Measurements of isolated prompt photons in $pp$ collisions at 7 TeV in ATLAS

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for the ATLAS Collaboration

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Theoretical relevance

- prompt photons in *hadron colliders* mainly produced in parton hard scattering
  - a test of *perturbative QCD* predictions (even without using jets)
- dominant process \((qg)\) involves gluons in the initial state
  - probe the *gluon content* of the proton
- understand QCD *backgrounds to new physics* (e.g. \(H \rightarrow \gamma\gamma\))
Isolated prompt photons at hadron colliders

- **Prompt** photons: direct (from the hard scatter) + (parton) fragmentation
  - **direct**: dominated by Compton at LHC, photon well separated from parton
  - **fragmentation**: more important at low $E_T(\gamma)$; photon closer to hadrons

- **Isolated**: isolation criterion imposed from the beginning
  - isolation energy = additional hadronic transverse energy near photon axis
  - reduces fragmentation (~30% of total xsec at 15 GeV, <10% above 35 GeV)
  - reduces main QCD backgrounds: photons from decays of $\pi^0/\eta$ in jets
Isolated prompt photon: inclusive production cross-section measurement at ATLAS

- Two measurements presented, in $pp$ collisions at $\sqrt{s} = 7$ TeV
  

  - $15 < E_T(\gamma) < 100$ GeV, $|\eta(\gamma)|$ in: [0,0.6) [0.6,1.37) [1.52, 1.81)

  - $(0.88\pm0.10)$ pb$^{-1}$, 10 GeV-threshold photon trigger


  - $45 < E_T(\gamma) < 400$ GeV, $|\eta(\gamma)|$ in: [0,0.6) [0.6,1.37) [1.52, 1.81) [1.81, 2.37)

  - $(34.6\pm1.2)$ pb$^{-1}$, 40 GeV-threshold photon trigger

  - Complementary $E_T(\gamma)$ ranges, fragmentation only affects low-$E_T$ measurement

  - Very similar analysis techniques
Cross section measurement ingredients

\[
\frac{d\sigma}{dE_T^\gamma} = \frac{N_{\text{yield}} U}{(\int L dt) \Delta E_T^\gamma \varepsilon_{\text{trigger}} \varepsilon_{\text{reco}} \varepsilon_{\text{ID}}}
\]

- **Signal** = prompt $\gamma$ with true ($E_T, \eta$) in acceptance, truth-particle-level $E_T^{\text{iso}} < 4$ GeV (truth-level particles within a cone of radius 0.4 in $\eta$-$\phi$ around the photon)
  - isolation criterion corresponds roughly to experimental one ($< 3$ GeV)
- $N_{\text{yield}} = N(\text{selected photon candidates}) - N(\text{estimated background})$
- $\varepsilon_{\text{reco}} = \text{photon reconstruction efficiency (vs true } E_T(\gamma))$
- $\varepsilon_{\text{ID}} = \text{photon identification efficiency (vs reco } E_T(\gamma))$
- $\varepsilon_{\text{trig}} = \text{trigger efficiency for photons passing the full selection}$
- $U = \text{unfolding-factors, close to 1 (true } \leftrightarrow \text{ reco } E_T(\gamma))$
ATLAS: A Toroidal LHC ApparatuS

• Inner Detector ($|\eta|<2.5$)
  • track charged particles
  • measure transition radiation
  ✓ reconstruct $\gamma$ conversions
  ✓ $e/\gamma$ discrimination

• Pb-LAr EM calorimeter
  • very fine layer 1 segmentation up to $|\eta|=2.37$
  ✓ $\gamma$ energy/direction measurement
  ✓ $\pi^0/\gamma$ discrimination (shower shape)
Photon/$\pi^0$ discrimination

- S3
- S2 (middle)
- S1 (strips)
- Pre-sampler

✓ loose and tight photon ID criteria based on shower shapes in calorimeters
Photon calorimeter isolation

