Early LHC data preparations for SUSY searches at CMS

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Introduction

- 7 TeV data of ~100 pb\(^{-1}\) should provide sensitivity to SUSY parameter space well beyond the current limits set by TEVATRON
- The sensitivity reach strongly depends on how well we understand the SM backgrounds
Introduction

- Strategies to suppress and measure SM backgrounds are studied in detail using MC in the past years

- 7 TeV data used (11-65 nb$^{-1}$) for testing some of these methods in the available phase-space (not yet where we expect SUSY signal)

- QCD is not expected to be dominant background for most of the search topologies, but poorly known (large!) cross sections, need to be measured from data:
  - Suppressing QCD using topological observables
  - Predicting QCD contributions to Missing $E_T$ (MET)
  - data-driven techniques to measure QCD background for lepton(s) + Jets +MET signatures

Material used in this presentation is documented in SUS-10-001, and see JME-10-004 for detailed MET studies for SUSY searches, see Slide 18 for full references
Suppressing QCD with $\alpha_T$

- A powerful variable for suppressing mis-measured QCD

$$\alpha_T \equiv \frac{p_T^2}{M_T} \quad \alpha_T = \frac{\sqrt{p_T^2 / p_T^1}}{\sqrt{2(1 - \cos \Delta \phi)}}$$

- Well measured back-to-back di-jet system $\alpha_T \approx 0.5$, if one jet is mis-measured $\alpha_T < 0.5$

$\sqrt{s} = 10 \text{ TeV}$ MC

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CMS preliminary 2010

- 2 Jets $H_T [80,120]$  
- 2 Jets $H_T > 120$ GeV  

Study fraction of events with $\alpha_T > 0.55$
H_{T} dependence of $\langle T \rangle$

- Rejection power of $\langle T \rangle$ is expected to get better with increasing H_{T}
- Examine this assumption in the available H_{T} range:

  - Expected decrease (approx. exponential) with H_{T} is observed for both 2-jet and ≥3-jets
  - Better performance with increasing H_{T} holds also for:
    - In $\gamma$+jet(s) events where photon is treated as a jet
    - Emulating extreme jet losses
    - Smearing jet energies
  - Extended also for leptonic search channels (not shown here)
Having verified $\alpha_T$ behavior with $H_T$, one can use data at lower $H_T$ to estimate SM background at high $H_T$ by exploiting its expected uniformity versus $\sqrt{s} = 10$ TeV MC.

The method was studied with 10 TeV MC.

Fraction of events with $\alpha_T > 0.55$ as a function of the leading jet.

- Flat behavior across $|n_l|$, even when a jet is removed.

SUSY + SM
Suppressing QCD with $\Delta\phi^*$

- A complementary observable, $\Delta\phi^*$, to diagnose background events where one jet mis-measured.
- Test each jet to see if it is responsible for the MHT (vectorial sum of the jet $p_T$)

$$\Delta\phi^* \equiv \min_{\text{jets } k} \left( |\Delta\phi(\bar{p}_k, - \sum_{\text{jets } i \neq k} \bar{p}_i)| \right)$$

- Expect small $\Delta\phi^*$ for QCD
- More uniform for real MET (emulated by removing one jet)

Data confirms the expected behavior in both di- and multi-jets

Resolution improves with $H_T$
Tracker (MPT) vs Calorimeter (MHT)

- Independent measurement of missing momentum from Tracker & Calorimeter

\[ MHT = \left| - \sum_i \vec{p}_T(jet_i) \right| \]

\[ MPT \equiv \left| - \sum_i \vec{p}_T(track_i) \right| \]

- Compare the direction of MPT and MHT, \( \Delta \phi(MPT, MHT) \)

✓ Very little correlation between the directions of MPT and MHT when no real MHT is present (QCD)

✓ peaks towards zero for real MHT (emulated by removing a random jet)

✓ Also useful to remove events with a fake MHT due to noise in the calorimeter
Predicting high MET tail

- MET background to lepton+jets+MET signatures from real MET (e.g. in W/Z) and MET due to mis-measurements
- Test the method for the latter
- Use MET templates from multi-jet events to predict MET for γ+jets events

Good agreement between predicted and observed distributions:

- for MET > 15 GeV
  - predicted = 12.5
  - observed = 11
Predicting MET tail in $\gamma\gamma$ search

- $\gamma\gamma + MET$ is one of the early search channels
  - Physics backgrounds $W\gamma/Z\gamma$
  - $W\gamma$, electron mis-id as $\gamma$
  - multi-jet (direct $\gamma\gamma$) + fake MET (dominant)

**Prediction:**
- Measure MET distribution in a control sample with 2 fake photons, selected by inverting Isolation requirement
- Use number of selected events at $MET < 10$ GeV to normalize the measured templates.

