Photons in LHC data @ 7 TeV
Results from ATLAS and CMS

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On behalf of the ATLAS and CMS Collaborations

Higgs Hunting : Discussions on Tevatron and first LHC results

29-31 July 2010
Orsay, France
I - Introduction
  • Physics with photons at the LHC
  • ATLAS and CMS: trackers and calorimeters

II - Using photons in performance studies
  • Photons from $\pi^0$ decays [CMS/ATLAS]
  • Conversions and Dalitz [CMS/ATLAS]

III - Prompt photons results
  • Photon identification [CMS/ATLAS]
  • Photon conversions [CMS/ATLAS]
  • Beam-halo background [CMS]
  • Prompt isolated photon signal and purity [ATLAS]
I- Introduction
For $m_H = 120$ GeV $\Rightarrow$ BR $\sim 0.2\%$

What can we extract from the first 10-100 nb$^{-1}$?

- Clean signature (2 high-$E_T$ isolated photons)
- Huge background from QCD photons and jets
Photon production

Among reconstructed photons:
- Jets with high-\(p_T\) \(\pi^0\) misidentified as photons
- Prompt photons (from ME and fragmentation)

In today's data:
- \(\gamma/\pi^0\) separation
- Energy + angular resolution
- Conversion recovery

Prompt photon measurements:
- Background to \(H \rightarrow \gamma\gamma, \ldots\)
- Perturbative QCD tests
• Material => non-negligible fraction of photon conversions (up to 50% in Si)
  → Consequences on photon ID, energy resolution, etc.
  → Use of conversions as a tool for material mapping
• ATLAS : add $O(2X_0)$ before EM Calo (solenoid coil, cryostat)
ATLAS and CMS: Calorimetry

- Pb + LAr sampling calorimeter
- 3 radial layers + pre-shower
- Design energy resolution:
  \[
  \frac{\Delta E}{E} = 10\% \oplus \frac{300\text{ MeV}}{\sqrt{E}} \oplus 0.7\%
  \]
- Outside solenoid coil

- PbWO\textsubscript{4} scintillating crystals
- Preshower in front of EE
- Design energy resolution:
  \[
  \frac{\Delta E}{E} = 2.9\% \oplus \frac{125\text{ MeV}}{\sqrt{E}} \oplus 0.3\%
  \]
- Inside solenoid coil
II – Photons in performance studies

• Reconstruction of $\pi^0$ peaks
• Material mapping with photon conversions and Dalitz in ATLAS
• Uniformity along $\phi$ : < 0.7% in EM Calorimeter ($|\eta| < 2.37$)
• Agreement data/MC in energy scale along $\eta$ ~ 1 – 2 %

• Channel-by-channel *in-situ* intercalibration precision:
  1.2% for $|\eta| < 0.8$ ($\pi^0$, $\phi$ symmetry)
• Agreement data/MC in energy scale ~ 1 – 3 % (Barrel – Endcap)
Converted photons in ATLAS and CMS

ATLAS Preliminary

Data
MC conversion candidates
MC true conversions

CMS Preliminary 2010

Data
Simulation: conversions
Simulation: fakes

Pixel support shift
~ 1 cm

3 pixel layers

Conversions:
Track-based conversion finding

Dalitz decays ($\pi^0 \rightarrow \gamma e^+e^-$):
Used to constrain material in the Beam pipe
Beam pipe = reference for material estimate

ATLAS Preliminary

Dalitz: Beam pipe

$\pi^0 \rightarrow \gamma e^+e^-$

Some discrepancies

Corrected from overall shift between tracker and reference frame

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III – Prompt photons results

• Photon identification
• Photon conversions
• Non-collision backgrounds
• Extraction of isolated photon signal and purity
• **Integrated luminosity**
  - ATLAS: $L = 15.8 \text{ nb}^{-1}$
  - CMS: $L = 74 \text{ nb}^{-1}$
  (53.6 nb$^{-1}$ for beam bkg study)

• **Event selection**
  - L1 trigger: $E_{\text{EM}} > 5 \text{ GeV}$
  - $\geq 1$ vertex with $\geq 3$ tracks

