Searches for Supersymmetry with the CMS detector

Niklas Mohr
on behalf of the CMS collaboration

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Introduction

- Split search program based on objects
  - Number of leptons, photons in the final state
  - Try to be as model independent as possible

- Dedicated background control samples
  - From data wherever possible/necessary

- Always 2 LSPs (MET)
  - $M_{T2}$, $M_R$, $R^2$, $\alpha_T$, $L_P$, $JZB$

- Often jets ($H_T = \sum p_T, i$)

- Long cascade that can involve many particles
- ~35 public analyses, 11 published
  - Had to be brief and pick few analysis
- Focus on new results using 5 fb\(^{-1}\) of LHC data
52 H\(_T\), MET signal regions

- **Background estimate**
  - Z\(\gamma\rightarrow ll(l)\) by photon to lepton fake-rate
  - Zjet\(\rightarrow ll(l)\) by track to lepton fake-rate
  - Irreducible backgrounds from MC

- **EWK production and RPV**

- **Yields are consistent with SM expectations**

- Null result interpreted as constraint on new physics

- Here, GMSM model: gravitino LSP, degenerate sleptons: co-NLSP neutralino is bino and next in mass
Same-sign dileptons

CMS Preliminary

$L_{\text{int}} = 4.7 \text{ fb}^{-1}$

- Rare process in SM, several $H_T$, MET signal regions
  - Fake leptons from data, charge mis-identification small, WZ, ZZ, ttW, ttZ from MC
Same-sign dileptons

CMS Preliminary

L_{int} = 4.7 \text{ fb}^{-1}

- \mu\mu
- \mu\tau
- ee
- \eta\tau
- \eta\mu
- \tau\tau

- Region 1
- Region 2
- Region 3
- Region 4

CMS Preliminary

L_{int} = 4.7 \text{ fb}^{-1}; \sqrt{s} = 7 \text{ TeV}

- Observed Limit (NLO+NLL with errors)
- Expected Limit (NLO+NLL)
- LEP2 \tilde{\tau}^+ (m(\tilde{g}) = 1000 \text{ GeV})
- LEP2 \tilde{\chi}_1^+ (m(\tilde{g}) = 500 \text{ GeV})
- Non-Convergent RGE's
- No EWSB

CMS-SUS-11-010

- Rare process in SM, several HT, MET signal regions
  - Fake leptons from data, charge mis-identification small, WZ, ZZ, ttW, ttZ from MC

Searches for SUSY

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Same-sign dileptons + b-tag

- Adding b-tag, several $H_T$, MET signal regions
  - Fake leptons from data, charge mis-identification small, WZ, ZZ, ttW, ttZ from MC

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Opposite-sign dileptons

- \( H_T, \) MET signal regions
- Dominant: top background
  - \( p_T(ll) = p_T(jj) \)
Opposite-sign off Z

- Search for an edge structure in mll
  - HT, MET selection
- Background from OF subtraction

Searches for SUSY

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Intermediate chargino, with probability. The leptons are produced democratically in the three families (by the OS lepton edge,

In the T3lh and T5lnu SMS, the neutralino or chargino, respectively, undergoes a 3-body decay while T5lnu avoids the region where the intermediate particle is effectively the mother. The LSP is reduced, for a fixed mother mass, as when there is a direct decay. When gluinos 3.1 SMS Construction

\[ m_{\tilde{g}} = \frac{4}{3} m_{\tilde{g}'} \]

The weak bosons decay inclusively, producing final states with combinations.

For the T5zz and T3w, the intermediate neutralino subsequently decays, and the spectrum of jet energies will depend on the ratio of gaugino masses. The invariant mass of the di-lepton final state is bounded by

\[ m(\tilde{q}) \gg m(\tilde{g}), x = 0.5 \]

In T5zz, the intermediate neutralino subsequently decays, while T5lnu produces SS lepton pairs and OS lepton pairs with equal probabilities.

\[ \prod_{f} \frac{1}{2} \mathcal{N}_{f} \times \mathcal{N}_{\chi_{0}^{0}} \times \mathcal{N}_{\chi_{1}^{0}} \]

\[ \sim \frac{1}{2} \mathcal{N}_{f} \times \mathcal{N}_{\chi_{0}^{0}} \times \mathcal{N}_{\chi_{1}^{0}} \]

\[ \chi_{1}^{0} \rightarrow Z \chi_{0}^{0}, m(\tilde{q}) \gg m(\tilde{g}), x = 0.5 \]

\[ JZB = \sum_{\text{jets}} p_{T} - |p_{T}(Z)| \]

- Flavour subtraction for dominant top background

Use Jet-Z-balance (JZB) to predict \( Z + \text{jets} \) tail
OS on Z (MET spectrum)

**MET templates derived from photon + jets data to model instrumental MET**

- Flavour subtraction for dominant top background

**Figure 4: Diagrams of T3w (left), T5zz (right).**

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4.7 fb\(^{-1}, \sqrt{s} = 7 \text{ TeV}\) Muons