- $E_T^{\text{iso}} = \Sigma(\text{calo cells})$ in cone $\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2} < 0.4$, not in core cluster (5x7 cells)
- Subtract out-of-core leakage
- Subtract soft-jet activity from pileup and underlying event (after Cacciari, Salam and Sapeta, JHEP 04 (2010) 065)
  - for events with 1 primary vertex: PYTHIA: 440 MeV, HERWIG: 550 MeV, DATA: 540 MeV
  - correction increases linearly with # of primary vertices
Final photon selection

- **Event preselection**
  - good data quality
  - at least 1 primary vertex

- **Signal photon candidates**
  - pass tight ID criteria
  - $E_T^{\text{iso}} < 3$ GeV
  - no requirement on the other jets in the event

- **Selected candidates**
  - $110e3$ (15-100 GeV, $|\eta|<1.81$, 0.9 pb$^{-1}$)
  - $174e3$ (45-400 GeV, $|\eta|<2.37$, 35 pb$^{-1}$)

- **Fraction of converted~30%**
Photon ID efficiency (15-100 GeV, 0.9 pb\(^{-1}\))

- From MC
  - shower shapes shifted to match data
  - separately for converted/unconverted candidates
- Verified with e from W→e\(\nu\) in data
- Main systematic uncertainties:
  - method, selection (≈ 5%→2%)
  - extra material (≈ 6%→1%)
  - pileup, generator (≈ 2-3%)
  - conversion fraction (≈2%→1%)
Photon ID efficiency (45-400 GeV, 35 pb$^{-1}$)

- Consistent with previous determination between 45 and 100 GeV
- Plateau at 90-95% above 100 GeV
Trigger and reconstruction efficiency

- $\varepsilon_{\text{trig \ (from data)}}$: plateau at $\sim 100\%$ for photons passing offline selection

10 GeV threshold
$\varepsilon_{\text{trig}} = (99.5\pm0.5)\%$

40 GeV threshold
$\varepsilon_{\text{trig}} = (99.4^{+0.6}_{-0.2})\%$

- $\varepsilon_{\text{reco \ (from MC)}}$: $\sim 80-85\%$ in barrel ($|\eta|<1.37$), $\sim 70\%$ in end-cap ($1.52<|\eta|<2.37$)
  - significant part of inefficiency (dead readout) recovered in 2011 winter shutdown
  - uncertainties: extra material not in MC (1-2%), generator and fraction of fragmentation photons (<2%), experimental isolation efficiency (3-4%)
Bkg subtraction: 2D sideband ("ABCD") method

A: signal region  B,C,D: bkg control regions

\[ N_{\text{A}}^{\text{sig}} = N_{\text{A}}^{\text{obs}} - N_{\text{A}}^{\text{bkg}} = N_{\text{A}}^{\text{obs}} - R^{\text{bkg}} \frac{(N_{\text{B}}^{\text{obs}} - N_{\text{B}}^{\text{sig}})(N_{\text{C}}^{\text{obs}} - N_{\text{C}}^{\text{sig}})}{N_{\text{D}}^{\text{obs}} - N_{\text{D}}^{\text{sig}}} \]

\[ N_{K}^{\text{sig}} = c_K N_{\text{A}}^{\text{sig}} \quad (K = B, C, D) \quad c_K \text{ from MC (c_B, c_C } \sim \text{ few\%)} \]

\[ R^{\text{bkg}} = \frac{N_{\text{A}}^{\text{bkg}} N_{\text{D}}^{\text{bkg}}}{N_{\text{B}}^{\text{bkg}} N_{\text{C}}^{\text{bkg}}} \] consistent with 1 in bkg MC

- Main systematic uncertainties from: MC inputs (up to \(~10\%\)); bkg control regions (up to 6%)
- Results cross-checked with isolation template fit (signal template: e from W/Z in data; bkg template: photons failing the tight ID criteria)
- Isolated electron contamination estimated from data and MC control samples
 Prompt photon purity (15-100 GeV, 0.9 pb⁻¹)

**ATLAS**

Data 2010, \( \sqrt{s} = 7\) TeV, \( \int L dt = 880\) nb⁻¹

\(|p_T| < 0.6\)

\( E_T^{\text{iso}} < 3\) GeV

\(|p_T| < 1.37\)

