Searches for Supersymmetry in Final States with Leptons or photons and missing energy

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On behalf of the CMS collaboration
SUSY has many properties:

- Provides dark matter candidates, solves the hierarchy problem, better unification of couplings etc.
- We do not know where it is, so we look generically everywhere.

Inclusive searches are defined:

- Categorized by the number of leptons in final state
- Generic missing energy signatures
- Many include jet requirements to be sensitive to strong production

Results of the studies not covered in this talk (including b-jets), can be found at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
In this talk, recent results from CMS using \( \sim 1 \text{ fb}^{-1} \) of 2011 data are summarized:

- Inclusive Searches with data driven background predictions
  - Opposite sign dileptons with Z veto
  - Opposite sign dileptons with Z in the final states
- Same sign dilepton searches
- Exclusion limits/Interpretation of results
  - Limits using CMSSM framework
  - Information to test variety of specific physics models
- Summary and Conclusion
Inclusive searches with data driven background predictions

- Opposite sign di-leptons studies with Z veto

- Counting experiment in signal region with large MET and $H_T$

- Search for kinematic edge in dilepton mass distribution

[CMS PAS SUS-11-011]

$H_T$ *is defined as the scale sum $p_T$ of the hadronic jets*
Opposite sign dilepton search

Requirement of di-leptons reduces W+Jets & QCD drastically, leaving mostly top

Use data driven techniques to predict bkg in tails of $H_T$ and MET distribution

Baseline selection:

- Two isolated leptons ($e$, $\mu$): one with $p_T > 20$ GeV, other with $p_T > 10$ GeV
- At least 2 jets with $p_T > 30$ and $|\eta| < 3.0$, MET $> 30$ GeV, $H_T > 100$ GeV
- Veto same-flavor pairs in Z mass window (76, 106) and $m_{ll} < 12$ GeV

Simulation shape (scale x 1.13) agrees with the data in various distributions
Define signal regions in tails of MET and $H_T$

- High MET signal region ($\text{MET} > 275 \text{ GeV}$, $H_T > 300 \text{ GeV}$)
- High $H_T$ signal region ($\text{MET} > 200 \text{ GeV}$, $H_T > 600 \text{ GeV}$)

Derive data driven background Estimations ⇒ See Next
Two data driven methods used in this search:

a) Lepton spectrum method ($p_T(ll)$) [V. Pavlunin, PRD 81, 035005 (2010)]

This method relies on the $p_T(ll)$ distribution to get $p_T(vv)$

In SM, the neutrino and the lepton $p_T$ are anti-correlated in a given event

- Overall spectra are similar

Corrections are needed to account for cuts on MET, polarization effects due to Ws. Both of these are well modeled in MC.

The observation is consistent with the prediction
b) ABCD' method (Use weakly correlated variables, $H_T$ & $y$)

- Measure in data the $H_T$ & $y = \text{MET}/\sqrt{H_T}$ distributions $f(y), g(H_T)$.
- Predict yields in a given region using:

$$\frac{\partial^2 N}{\partial y \partial H_T} = f(y)g(H_T)$$

- Method validated using toy MC studies ($\sim 1 \text{fb}^{-1}$)

Bin contents of $f(y)$ and $f(H_T)$ are smeared according to their poisson uncertainties for stat uncert. in the bkg prediction.
Opposite sign dilepton search (ABCD' method)

b) ABCD' method

<table>
<thead>
<tr>
<th></th>
<th>high $E_T^{\text{miss}}$ 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>$4.0 \pm 1.0 \text{ (stat)} \pm 0.8 \text{ (syst)}$</td>
<td>$4.5 \pm 1.6 \text{ (stat)} \pm 0.9 \text{ (syst)}$</td>
</tr>
<tr>
<td>$p_T(\ell\ell)$ prediction</td>
<td>$14.3 \pm 6.3 \text{ (stat)} \pm 5.3 \text{ (syst)}$</td>
<td>$10.1 \pm 4.2 \text{ (stat)} \pm 3.5 \text{ (syst)}$</td>
</tr>
</tbody>
</table>