✓ Prediction consistent with number of observed events,
For $MET > 20$ GeV:
  - Predicted = $4.2 \pm 1.5$
  - Observed = 4 events
QCD background for e+Jets+MET

- QCD contributes to e + Jets+ MET signature
  - heavy-flavor decays and jets mis-identified as electron
  - electrons due to photon conversion
- Select control samples dominated by each of above sources by inverting selection cuts perform fit using Relative Isolation distributions
- Isolation template for $W \rightarrow e\nu$ contribution from MC

![Graph showing Relative Isolation distributions for CMS preliminary data with MET < 20 GeV.](image1)

\[ \text{RelIso} = \frac{\sum (p_T^\text{Calo+Trk})_{R<0.3}}{p_T(e)} \]

- (RelIso<0.3) Predicted: 224 ± 13
  - Observed: 263

- (RelIso<0.3) Predicted: 215 ± 13
  - Observed: 215

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QCD background for $\ell^+{\text{Jets}}+\text{MET}$

- QCD contributes to $\ell^+{\text{Jets}}+\text{MET}$ signature:
  - mainly due to heavy-flavor decays to muons
  - A fit procedure for Relative Isolation to predict bckgrd from non-prompt muons

Good agreement between Predicted and Observed event yield in the signal region

- MET > 20 GeV
  - Prompt: $251.2 \pm 17.9$, Observed: 248
  - Bckgrd: $66.2 \pm 11.3$, Observed: 72

- MET < 20 GeV
  - $\chi^2/\text{ndf} = 1.3$
  - $H_T > 20$ GeV
ttBar is the dominant background for Same-Sign (SS) di-\(\mu\) signature: one from W and the other from b-decays

- Isolation is the main handle
- Tag&Probe method to measure isolation distribution of muons coming from heavy flavor decays

![Graphs showing relative isolation for different jet multiplicities](image)

- Strong dependency on the event topology, e.g. jet multiplicity
- Significant differences in jet multiplicity and $p_T(\mu)$ in $t\bar{t}$Bar and generic QCD
- Re-weighting procedure to take this difference into account

✓ The agreement between QCD MC (data-driven) and $t\bar{t}$Bar MC (matching to the generator level) demonstrates the principle of the method
✓ Data agrees qualitatively with $t\bar{t}$Bar MC, for a quantitative prediction more data is necessary
QCD background for SS di-μ

- QCD is expected to be the subdominant background for SS di-μ signature
- Exploit the fact that some selection cuts are uncorrelated \( \Rightarrow \) selection efficiency for each cut can be measured in control samples

\[
\begin{align*}
\varepsilon_{\text{IsoCut}(\mathcal{J}_1)} & : \text{Isolation of } \mathcal{J}_1, \ \varepsilon_{\text{iso}1} \\
\varepsilon_{\text{IsoCut}(\mathcal{J}_2)} & : \text{Isolation of } \mathcal{J}_2, \ \varepsilon_{\text{iso}2} \\
\varepsilon_{\text{METCut}} & : \text{third jet and MET, } \varepsilon_{\text{MET}} \\
\varepsilon_{\text{AllCuts}} & = \varepsilon_{\text{iso}1} \cdot \varepsilon_{\text{iso}2} \cdot \varepsilon_{\text{MET}} \\
\end{align*}
\]

- test the factorization of cuts
  \( \text{IsoCut}(\mathcal{J}_1) \ \text{and} \ \text{IsoCut}(\mathcal{J}_2) \), no jet & MET requirement yet

\( \checkmark \) data indicates isolation of the \( \mathcal{J}_1 \) and \( \mathcal{J}_2 \) can be factorized
SM background for SS di-lepton

- Data driven method for estimating SM background for SS $ee$, $e\mu$, and $\mu\mu$ channels
- Use a control sample (loose lepton-id & isolation) to measure efficiency of passing all analysis cuts, ("TL ratio"), as a function of lepton kinematics.

Monitor measured Tight-to-Loose-Ratios using different jet-triggered samples.

Predictions obtained using HLT_Jet15U

<table>
<thead>
<tr>
<th>Channel</th>
<th>Predicted</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ee$</td>
<td>$0.43^{+0.18}_{-0.14}$</td>
<td>0</td>
</tr>
<tr>
<td>$e\mu$</td>
<td>$0.14^{+0.18}_{-0.09}$</td>
<td>1</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>$0.22^{+0.51}_{-0.18}$</td>
<td>0</td>
</tr>
</tbody>
</table>

- Measured TL ratio is stable within 50%
- Predicted & observed number of SS di-lepton events consistent
✓ Understanding of the SM background is the first step towards BSM searches

✓ Dedicated methods to suppress the backgrounds and data-driven techniques to measure them from data are in place

✓ The data collected by CMS at 7 TeV allowed us to test some of these methods; data confirms the performance of the methods obtained with MC

✓ LHC performs very well; as of today four times more (~300 nb⁻¹) data than what is presented here is available

✓ Stay tuned for updates, we are at the beginning of an exciting journey
References

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

1. “Performance of Methods for Data-Driven Background Estimation in SUSY Searches”, CMS Physics Analysis Summary: SUS-10-001

2. “CMS MET Performance in Jet Events from pp Collisions at sqrt s= 7 TeV”, JME-10-004.

3. “The CMS physics reach for searches at 7 TeV “, CMS-NOTE-2010-008

4. “SUSY searches with dijet events”, CMS Physics Analysis Summary: SUS-08-005

5. “Search strategy for exclusive multi-jet events from supersymmetry at CMS”, CMS Physics Analysis Summary: SUS-09-001

6. “Data-Driven Background Estimates for SUSY Di-Photon Searches”, CMS Physics Analysis Summary: SUS-09-004