\( 0.6 \leq |\eta| < 1.37\)

\( E_T^{\text{iso}} < 3\) GeV

\(|p_T| < 1.81\)

\( 1.52 \leq |\eta| < 1.81\)

\( E_T^{\text{iso}} < 3\) GeV

Giovanni Marchiori
Prompt photon purity (45-400 GeV, 35 pb$^{-1}$)

✓ Photon purity rapidly increases from 50% (15 GeV) to >95% above 100 GeV
Unfolding factors and theoretical predictions

- **unfolding-factors:**
  - use MC $E_T$-response matrix (several techniques: bin-by-bin, iterative, SVD)
  - largest syst. uncertainty: EM energy scale (3% from testbeams, 1.5% from $Z\rightarrow ee$ peak)
    - translate into 5-10% uncertainty on xsection
    - CTEQ 6.6 PDFs [MSTW 2008: 3-5% difference] (PDF uncertainty: 4% → 2%)
    - scales (fragmentation/factorization/renormalization) = $E_T(\gamma)$, varied between .5 and 2 $E_T(\gamma)$ (scale uncertainty: 20% → 8%)
    - parton isolation energy < 4 GeV in cone $\Delta R = 0.4$ (varied between 2 and 6 GeV: ±2%)
x-section: data vs theory (central region: $|\eta|<1.37$)

- Results **systematically limited** across full $E_T$ range
- The **two measurements** are **consistent** in the overlapping $E_T$, $\eta$ bins
- **Data/(NLO pQCD)** comparison:
  - experimental uncertainty comparable to theoretical one
  - disagreement (ratio data/theory<1) below 35 GeV, good agreement above
x-section: data vs theory (forward region: $|\eta| > 1.52$)

• No previous measurement below 45 GeV by ATLAS in this $|\eta|$ range
Conclusion

• Prompt photon production **clearly observed** in ATLAS
  • $15 < E_T < 400 \text{ GeV} \ (0.004 < x < 0.114), \ |\eta|<2.37$

• Good **efficiency** (reco $\sim 85\%$, ID $\sim 95\%$) and high **purity** ($>95\%$) above 100 GeV
  • reconstruction **inefficiencies** largely recovered in winter 2011 shutdown

• Inclusive production **cross section measured**
  • **good agreement** with NLO pQCD above $\sim 35 \text{ GeV}$
  • **discrepancies** below 35 GeV: need to go beyond NLO? Systematic uncertainty related to **fragmentation** underestimated in the theory?

• More results ($\gamma$-jet, $\gamma\gamma$) and more data in the near future
  • reduce photon energy scale, resolution, efficiency systematic ($Z\rightarrow ee, \mu\mu\gamma$)
More slides
Inner detector (charged particle tracking)

- **Transition Radiation Tracker**
  - 350k channels
  - 4mm (diameter) straws
  - TR $\Rightarrow e/\pi$ discrimination
  - $\approx$36 hits/track
  - $\approx$130 $\mu$m resolution

- **Semi-Conductor Tracker**
  - 6.3M channels
  - 4 cylinders, 8 hits/track
  - $\approx$17 $\mu$m resolution

- **Pixel Tracker**
  - 80M channels, 3 layers
  - $\approx$10 $\mu$m resolution
  - Converted $\gamma$ reconstruction
  - e/$\gamma$ discrimination
ATLAS liquid argon calorimeters

- EM Barrel: $|\eta| < 1.475$ [Pb-LAr]
- EM End-caps: $1.4 < |\eta| < 3.2$ [Pb-LAr]
- Hadronic End-cap: $1.5 < |\eta| < 3.2$ [Cu-LAr]
- Forward Calorimeter: $3.2 < |\eta| < 4.9$ [Cu,W-Lar]

![Calorimeter Diagram]

- **EM Calorimeter**
  - PB-LAr Accordion
  - $\Delta E/E = (10\%/\sqrt{E}) \oplus 0.7\%$
  - $0.025 \times 0.025$ cells ($\eta \times \phi$)
  - Angular res.: 50 mrad / $\sqrt{E}$