Prediction yields are consistent with MC and the observation.
Opposite sign dileptons – Opposite flavour Subtraction

- Predict number of ttbar from dileptons $\mu\mu$
  and $ee$ from $e\mu$ events

- Lepton $p_T > 10$ GeV

Relies on $r_{\mu e} = N(Z \rightarrow ee)/N(Z \rightarrow \mu\mu)$
  - Known within 2% syst.

Quantify the excess of SF Vs OF events using:

$$\Delta = 1/r_{\mu e} N(ee) + r_{\mu e} N(\mu\mu) - N(e\mu)$$

Note: $\Delta = 0$ for dominant SM bkg's (ttbar, WW, DY $\rightarrow \tau\tau$)

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<tbody>
<tr>
<td>observed $\Delta$</td>
<td>$3.6 \pm 2.9$ (stat) $\pm 0.4$ (syst)</td>
</tr>
</tbody>
</table>

No evidence of any excess
Search for kinematic edge in m(\(ll\)) distribution

- Perform extended maximum likelihood fit simultaneously to ee, \(\mu\mu\), e\(\mu\) events
  - ee/\(\mu\mu\) with signal + Z + bkg
  - em: bkg only
- Validate fit in control region dominated by ttbar (MET > 100 GeV, 100 < H\(_T\) < 300)
- Search for NP in signal region (MET > 100 GeV, H\(_T\) > 300 GeV)
- Observe no evidence for kinematic edge \(\Rightarrow\) Set upper limit on the signal

\[ \chi_2^0 \rightarrow \ell\ell' \rightarrow \chi_1^0\ell+\ell' \]

Shape depends on 1 parameter (position of the edge)
- Perform fit to m\(_{\text{cut}}\) for LM1 benchmark point
- Scan edge position and extract Upper limit
Upper Limits from Opposite sign dilepton studies

- Extract **model independent limits** on non-SM contributions to yields
- For generic search, use error-weighted average of 2 data-driven estimates
- Compute 95% CL UL, compare to the NLO yields from benchmark points*

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<td>$7.3 \pm 2.2$</td>
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</tr>
<tr>
<td>ABCD' prediction</td>
<td>$4.0 \pm 1.0$ (stat) ± 0.8 (syst)</td>
<td>$4.5 \pm 1.6$ (stat) ± 0.9 (syst)</td>
</tr>
<tr>
<td>$p_T(\ell\ell)$ prediction</td>
<td>$14.3 \pm 6.3$ (stat) ± 5.3 (syst)</td>
<td>$10.1 \pm 4.2$ (stat) ± 3.5 (syst)</td>
</tr>
<tr>
<td>$N_{bkg}$</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>

**Generic results**

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<tbody>
<tr>
<td>observed $\Delta$</td>
<td>$3.6 \pm 2.9$ (stat) ± 0.4 (syst)</td>
<td>$-0.9 \pm 1.8$ (stat) ± 1.1 (syst)</td>
</tr>
<tr>
<td>UL</td>
<td>7.9</td>
<td>3.6</td>
</tr>
<tr>
<td>LM1</td>
<td>$27 \pm 6.0$</td>
<td>$24 \pm 7.6$</td>
</tr>
<tr>
<td>LM3</td>
<td>$3.2 \pm 0.9$</td>
<td>$3.3 \pm 1.1$</td>
</tr>
<tr>
<td>LM6</td>
<td>$2.0 \pm 0.2$</td>
<td>$1.9 \pm 0.3$</td>
</tr>
</tbody>
</table>

**correlated flavor results**

*benchmark points are defined in backup slides*
Inclusive Searches with data driven background predictions

Opposite sign di-leptons with Z

- *Jet-Z balance method* (CMS SUS-11-012)