• **(Super)Clusters**
  - ATLAS: $E_{\text{Cl}} > 10 \text{ GeV}$
  - CMS: $E_{\text{SC}} > 20 \text{ GeV}$
  - $|\eta| < 2.37 / 2.5$, out of crack
  - Remove problematic regions / anomalous signals
  - ATLAS: $2.3 \times 10^5$ photon cand.
  - CMS: $1.3 \times 10^5$ events

In the next plots
### Identification of photons in ATLAS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic leakage</td>
<td>$E_T(\text{Had})/E_T$</td>
</tr>
<tr>
<td>$R_\eta$</td>
<td>$E_{3x7}/E_{7x7}$</td>
</tr>
<tr>
<td>$w_{\eta^2}$</td>
<td>RMS of energy in $\eta$ in middle layer</td>
</tr>
<tr>
<td>$R_\phi$</td>
<td>$E_{3x3}/E_{3x7}$</td>
</tr>
<tr>
<td>$w_{\text{stot}}$</td>
<td>RMS of energy in $\eta$ in strips</td>
</tr>
<tr>
<td>$E_{\text{ratio}}$</td>
<td>Asymmetry between 1\textsuperscript{st} and 2\textsuperscript{nd} max</td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>Difference between 2\textsuperscript{nd} max and min (between the 2 max)</td>
</tr>
<tr>
<td>$F_{\text{side}}$</td>
<td>Fraction of energy in 7 cells outside the core of 3 cells</td>
</tr>
<tr>
<td>$w_{s3}$</td>
<td>RMS of energy in $\eta$ in the core of 3 cells</td>
</tr>
</tbody>
</table>

#### Loose selection

$\rightarrow$ Had. Leakage + Middle variables

#### Tight selection

$\rightarrow$ Loose + Strips variables

(different cuts for converted and unconverted photons)

- **Isolation**
  $\rightarrow$ Treated separately (see after)
Shower shapes in the ATLAS EM Calorimeter

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Efficiencies computed from $H \rightarrow \gamma\gamma$ MC ($E_T > 20$ GeV):
- Loose: $\varepsilon \sim 95\%$
- Tight: $\varepsilon \sim 88\%$

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**Transverse shape $R_\eta$**

- $E_{3x7} / E_{7x7}$

**Containment in strips (Fside)**

- $E_{\text{out}} / E_{7\text{strips}}$

**$E_{\text{ratio}}$**

- Good agreement between Data and MC after loose ID cut

**$F_{\text{side}}$**

- Loose candidates

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**ATLAS Preliminary**

- Unconverted photons
  - $\sqrt{s} = 7$ TeV, $Ldt = 15.8$ nb$^{-1}$
  - $|\eta| < 0.6$
  - Data 2010

- Simulation (all $\gamma$ candidates)
- Simulation (prompt $\gamma$)

---

**Loose candidates**

- $|\eta| < 0.6$
- Data 2010

- Simulation (all $\gamma$ candidates)
- Simulation (prompt $\gamma$)

---

**$E_{\text{ratio}}$**

\[
E_{\text{ratio}} = \frac{E_{\text{max}1} - E_{\text{max}2}}{E_{\text{max}1} + E_{\text{max}2}}
\]

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**$E_{\text{max}1}$**

- Strips

---

**$E_{\text{max}2}$**

- Strips

---

**$E_{\text{out}}$**

- Strips

---

**$E_{\text{7strips}}$**

- Strips

---

**$F_{\text{side}}$**

- $|\eta| < 0.6$
- Data 2010

- Simulation (all $\gamma$ candidates)
- Simulation (prompt $\gamma$)

---

**containment in strips (Fside)**

- $E_{\text{out}} / E_{7\text{strips}}$
<table>
<thead>
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<th>Variable</th>
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<tbody>
<tr>
<td>$R_9$</td>
<td>$E_{3x3}/E_{SC}$</td>
</tr>
<tr>
<td>Pixel seed</td>
<td>Match with track in pixels</td>
</tr>
<tr>
<td>Tracker Iso.</td>
<td>$\text{Sum}(p_T)$ in a ring between $R = 0.04$ and $R = 0.4$</td>
</tr>
<tr>
<td>ECAL Iso.</td>
<td>$\text{Sum}(E_T(EM))$ in a ring between $R = 0.06$ and $R = 0.4$</td>
</tr>
<tr>
<td>HCAL Iso.</td>
<td>$\text{Sum}(E_T(HCAL))$ in a ring between $R = 0.15$ and $R = 0.4$</td>
</tr>
<tr>
<td>$\sigma_{\eta-\eta}$</td>
<td>Width in $\eta$ of the SC</td>
</tr>
<tr>
<td>Hadronic fraction</td>
<td>$H/E = E_T(\text{Had})/E_T$</td>
</tr>
</tbody>
</table>