- **Hadronic Calorimeter**
  - Fe-scintillator for $|\eta| < 1.7$
  - $\Delta E/E = (50\%/\sqrt{E}) \oplus 6\%$
  - Cu-LAr for $1.5 < |\eta| < 3.2$
  - $\Delta E/E = (50\%/\sqrt{E}) \oplus 3\%$

✓ Reject fake photons (mostly from $\pi^0$ in jets) based on shower shape
ATLAS EM calorimeter

\[ \sigma_E^2 = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus C \]

- S0 (Presampler): Energy loss correction
- S1 (Strips): \( \gamma/\pi^0 \) separation
- S2 (Middle): Main energy deposit
- S3 (Back): High energy showers, hadr/em separation

1 sector: \( \Delta \eta = 0.2 \)

Signal layer for barrel electrode

Lead thickness: 1.53 mm

1.13 mm
Segmentation of the LAr EM calorimeter

- **Presampler in front**
  - Cells in Layer 1
  - $\Delta \phi \times \Delta \eta = 0.025 \times 0.1$

- **Strips**
  - $\Delta \eta = 0.026$
  - $37.5 \text{mm} / 8 = 4.69 \text{mm}$

- **Middle**
  - Cells in Layer 2
  - Square cells
  - $\Delta \phi = 0.0245$
  - $1.7X_0$
  - $\Delta \phi = 0.0245 \times 4$
  - $36.8 \text{mm} \times 4 = 147.3 \text{mm}$

- **Back**
  - Cells in Layer 3
  - $\Delta \phi \times \Delta \eta = 0.0245 \times 0.05$

- **Trigger Tower**
  - $\Delta \eta = 0.1$

**Y candidate**
- Cut on HAD leakage, 2nd sampling of EM
- Rejects jets with high energy pions and wide showers

**Isolation cuts**
- (ID or EM calo)
- Cuts on 1st sampling of EM calo

**Rejections**
- Rejects jets with one or more $\pi^0, \eta, \ldots$
- Isolation cuts
- Rejects low multiplicity $\pi^0$ jets
Discriminating variables for photon ID

**Hadronic leakage**

\[ R_{\text{had}} = \frac{E_{\text{had}}}{E_T} \]

\( E_{\text{had}} \) is the energy in the first layer of the hadronic calorimeter behind EM cluster.

**Middle layer (S2) variables**

- **\( R_{\eta} = \frac{E_{S2}^{3\times7}}{E_{S2}^{7\times7}} \)**
  - Containment in \( \eta \)

- **\( R_{\phi} = \frac{E_{S2}^{3\times3}}{E_{S2}^{3\times7}} \)**
  - Containment in \( \phi \)

\( E_{S2,XY} \) is the summed energy of S2 cells in a window of size \( X \times Y \) (\( \eta \times \phi \) units)

- **\( w_2 = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left( \frac{\sum E_i \eta_i}{\sum E_i} \right)^2} \)**
  - Lateral width (physical units)
  - Calculated in a window of size \( 3 \times 5 \) (\( \eta \times \phi \) units)
Discriminating variables for photon ID

**Front Layer (Strip, S1) Variables**

![Histograms showing the distribution of variables for photon identification.](image)

\[
F_{\text{side}} = \frac{E(\pm 3) - E(\pm 1)}{E(\pm 1)}
\]

Containment in \(\eta\)

E(\pm n) is the sum of E in ±n strips about max

\[
\Delta E = \left[ E_{2\text{nd max}}^{S1} - E_{\text{min}}^{S1} \right] / \text{MeV}
\]

\(E_{\text{S1 min}}^{S1}\) is the energy of the strip cell with least energy between the 1\(^{st}\) and 2\(^{nd}\) maxima

\[
E_{\text{ratio}} = \frac{E_{1\text{st max}}^{S1} - E_{2\text{nd max}}^{S1}}{E_{1\text{st max}}^{S1} + E_{2\text{nd max}}^{S1}}
\]