- MET template method (CMS SUS-11-017)
Search for SUSY in $Z + \text{Jets} + \text{MET}$ final state (e.g. $\chi^0_2 \rightarrow Z \chi^1_0$)

- Two isolated leptons (e, $\mu$): $p_T > 20$ GeV
- At least 3 jets with $p_T > 30$ and $|\eta| < 3.0$, MET > 30 GeV
- Require same-flavor pairs in Z mass window $|m_{ll} - Z| < 20$ GeV

**Backgrounds:**
- $Z + \text{Jets} + \text{instrumental MET}$
- OSSF dileptons from $t\bar{t}$bar
  (Predict using OSOF subtraction method)

Define:
\[
J_{ZB} = \sum_{\text{jets}} p_T - |p_T^Z|
\]

$J_{ZB} < 0$: Control region

Use $J_{ZB} (<0)$ peak events to predict
$J_{ZB} (>0)$ peak events after the $e\mu$ subtraction

Substantial tail for SUSY in $J_{ZB} > 0$ events
Two regions defined: $JZB > 50$ GeV (reference region); $JZB > 100$ GeV (search region)

The background prediction has been fitted to $\pm \sigma$ display uncert. band

<table>
<thead>
<tr>
<th>Region</th>
<th>Observed events</th>
<th>Background prediction</th>
<th>MC expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JZB &gt; 50$ GeV</td>
<td>20</td>
<td>$24 \pm 6$ (stat) $\pm 1.4$ (peak) $^{+1.2}_{-2.4}$ (sys)</td>
<td>$16.0 \pm 1.2$ (MC stat)</td>
</tr>
<tr>
<td>$JZB &gt; 100$ GeV</td>
<td>6</td>
<td>$8 \pm 4$ (stat) $\pm 0.1$ (peak) $^{+0.4}_{-0.8}$ (sys)</td>
<td>$3.6 \pm 0.4$ (MC stat)</td>
</tr>
</tbody>
</table>

Prediction agrees well with the observation in both regions
Opposite sign di-leptons with Z (MET template method)

New physics search similar to previously outlined:
- It uses MET as the major discriminant
  - Two isolated leptons (e, \(\mu\)): \(p_T > 20\) GeV
  - At least 2 jets with \(p_T > 30\) and \(|\eta| < 3.0\)
  - Require same-flavor pairs in Z mass window (81 – 101) GeV

Two signal regions:
- Loose region: MET > 100 GeV
- Tight region: MET > 200 GeV

Dominant bkg from: Z + Jets & ttbar.

Use data-driven bkg estimation:
- MET template to model Z + Jets
- Flavor subtraction to model ttbar bkg.

Predicted MET in Z events from 2 complementary control samples are consistent within uncertainties

Construct MET templates by studying MET in control samples (QCD & photon +Jets)
- Bin in Scalar sum \(p_T\) and njets
- Binning accounts for MET dependence on these two variables
- Form prediction by summing templates corresponding to sum jet \(p_T\) and njet of each

Z event passing pre selection (Verified the prediction using MC)
Opposite sign di-leptons with Z (MET template method)

