Recent results from CMS on SUSY searches in leptonic final states

8th VIENNA CENTRAL EUROPEAN SEMINAR on Particle Physics and Quantum Field Theory

Robert Schöfbeck on behalf of the CMS Collaboration
At the LHC, colored production of squarks and gluinos will be dominant

followed by cascade decays involving jets and (di-)leptons, photons, ...

Under moderate assumptions (e.g. R-parity) there is a stable LSP responsible for MET
single lepton channel

- Small QCD background
- TTbar and W+Jets dominate

<table>
<thead>
<tr>
<th>0-leptons</th>
<th>1-lepton</th>
<th>OSDL</th>
<th>SSDL</th>
<th>≥ 3 leptons</th>
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<td>Di-photon + jet + MET</td>
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ICPP, 20-25 June 2011
OS dilepton channel

- reduced W background
- $TT$ dominates
- two channels:
  - veto $m(l^+l^-) \sim m_Z$

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OS dilepton channel (JZB)

- Reduced W background
- TTbar dominates

Two channels:
- Z + jets + MET
- Require \( m(l^+l^-) \sim m_Z \)

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Slide 5
SS dilepton channel

- very little SM background (tau final state)

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very little SM background
many channels (tau final state)
in general we have
multiple methods of data-driven background estimation for each channel

Parametrization
- detector response
- simplified models

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single lepton channel

- **pre-selection:**
  - $1 \ e$ or $\mu$, $P_T > 20 \ GeV$
  - $\geq 4$ jets, $E_T > 30 \ GeV$, $|\eta| < 2.4$

- **signal selection:**
  - $H_T > 500 \ GeV$ (scalar sum of jet $p_T$s),
  - $MET > 250$ (loose) or $350 \ GeV$ (tight)

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Lepton spectrum (LS) method: use the fact that, for $W$ decays, charged lepton and neutrino $P_T$ spectrum are similar

Idea: Take $\mu$-$P_T$ spectrum as model for $MET$

Correct for acceptance, efficiency, polarization

MET resolution worse than $e/\mu$: smear $\mu$-$P_T$

2nd method: Lepton projection (LP)
single lepton: results

Background contributions

- **W+Jets and TTbar → lepton + jets**: ~ 75%
- **tt dilepton with one lost lepton** (ID or acceptance): ~ 10%
  - estimated from dilepton data by scaling with probability to lose lepton
- **tt, W+Jets → τ → (e, μ)**: ~ 15%
  - estimate with μ + jets data by replacing the μ with the τ response

Event counts in signal region:

<table>
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<tr>
<th>MET &gt; 250 GeV</th>
<th>MET &gt; 350 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>predicted</td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td></td>
</tr>
</tbody>
</table>

- no excess seen
- set limits in cMSSM plane
**OSDL: search strategy**

**Signal selection:**
- $p_T(\mu,e) > 10/20\text{GeV} \ (ee/e\mu/\mu\mu)$
- Z-Veto: $|m_{ll} - m_Z| > 20 \text{ GeV}$
- 2 jets $> 30 \text{ GeV}$
- $H_T > 100 \text{ GeV}$ $E_T^{\text{miss}} > 50 \text{ GeV}$

**Background prediction:**
- $t\bar{t}$bar (dominant)
  - Matrix method in $H_T$ and $S_{\text{MET}}(y)$
  - exploit that $y = \text{MET}/\sqrt{H_T}$
  - and $H_T$ are nearly uncorrelated
- pT(ll) method (di-lepton spectrum m.) OF subtraction
- QCD (small) estimation
  - ‘tight-to-loose’

Good Data/MC agreement in preselection regions!