Asymmetry between 1\(^{st}\) and 2\(^{nd}\) maxima

\[
w_{S3} = \sqrt{\frac{\sum E_i(i - i_{\text{max}})^2}{\sum E_i}}
\]

Width (cell units) using 2 strips about max.

\[
w_{S\text{ tot}}
\]

Width (cell units) using ~ 40 strip cells, 20 in \(\eta\) and 2 in \(\phi\).
A prompt photon candidate
A fake photon ($\pi^0$) candidate
Ambient transverse-energy density

- Voronoi tessellation of $\eta$-$\phi$ plane based on jet axis coordinates and jet $E_T$
- Take median density ($E_T$/Area) as ambient energy density in event
- Multiply by area of isolation cone

For events with 1 PV (no pileup):
- PYTHIA: 440 MeV
- HERWIG: 550 MeV
- DATA: 540 MeV

$\int L \, dt = 880 \text{ nb}^{-1}$
- Data 2010, $\sqrt{s} = 7 \text{ TeV}$

Tight Photons
$E_T^\gamma > 15 \text{ GeV}$
Isolation template fit

- Fit isolation distribution in data with sum of signal and background templates

bkg template: data driven, from photon candidates failing a few strip shape variables (weakly correlated with $E_T^{\text{iso}}$)

signal template: data driven, from electrons from $W\to e\nu$ and $Z\to ee$

MTL fit for signal yield for $E_T^{\text{iso}} < 3$ GeV

Results compatible with ABCD method

Agree within uncorrelated uncertainties

$\sqrt{s} = 7$ TeV, $\int L dt = 880$ nb$^{-1}$

$|\eta| < 0.6$

$|\eta| < 1.37$

$|\eta| < 1.52$

$|\eta| < 1.81$
Non collision backgrounds

- Dominant background: a fake photon (from cosmic / beam halo event) overlapping a minimum bias collision

- Use low-EM-threshold calorimeters activated when 0 or 1 bunches in IR

- Estimated to be negligible (~0.1%)
Measured xsection (15-100 GeV, $|\eta|<0.6$)

Table III. The measured isolated prompt photon production cross section, for $0.00 \leq |\eta^\gamma| < 0.60$. The systematic uncertainties originating from the purity measurement, the photon selection, the photon energy scale, the unfolding procedure and the luminosity are shown. The total uncertainty includes both the statistical and all systematic uncertainties, except for the uncertainty on the luminosity.

<table>
<thead>
<tr>
<th>$E_T^\gamma$ [GeV]</th>
<th>$\frac{d\sigma}{dE_T^\gamma}$ [nb/GeV]</th>
<th>stat</th>
<th>syst (purity)</th>
<th>syst (efficiency)</th>
<th>syst (en. scale)</th>
<th>syst (unfolding)</th>
<th>syst (luminosity)</th>
<th>total uncertainty</th>
<th>$\frac{d\sigma}{dE_T^\gamma}$ total [nb/GeV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[15, 20)</td>
<td>5.24</td>
<td>±0.11</td>
<td>+0.52</td>
<td>±0.88</td>
<td>±0.11</td>
<td>±0.51</td>
<td>±0.46</td>
<td>±1.3</td>
<td>6.8</td>
</tr>
<tr>
<td>[20, 25)</td>
<td>1.88</td>
<td>±0.05</td>
<td>+0.18</td>
<td>±0.20</td>
<td>±0.14</td>
<td>±0.04</td>
<td>±0.14</td>
<td>±0.36</td>
<td>2.38</td>
</tr>
<tr>
<td>[25, 30)</td>
<td>0.88</td>
<td>±0.03</td>
<td>±0.07</td>
<td>±0.08</td>
<td>±0.09</td>
<td>±0.02</td>
<td>±0.08</td>
<td>±0.16</td>
<td>1.01</td>
</tr>
<tr>
<td>[30, 35)</td>
<td>0.461</td>
<td>±0.016</td>
<td>+0.029</td>
<td>±0.019</td>
<td>±0.045</td>
<td>±0.009</td>
<td>±0.035</td>
<td>±0.07</td>
<td>0.50</td>
</tr>
<tr>
<td>[35, 40)</td>
<td>0.254</td>
<td>±0.011</td>
<td>+0.017</td>
<td>±0.015</td>
<td>±0.027</td>
<td>±0.005</td>
<td>±0.035</td>
<td>±0.04</td>
<td>0.28</td>
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<tr>
<td>[40, 50)</td>
<td>0.115</td>
<td>±0.005</td>
<td>+0.008</td>
<td>±0.006</td>
<td>±0.009</td>
<td>±0.0002</td>
<td>±0.008</td>
<td>±0.04</td>
<td>0.013</td>
</tr>
<tr>
<td>[50, 60)</td>
<td>0.050</td>
<td>±0.003</td>
<td>+0.003</td>
<td>±0.002</td>
<td>±0.006</td>
<td>±0.001</td>
<td>±0.003</td>
<td>±0.04</td>
<td>0.052</td>
</tr>
<tr>
<td>[60, 100]</td>
<td>0.0120</td>
<td>±0.0007</td>
<td>+0.0007</td>
<td>±0.0006</td>
<td>±0.0013</td>
<td>±0.0002</td>
<td>±0.0013</td>
<td>±0.04</td>
<td>0.0121</td>
</tr>
</tbody>
</table>
Measured xsection (15-100 GeV, 0.6≤|η|<1.37)