Use photon + Jets events for the MET template

<table>
<thead>
<tr>
<th></th>
<th>$E^\text{miss}_T &gt; 30$ GeV</th>
<th>$E^\text{miss}_T &gt; 60$ GeV</th>
<th>$E^\text{miss}_T &gt; 100$ GeV</th>
<th>$E^\text{miss}_T &gt; 200$ GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z Pred</td>
<td>2060.3 ± 29.1 ± 309.1</td>
<td>60.8 ± 4.1 ± 9.1</td>
<td>5.1 ± 1.0 ± 0.8</td>
<td>0.09 ± 0.04 ± 0.01</td>
</tr>
<tr>
<td>t\bar{t} Pred</td>
<td>246.6 ± 6.3 ± 22.2</td>
<td>152.5 ± 4.9 ± 13.7</td>
<td>50.6 ± 2.8 ± 4.6</td>
<td>3.2 ± 0.7 ± 0.3</td>
</tr>
<tr>
<td>Prediction</td>
<td>2306.9 ± 29.7 ± 309.9</td>
<td>213.0 ± 6.4 ± 16.5</td>
<td>55.7 ± 3.0 ± 4.6</td>
<td>3.3 ± 0.7 ± 0.3</td>
</tr>
<tr>
<td>Data</td>
<td>2287 (1145,1142)</td>
<td>206 (114,92)</td>
<td>57 (25,32)</td>
<td>4 (1,3)</td>
</tr>
<tr>
<td>UL</td>
<td>498</td>
<td>37</td>
<td>20</td>
<td>5.9</td>
</tr>
</tbody>
</table>

No excess of data over prediction in signal regions ⇒ Upper limit
Inclusive Searches with data driven background predictions

- Same sign di-leptons searches (CMS SUS-11-010)
Same sign dilepton search

- Isolated same sign dileptons (SS) are very rare in the SM
- Several search regions with three lepton flavors (e, µ, τ) are studied
- A natural SUSY signature
- All cross channels are included in three lepton flavors:

![Graphs showing search regions and lepton pair distributions](image)

**CMS Preliminary**

- $L_{int} = 0.98 \text{ fb}^{-1}$
- $p_t(\mu/\tau) > 5/10 \text{ GeV}$
- $p_t(l/\ell) > 20/10 \text{ GeV}$
- $p_t(\mu/\tau) > 5/10/15 \text{ GeV}$
Same sign dilepton search

Major Backgrounds:
- "Fake" leptons from ttbar (b/c → e,μ)
- Charge Mis-reconstruction
- QCD fakes in case of tau final states

- **We use data-driven methods based upon an extrapolation from the analysis selection to a region defined by looser lepton requirements.**
- **Two distinct methods for both electrons and muons**
  - **Method A**
    - Method A1 (applied to inclusive and high-$p_T$ leptons)
    - Method A2 (applied to high-$p_T$ leptons)
  - **Method B** (applied to inclusive leptons)
    - Assumes that single fakes come from b-decays in ttbar events
    - Uses different methods to estimate single and double fakes.

- **For taus:**
  - Loose tau selection relaxes isolation and requirement that the tau pass the hadronic decay mode reconstruction.
SS Background estimation – Method A

Define a “Tight” and a “Loose” lepton selection:
- “Loose” is essentially extrapolation in isolation

Measure “Tight-to-Loose Ratio” a.k.a “Fake Rate” in an unbiased sample

\[ FR = \frac{\text{# evts passing tight}}{\text{# evts passing loose}} \]

Measure this as a function of \( f(p_T, \eta) \).

Apply to \( f(p_T, \eta) \) sample with:
- Two loose to estimate double fake (QCD)
- One tight one loose to estimate single fakes
- Total = Combination of the above two estimates

Methods A1(A2) use different extrapolations.
- A1 uses extrapolation in lepton isolation
- A2 uses extrapolation in ID and Isolation

The systematic uncert. is evaluated based on closure tests and dependence of the TL ratio on the away jet \( p_T \) and the sample composition
SS Background estimation – (Method B)

Measure background from $b/c \to e, \mu$

- Use tag and probe in $b\bar{b}c\bar{c}$ (QCD) events to measure isolation efficiency
- Re-weight this distribution to reflect lepton $p_T$ and $N_{jets}$ in $t\bar{t}b\bar{t}$ expectation
- Use this isolation efficiency to determine background
Electron momentum is measured (mostly) by ECAL
Electron charge is measured (mostly) by tracker

- Charge mis-measurement leaves the momentum unchanged

Same sign Z to ee in data and MC (veto W using MET < 20 and $M_T < 25$ GeV requirements)
Measure the mis-measurement rates in data Or MC [e.g: SS/(OS + SS) Z bosons]

