Searches for Supersymmetry in Final States with Leptons with the CMS Detector at the LHC

Ben Hooberman, on behalf of the CMS Collaboration
• Introduction

• SUSY Searches
  – Single Lepton
  – Same-sign leptons
  – Opposite-sign leptons
    • Generic (non-Z)
    • Z

• Interpretation of Results
Intro to **SUperSYmmetry**

- Standard Model (SM) describes known particles/forces. Extremely successful at low energy, but several problems:
  - hierarchy problem
  - gauge coupling non-unification
  - dark matter (DM): preferred explanation WIMP with mass $O(100 \text{ GeV}) \rightarrow \text{no SM candidate}$

- SUSY: popular extension to SM, introduces “superpartners” to each SM particle
  - Solves many problems intrinsic to SM
  - Lightest SUSY particle (LSP): stable, weakly-interacting particle at EWSB scale $\sim 100 \text{ GeV} \rightarrow \text{natural DM candidate}$
  - Implies DM may be produced at LHC!
SUSY Production at Colliders

• Many SUSY models postulate conserved quantum number:

  “R-parity” = \{ +1 \text{ for SM particles} \\
  -1 \text{ for SUSY particles} \\
  \\
  - SUSY particles produced in pairs (usually strongly produced squarks/gluinos) \\
  - LSP is stable

• Squarks/gluinos decay via cascade, producing jets, (leptons), 2 LSP’s → spectacular events with several high $p_T$ jets + (leptons) + MET

• Strategy: search for excess of events w/ large MET, $H_T$ (sum of jet $p_T$’s)

hadronic jets | leptons

LSP → WIMP

missing transverse energy (MET)
Why Search for New Physics with Leptons?

- **Isolated leptons** are very rare → reduction of huge QCD/strong bkg
  - Clean environment to search for NP
- Leptons provide additional kinematic info related to SUSY particle masses
  - eg. search for kinematic edge in OS dilepton $M(\ell\ell)$ (see talk D. Barge)
The LHC

- 27 km circumference ring on French-Swiss border
- Provides proton-proton collisions at $\sqrt{s} = 7$ Trillion eV (TeV)
- Data collected by 1 of 4 experiments:
  - CMS, ATLAS, LHCb, ALICE
- Total integrated lumi presented in this talk: 0.98 fb$^{-1}$ 2011 data
• Most particles are hadrons → electrons/muons very rare
• Electrons: electromagnetic shower in EM calorimeter → deposit full energy
• Muons: minimum ionizing → penetrate deeply into muon system
Overview of SUSY searches

- Perform broad program of searches in several final states
  - This talk: overview of newest results, followed by more detailed talks
- Maintain sensitivity to broad range of models $\rightarrow$ signature-based searches, not optimized for any particular SUSY model
- Estimate backgrounds from data (data-driven bkg estimate) $\rightarrow$ minimize reliance on MC simulation (especially for bkg’s with detector (mis)reconstruction effects, estimation of “tails” of kinematic distributions)

<table>
<thead>
<tr>
<th>channel</th>
<th>Signature</th>
<th>DPF talks</th>
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<tbody>
<tr>
<td>all-hadronic</td>
<td>jets + MET</td>
<td>S. Paramesvaran</td>
</tr>
<tr>
<td>single lepton</td>
<td>e/$\mu$ + jets + MET</td>
<td></td>
</tr>
<tr>
<td>lepton-photon</td>
<td>e/$\mu$ + $\gamma$ + MET</td>
<td></td>
</tr>
<tr>
<td>di-lepton</td>
<td>same-sign leptons + jets + MET</td>
<td>M. Weinberg</td>
</tr>
<tr>
<td></td>
<td>opposite-sign leptons + jets + MET</td>
<td>D. Barge</td>
</tr>
<tr>
<td></td>
<td>$Z +$ jets + MET</td>
<td>D. Barge</td>
</tr>
<tr>
<td>multi-lepton</td>
<td>$\geq$3 leptons</td>
<td>S. Maruyama</td>
</tr>
<tr>
<td>photon(s)</td>
<td>$\gamma / \gamma\gamma +$ jets + MET</td>
<td>D. Nguyen</td>
</tr>
</tbody>
</table>
Outline