TABLE IV. The measured isolated prompt photon production cross section, for 0.60 ≤ |ηγ| < 1.37. The systematic uncertainties originating from the purity measurement, the photon selection, the photon energy scale, the unfolding procedure and the luminosity are shown. The total uncertainty includes both the statistical and all systematic uncertainties, except for the uncertainty on the luminosity.

<table>
<thead>
<tr>
<th>$E_T^\gamma$</th>
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<th>stat</th>
<th>syst (purity)</th>
<th>syst (efficiency)</th>
<th>syst (en. scale)</th>
<th>syst (unfolding)</th>
<th>syst (luminosity)</th>
<th>total uncertainty</th>
<th>JETPHOX $\frac{d\sigma}{dE_T^\gamma}$</th>
<th>total uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>[15, 20)</td>
<td>5.9</td>
<td>±0.2</td>
<td>+1.8</td>
<td>±0.1</td>
<td>±0.5</td>
<td>±0.6</td>
<td>±0.1</td>
<td>±0.6</td>
<td>±2.3</td>
<td>8.5</td>
</tr>
<tr>
<td>[20, 25)</td>
<td>2.23</td>
<td>±0.07</td>
<td>+0.49</td>
<td>±0.1</td>
<td>±0.18</td>
<td>±0.16</td>
<td>±0.04</td>
<td>±0.24</td>
<td>±0.6</td>
<td>3.0</td>
</tr>
<tr>
<td>[25, 30)</td>
<td>1.05</td>
<td>±0.03</td>
<td>+0.16</td>
<td>±0.06</td>
<td>±0.10</td>
<td>±0.10</td>
<td>±0.021</td>
<td>±0.12</td>
<td>±0.19</td>
<td>1.28</td>
</tr>
<tr>
<td>[30, 35)</td>
<td>0.52</td>
<td>±0.02</td>
<td>+0.06</td>
<td>±0.03</td>
<td>±0.04</td>
<td>±0.05</td>
<td>±0.011</td>
<td>±0.06</td>
<td>±0.11</td>
<td>0.64</td>
</tr>
<tr>
<td>[35, 40)</td>
<td>0.313</td>
<td>±0.014</td>
<td>+0.029</td>
<td>±0.021</td>
<td>±0.04</td>
<td>±0.035</td>
<td>±0.032</td>
<td>±0.006</td>
<td>±0.034</td>
<td>±0.06</td>
</tr>
<tr>
<td>[40, 50)</td>
<td>0.146</td>
<td>±0.006</td>
<td>+0.014</td>
<td>±0.011</td>
<td>±0.009</td>
<td>±0.013</td>
<td>±0.013</td>
<td>±0.003</td>
<td>±0.016</td>
<td>±0.05</td>
</tr>
<tr>
<td>[50, 60)</td>
<td>0.062</td>
<td>±0.004</td>
<td>+0.005</td>
<td>±0.004</td>
<td>±0.003</td>
<td>±0.006</td>
<td>±0.006</td>
<td>±0.001</td>
<td>±0.007</td>
<td>±0.010</td>
</tr>
<tr>
<td>[60, 100)</td>
<td>0.0138</td>
<td>±0.0008</td>
<td>+0.0013</td>
<td>±0.0009</td>
<td>±0.0007</td>
<td>+0.0016</td>
<td>±0.0014</td>
<td>±0.0003</td>
<td>±0.0015</td>
<td>±0.0025</td>
</tr>
</tbody>
</table>
Measured xsection (15-100 GeV, 1.52≤|η|<1.81)