- Mis-Charge Rate $\sim 10^{-4}$ in barrel, and $\sim 10^{-3}$ at $|\eta| \sim 1.5$.
Apply the rate to OS dilepton sample with exact same selections to get a prediction:

Control region: $N(\text{Observed}) = 129, N(\text{Predicted}) = 100 \pm 0.3$, Expect 8 ± 4 from fake electrons
### Results with High-$p_T$ dileptons

<table>
<thead>
<tr>
<th>Search Region (minimum $H_T/E_T^{\text{miss}}$)</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>Total</th>
<th>95% CL UL yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region 1 (400/120)</td>
<td>$0.4 \pm 0.3$</td>
<td>$0.4 \pm 0.3$</td>
<td>$0.7 \pm 0.4$</td>
<td>$1.4 \pm 0.7$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A1)</td>
<td>$0.4 \pm 0.3$</td>
<td>$0.4 \pm 0.3$</td>
<td>$0.7 \pm 0.4$</td>
<td>$1.4 \pm 0.7$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A2)</td>
<td>$0.7 \pm 0.5$</td>
<td>$0.4 \pm 0.3$</td>
<td>$0.4 \pm 0.3$</td>
<td>$1.4 \pm 0.7$</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
<td>$0$</td>
<td>$3.0$</td>
</tr>
<tr>
<td>Region 2 (400/50)</td>
<td>$1.4 \pm 0.8$</td>
<td>$1.3 \pm 0.8$</td>
<td>$1.3 \pm 0.6$</td>
<td>$4.0 \pm 1.7$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A1)</td>
<td>$1.4 \pm 0.8$</td>
<td>$1.3 \pm 0.8$</td>
<td>$1.3 \pm 0.6$</td>
<td>$4.0 \pm 1.7$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A2)</td>
<td>$1.5 \pm 0.8$</td>
<td>$0.8 \pm 0.4$</td>
<td>$1.0 \pm 0.5$</td>
<td>$3.3 \pm 1.2$</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>$1$</td>
<td>$2$</td>
<td>$2$</td>
<td>$5$</td>
<td>$7.5$</td>
</tr>
<tr>
<td>Region 3 (200/120)</td>
<td>$1.2 \pm 0.7$</td>
<td>$1.5 \pm 0.8$</td>
<td>$1.8 \pm 0.8$</td>
<td>$4.5 \pm 1.9$</td>
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<td>Predicted background by (A2)</td>
<td>$1.3 \pm 0.7$</td>
<td>$1.8 \pm 0.8$</td>
<td>$1.8 \pm 0.7$</td>
<td>$4.9 \pm 1.8$</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>$0$</td>
<td>$2$</td>
<td>$1$</td>
<td>$3$</td>
<td>$5.2$</td>
</tr>
<tr>
<td>Region 4 (80/100)</td>
<td>$2.5 \pm 1.2$</td>
<td>$2.6 \pm 1.2$</td>
<td>$4.9 \pm 2.2$</td>
<td>$10 \pm 4$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A1)</td>
<td>$2.5 \pm 1.2$</td>
<td>$2.6 \pm 1.2$</td>
<td>$4.9 \pm 2.2$</td>
<td>$10 \pm 4$</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A2)</td>
<td>$2.4 \pm 1.0$</td>
<td>$3.6 \pm 1.6$</td>
<td>$4.4 \pm 1.6$</td>
<td>$10 \pm 4$</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>$3$</td>
<td>$2$</td>
<td>$2$</td>
<td>$7$</td>
<td>$6.0$</td>
</tr>
</tbody>
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No sign of any new physics anywhere
### Results with inclusive dileptons with $H_T$ trigger