Additional cut: $E_T > 30$ GeV

- **Efficiencies computed on MC isolated photons:**
  - EB: $\varepsilon \approx 90\%$
  - EE: $\varepsilon \approx 80\%$

- Purity (from MC) ~ 50%
- Increases with $E_T$
Identification variables in the CMS ECAL

- Good agreement between Data and MC
- Signal contribution visible

On selected photons
Selected photons:

- No pixel seed
- \( E_T > 30 \) GeV
- Track Iso < 2 GeV
- ECAL Iso. < 4.2 GeV
- HCAL Iso. < 2.2 GeV
- \( H/E < 0.05 \)
- \( \sigma_{\text{in-in}} < 0.01 \) (0.03)
- \( |\Delta\phi| < 0.2 \)
- \( |\Delta\cot\theta| < 0.3 \)
- \( P(\text{vertex}) > 5 \times 10^{-4} \)

Selected photons (tight selection):

- \( E_T > 20 \) GeV
- Isolation < 3 GeV

Distributions compatible with isolated converted photons

\( L = 62 \text{nb}^{-1} \)
Non-collision background (I)

Non-collision events = background to studies with photons or MET

- **HALO**:  
  - No reco track  
  - MET > 25 GeV  
  - tagged in Had Endcap (HE) or Muon System Endcap (EMU)

- **PROMPT**:  
  - > 3 reco tracks  
  - MET < 15 GeV  
  - $|t_{\text{seed}}| < 3$ ns  
  - no tag

- **CANDIDATE**:  
  - > 3 reco tracks  
  - MET > 25 GeV  
  - photon with ET > 30 GeV  
  - $|t_{\text{seed}}| < 3$ns  
  - no tag

⇒ Time of seed in ECAL: $t_{\text{seed}}$  
⇒ Angle of shower in $\eta-\phi$ plane w.r.t beam axis: $A$
Non-collision background (II)

**Candidate Sample**

- **CMS Preliminary 2010**  
- **Candidate Sample Entries (351)**
- **Halo, 95% CL limit**
- **Prompt**

$\sqrt{s} = 7$ TeV  
$L_{int} = 53.6$ nb$^{-1}$

- Data driven method to estimate candidate contamination
- Estimate < 5.9 halo events in “candidate” sample (351 candidates) with MET > 25 GeV
Isolation

- **Energy in ring includes:**
  - Photon leakage out of the core
  - Depends on photon pT
  - Subtracted from the ring energy
  - Pile-up / Underlying Event effects
  - Ambient energy density from low E jets
  - Subtracted from the ring energy
  - Nearby hadronic activity

Isolation energy

Candidates already passing the loose ID cut

ATLAS Preliminary

\( \sqrt{s} = 7 \text{ TeV}, \int L dt = 15.8 \text{ nb}^{-1} \)

- Data 2010
  - Simulation (all \( \gamma \) candidates)
  - Simulation (prompt \( \gamma \))

This definition of isolation is closer to theoretical parton-level isolation.
Signal extraction (I)

Two corrections:

- **Correlation between ID and isolation cuts**
  → Reverse only a subset \((E_{\text{ratio}}, \Delta E, F_{\text{side}}, W_{s3})\) of the strips shower shape variables to minimize correlation

- **Signal contamination in control regions**
  → Use fraction of signal in the control regions from MC \((c_1, c_2, c_3)\)

**Corrected formula**:

\[
N_{\text{sig}}^A = \left( N^A - c_1 N_{\text{sig}}^A \right) \frac{M^A - c_2 N_{\text{sig}}^A}{M^B - c_3 N_{\text{sig}}^A} \left( \frac{N^A_{\text{bkg}}}{M^A_{\text{bkg}}} \right) \left( \frac{N^B_{\text{bkg}}}{M^B_{\text{bkg}}} \right)
\]