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    – Opposite-sign leptons
      • Generic (non-Z)
      • Z
• Interpretation of Results
Intro: Single Lepton Search

- **Signature:** e/µ + ≥4 jets + MET
  - Dominant bkgs: tt → lepton+jets, W+jets

- **Event preselection**
  - exactly 1 isolated e (p_T > 20 GeV, |η| < 2.4) or µ (p_T > 15 GeV, |η| < 2.1)
  - ≥4 jets (p_T > 30 GeV, |η| < 2.4)
  - MET > 25 GeV (moderate requirement)

**Example signal:**
SUSY with χ^± decay

Single Lepton Search Results

- Define signal region: MET > 250 GeV
- Predict bkg with data-driven technique: for dominant bkgss, tt, W+jets, $p_T(l)$ and $p_T(v)$ ∼ MET distributions related
  - Use $p_T(l)$ to model MET → predict bkg yield in signal region
  - Good agreement observation vs. prediction → no evidence for SUSY

<table>
<thead>
<tr>
<th></th>
<th>μ-channel</th>
<th>e-channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>observed signal region</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>total prediction</td>
<td>$1.8 \pm 1.1$ (stat) ± 0.8 (syst)</td>
<td>$1.4 \pm 0.9$ (stat) ± 0.5 (syst)</td>
</tr>
</tbody>
</table>

Set 95% CL upper limit on non-SM yield: 3.8 events
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Intro: Same-Sign Dilepton Search

- SS lepton pairs extremely rare in SM, but appear naturally in many BSM scenarios
  - SUSY, universal extra dimensions, SS top pair production, heavy Majorana neutrinos

- Dominant SM backgrounds:
  - $tt$ with “fake” leptons (eg. $b/c \rightarrow e/\mu$)
  - Charge misreconstruction
  - Rare SM processes: $qq \rightarrow q'q'W^{\pm}W^{\pm}$, $ttW$

NEW! CMS PAS-SUS-11-010 0.98 fb$^{-1}$

Example signal:
SUSY with 2 $\chi^{\pm}$ decays

Dominant background:
$tt$ with fake lepton

2 isolated leptons: $\frac{1}{2}$ SS, $\frac{1}{2}$ OS

Isolated lepton

Non-isolated lepton = “fake” lepton
Search Regions

• Search for new physics in 3 complementary samples
  – High $p_T$ dileptons: will focus on this sample, for others see talk by M. Weinberg
  – Inclusive leptons: extend search to low lepton $p_T$ → compensate trigger rate by increasing $H_T$ cut
  – $\tau \rightarrow$ hadrons: improve sensitivity to 3$^{rd}$ generation

• Define preselection regions in MET-$H_T$ plane (veto shaded regions)
  – Validate data-driven bkg estimates with ~10-100 events

• Define 4 search regions by adding MET, $H_T$ requirements → estimate bkg’s with data-driven techniques + MC estimates
Results of SS Search

- All 4 signal regions: good agreement between observed yields and predicted background
- No evidence for SUSY → set 95% CL upper limits on non-SM yield
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Sources of OS Dileptons in SUSY

neutralino decays

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

Z production in cascade decays

\[ \tilde{g} \rightarrow q \tilde{q} \chi_2^0 \rightarrow \chi_1^0 \ell^+ \ell^- \]

Perform separate OS SUSY searches outside vs. inside Z mass region
Intro: OS Non-Z Search

- **Signature:** OS leptons + ≥2 jets + MET
  - Dominant background: $t\bar{t} \rightarrow$ dilepton
- **Perform preselection to reject non-$t\bar{t}$ bkgs:**
  - ≥2 isolated leptons: (e or $\mu$) $p_T > (20,10)$ GeV
  - Reject same-flavor pairs consistent with Z mass
  - ≥2 jets ($p_T > 30$ GeV, $|\eta| < 3.0$), $H_T > 100$ GeV, MET > 50 GeV
- **Preselection region results**
  - Background is >90% $t\bar{t}$ (from MC)
  - Reasonable data/MC agreement in yields, kinematic distributions

