Search for New Physics in the Low MET Monophoton Channel with the CMS Detector

Toyoko Orimoto, Northeastern University

APS DPF Conference
5 August 2015
Monophotons: A Powerful Tool for Constraining BSM

- Low $E_T$ monophoton ($\gamma + \text{MET}$) search can constrain:
  - **Dark Matter**: At LHC, DM ($\chi$) can be pair produced via $q\bar{q} \rightarrow \gamma \chi \chi$; Traditional search is in high energy regime
  - **SM $H \rightarrow Z(\rightarrow \nu\nu)\gamma$**: Both $H \rightarrow \gamma\gamma$ & $H \rightarrow Z\gamma$ are only possible through loops, making them sensitive to new physics
    - Low sensitivity with Run I data due to small rate and challenging background
  - **Exotic Higgs Decays**: In framework of supersymmetry
Exotic Higgs Decays to Low \( E_T \) Monophoton

- Low-scale (~TeV) SUSY breaking provides possibility for exotic Higgs decays into monophoton channel

**SM Higgs boson (125 GeV) produced via gluon fusion**

**Neutralino NLSP decays promptly into photon + gravitino LSP**

- Higgs decays to neutralino NLSP + gravitino LSP
- For neutralino mass \( m_\chi < m_h/2 \), Higgs favors decay into 2 neutralinos (\( \gamma\gamma+\text{MET} \))
Backgrounds Estimated with Combo of Data-Driven and MC

**Irreducible**
- $Z(\rightarrow \nu\nu)\gamma$

**Partially Reducible**
- $W(\rightarrow l\nu)\gamma$

**Mis-identified Photons**
- Jets faking photons*
  - QCD
  - $Z+$jets
  - $W+$jets
- Electrons faking photons*
  - $W\rightarrow e\nu$

**Fake MET**
- $\gamma+$jets

**Non-Collision**
- Beam Halo*
- Anomalous signals*
## Discriminating Event Selection

### Photon Selection
- Barrel only, $E_T > 45$ GeV
- Photon ID: 85% eff
- Pixel seed veto
- $R_9 > 0.9$

### Trigger
- Central photon with $E_T > 30$ GeV & MET > 25 GeV
- Loose calo-based photon ID and shower shape
- 7.3 fb$^{-1}$ integrated lumi

### Lepton Veto
- Electrons & Muons:
  - Pass Loose ID
  - $p_T > 10$ GeV
  - $\Delta R > 0.3$ separated from $\gamma$

### MET Selection
- PFlow MET > 40 GeV

### Anomalous Signal Rejection
- $R_9 < 1$; $\sigma_{\eta\eta} > 0.001$; $\sigma_{\phi\phi} > 0.001$; Swiss cross > 0.9

---

Toyoko Orimoto, Northeastern
Optimized MET Cuts for Model-Specific Selection

Jet Selection
• PF jets with anti-\(k_T\) 0.5
• \(p_T > 30\) GeV & \(|\eta| < 2.4\)
• Separated from \(\gamma\) \(\Delta R > 0.5\)
• ID based on trajectory of tracks, topology of jet shape, multiplicity of objects used to separate PU jets

Model-Independent Selection
• Reject events with \(\geq 2\) jets
• \(\Delta \phi(\gamma, \text{jet}) < 2.5\)

SUSY Analysis
• Min MET > 45 GeV, Prob (\(\chi^2\)) < 10\(^{-3}\), MET Sig > 20
• \(M_T > 100\) GeV
\[
M_T = \sqrt{2p_T^\gamma E_T (1 - \cos \Delta \phi(\gamma, E_T))}
\]
• Scalar sum of \(p_T\) of jets \(H_T < 100\) GeV
• Angle between beam direction and major axis of cluster: \(\alpha > 1.2\)
• Photon E\(_T\) < 60 GeV
Data-Driven Estimates of Mis-Identified Photons

- Jets fake photons: QCD multijets in which high $E_T$ jets fragments into isolated $\pi^0$
- Measure rate in EM-enriched control sample of multijets
- Systematic uncertainty 35%

- Electrons can be misidentified as photons if pixel seed in tracker not reconstructed, mainly from $W \rightarrow e\nu$
- Electron-faking-$\gamma$ rate of pixel seed veto (PSV) is measured from data using a tag-and-probe method with $Z \rightarrow ee$ events
- $R = 2.38 \pm 0.03 \%$ with systematic uncertainty of 6%
MC Based Backgrounds