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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted background by (B)</td>
<td>0.2 ± 0.1</td>
<td>0.9 ± 0.3</td>
<td>0.9 ± 0.3</td>
<td>2.0 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>Predicted background by (A1)</td>
<td>0.4 ± 0.4</td>
<td>1.2 ± 0.8</td>
<td>0.7 ± 0.4</td>
<td>2.3 ± 1.2</td>
<td></td>
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<tr>
<td>Observed</td>
<td>0</td>
<td>1</td>
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<td>1</td>
<td>3.7</td>
</tr>
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<td>Region 2 (400/50)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>1.0 ± 0.4</td>
<td>2.3 ± 0.7</td>
<td>3.0 ± 1.0</td>
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<td>Predicted background by (A1)</td>
<td>1.3 ± 0.7</td>
<td>2.5 ± 1.5</td>
<td>1.4 ± 0.7</td>
<td>5.3 ± 2.4</td>
<td>8.9</td>
</tr>
<tr>
<td>Observed</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Region 3 (200/120)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted background by (B)</td>
<td>0.8 ± 0.4</td>
<td>3.6 ± 1.3</td>
<td>3.4 ± 1.3</td>
<td>7.8 ± 2.9</td>
<td></td>
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<td>4</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Include hadronic $\tau$ channels: $e\tau$, $\mu\tau$ and $\tau\tau$

- Backgrounds from QCD jets faking hadronic $\tau$'s
- Use similar tight to loose probability to predict the background

### No sign of any new physics anywhere
Exclusion limits/Interpretation of results
- CMS exclusion reach is well beyond previous Tevatron limits

- **Assuming same squarks and gluino masses**

CMS using 0.98 fb\(^{-1}\) excludes @ 95% CL., \(M_{\text{SUSY}} \approx 825\) GeV
We provide additional information needed for Model Testing

1. Different lepton efficiencies and Jet/MET response parameterizations are provided in order to test specific models

2. Upper limit on \((\sigma \times BR \times Acceptance)\) is provided for all presented analyses

(See details in the references)
Presented new SUSY searches with di-leptons, including opposite and same-sign dileptons

In all cases, dominant backgrounds are estimated from the data itself with minimal reliance on Monte Carlo

Unfortunately using \( \sim 0.98 \text{ fb}^{-1} \) no new physics was found

\[ \Rightarrow \text{We set limits using different SUSY frameworks} \]

CMS experimental exclusions covers a new territory in the \((m_0 \& m_{1/2})\) squark and gluino mass regime

\[ \Rightarrow \text{Extended the limits significantly} \]
Backup Slides
CMS benchmark points

MSUGRA, tanβ = 10, A₀ = 0, μ > 0

m₀ (GeV) vs. m₁/₂ (GeV)

- τ₁ LSP
- Br(τ₂⁻→τ₁ν₁) > 0.15
- mₜ < mₔ
- mₜ = 103 GeV
- mₜ = 114 GeV
- NO EWSB
- m₟ = 122 GeV
- m₟ = 120 GeV
- Br(χ₂⁻→χ₁h₀) > 0.5
- Br(χ₈⁻→χ₄h₀²) > 0.5

Points:
- HM1
- HM2
- HM3
- LM1
- LM2
- LM3
- LM4
- LM6
- LM5
- LM7
- LM9
- Tevatron
Isolated same sign dileptons (SS) are very rare in the SM

Several search regions with three lepton flavors ($e$, $\mu$, $\tau$) are studied