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\sigma$ [pb]</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t} \rightarrow \ell^+\ell^-$</td>
<td>17</td>
<td>412.8 ± 8.9</td>
<td>465.4 ± 9.0</td>
<td>1095.6 ± 14.2</td>
<td>1973.8 ± 19.0</td>
</tr>
<tr>
<td>$t\bar{t} \rightarrow$ fake</td>
<td>141</td>
<td>12.6 ± 1.6</td>
<td>3.7 ± 0.8</td>
<td>22.7 ± 2.0</td>
<td>390 ± 2.7</td>
</tr>
<tr>
<td>$DY \rightarrow \ell^+\ell^-$</td>
<td>16677</td>
<td>18.6 ± 5.0</td>
<td>26.6 ± 6.0</td>
<td>37.6 ± 7.1</td>
<td>82.8 ± 10.6</td>
</tr>
<tr>
<td>$W^+W^-$</td>
<td>43</td>
<td>4.0 ± 0.5</td>
<td>4.3 ± 0.4</td>
<td>9.5 ± 0.7</td>
<td>17.7 ± 0.9</td>
</tr>
<tr>
<td>$W^\pm Z^0$</td>
<td>18</td>
<td>0.8 ± 0.1</td>
<td>1.0 ± 0.1</td>
<td>1.9 ± 0.1</td>
<td>3.8 ± 0.2</td>
</tr>
<tr>
<td>$Z^0Z^0$</td>
<td>5.9</td>
<td>0.3 ± 0.0</td>
<td>0.4 ± 0.0</td>
<td>0.4 ± 0.0</td>
<td>1.2 ± 0.1</td>
</tr>
<tr>
<td>single top</td>
<td>102</td>
<td>12.6 ± 0.6</td>
<td>14.0 ± 0.6</td>
<td>33.2 ± 1.0</td>
<td>59.9 ± 1.3</td>
</tr>
<tr>
<td>$W$ + jets</td>
<td>96648</td>
<td>12.6 ± 5.4</td>
<td>0.0 ± 0.0</td>
<td>7.8 ± 4.6</td>
<td>20.5 ± 7.1</td>
</tr>
<tr>
<td><strong>total SM MC</strong></td>
<td></td>
<td>474.5 ± 11.7</td>
<td>515.4 ± 10.8</td>
<td>1208.6 ± 16.7</td>
<td>2198.5 ± 23.1</td>
</tr>
<tr>
<td><strong>data</strong></td>
<td></td>
<td>524</td>
<td>576</td>
<td>1381</td>
<td>2481</td>
</tr>
</tbody>
</table>
OS Dilepton Results

- Define 2 signal regions:
  - High $E_{T}^{\text{miss}}$ signal region: MET > 275 GeV, $H_{T} > 300$ GeV
  - High $H_{T}$ signal region: MET > 200 GeV, $H_{T} > 600$ GeV

<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 ± 2.2</td>
<td>7.1 ± 2.2</td>
</tr>
<tr>
<td>ABCD' prediction</td>
<td>4.0 ± 1.0 (stat) ± 0.8 (syst)</td>
<td>4.5 ± 1.6 (stat) ± 0.9 (syst)</td>
</tr>
<tr>
<td>$p_{T}(\ell\ell)$ prediction</td>
<td>14.3 ± 6.3 (stat) ± 5.3 (syst)</td>
<td>10.1 ± 4.2 (stat) ± 3.5 (syst)</td>
</tr>
<tr>
<td>$N_{bkg}$</td>
<td>4.2 ± 1.3</td>
<td>5.1 ± 1.7</td>
</tr>
<tr>
<td>non-SM yield UL</td>
<td>10</td>
<td>5.3</td>
</tr>
</tbody>
</table>

- Estimate bkg in signal regions with 2 data-driven techniques → consistent predictions
  - ABCD’: variant of ABCD method using 2 weakly-correlated variables: $y \equiv MET/\sqrt{H_{T}}$ and $H_{T}$
  - $p_{T}(\ell\ell)$: use $p_{T}(\ell\ell)$ to model $p_{T}(\nu\nu) \sim MET$
  - $N_{bkg}$: error-weighted average of 2 predictions

- Observed yields consistent with MC, data-driven bkg estimates → no evidence for SUSY

- Extract 95% CL upper limits on non-SM yields
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• Interpretation of Results
Introduction: Z+MET Search