• $Z(\nu\nu)+\gamma$ and $W(l\nu)+\gamma$: Simulated at LO with MadGraph
  • NLO cross-sections from MCFM
• $\gamma+\text{Jet}$: generated with MadGraph
  • Data driven technique to adjust the cross section in two event classes: 0-jet and $\geq1$ jet
  • Data control sample from pre-scaled single photon trigger events with MET requirement reversed
  • Correction factor is 1.7 for 0-jet, 1.1 for $\geq1$ jet
  • 16% systematic uncertainty
Control Regions to Validate

- Two control regions used to check that data are well modeled through MC and data driven methods described

- \( \gamma + \text{Jets} \): defined by kinematic cuts, anomalous signal rejection and lepton veto

- \( W_\gamma \): defined by inverting lepton veto at preselection level
Model Independent Results

- Results for generic signal with model-independent selection
- Less discriminating power, but less model dependence

![Graphs showing model-independent results with CMS data for ggH (125,120) and ggH (125,120) -1 with Data and Bkg. in GeV.]
Model Independent Limits

- Asymptotic CL$_S$ method with systematic uncertainties in signal and background predictions treated as nuisance parameters with log-normal prior distributions.

<table>
<thead>
<tr>
<th>Process</th>
<th>of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma +$ jets</td>
<td>$(313 \pm 50) \times 10^3$</td>
</tr>
<tr>
<td>jet $\rightarrow \gamma$</td>
<td>$(906 \pm 317) \times 10^2$</td>
</tr>
<tr>
<td>$e \rightarrow \gamma$</td>
<td>$(1035 \pm 62) \times 10^1$</td>
</tr>
<tr>
<td>$W(\rightarrow \ell\nu) + \gamma$</td>
<td>$2239 \pm 111$</td>
</tr>
<tr>
<td>$Z(\rightarrow \nu\bar{\nu}) + \gamma$</td>
<td>$2050 \pm 102$</td>
</tr>
<tr>
<td>Other</td>
<td>$1809 \pm 91$</td>
</tr>
<tr>
<td>Total background</td>
<td>$(420 \pm 82) \times 10^3$</td>
</tr>
<tr>
<td>Data</td>
<td>$442 \times 10^3$</td>
</tr>
</tbody>
</table>
SUSY Higgs Limits

- Supersymmetric decay of Higgs: $gg \rightarrow h \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \gamma \tilde{G} \tilde{G}$
- Includes misidentified MET rejection and thus better $S/\sqrt{B}$

<table>
<thead>
<tr>
<th>Process</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ + jets</td>
<td>179 ± 28</td>
</tr>
<tr>
<td>jet $\rightarrow \gamma$</td>
<td>269 ± 94</td>
</tr>
<tr>
<td>e $\rightarrow \gamma$</td>
<td>355 ± 28</td>
</tr>
<tr>
<td>$W(\rightarrow \ell\nu) + \gamma$</td>
<td>154 ± 15</td>
</tr>
<tr>
<td>$Z(\rightarrow \nu\bar{\nu}) + \gamma$</td>
<td>182 ± 13</td>
</tr>
<tr>
<td>Other</td>
<td>91 ± 10</td>
</tr>
<tr>
<td>Total background</td>
<td>1232 ± 188</td>
</tr>
<tr>
<td>Data</td>
<td>1296</td>
</tr>
</tbody>
</table>

- $M_{\tilde{\chi}_1^0} = 65$ GeV: 653.0 ± 77
- $M_{\tilde{\chi}_1^0} = 95$ GeV: 1158.1 ± 137
- $M_{\tilde{\chi}_1^0} = 120$ GeV: 2935.0 ± 349

CMS-PAS-HIG-14-024

Toyoko Orimoto, Northeastern
Improve Sensitivity by Combining with ZH

- CMS also searches for Higgs produced in association with Z
- Less signal, but less background

\[ \sigma B / \sigma_{SM} \]

\[ \tilde{\chi}_1^0 \text{ mass [GeV]} \]

arXiv:1507.00359 [hep-ex]
Conclusions

• Monophoton signatures at the LHC are phenomenologically rich, potentially providing a path to discover exotic decays of the Higgs, dark matter, or other BSM physics

• Low $E_T$ monophoton: challenging analysis, yet can probe a complementary phase space to the traditional high energy search and constrain low scale SUSY breaking

• https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig14024TWiki