Isolated Photons at CMS

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on behalf of CMS collaboration

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Outline

• Introduction
• ECAL and photon
• Photon ID and isolated photons
• Photon conversion
• Non-collision backgrounds
• Summary
Introduction

- Study of single isolated photon production gives a good test and information on pQCD as well as PDFs.
- Provide basic understanding of photons in CMS
- Foundation of photon+X analyses, such as photon +jet or Higgs to 2 photons.

JetPhox 7TeV >6x10^4 photons in 1.0pb^{-1} in CMS fiducial

```
<table>
<thead>
<tr>
<th>P_T (GeV)</th>
<th>dN/dP_T (pb/GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10^5</td>
</tr>
<tr>
<td>20</td>
<td>10^4</td>
</tr>
<tr>
<td>40</td>
<td>10^3</td>
</tr>
<tr>
<td>60</td>
<td>10^2</td>
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<tr>
<td>80</td>
<td>10</td>
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<tr>
<td>100</td>
<td>1</td>
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<tr>
<td>120</td>
<td>1</td>
</tr>
<tr>
<td>140</td>
<td>1</td>
</tr>
<tr>
<td>160</td>
<td>1</td>
</tr>
<tr>
<td>180</td>
<td>1</td>
</tr>
</tbody>
</table>
```
EB : PbWO$_4$ with APDs
22mm x 22mm x 25.8$X_0$
(Molière radius 22mm)

EE : PbWO$_4$ with VPTs
29mm x 29mm x 24.7$X_0$

ES : silicon strip sensors
strip width 1.9mm

Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 Tesla

$\eta$ : pseudo-rapidity = $-\ln(\tan(\theta/2))$
ECAL and photon
Commissioning of ECAL

- A SuperCluster is a group of clusters in ECAL that recovers energy loss due to bremsstrahlung or conversions
- Good agreement between data and MC in modeling event characteristics and ECAL performance
Resonances seen in ECAL

- Resonances are seen in different energy scale of photons
- Reconstructing $\pi^0$, $\eta$ and $Z$ improves the understanding and calibration of ECAL detector

![Graphs showing resonance peaks for $\pi^0$ and $\eta$ in CMS PAS EGM-10-003 and CMS PAS EWK-10-002.]
Photon Trigger

- L1 (hardware trigger) on ECAL trigger object with $E_T > 5\text{GeV}$
- High Level Trigger (software trigger, after L1) with SuperCluster above $15\text{GeV}$. Quick turn-on and fully efficient after $20\text{GeV}$.

![Efficiency Graph](image1)

![Photon HLT Efficiency](image2)
Photon ID and isolated photons
This event shows a photon+jet event with good balance on $E_T$ and $\phi$.

Photon is isolated with energy spread (shower shape) match expectation of a photon.
**Photon ID Variables**

- MC sample compositions based on PYTHIA cross sections.
- Use 74 nb\(^{-1}\) data for the following results, MC distributions are normalized to data observed.
- Require not to match pixel hit consistent with a track from interaction point.

**SuperCluster**

Assuming a charged track and look for pixel hit

- **Barrel**

- **Endcap**

  Discrepancy due to mis-alignment of endcap

* MC normalized to data
Isolation Variables

- Cone isolation variables (radius of $\Delta R=0.4$) in ECAL / HCAL / tracker identify isolated objects.
Shower Shape

- Powerful shape variable $\sigma_{i\eta i\eta}$ (shower width in $\eta$) to distinguish photons from fakes.

- Can be used to extract photon yields or purity of the sample

* MC normalized to data
Photon ID

- Apply selection cut to enhance prompt photons over fakes ($\pi^0$ or jets)
- Based on MC, the efficiency is around 90% for Barrel and 80% for Endcap.
- Signal photons from hard-process, not decays.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Barrel photon</th>
<th>Endcap photon</th>
</tr>
</thead>
<tbody>
<tr>
<td>photon $E_T$</td>
<td>&gt; 30 GeV</td>
<td></td>
</tr>
<tr>
<td>tracker isolation</td>
<td>&lt; 2.0 GeV</td>
<td></td>
</tr>
<tr>
<td>ECAL isolation</td>
<td>&lt; 4.2 GeV</td>
<td></td>
</tr>
<tr>
<td>HCAL isolation</td>
<td>&lt; 2.2 GeV</td>
<td></td>
</tr>
<tr>
<td>(hadonic/EM) energy</td>
<td>&lt; 0.05</td>
<td></td>
</tr>
<tr>
<td>shower shape ($\sigma_{\text{sh}}$)</td>
<td>&lt; 0.01</td>
<td>&lt; 0.03</td>
</tr>
<tr>
<td></td>
<td>Require not to match a pixel hit</td>
<td></td>
</tr>
</tbody>
</table>