2 search regions defined
- high $E_T^{\text{miss}}$
  - $H_T > 300 \text{ GeV}$ $E_T^{\text{miss}} > 275 \text{ GeV}$
- high $H_T$
  - $H_T > 600 \text{ GeV}$ $E_T^{\text{miss}} > 200 \text{ GeV}$
### OSDL: results

#### Vienna Seminar on Particle Physics

<table>
<thead>
<tr>
<th></th>
<th>high $E_{\text{miss}}$ signal region</th>
<th>high $H_T$ signal region</th>
</tr>
</thead>
<tbody>
<tr>
<td>observed yield</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>MC prediction</td>
<td>$7.3 \pm 2.2$</td>
<td>$7.1 \pm 2.2$</td>
</tr>
<tr>
<td>ABCD' prediction</td>
<td>$4.0 \pm 1.0$ (stat) $\pm 0.8$ (syst)</td>
<td>$4.5 \pm 1.6$ (stat) $\pm 0.9$ (syst)</td>
</tr>
<tr>
<td>$p_T(\ell\ell)$ prediction</td>
<td>$14.3 \pm 6.3$ (stat) $\pm 5.3$ (syst)</td>
<td>$10.1 \pm 4.2$ (stat) $\pm 3.5$ (syst)</td>
</tr>
<tr>
<td>$N_{\text{bg}}$</td>
<td>$4.2 \pm 1.3$</td>
<td>$5.1 \pm 1.7$</td>
</tr>
<tr>
<td>non-SM yield UL</td>
<td>10</td>
<td>5.3</td>
</tr>
<tr>
<td>LM1</td>
<td>$49 \pm 11$</td>
<td>$38 \pm 12$</td>
</tr>
<tr>
<td>LM3</td>
<td>$18 \pm 5.0$</td>
<td>$19 \pm 6.2$</td>
</tr>
<tr>
<td>LM6</td>
<td>$8.1 \pm 1.0$</td>
<td>$7.4 \pm 1.2$</td>
</tr>
</tbody>
</table>

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8th Vienna Seminar on Particle Physics  
Slide 11
- Z + Jets has no genuine $E_T^{miss}$, only fake $E_T^{miss}$ from the Jet system
- Fake $E_T^{miss}$ can be measured in photon or QCD templates in bins of HT and njet.
- t-tbar background estimated from $e\mu$ data

2nd method using Z-jets balancing
(→ backup)
Prediction consistent with SM!
same-sign dilepton search

- example: Gluino production will give SS:OS = 1:1
- Very little SM background
  Leading in μ channel:
  - ttbar with a SS fake μ from a decay in a jet (i.e. not charge-mis-ID)
- Pursue different trigger strategies:
  - inclusive dilepton: HT and di-lep
  - high-p_T di-lep: no H_T requirement
  - tau dileptons: H_T, MET and (1 or 2 had. τ)
Backgrounds:

- **Prompt SS leptons (WW/WZ/ZZ)**
  very small, never measured in pp: take from MC

- **charge mis-ID (for electron channel)**
  use the ratio SS/OS for ee events in a 
  Z mass window to estimate charge mis-ID rate.
  Result from measurement: $2 \cdot 10^{-4}$ to $3 \cdot 10^{-3}$

- **dominating background:**
  non-prompt leptons from jets (WJets, TTbar, QCD)
  measure from data with tight-to-loose method.
Study events with two fakes; uncorrelated cuts: Iso of lepton 1 and 2, MET

If the assumption holds: \( N_{\text{pred}} = N_{\text{preselected}} \varepsilon_{\text{Iso1}} \varepsilon_{\text{Iso2}} \varepsilon_{\text{MET}} \)

Left: Factorization of \( \mu \) isolation cuts

Right: RelIso efficiency as fkt. of MET (reduce \( W \) with impact parameter cut)
Acceptance model defined wrt. stable generator particles

- $H_T$: calculated from $u,d,c,s,b,g$ with $p_T > 30$ in final state, resolution $\sim 20\%-30\%$
- MET: calculated from non-interacting particles resolution $\sim 10\%$
  $(H_T$ and MET resolutions depend on $H_T$)

Lepton efficiencies:

$$e(x) = \text{par}(1) + \text{par}(2) \cdot \left( \text{erf} \left( \frac{x-x_0}{\text{par}(3)} \right) - 1 \right)$$

Isolation corrections:

$$\Delta \varepsilon = -0.10 \frac{<n>-25}{15}$$

where $<n>$ is the average number of stable charged particles $|\eta|<2.4 \ p_T>3$ GeV

→ efficiency model to interface with theory!
SSDL results

Exclusion region in the CMSSM for the signal region 1 (high-$H_T$ high-$E_T^{miss}$) of the high-$p_T$ search (left)
Multi lepton channels