- **Signature:** $Z \rightarrow ee/\mu\mu + \geq 2 \text{ jets} + \text{large MET}
- **Dominant backgrounds:**
  - fake MET: $Z+$jets (fake MET from jet mismeasurements)
  - real MET: $tt$ (dominant), $DY \rightarrow \tau^+\tau^-, W^+W^-$
- **Event preselection**
  - $2$ isolated electrons/muons ($p_T > 20$ GeV, $|\eta| < 2.5$)
  - $\geq 2$ jets from strong production ($p_T > 30$ GeV, $|\eta| < 3.0$)

NEW! CMS PAS-SUS-11-017 0.98 fb$^{-1}$

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August 9th, 2011

DPF2011
Results of Z+MET Search

- Compare observed MET distribution with sum of 2 data-driven predictions:
  - **fake MET**: Z+jets MET predicted from γ+jets control sample
  - **real MET**: tt/DY→τ+τ⁻/W⁺W⁻ MET predicted from eμ events

- Define 2 signal regions:
  - **(loose)**
  - **(tight)**

- Total (ee, μμ)

- Good agreement between observed, predicted yields → **no evidence for SUSY**

- Set 95% CL upper limits on non-SM yields

---

**Define 2 signal regions:**

<table>
<thead>
<tr>
<th></th>
<th>(loose)</th>
<th>(tight)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(E_T^{\text{miss}} &gt; 100 \text{ GeV})</td>
<td>(E_T^{\text{miss}} &gt; 200 \text{ GeV})</td>
</tr>
<tr>
<td>Z Pred</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>50.6 ± 2.8 ± 4.6</td>
<td>3.2 ± 0.7 ± 0.3</td>
</tr>
<tr>
<td>Prediction</td>
<td>55.7 ± 3.0 ± 4.6</td>
<td>3.3 ± 0.7 ± 0.3</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>57 (25,32)</td>
<td>4 (1,3)</td>
</tr>
<tr>
<td><strong>UL</strong></td>
<td>20</td>
<td>5.9</td>
</tr>
</tbody>
</table>
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• Interpretation of Results
Step 1) **Model-Independent** Yield Upper Limits

<table>
<thead>
<tr>
<th>Channel</th>
<th>Lumi</th>
<th>Signal Region</th>
<th>Non-SM Yield UL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single lepton</td>
<td>36 pb⁻¹</td>
<td>MET &gt; 250 GeV, ( H_T &gt; 500 ) GeV</td>
<td>3.8 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 120 GeV, ( H_T &gt; 400 ) GeV</td>
<td>3.0 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 50 GeV, ( H_T &gt; 400 ) GeV</td>
<td>7.5 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 120 GeV, ( H_T &gt; 200 ) GeV</td>
<td>5.2 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 100 GeV, ( H_T &gt; 80 ) GeV</td>
<td>6.0 events</td>
</tr>
<tr>
<td>Same-sign leptons</td>
<td>0.98 fb⁻¹</td>
<td>MET &gt; 275 GeV, ( H_T &gt; 300 ) GeV</td>
<td>10 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 200 GeV, ( H_T &gt; 600 ) GeV</td>
<td>5.3 events</td>
</tr>
<tr>
<td>Opposite-sign leptons</td>
<td>0.98 fb⁻¹</td>
<td>MET &gt; 100 GeV</td>
<td>20 events</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MET &gt; 200 GeV</td>
<td>5.9 events</td>
</tr>
</tbody>
</table>

- Extract 95% CL upper limits on non-SM yields for each channel, in various kinematic regions
- **Any new physics model which predicts a yield in excess of one of these upper limits is excluded**
Step 2) Detector Efficiencies

- **SS lepton selection**
  - lepton efficiency
  - $H_T$ efficiency
  - MET efficiency

- **Efficiency vs. Generator-Level Quantities**
  - plateau efficiency $\approx 100\%$

- **Efficiency**
  - mid-points match reco cut

- **Efficiency** vs.
  - generator lepton $p_T$ (GeV)
  - generator $H_T$ (GeV)
  - generator MET (GeV)

- **Provide information on detector selection efficiencies vs. generator-level quantities** → allows to estimate selection efficiency for arbitrary new physics model

- **Use efficiency to estimate signal region yield** → compare with quoted upper limits to determine if excluded
Step 3) CMSSM Exclusion