**TABLE V.** The measured isolated prompt photon production cross section, for 1.52 ≤ |ηγ| < 1.81. The systematic uncertainties originating from the purity measurement, the photon selection, the photon energy scale, the unfolding procedure and the luminosity are shown. The total uncertainty includes both the statistical and all systematic uncertainties, except for the uncertainty on the luminosity.

|        | Measured |        |        |        |        |        | measured xsection (15-100 GeV, 1.52≤|η|<1.81)  |
|--------|----------|--------|--------|--------|--------|--------|-----------------------------------------------|
|        | Eγ        | dσ/γ    | stat   | syst   | syst   | syst   | syst   | syst   | total  | dσ/γ    | total  |
| [GeV]  | [nb/GeV]  | [nb/GeV]| [nb/GeV]| [nb/GeV]| [nb/GeV]| [nb/GeV]| [nb/GeV]| [nb/GeV]| uncertainty | [nb/GeV]| uncertainty |
|        |          |         |         |         |         |         |         |         |          |         |          |
| [15, 20] | 2.9      | ±0.1    | +0.8   | -0.3   | ±0.5   | +0.3   | -0.3   | ±0.1   | ±0.3   | +1.1    | -0.7    | 3.1     | +0.6    | -0.5    |
| [20, 25] | 1.12     | ±0.04   | +0.15  | -0.08  | ±0.16  | +0.08  | -0.08  | ±0.02  | ±0.12  | +0.27   | -0.24   | 1.10    | +0.20   | -0.15   |
| [25, 30] | 0.47     | ±0.02   | +0.06  | -0.04  | ±0.05  | +0.05  | -0.04  | ±0.01  | ±0.05  | +0.11   | -0.09   | 0.46    | +0.07   | -0.06   |
| [30, 35] | 0.240    | ±0.013  | +0.028 | -0.016 | ±0.023 | +0.025 | -0.026 | ±0.005 | ±0.026 | +0.052  | -0.045  | 0.233   | +0.037  | -0.030  |
| [35, 40] | 0.142    | ±0.009  | +0.018 | -0.010 | ±0.012 | +0.014 | -0.013 | +0.0032| ±0.016 | +0.030  | -0.026  | 0.126   | +0.020  | -0.015  |
| [40, 50] | 0.062    | ±0.004  | +0.005 | -0.004 | ±0.005 | +0.006 | -0.006 | ±0.0013| ±0.007 | +0.011  | -0.010  | 0.058   | +0.008  | -0.007  |
| [50, 60] | 0.0237   | ±0.0025 | +0.0026| -0.0028| ±0.0019| +0.0024| -0.0022| ±0.0005| ±0.003 | +0.005  | 0.0243  | +0.00033| -0.0027 |
| [60, 100]| 0.0066   | ±0.0005 | +0.0005| -0.0003| ±0.0005| +0.0008| -0.0007| ±0.0002| ±0.0007| +0.0013 | -0.0012 | 0.0057  | +0.0007 | -0.0006 |
# Systematic uncertainties (45-400 GeV analysis)