- Include most of 3L and ≥4L combinations
  - μμμ, eee, μμe, eem
  - μμτ, eet, eμτ
  - μττ, eττ
  - All ≥4L combinations with ≤2τ
- Low SM backgrounds for multi-lepton channels
  - Reduce backgrounds further by requiring one or more of
    - $H_T > 200$ GeV
    - MET > 50 GeV
    - Veto $m(l^+l^-) < 12$ GeV
    - Veto Z’s: $75 < m(l^+l^-) < 105$ GeV

52 channels considered!
### Results for multi leptons

<table>
<thead>
<tr>
<th>Selection</th>
<th>$N(\tau)=0$</th>
<th>$N(\tau)=1$</th>
<th>$N(\tau)=2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>obs</td>
<td>expected SM</td>
<td>obs</td>
</tr>
<tr>
<td><strong>≥FOUR Lepton Results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET&gt;$50, H_T &gt;200, noZ$</td>
<td>0</td>
<td>$0.003 \pm 0.002$</td>
<td>0</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &gt;200, Z$</td>
<td>0</td>
<td>$0.06 \pm 0.04$</td>
<td>0</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &lt;200, noZ$</td>
<td>1</td>
<td>$0.014 \pm 0.005$</td>
<td>0</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &lt;200, Z$</td>
<td>0</td>
<td>$0.43 \pm 0.15$</td>
<td>2</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &gt;200, noZ$</td>
<td>0</td>
<td>$0.0013 \pm 0.0008$</td>
<td>0</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &gt;200, Z$</td>
<td>1</td>
<td>$0.28 \pm 0.11$</td>
<td>0</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &lt;200, noZ$</td>
<td>0</td>
<td>$0.08 \pm 0.03$</td>
<td>4</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &lt;200, Z$</td>
<td>11</td>
<td>$9.5 \pm 3.8$</td>
<td>14</td>
</tr>
<tr>
<td><strong>THREE Lepton Results</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET&gt;$50, H_T &gt;200, no-OSSF$</td>
<td>2</td>
<td>$0.87 \pm 0.33$</td>
<td>21</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &lt;200, no-OSSF$</td>
<td>4</td>
<td>$3.5 \pm 1.2$</td>
<td>88</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &gt;200, no-OSSF$</td>
<td>1</td>
<td>$0.50 \pm 0.33$</td>
<td>12</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &lt;200, no-OSSF$</td>
<td>7</td>
<td>$5.0 \pm 1.7$</td>
<td>245</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &gt;200, noZ$</td>
<td>5</td>
<td>$1.9 \pm 0.5$</td>
<td>7</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &gt;200, Z$</td>
<td>8</td>
<td>$8.1 \pm 2.7$</td>
<td>10</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &lt;200, noZ$</td>
<td>19</td>
<td>$11.6 \pm 3.2$</td>
<td>64</td>
</tr>
<tr>
<td>MET&gt;$50, H_T &lt;200, Z$</td>
<td>5</td>
<td>$2.0 \pm 0.7$</td>
<td>24</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &gt;200, noZ$</td>
<td>58</td>
<td>$57 \pm 21$</td>
<td>47</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &gt;200, Z$</td>
<td>6</td>
<td>$8.2 \pm 2.0$</td>
<td>90</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &lt;200, noZ$</td>
<td>86</td>
<td>$82 \pm 21$</td>
<td>2566</td>
</tr>
<tr>
<td>MET&lt;$50, H_T &lt;200, Z$</td>
<td>335</td>
<td>$359 \pm 89$</td>
<td>9720</td>
</tr>
<tr>
<td><strong>Totals 4L</strong></td>
<td>13.0</td>
<td>$10.4 \pm 3.8$</td>
<td>20.0</td>
</tr>
<tr>
<td><strong>Totals 3L</strong></td>
<td>536</td>
<td>$539 \pm 94$</td>
<td>12894</td>
</tr>
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No excess beyond SM seen.
Set limits in cMSSM plane

(All LHC and Tevatron results are given for the other MSSM parameters fixed at \( \tan \beta = 3, A_0 = 0, \mu > 0 \))