→ *Data driven* extraction of number of isolated signal
Signal extraction (II)

**Excess in the isolated region (→ signal)**

**Excess in the tight ID cut region (→ signal)**

**Signal yield with 15.8 nb\(^{-1}\) of data**

<table>
<thead>
<tr>
<th>ET interval</th>
<th>Estimated signal yield (+/- stat. +/- syst.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 – 15 GeV</td>
<td>1289 ± 297 ± 1362</td>
</tr>
<tr>
<td>15 – 20 GeV</td>
<td>706 ± 69 ± 86</td>
</tr>
<tr>
<td>&gt; 20 GeV</td>
<td>618 ± 42 ± 59</td>
</tr>
</tbody>
</table>

Systematics dominated by choice of first layer ID cuts, isolation cut and correlations.
Signal extraction (III) : Photon purity

\[ P = \frac{N^A_{\text{sig}}}{N^A} \]

**Estimated purity with 15.8 nb\(^{-1}\) of data**

<table>
<thead>
<tr>
<th>ET interval</th>
<th>Estimated purity in % (+/- stat. +/- syst.)</th>
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<tbody>
<tr>
<td>10 – 15 GeV</td>
<td>24 ± 5 ± 24</td>
</tr>
<tr>
<td>15 – 20 GeV</td>
<td>58 ± 5 ± 8</td>
</tr>
<tr>
<td>&gt; 20 GeV</td>
<td>72 ± 3 ± 6</td>
</tr>
</tbody>
</table>

Systematics dominated by choice of first layer ID cuts, isolation cut and correlations.
Conclusions
Conclusions

- Performance with photons
- Check of photon ID variables
- Signal of prompt photons (incl. conversions)
- Good agreement between data and MC in general
  - Though some discrepancies to understand

Experiments are ready for next steps: (differential) cross section measurements, prompt di-photon signal, ...
Backup
• **Photon identification efficiency**
  → Estimated from MC
  → Systematic uncertainties:
    • Material description
    • Cross-talk
    • Classification of conversions

• **Photon trigger efficiency** (L1 Calo 5 GeV)
  → Estimated from Data (bootstrap)
    • Sample of Min Bias triggered events
    • Lower threshold L1Calo trigger (2 GeV)
  → Systematic uncertainty:
    • < 0.3%, estimated from signal/background differences, from MC
CMS L1 electron/photon trigger efficiency

![Graph showing CMS L1 electron/photon trigger efficiency vs. E_T [GeV]. The graph includes data points for ECAL Barrel and ECAL Endcaps, with a CMS Preliminary 2010 (7 TeV) integration L dt = 63 nb^{-1}.]
Non-collision background (I)

- **Had. Endcap (HE) tag:**
  - $E_{HE} > 1$ GeV
  - $115 \text{ cm} < R_{HE} < 130 \text{ cm}$
  - $\Delta\phi_{ph-HE} < 0.2$

- **Muon System Endcap (EMU) tag:**
  - $115 \text{ cm} < R_{EMU} < 170 \text{ cm}$
  - $\Delta\phi_{ph-EMU} < 0.2$

- **HALO:**
  - No reco track
  - MET $> 25$ GeV
  - HE or EMU tag

- **PROMPT:**
  - $> 3$ reco tracks
  - MET $< 15$ GeV
  - $|t_{seed}| < 3 \text{ ns}$
  - no tag

- **CANDIDATE:**
  - $> 3$ reco tracks
  - MET $> 25$ GeV
  - photon with ET $> 30$ GeV
  - $|t_{seed}| < 3 \text{ ns}$
  - no tag

- **Selected photons:**
  - No pixel seed
  - MET $> 25$ GeV
  - HE or EMU tag
  - $|t_{seed}| < 3 \text{ ns}$
  - no tag
  - $E_2/E_{5x5} < 0.95$
  - HCAL Iso. $< 2.2$ GeV
  - $H/E < 0.05$
  - ECAL Iso. $< 4.2$ GeV

⇒ Time of seed in ECAL
⇒ Angle w.r.t beam axis