Inclusive isolated photons in pp and PbPb collisions at 2.76 TeV with CMS

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Why photons?

- Photons from CMS recently used to explore the fundamental origin of mass

Higgs(?)→γγ

- BUT ...

arXiv:1207.7235 (accepted by PLB)
Why photons?

- Higgs mechanism provides only a few % of the mass of things most non-physicists care about (stars, planets, people, iPads ...)
  - The vast majority of the mass is provided by non-perturbative interactions of quarks & gluons

- CMS photons also used to study this “other” source of mass
  - Probe quarks & gluons pushed to extremes of temperature and density
Why photons?

- Yield of directly produced high $p_T$ photons can be predicted theoretically
  > Properties of the initial state (parton density functions in nuclei, number of nucleon-nucleon collisions)
- Photons are unaffected by the medium

This talk: Test these two assumptions
What is an *isolated* photon?

- An “isolated” photon is one which has very little, if any, energy carried by particles emitted close to the photon direction.
Why *isolated* photons?

- Photons mechanisms: Direct production (the needle we want), particle decay (the haystack), fragmentation (small effect), bremsstrahlung (negligibly small effect)

Processes we *want* produce *isolated* photons

Processes we *don’t want*, incl. decay (not shown), dominated by *non-isolated* photons

PYTHIA photons ~80% decay ~15% direct ~5% fragmentation
Inner tracker: charged particles for isolation

EM and Hadron calorimeters: photons, $E_{\text{hadronic}}$ for isolation

Photons

Other particles

Region used

| $|\eta|< 2.4$ |
|----------------|
| Muon           |

| $|\eta|< 5.2$ |
|----------------|
| HCAL           |

| $|\eta|< 3.0$ |
|----------------|
| ECAL           |

| $|\eta|< 2.5$ |
|----------------|
| Tracker       |
• In PbPb collisions, almost \textit{no} photons are isolated due to other particles from the underlying event

• Use the mean $E_T$ per unit area in an $\eta$ strip to subtract background inside the isolation cone $\Delta R < 0.4$
Generator level: $\Delta R < 0.4$
$\Sigma E_T^{\text{IsoCone}} < 5$ GeV
with only particles from the same hard scattering

CMS Data: $\Delta R < 0.4$
$\Sigma E_T^{\text{IsoCone}} < 5$ GeV
using the calorimeter and tracker minus background
Removing electrons

- Isolated electrons are rejected using tracking
  - Reject “photons” that are close in $\eta$ and $\phi$ to tracked electron candidates

- Fraction of electrons that “escape” these cuts estimated from PYTHIA $W \rightarrow e\nu$ decays embedded into minimum bias PbPb data

- Small correction (~4-8%) to photons found using this “escape” ratio and measured electron yields
Removing decay photons

- Take advantage of CMS ECAL’s fine segmentation
  \[ \Delta \eta \times \Delta \Phi = 0.0174 \times 0.0174 \]
- Define a “width” parameter:
  \[
  \sigma_{\eta \eta}^2 = \frac{\sum w_i (\eta_i - \langle \eta \rangle)^2}{\sum w_i}
  \]
  \[
  w_i = \max \left( 0, 4.7 + \ln \left( \frac{E_i}{E_{\text{Total}}} \right) \right)
  \]
Removing decay photons

After isolation & shower shape cut:
~70% direct
~20% decay
~10% fragmentation

\[ \sigma_{\eta\eta} = \frac{\sum w_i (\eta_i - \langle \eta \rangle)^2}{\sum w_i} \]

\[ w_i = \max \left( 0, 4.7 + \ln \left( \frac{E_i}{E_{Total}} \right) \right) \]
Details of removing decay photons

A technique also used in CMS pp analysis:

- **Signal template**: obtained from PYTHIA+MinBias data
- **Decay template**: Using a data-driven method with non-isolated photons: $\Delta R<0.4$, $6 \text{ GeV} < \Sigma E_{T}^{\text{IsoCone}} < 11 \text{ GeV}$
Signal template and background (decay) template extracted in separate bins of photon $E_T$ and collision centrality.

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### Systematic uncertainties

<table>
<thead>
<tr>
<th>Source</th>
<th>pp</th>
<th>PbPb centrality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–10%</td>
<td>10–30%</td>
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<tr>
<td>Efficiency</td>
<td>1–5%</td>
<td>5–9%</td>
</tr>
<tr>
<td>Signal modeling</td>
<td>3–5%</td>
<td>1–5%</td>
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<tr>
<td>Background modeling</td>
<td>9–13%</td>
<td>15–23%</td>
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<tr>
<td>Electron veto</td>
<td>1%</td>
<td>3–6%</td>
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<td>Photon isolation definition</td>
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<tr>
<td>Energy scale</td>
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<td>9%</td>
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<td>Energy smearing</td>
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<td>Shower-shape fit</td>
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<td>5%</td>
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<td>Anomalous signal cleaning</td>
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<td>1%</td>
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<tr>
<td>NMB</td>
<td>–</td>
<td>3%</td>
</tr>
<tr>
<td>Luminosity</td>
<td>6%</td>
<td>–</td>
</tr>
<tr>
<td>Total without $T_{AA}$</td>
<td>14–16%</td>
<td>23–30%</td>
</tr>
</tbody>
</table>

| $T_{AA}$                              | –    | 4%     | 6%     | 12%    |
| Total                                 | 14–16%| 23–30% | 23–26% | 26–31% |

**Main sources of systematic uncertainties:**

Background modeling and photon energy scale
Reconstructed photon spectra scaled by $T_{AA}$
Consistent with JETPHOX using pp PDF (CT10).
Isolated photon $R_{AA}$ in 0-10% PbPb collisions

- CMS extracted first $R_{AA}$ for isolated photons
- pp reference: pp data at 2.76 TeV
- $R_{AA}$ consistent with 1
- Compare to NLO with nPDFs: EPS09, nDS, HKN07

$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}}{dp_T d\eta} / \frac{d^2 \sigma_{pp}}{dp_T d\eta}$$

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Isolated photon $R_{AA}$ vs $E_T$ & Centrality

No dependence on centrality or $E_T$

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Conclusions

- Results are consistent with expectations:
  > Hard scattering processes scale with the number of nucleon-nucleon collisions
  > Photons not quenched
  
- Establishes the basis for studies using photons as unmodified hard probes
  > Photons as "tags" for unquenched jet energy
    - Talk by Yue Shi Lai yesterday
    - See also arXiv:1205.0206

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