GMSB scenario with slepton co-NLSP decaying into l + gravitino. The next higher state is a bino-like neutralino, leading to a four lepton + MET final state.
**Simplified models**

CMS preliminary

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

<table>
<thead>
<tr>
<th>Model</th>
<th>Mass Scale (GeV/c^2)</th>
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<tr>
<td>$\tilde{g} \to q\bar{q}^* \tilde{\chi}^0$</td>
<td>$\tilde{g} \to q\bar{q}^* \tilde{\chi}^0$, gluino</td>
</tr>
<tr>
<td>$\tilde{t}_1 \to t\tilde{\chi}^0$</td>
<td>$\tilde{t}_1 \to t\tilde{\chi}^0$, squark</td>
</tr>
<tr>
<td>$\tilde{q}_1 \to q\tilde{\chi}^0$</td>
<td>$\tilde{q}_1 \to q\tilde{\chi}^0$, gluino</td>
</tr>
<tr>
<td>$\tilde{t}<em>{1b} \to b\tilde{\chi}^0, \tilde{t}</em>{1b} \to b\tilde{\chi}^0$</td>
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**For limits on $m(\tilde{g}), m(\tilde{g}) > m(\tilde{g})$ (and vice versa), $\sigma_{\text{prod}} = \sigma_{\text{NLO-QCD}}$.**


$\sigma_{\text{prod}} = \frac{m(\tilde{g}) + m(\tilde{g})}{2}$

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g}) - 200$ GeV/c^2 (light blue).
CMS preformed a variety of SUSY searches with up to 2 fb\(^{-1}\)

Multiple methods for data-driven background estimations have been validated and used for early 2011 data.

We have not seen significant evidence for BSM.

Almost 5 fb\(^{-1}\) are being analyzed right now!
latest public results of CMS:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Further interpretation of SUSY searches, CMS PAS SUS-11-001

Search for supersymmetry in events with opposite-sign dileptons and missing energy, CMS PAS SUS-11-011

Search for supersymmetry in events with same-sign dileptons and missing energy, CMS PAS SUS-11-010

Search for supersymmetry in events with a Z boson and missing energy, CMS PAS SUS-11-012, SUS-11-017

Search for supersymmetry in events with three or more leptons and missing energy, CMS PAS SUS-11-013
Backup
Three methods for fake lepton predictions **prompt-fake**, **fake-fake**

**Tight to Loose (TL)**
- ratio measured in QCD multijet;
- two sets of loose definition (A1/2):
  - (different isolation requirements)

**Factorization Method** (next slide):
- factorize isolation and $E_T^{\text{miss}}$ efficiency

**B Tag-and-Probe:**
- relax isolation requirement and measure efficiency in a b-enriched control sample
**Z+Jets+MET search with JZB**

- **Signal selection:**
  - $P_T(\mu, e) > 10/20\text{GeV}$ (same flavour)
  - $Z$-requirement: $|m_{ll} - m_Z| < 20 \text{ GeV}$
  - $\geq 2$ Jets with $p_T > 30 \text{ GeV}$

- **Jet-Z Balance:**
  \[ JZB = \left| \sum_{\text{jets}} \vec{p}_T - \vec{p}_T(Z) \right| \]

- **Dominant backgrounds:** Z+Jets, ttbar
  - Use JZB<0 to predict Z+Jets in JZB>0
  - Use $\mu\ell$ pairs to predict ttbar in JZB>0
  - new physics is preferentially positive for JZB since jets balance Z+MET
JZB: results with 191 pb$^{-1}$

<table>
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<th>Region</th>
<th>Observed</th>
<th>Predicted</th>
<th>UL</th>
</tr>
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<tbody>
<tr>
<td>JZB $&gt; 50$</td>
<td>20</td>
<td>$24 \pm 6$ (stat) $\pm 1.4$ (peak) $^{+1.2}_{-2.4}$ (sys)</td>
<td>11.1</td>
</tr>
<tr>
<td>JZB $&gt; 100$</td>
<td>6</td>
<td>$8 \pm 4$ (stat) $\pm 0.1$ (peak) $^{+0.4}_{-0.8}$ (sys)</td>
<td>6.6</td>
</tr>
</tbody>
</table>