CMS PAS EGM-10-005
Isolated Photons

- With photon ID applied, clear component from prompt isolated photons can be seen.
- Purity is estimated between 40 to 100% depending on photon $E_T$
Photon conversions
Finding Conversions

• Significant amount of photon conversion is expected in CMS due to tracker material

• Look for pair of electrons based on two legs associated with the same SuperCluster.
  • start from a SuperCluster
  • look for a track toward IP
  • from innermost hit find 2nd track back to SuperCluster
Conversion variables

At ECAL level

- Start from SC
- Look for a track toward IP
- From innermost hit find 2nd track back to SC

At vertex level

- Used for conversion selection

* MC normalized to data
Converted Photons

- Agreement between data and MC on distributions of conversion legs.

- Additional cut on top of photon ID is used for conversion selection
  - $|\Delta \phi| < 0.2$
  - $|\Delta \cot \theta| < 0.3$
  - Fit probability $> 5 \times 10^{-4}$

- Contribution from prompt photons can be seen.

Applying all selections

*MC normalized to data*
Non-collision backgrounds
Beam Halo

- Halo contribution is estimated from data by
- Halo events: tagged by muon chamber
- Prompt events: seed crystal timing $|t_{seed}| < 3\text{ns}$ with missing $E_T < 15\text{GeV}$
- Candidate events: $|t_{seed}| < 3\text{ns}$ with missing $E_T > 25\text{GeV}$

**Halo has shorter path compare to collisions.**

<table>
<thead>
<tr>
<th>Muon chamber</th>
<th>ECAL Barrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCAL Endcap</td>
<td>IP</td>
</tr>
</tbody>
</table>

**Plot:**

- **Prompt / Candidate**
- **Halo**

$\pm 3\text{ns}$
Beam Halo Contribution

• Within candidate events, no evidence in low value of angle(\(A\)) between beam line and major axis of photon shower
• The estimate of contribution is less than 5.9 event in 53.6 nb\(^{-1}\).

Candidate Sample Entries (351) Halo, 95% CL limit Prompt = 7 TeV\(\text{s}^{-1}\) = 53.6 nb\(^{\text{int}}\) L

Candidate Sample

CMS Preliminary 2010

Candidate Sample Entries (351)

Halo, 95% CL limit

Prompt

\(\sqrt{s} = 7\ \text{TeV}\)

L\(_{\text{int}}\) = 53.6 nb\(^{-1}\)
Summary

• We have studied the photon objects at CMS with collision data

• Applying photon ID, clear contribution from prompt isolated photons can be seen

• Analysis of photon production is on-going as the baseline of multiple photon+X analyses.
backup slides
JetPhox

Expected production in CMS Fiducial with 0.5pb$^{-1}$

JetPhox 7TeV

Entries / bin

$P_T^\gamma$ (GeV)

$10^5$

$10^4$

$10^3$

$10^2$

$10^1$

$10^0$

$10^{-1}$

$10^{-2}$

$10^{-3}$

$10^{-4}$

Entries / bin

$P_T^\gamma$ (GeV)
Photon ID variables

- ECAL isolation: Jurassic cone with inner cone 0.06, outer cone 0.4 and eta slice of 3 crystals.
- HCAL isolation: Inner cone 0.15 and outer cone 0.4.
- Tracker isolation: Inner cone 0.04 and outer cone 0.4.
- Shower shape: $\eta$ distribution of shower

$$\sigma_{\eta\eta}^2 = \frac{\sum_i^{5\times5} w_i (\eta_i - \eta_{seed})^2}{\sum_i^{5\times5} w_i}, \quad w_i = \max(0, 4.7 + \ln \frac{E_i}{E_{5\times5}}).$$
Isolation of EE

\[ R = 0.4 \text{ (GeV/c)} \]

\[ \text{Isolation} = \frac{\text{Track}}{5} \]

<table>
<thead>
<tr>
<th>Track</th>
<th>Data</th>
<th>MC partonic</th>
<th>MC ISR/FSR</th>
<th>MC other</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>200</td>
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<tr>
<td>400</td>
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<tr>
<td>800</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* MC normalized to data

CMS Preliminary 2010
\[ \sqrt{s} = 7 \text{ TeV} \]
\[ L = 74 \text{ nb}^{-1} \]
\[ 1.566 < \mid p \mid < 2.5 \]
Sum of isolation

- Sum of isolation for candidate photons.
- Prompt photons contribute in low value bins.