<table>
<thead>
<tr>
<th>Systematic</th>
<th>Reco. Eff.</th>
<th>ID Eff.</th>
<th>Yield</th>
<th>Unfolding</th>
<th>Theory</th>
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<td>&lt; 1%</td>
<td>~ 1%</td>
<td>&lt; 2%</td>
<td>3%</td>
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<td>$E_T$ Resolution</td>
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<tr>
<td>Background Correlations</td>
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<td>Transverse Energy Leakage</td>
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<td>Hard/Brem Composition</td>
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<td>1% – 7%</td>
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<td>Intrinsic Precision</td>
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<td>Parton level Isolation</td>
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</table>
Selected data/MC comparison

**ATLAS**

**Preliminary**

Unconverted photons

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

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

\( R_\eta \)

\( \eta \) distribution

\( \phi \) distribution

**Isolation** [GeV]

\( \sqrt{s} = 7 \text{ TeV}, \int \text{Ldt} = 878 \text{ nb}^{-1} \)

- Data 2010
  - Simulation (fake \( \gamma \))
  - Simulation (isolated prompt \( \gamma \))
  - Simulation (non-isolated prompt \( \gamma \))

\( \eta \) distribution

Giovanni Marchiori

Measurements of isolated prompt photons at ATLAS
Using MSTW 2008 PDFs (barrel)
Using MSTW 2008 PDFs (end-cap)

\[ \frac{d\sigma}{dE_T} \text{ [pb GeV}^{-1}] \]

\[ \int L dt = 35 \text{ pb}^{-1} \]

luminosity uncertainty

JETPHOX MSTW 2008

ATLAS Preliminary

\[ 1.52 < |\eta| < 1.81 \]

\[ E_T [\text{GeV}] \]

\[ \text{data/theory} \]

\[ 50 \quad 100 \quad 150 \quad 200 \quad 250 \quad 300 \quad 350 \quad 400 \]

\[ 0.4 \quad 0.6 \quad 0.8 \quad 1 \quad 1.2 \quad 1.4 \quad 1.6 \]
Using MSTW 2008 (15-100 GeV)

\[
\frac{d\sigma}{dE_T} \text{[pb GeV}^{-1}\text{]} = \begin{cases} \text{MSTW PDFs} \\ \text{JETPHOX NLO pQCD} \end{cases}
\]

\[\sqrt{s} = 7 \text{ TeV} \]
\[E_T^{\text{iso}} < 3 \text{ GeV} \]

\[\Delta t = 880 \text{ nb}^{-1} \]

\[\text{Data 2010, luminosity uncertainty} \]

\[JETPHOX \text{ systematic uncertainty} \]

\[\mu_I = \mu_F = \mu_R = E_T^{\gamma} \]

\[\text{MSTW 2008, JETPHOX NLO pQCD} \]

\[\text{Luminosity uncertainty} \]

\[\text{Data 2010} \]

\[\text{ATLAS} \]

\[\text{Measurements of isolated prompt photons at ATLAS} \]

\[\text{Giovanni Marchiori} \]

\[\text{Les Houches Winter Workshop- 16 February 2011} \]
Theoretical predictions

• pQCD predictions for the inclusive isolated prompt photon cross sections are estimated with JetPhox 1.2.2 (Fontannaz et al, Eur. Phys. J. C21 (2001) 303)

  • NLO, parton-level standalone event generator

  • use CTEQ 6.6 PDFs as default (cross-checked with MSTW2008: 3-5% difference)

  • scales (fragmentation/factorization/renormalization) set to $E_T(\gamma)$

    • no point of minimal sensitivity to scale variation found

  • isolation criterion implemented in theoretical computation: $E_T^{\text{iso}}<4$ GeV from (colored) partons within $\eta$-$\phi$ cone of radius 0.4 around the photon
Theoretical uncertainties

- **PDFs uncertainties**: CTEQ 6.6 PDFs varied between 68% CL bands
  - 4% uncertainty at $E_T(\gamma)=15$ GeV, 2% at 100 GeV and above
- **scale uncertainties**: scales varied independently between 0.5x and 2.0x $E_T(\gamma)$
  - 20% uncertainty at 15 GeV, 12% at 100 GeV, 8% at 400 GeV
- **isolation cut uncertainty** (when matched to particle-level isolation criterion): vary isolation cut by +/- 2GeV
  - uncertainty ~2%