- **S\(_T\)** (I+MET) and L\(_p\) selection
- Background predicted by extrapolation in polarization

**Single lepton (L\(_p\))**

**Searches for SUSY**

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3.1 SMS Construction

Events / 50 GeV

CMS preliminary 2011

4.7 fb⁻¹, √s = 7 TeV
1 e or μ, ≥ 4 jets, H_T ≥ 750 GeV

- Data
- Total prediction
- Prediction for taus/dileptons
- SUSY (LM3)
- SUSY (LM6)

CMS Preliminary

L_{int} = 4.7 fb⁻¹, √s = 7 TeV

- LS, HT>750(GeV), 95% C.L. Limits:
  - Observed Limit
  - Median Expected
  - Expected ± 1 σ exprt
  - Observed ± 1 σ theory
  - Expected ± 1 σ theory

- tan(β)=10
- A_0 = 0 GeV
- μ > 0
- m_t = 173.2 GeV

LEP2 $\tilde{\tau}^+$
$\tilde{\chi}_1^0$

- MET distribution predicted using lepton p_T spectrum

- H_T, MET selection

Searches for SUSY

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• $H_T$, MET selections

• $\gamma\gamma$ (electron control), multijet control for jet→$\gamma$
**Photon Searches for SUSY**

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**Photons**

CMS preliminary \(4.3\) fb\(^{-1}\) \(\sqrt{s} = 7\) TeV \(\geq 1\gamma\), \(\geq 2\) jets

**GGM wino-like** \(\tilde{\chi}\)

\(m_{\tilde{\chi}_1} = 375\) GeV

NLO limits
- Observed
- \(\pm 1\sigma\) (theory)
- Expected
- \(\pm 1\sigma\) (exper.)

Excluded

**GGM bino-like** \(\tilde{\chi}\)

\(m_{\tilde{\chi}_1} = 375\) GeV

NLO limits
- Observed
- \(\pm 1\sigma\) (theory)
- Expected
- \(\pm 1\sigma\) (exper.)

Excluded

\(\gamma +\)jets + MET"classic"

**In General**

Gauginos and higgsino are the Lightest SUSY Particle (LSP)

- Next to Lightest SUSY Particle (NLSP) is neutralino decaying to gravitino and SM particle

Different gaugino mixing scenarios prefer different VY Bosons \((\gamma, W, Z)\) in decay:

- Bino-like neutralino: photon preferred \(Y > \) diPhoton
- Wino-like neutralino: \(W, Z\) preferred \(Y > \) single photon, photon + lepton

Photon + jet + MET searches have typically very small background

2. March 2012 Markus Stoye (CERN)

CMS-SUS-12-001

Ruderman, Shih, 1103.6083
All hadronic $M_{T2}$

- All hadronic search based on $M_{T2}$
  - STransverse mass
  - Good QCD rejection
  - Sensitive to particle masses

- All backgrounds predicted individually from data
  - QCD (Factorization method)
  - $W \rightarrow \mu \nu$ (lost lepton method)
  - $Z \rightarrow \nu \nu$ ($\gamma+$jets/$W \rightarrow \mu \nu$)

Additional models are constructed by adding an intermediate particle in the decay chain, so that the gluino can undergo a direct three-body decay into jets and a chargino or a neutralino that is heavier than the LSP. Such SMS are illustrated in Figures 3 and 4. Both the chargino and the neutralino would then subsequently decay into a gauge boson and $\tilde{c}_0$ or undergo a 3-body decay including the LSP. The SMS with cascade decays are interesting to study, since the amount of energy available for the LSP is less, for the same mother mass, as when there is a direct decay. When gluinos...
• Prediction in several bins of $H_T$, $M_{T2}$

• b-tagged part of the analysis
  - Sensitive to third generation signatures
CMS-SUS-12-005

- $M_R$, $R^2$ (RAZOR)
  - Sensitive to scale, QCD rejection

- Backgrounds predicted via 2-D multi-component fit

Searches for SUSY

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• Inclusion of **leptonic boxes** using same method for background prediction

• Unbinned likelihood used to derive the limit

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**Razor (Inclusive)**

![Graph](image)

**Figure 10:** Observed (solid curve) and median expected (dot-dashed curve) 95% CL limits in the \((m_0, m_{1/2})\) CMSSM plane with \(\tan(\beta) = 10, A_0 = 0 \text{ GeV} \), \(\mu > 0\), and \(\text{sgn}(\mu) = +1\) from the razor analysis.

- The ± one standard deviation equivalent variations in the uncertainties are shown as a band around the median expected limit.