Constrained Minimal SUSY extension to the SM: simplified SUSY model with 5 parameters:

$m_{1/2} (m_0)$: mass of spin $\frac{1}{2}$ (0) particles at GUT scale
$tan\beta$: ratio of 2 Higgs VEV’s
$\mu$: Higgsino mass parameter
$A_0$: trilinear coupling

- Example of interpretation in specific new physics scenario → exclusion in CMSSM parameter space
  - Allows comparison of sensitivity with other analyses, experiments
- CMS results extend well beyond previous Tevatron/LEP exclusions

CMS Preliminary: $\sqrt{s} = 7$ TeV, $\int L dt = 1$ fb$^{-1}$

- 2011 Limits
- 2010 Limits
- $tan\beta = 10, A_0 = 0, \mu > 0$
- $C_{DF} g, \tilde{q}, tan\beta = 5, \mu < 0$
- $D0 g, \tilde{q}, tan\beta = 3, \mu < 0$
- $LEP2 \tilde{\chi}^+_1$
- $LEP2 \tilde{\chi}^-$

2011 Limits
- $LEP2 \tilde{\chi}^+_1$
- $LEP2 \tilde{\chi}^-$
- $SS Dilepton$
- $OS Dilepton$

(this talk)
Summary

• Performed broad program of SUSY searches in various final states with leptons
  – Signature based searches → not optimized for particular SUSY scenario
  – Backgrounds determined with data-driven methods
• No evidence for new physics observed in 1 fb$^{-1}$…
  – Extracted upper limits on non-SM yields in various channels, kinematic regions
  – Provided information to allow testing if specific new physics models are excluded by our results
  – Performed CMSSM exclusion
**p_T(\ell\ell) Method Results**

### p_T(\ell\ell) Method Results

**Predicted yields consistent with MC, observed yields**

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</table>
Intro to Single Lepton Search

• Signature: $e/\mu + \geq 4$ jets + MET
  – Dominant bkg: $tt \rightarrow$ lepton + jets
• Strategy
  – Define preselection $\rightarrow$ compare data/MC yields/kinematic distributions
  – Define signal regions by adding requirements of large $H_T = \text{sum of jet } p_T$’s, large MET
  – Cut-and-count in signal regions: compare yield to 2 data-driven bkg estimates
    • ABCD and lepton $p_T$ methods
  – No excess observed $\rightarrow$ set upper limits on SUSY

August 9th, 2011 DPF2011
ABCD Background Estimate

- Exploit 2 weakly correlated variables: \( Y_{\text{MET}} = \frac{\text{MET}}{\sqrt{H_T}} \) and \( H_T \)
- Define signal region (D): \( H_T > 650 \text{ GeV}, Y_{\text{MET}} > 5.5 \text{ GeV}^{1/2} \)
- Predicted background in signal region D: \( N_D = N_C \times N_B / N_A \)

No evidence of excess beyond MC and data-driven bkg estimates

<table>
<thead>
<tr>
<th></th>
<th>(\mu)-channel</th>
<th>e-channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>data</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>MC prediction</td>
<td>(3.4 \pm 0.2)</td>
<td>(2.9 \pm 0.2)</td>
</tr>
<tr>
<td>ABCD prediction</td>
<td>(1.7 \pm 0.9) (stat) (\pm 0.3) (syst)</td>
<td>(1.5 \pm 0.8) (stat) (\pm 0.3) (syst)</td>
</tr>
</tbody>
</table>
The ABCD’ Method

- Exploits 2 weakly-correlated kinematic variables
  - \( y \equiv \text{MET}/\sqrt{(H_T)} \) and \( H_T \)
  - ABCD method: predict bkg in \((y,H_T)\) region \( D: N_D = N_A \times N_C / N_B \)
  - Searches in \((\text{MET},H_T)\) region more sensitive: ABCD can’t predict bkg
- Predict bkg in \((\text{MET}, H_T)\) region using variant of ABCD method \(\rightarrow\) ABCD’ method
  - **Measure in data** the \( f(y), g(H_T) \) distributions in control regions dominated by bkg
  - Predict yield in signal region using:
    \[
    \frac{\partial^2 N}{\partial y \partial H_T} = f(y)g(H_T)
    \]
- Method validated using toy MC studies with event sizes corresponding to \( \sim 1 \text{ fb}^{-1} \)
OS Search Results Results

- Observed yields consistent with MC, ABCD’ prediction
- Extract 95% CL upper limits on non-SM yields

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<td>non-SM yield UL</td>
<td>10</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Interpretation of Results

• Challenge: present results which can be applied to a broad class of models
  – Allow testing whether specific models are excluded

• Strategy:
  – Present model-independent yield upper limits
  – Give quantitative information on detector response/efficiencies → allows to estimate efficiency for a specific model → estimate yield in signal region and compare to UL to determine if excluded
  – As an example of interpretation in specific model, quote limits in context of CMSSM
    • Constrained minimal supersymmetric extension of the SM → simplified SUSY model with 5 free parameters
Background Estimates

**Signal sample: Z+jets**

- FAKE MET: (Z+jets)
  - MET dominated by jet mismeasurements → model using control
    samples with similar topology, and no real MET: γ + jets
  - MET templates method: for each Z event, model MET using γ + jets
    events with same jet multiplicity and $H_T$
  - Cross-check with QCD control sample → consistent predictions

**Control sample: γ+jets**

- REAL MET: (tt (dominant), DY → $\tau^+\tau^-$, $W^+W^-$)
  - These backgrounds have uncorrelated lepton flavors → same-flavor
    (ee+$\mu\mu$) yield = opposite-flavor (e$\mu$) yield
  - OF prediction: predict yield in same-flavor final state using e$\mu$ yield,
    corrected for (small) difference e vs. $\mu$ selection efficiency
Data-Driven Background Estimates

- Backgrounds from detector (mis)reconstruction events not necessarily well-modeled in MC → use data-driven methods
- **Fake leptons**
  - “Fake rate” method: define 2 lepton selections:
    - tight (same as analysis selection)
    - loose (relax ID and/or iso requirements)
  - Measure “fake rate” \( FR = \frac{\text{#tight leptons}}{\text{#loose leptons}} \) in independent data control sample
    - Measure vs. \( p_T, \eta \rightarrow FR(p_T, \eta) \sim 10\text{-}40\% \)
  - In signal sample, count events with leptons passing loose lepton selection, weight events by \( FR/(1-FR) \ → \text{sum of weights is data-driven prediction} \)
- **Charge misreconstruction**
  - Estimate electron mis-charge rate using same-sign Z sample (negligible muon mischarge rate)
  - Mischarge rate = \( \frac{N(SS)}{N(SS)+N(OS)} \) = \( \sim 10^{-4} \) (barrel), increasing to \( \sim 10^{-3} \) for \( |\eta| \sim 1.5 \)
Why Search for New Physics with Leptons?

- **Isolated leptons** are very rare → reduction of huge QCD background
  - Provides clean environment to search for new physics
- Leptons provide additional kinematic info related to SUSY particle masses
  - eg. search for kinematic edge in OS dilepton $M(\ell\ell)$ (see talk D. Barge)

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• Many SUSY models postulate conserved quantum number:
  
  “R-parity” = \{ +1 \text{ for SM particles} \\
  -1 \text{ for SUSY particles} 
  \}

  – SUSY particles (heavy, colored squarks/gluinos) produced in pairs
  – LSP is stable

• Squarks/gluinos decay via cascade, producing jets, (leptons), MET \rightarrow \text{spectacular events with several high } p_T \text{ jets + (leptons) + MET}

• **Strategy:** search for excess of events w/ large MET, \( H_T \) (sum of jet \( p_T \)'s)

\[ \begin{align*}
\text{hadronic jets} & \quad \text{leptons} \\
q & \quad q & \quad q & \quad \tilde{q} & \quad \tilde{g} & \quad \tilde{q} & \quad \tilde{q} & \quad \tilde{\chi}_2^0 & \quad \tilde{\chi}_1^0 & \quad \tilde{\chi}_1^0 \\
p & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow & \quad \rightarrow \\
\text{LSP} & \quad \rightarrow & \quad \text{WIMP} \\
\end{align*} \]
Random Stuff

The Bullet Cluster

dark matter
(gravitational lensing)
luminous matter
(Chandra X-ray)