**Region 1** ($ee$, $\mu\mu$, $ee$):
- Leptons $p_T > 20/10$
- $H_T > 400$ MET > 120

**Region 2** ($ee$, $\mu\mu$, $ee$):
- Leptons $p_T > 20/10$
- $H_T > 200$ MET > 120

**Region 3** ($ee$, $\mu\mu$, $ee$):
- Leptons $p_T > 20/10$
- $H_T > 400$ MET > 50

**Region 4** ($ee$, $\mu\mu$, $ee$):
- Leptons $p_T > 20/10$
- $H_T > 80$ MET > 100

**Region 1** ($ee$, $\mu\mu$, $ee$):
- Muons $p_T > 5$, electrons $p_T > 10$
- $H_T > 400$ MET > 120

**Region 2** ($ee$, $\mu\mu$, $ee$):
- Muons $p_T > 5$, electrons $p_T > 10$
- $H_T > 200$ MET > 120

**Region 3** ($ee$, $\mu\mu$, $ee$):
- Muons $p_T > 5$, electrons $p_T > 10$
- $H_T > 400$ MET > 50

**Region 1** ($e\tau$, $\mu\tau$, $\tau\tau$):
- Muons $p_T > 5$, electrons $p_T > 10$, tau $p_T > 15$
- $H_T > 400$ MET > 120
SS Yields -signal regions

CMS preliminary $L_{\text{int}}=0.98\text{ fb}^{-1}, \sqrt{s}=7\text{ TeV}$

Events

- Data
- bkg prompt-fake
- bkg fake-fake
- bkg SS prompt-prompt
- bkg OS prompt-prompt

$H_T>400\ E_T^{miss}>120$
$H_T>400\ E_T^{miss}>50$
$H_T>200\ E_T^{miss}>120$
$\sum H_T>400\ E_T^{miss}>120$
Hadronic triggers (a few examples from recent runs):

<table>
<thead>
<tr>
<th>Path</th>
<th>Rate @ 2.3e32</th>
<th>Rate @ 5e32</th>
<th>Estimate @ 5e32</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT250_MHT60</td>
<td>6.5</td>
<td>14.1</td>
<td>14.0</td>
</tr>
<tr>
<td>HT300_MHT75</td>
<td>1.8</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Meff440</td>
<td>6</td>
<td>13.0</td>
<td></td>
</tr>
<tr>
<td>Meff520</td>
<td>2.8</td>
<td>6.1</td>
<td>9.4*</td>
</tr>
</tbody>
</table>

Leptonic triggers (a few examples from recent runs):

<table>
<thead>
<tr>
<th>Path</th>
<th>Rate @ 2.3e32</th>
<th>Rate @ 5e32</th>
<th>Estimate @ 5e32</th>
</tr>
</thead>
<tbody>
<tr>
<td>DoubleMu6</td>
<td>4.2</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>DoubleMu7</td>
<td>2.2</td>
<td>4.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Ele17_CaloldL_CaloIsoVL_Ele8_CaloldL_CaloIsoVL</td>
<td>3</td>
<td>6.5</td>
<td>11</td>
</tr>
<tr>
<td>Mu17_Ele8_CaloldL</td>
<td>0.8</td>
<td>1.7</td>
<td>2</td>
</tr>
<tr>
<td>Mu8_Ele17_CaloldL</td>
<td>2</td>
<td>4.3</td>
<td>7</td>
</tr>
</tbody>
</table>
Cross triggers (a few examples from recent runs):

<table>
<thead>
<tr>
<th>Path</th>
<th>Rate @ 2.3e32</th>
<th>Rate @ 5e32</th>
<th>Estimate @ 5e32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ele10_CaloldL_CalolisoVL_TrkldVL_TrkIsoVL_HT20</td>
<td>2.6</td>
<td>5.7</td>
<td>~7 Hz</td>
</tr>
<tr>
<td>Ele10_CaloldT_CalolisoVL_TrkldT_TrkIsoVL_HT200</td>
<td>1.1</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Mu5_HT200</td>
<td>5</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>Mu8_HT200</td>
<td>2.5</td>
<td>5.4</td>
<td>5.5</td>
</tr>
<tr>
<td>DoubleMu3_HT160</td>
<td>0.4</td>
<td>0.9</td>
<td>2.0</td>
</tr>
<tr>
<td>DoubleMu3_HT200</td>
<td>0.25</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Mu3_Ele8_CaloldL_TrkldVL_HT160</td>
<td>1.3</td>
<td>2.8</td>
<td>3</td>
</tr>
<tr>
<td>Mu3_Ele8_CaloldLT_TrkldVL_HT160</td>
<td>0.5</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>DoubleEle8_CaloldL_TrkldVL_HT160</td>
<td>1.2</td>
<td>2.6</td>
<td>2</td>
</tr>
<tr>
<td>DoubleEle8_CaloldT_TrkldVL_HT160</td>
<td>0.3</td>
<td>0.7</td>
<td>1</td>
</tr>
</tbody>
</table>
Measurements of jet cross sections and MET resolution

Jets and MET in good shape
Measurements of jet cross sections and MET resolution

Jets and MET in good shape
We decided on 5 T2s to receive the MinBias PDs whenever collisions start. First collisions (probably) happened around 14:30. Announcement that data was coming out of T0 came in hn-cms-datasets at 19:57.

- Beautiful reconstruction of W and Z bosons
- Leptons and MET reconstruction performing well
Consider Higgs mass limits from LEP (without uncert.)

Using Softsusy + Higgsbounds (SLHA interface via SuperIso 3.0): Plots by Sezen Sekmen

Results from hadron colliders (Tevatron, LHC) can probe direct squarks/gluino production to the highest scales in the world.

Major region of phase space is already excluded based on LEP higgs mass limit with this “EXACT” choice of parameters in the model

We use them in order to compare with previous LEP/Tevatron results
Lepton spectrum method

In SM events, the neutrino and lepton $p_T$ are anti-correlated in a given event

⇒ Overall spectra are similar

In SUSY event, the correlation between MET and lepton $p_T$ is very different.

- Main backgrounds: ttbar, W + Jets
- Use the muon $p_T$ spectrum to predict the MET spectrum
- MET resolutions and W polarization effects are accounted for
Lepton spectrum method

- While lepton and neutrino $p_T$ spectra are different in a given event, their spectra are very similar in SM processes.
- Strong physics foundation for method but many details to check before lepton spectrum can be used to quantitatively predict the MET for SM
  - **MET resolution/scale**: Resolution of MET and lepton $p_T$ are quite different and energy scale uncertainty on MET much be taken into account.
  - **W polarization**: Due to V-A effects, W polarization of the W boson, in either Wjets or $t\bar{t}$ can lead to different angular distributions for the lepton and neutrino in the W rest frame. This can produce differences in lepton, neutrino $p_T$ in lab frame.
  - **Non single lepton background**: Lepton spectrum method predicts single lepton events but not $\tau \rightarrow \mu, e$ background and feed down from dilepton $t\bar{t}$ bar events.
  - **Threshold on lepton $p_T$**: Not applied to neutrino.

Have investigated all these points and many more.
Helicity fractions of $W$ bosons from top quark decays at NNLO in QCD

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Jan H. Piclum
Department of Physics, University of Alberta, Edmonton, Alberta T6G 2G7, Canada
(Dated: May 18, 2010)

Decay rates of unpolarized top quarks into longitudinally and transversally polarized $W$ bosons are calculated to second order in the strong coupling constant $\alpha_s$. Including the finite bottom quark mass and electroweak effects, the Standard Model predictions for the $W$ boson helicity fractions are $\mathcal{F}_L = 0.687(5)$, $\mathcal{F}_+ = 0.0017(1)$, and $\mathcal{F}_- = 0.311(5)$.

- Helicity fractions are very precise prediction in SM theory, have been calculated with QCD corrections to NNLO.
- Errors on $F_L$ and $F_-$ are $O(1\%)$; due to $m($top$)$ uncertainty
- Reduces uncertainties due to $W$ polarization in top events to very low level
- The boost is the same for lepton, neutrino
- Lepton, neutrino spectra are result of polarizations
- In $t\bar{t}$bar understand fully where any differences in lepton, neutrino spectrum come from