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**CMS-SUS-12-005**
As all analyses yielded null results
- Exclusion are performed in limited set of models

Allow comparison to other theories
- Publish acceptance and efficiencies
### CMS Preliminary

Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}_i^0)$

<table>
<thead>
<tr>
<th>Model</th>
<th>Process</th>
<th>Limit</th>
<th>Mass Range (GeV/$c^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>$\alpha_T$, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>$E_T + jets$, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>MT2, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T2: $\tilde{q} \rightarrow q\tilde{\chi}_1^0$</td>
<td>$\alpha_T$, 1.1 fb$^{-1}$, squark</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T2: $\tilde{q} \rightarrow q\tilde{\chi}_1^0$</td>
<td>$E_T + jets$, 1.1 fb$^{-1}$, squark</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1b:: $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$</td>
<td>$E_T + b$, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1b:: $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$</td>
<td>MT2, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1nu: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^{\pm}$</td>
<td>$l^\pm l^\mp$, 0.98 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1h: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0</td>
<td>\chi_0^0</td>
<td>$</td>
<td>$l^\pm l^\mp$, 0.98 fb$^{-1}$, gluino</td>
</tr>
<tr>
<td>T5zz: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>$Z + E_T$, 0.98 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T5zz: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>JZB, 2.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T5zz: $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$</td>
<td>$E_T + jets$, 1.1 fb$^{-1}$, gluino</td>
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<td>$\alpha_T$, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
<tr>
<td>T1lttt: $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$</td>
<td>$l^\pm l^\mp$, 1.1 fb$^{-1}$, gluino</td>
<td></td>
<td>0-1000</td>
</tr>
</tbody>
</table>

For limits on $m(\tilde{g}), m(\tilde{q}) > m(\tilde{\chi}_1)$ (and vice versa), $\sigma_{\text{prod}}^{\text{NLO−QCD}} = m(\tilde{\chi}_1^*) \\ m(\tilde{\chi}_1^0)$ is varied from 0 GeV/$c^2$ (dark blue) to $m(\tilde{g}) - 200$ GeV/$c^2$ (light blue).

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### Exclusion at the TeV range for squarks and gluinos
- Only for $m_{\text{LSP}} \ll m_{\tilde{g}}$

### Room for SUSY with compressed spectra
- Extending searches to address compressed spectra
• Searches for SUSY can be summarized
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• Empty box: No excess found
  - $m(q) > 1.4$ TeV, $m(g) > 800$ GeV
• Searches for SUSY can be summarized

• Empty box: No excess found
  - \( m(q) > 1.4 \text{ TeV}, m(g) > 800 \text{ GeV} \)

• Dedicated searches addressing natural SUSY (light stop) are ongoing
  - Holes in coverage in compressed spectra are being filled
• Searches for SUSY can be summarized

• Empty box: No excess found
  - $m(q) > 1.4 \text{ TeV}, m(g) > 800 \text{ GeV}$

• Dedicated searches addressing natural SUSY (light stop) are ongoing
  - Holes in coverage in compressed spectra are being filled

• Looking forward to 8 TeV LHC data
• **Searches for SUSY can be summarized**

• **Empty box: No excess found**
  - $m(q) > 1.4$ TeV, $m(g) > 800$ GeV

• **Dedicated searches addressing natural SUSY (light stop) are ongoing**
  - Holes in coverage in compressed spectra are being filled

• **Looking forward to 8 TeV LHC data**

• **Many more details and interesting SUSY results**

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
Razor variables

\[ M_R = \sqrt{(|\vec{p}_{j1}| + |\vec{p}_{j2}|)^2 - (p_{z1}^j + p_{z2}^j)^2} \]

\[ M_T^R = \sqrt{E_T^{\text{miss}}(p_T^{j1} + p_T^{j2}) - \frac{E_T^{\text{miss}} \cdot (p_T^{j1} + p_T^{j2})}{2}} \]

\[ R = \frac{M_T^R}{M_R} \]

Peaks at \[ M_\Delta = \frac{M_S^2 - M_{LSP}^2}{M_S} \]

Edge at \[ M_\Delta \]

Ratio of two estimators of SUSY scale – describes transverse shape of event
Multilepton RPV

CMS Preliminary $\sqrt{s} = 7$ TeV, $L_{int} = 4.7$ fb$^{-1}$

95% C.L. CLs Limits
- NLO observed
- NLO expected $\pm 1\sigma$
- NLO expected $\pm 2\sigma$

CMS Preliminary $\sqrt{s} = 7$ TeV, $L_{int} = 4.7$ fb$^{-1}$

95% C.L. CLs Limits
- NLO observed
- NLO expected $\pm 1\sigma$
- NLO expected $\pm 2\sigma$

CMS-EXO-11-013
JZB variable

\[ JZB = \sum_{\text{jets}} p_T - |\vec{p}_T(Z)| \]

- Use Jet-Z-balance (JZB) to predict Z +jets tail
  - Flavour subtraction for dominant top background
- Several JZB selections,
  - need always jets
Lp variable

- Measurement 2011
- Polarization fraction as expected in SM

\[ L_p = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2} \]

CMS Simulation

\[ \int L \, dt = 4.7 \, fb^{-1} \]

\[ \sqrt{s} = 7 \, TeV \]
• top and W-events
  - $p_T(l) = p_T(\nu)$

• Can be used to predict MET tail for SUSY
• **SM cross-sections**
  - All in good agreement to theory

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults