</td>
</tr>
<tr>
<td>HT [GeV]</td>
<td>500 -</td>
<td>500-800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>800-1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1000-1250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1250-1500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1500 -</td>
</tr>
<tr>
<td>MHT [GeV]</td>
<td>200 -</td>
<td>200-300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>300-450</td>
</tr>
<tr>
<td></td>
<td></td>
<td>450-600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>600 -</td>
</tr>
</tbody>
</table>

Backgrounds

- QCD multi-jet production
  - MHT from jet resolution and mis-measurements
- \( W/\tt \rightarrow (e/\mu) + \text{jets} \)
  - Lepton is not reconstructed
- \( Z \rightarrow \nu\bar{\nu} \)
- \( W+\text{jets} \rightarrow \tau + \text{jets} \)

\( \Rightarrow \) All are estimated using data-driven methods
Background estimation

- QCD multijet estimation

\[ \text{Jet 2} \rightarrow \text{Rebalance} \rightarrow \text{Jet 2} \]

\[ \text{Jet 2} \rightarrow \text{Smear} \rightarrow \text{Jet 2} \]

- \( tt/W \rightarrow (e/\mu) + \text{jets, where the lepton is lost} \)

\[ e/\mu \begin{array}{c} \text{Acceptance} \\
\text{Fail} \\
\text{Out of acceptance} \end{array} \begin{array}{c} \text{reconstruction} \\
\text{Fail} \\
\text{Not reconstructed} \end{array} \begin{array}{c} \text{isolation} \\
\text{Fail} \\
\text{Not isolated} \end{array} \]

- \( \Rightarrow \text{Lepton found!} \)

- \( \Rightarrow \text{Control sample (isolated muon)} \)

Weighted according to lepton acceptance, isolation, and reconstruction efficiencies.

\( \Rightarrow \text{Signal selection (lepton-veto)} \)
Background estimation

- **Z → νν from γ+jets**
  - Z/γ similar at high boson pT
  - Replace γ with MET
  - Correct Z/γ ratio using simulation
  - Apply γ acceptance & efficiency corrections

- **tt/W → τ(→hadrons) + jets**
  - Isolated µ control sample
  - µ replaced by tau response according to template (each µ sampled 100 times)
  - µ trigger, acceptance, efficiency, and branching ratio µ / ν corrections
Results of the Jets plus MET search

CMS Preliminary, $L = 19.5\, \text{fb}^{-1}$, $\sqrt{s} = 8\, \text{TeV}$

- Data
- $Z \rightarrow \nu \bar{\nu} + \text{Jets}$
- $W/\bar{t}(e/\mu + \nu) + \text{Jets}$
- $W/\bar{t}(\tau + \nu) + \text{Jets}$
- QCD

Total uncertainty on measured background
Cross section limit and Interpretation in SMS

Gluino-gluino pair-production

Squark-squark pair-production
- First two squark generations mass degenerate
- Only one accessible squark

CMS Preliminary, 19.5 fb⁻¹, √s = 8 TeV

pp → g̅g, g̅ → q̅q̅χ₀ LLO+NLO exclusion
- Observed ± 1σ_{theory}
- Expected ± 1σ_{experiment}

95% C.L. upper limit on cross section (pb)

Gluino-gluino pair-production

Squark-squark pair-production
- First two squark generations mass degenerate
- Only one accessible squark

CMS Preliminary, 19.5 fb⁻¹, √s = 8 TeV

pp → q̅q̅, q̅ → q̅χ₀ NLO+NLL exclusion
- Observed ± 1σ_{theory}
- Expected ± 1σ_{experiment}

95% C.L. upper limit on cross section (pb)
Conclusion

- CMS has searched for New Physics using 19.5 fb$^{-1}$ of 8 TeV data of the full 2012 dataset
  - Multi-lepton search SUS-13-008
  - Jets and missing transverse energy SUS-13-012
- No significant excess has been observed
- CLs limits at 95% C.L. on the signal cross section have been calculated
- Interpretation in various simplified model spectra (SMS)

References
CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
Additional Material
## Jets plus MET search bins

<table>
<thead>
<tr>
<th>$N_{\text{Jets}}$</th>
<th>$H_T(\downarrow)$</th>
<th>$H_T$</th>
<th>$H_T$</th>
<th>$H_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>[3,5]</td>
<td>[500-800]</td>
<td>[200,300]</td>
<td>[200,300]</td>
<td>≥ 200</td>
</tr>
<tr>
<td></td>
<td>[800,1000]</td>
<td>[300,450]</td>
<td>[300,450]</td>
<td>≥ 450</td>
</tr>
<tr>
<td></td>
<td>[1000,1200]</td>
<td>[450,600]</td>
<td>≥ 600</td>
<td></td>
</tr>
<tr>
<td>[6,7]</td>
<td></td>
<td>$H_T$</td>
<td>$H_T$</td>
<td>$H_T$</td>
</tr>
<tr>
<td>≥8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $H_T(\downarrow)$ refers to the transverse momentum of the leading jet.
- $H_T$ is the total transverse momentum of all jets.

### Parameters
- $N_{\text{Jets}}$: Number of jets.
- $H_T$: Total transverse momentum.

### Bins
- **N_{Jets}** bins: [3,5], [6,7], ≥8.
- **$H_T(\downarrow)$** bins: [500-800, 800,1000, 1000,1200], [1200,1500], ≥1500.

### Values
- $H_T$: [200,300], [300,450], [450,600] for different $N_{\text{Jets}}$ and $H_T(\downarrow)$ bins.
- $H_T$: [200,300], [300,450], ≥450 for different $N_{\text{Jets}}$ and $H_T(\downarrow)$ bins.

### Requirements
- $H_T$: ≥200 for all $N_{\text{Jets}}$ and $H_T(\downarrow)$ bins.