Photon and diphoton production at ATLAS

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on behalf of the ATLAS Collaboration

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Why measure prompt photons?

probe the gluon content of the proton

QCD backgrounds to new physics

test NLO $pQCD$
predictions using a measurement without jets

resummation

$k_T$ factorisation

fragmentation important at low $E_T$, suppressed by isolation cut. MCs rely on fragmentation function to compute

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Photon physics at the LHC with the ATLAS detector
We measure *isolated prompt* photons

**prompt**

- Direct from the hard scatter
- Parton fragmentation
  - More important at low $E_T$

**isolated**

- Isolation criterion imposed to reduce QCD background
  - Photons from neutral meson decays in jets
- Reduces fragmentation component
  - ~30% of inclusive cross section at 15 GeV
  - <10% above 35 GeV
ATLAS prompt photon measurements

  - 0.88 pb\(^{-1}\), 10 GeV-threshold photon trigger
  - 15 < \( E_T \) < 100 GeV
  - |\( \eta \)| in [0,0.6) [0.6,1.37) [1.52, 1.81)

  - 35 pb\(^{-1}\), 40 GeV-threshold photon trigger
  - 45 < \( E_T \) < 400 GeV
  - |\( \eta \)| in [0,0.6) [0.6,1.37) [1.52, 1.81) [1.81, 2.37)

  - 37 pb\(^{-1}\), 15 GeV-threshold diphoton trigger
  - \( E_T > 16 \) GeV
  - \( m_{\gamma\gamma} < 200 \) GeV
Measuring photons with ATLAS

- **Inner detector**
  - track charged particles
  - measure transition radiation
  - e/γ discrimination
  - γ conversion reconstruction

- **Pb-LAr EM calorimeter**
  - η/φ/longitudinal segmentation
  - fine granularity in 1st layer up to η<2.37
  - γ energy and direction
  - γ/π⁰ separation (EM shower moments)
Photon identification

S3 ("Back")

S3 ("Middle")

S1 ("Strips")

Presampler

• **loose and tight selections**
• optimized separately for unconverted and converted $\gamma$

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**Photon Identification at ATLAS**

- Photon identification is crucial for understanding the properties of particles at the Large Hadron Collider (LHC).
- ATLAS detector is used to study various processes, including diphoton production.
- The identification criteria are optimized separately for unconverted and converted photons.
- Loose and tight selections are used to improve the signal-to-background ratio.

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**Graphical Representation**

- The graphs show the distribution of events based on different selection criteria.
- The x-axis represents $R$, a variable related to the pseudorapidity ($\eta$).
- The y-axis shows the number of entries per 0.025 bin.
- Data from 2010 are compared with simulation results for both unconverted and converted photons.

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**Technical Details**

- ATLAS Preliminary
- $\sqrt{s} = 7$ TeV, $\int L dt = 15.8$ nb$^{-1}$
- $|\eta| < 0.6$

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**Conclusion**

- The results from ATLAS provide valuable insights into high-energy physics.
- Further analysis and improvements in photon identification are ongoing to enhance the precision of measurements.
 Photon isolation

- Define an isolated photon comparable to theory
- Isolation energy corrected event-by-event for leakage, pileup and underlying event

✓ Following Cacciari, Salam and Sapeta, JHEP 04, 065 (2010)
✓ Average correction for 1 Primary vertex
  - PYTHIA: 440 MeV
  - HERWIG: 550 MeV
  - DATA: 540 MeV

avoid model-dependent underlying event corrections
Photon identification efficiency

**ATLAS**

- Simulation $\sqrt{s} = 7$ TeV
- Systematic uncertainty

**Unconverted $\gamma$**
- $|\eta|<0.6$
- $E_T^{\text{iso}} < 3$ GeV

**Efficiency**

$\epsilon_{\text{ID}} \sim 95\%$ for $E_T > 100$ GeV

$\epsilon_{\text{trigger}} \sim 100\%$ for $\gamma$ passing the offline selections

$\epsilon_{\text{reco}} \sim 85 (70)\%$ in EM Barrel (EndCaps)

- Main loss due to dead readouts, recovered in Winter shutdown

**From MC, corrected for Data/MC discrepancies** (EM shower moments)

- Separately for unconverted and converted $\gamma$

- Combined in $\gamma\gamma$ event efficiency according to $\gamma\gamma$ $E_T$ spectrum and conversion composition

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photon and diphoton production at ATLAS
inclusive photon cross section
Background estimate

\[ N_{\text{sig}}^A = N^A - N^B \frac{M^A}{M^B} \]

\[ P = 1 - \frac{N^B}{N^A} \frac{M^A}{M^B} \]
Prompt photon purity

Main systematic uncertainties:
- MC inputs (e.g. signal leakage correction, up to 10%)
- Background control region definition (up to 6%)

Isolated electron contamination estimated from data and MC control samples.
Inclusive isolated cross section

JETPHOX isolation < 4 GeV in cone $\Delta R = 0.4$
(vary isolation from 2 to 6 GeV)
CTEQ 6.6 PDFs. MSTW 2008: 3-5% difference

JETPHOX uncertainty dominated by scale variation
(independently from $\mu = 0.5 E_T \gamma$ to $\mu = 2E_T \gamma$):
20% $\rightarrow$ 8%
Inclusive isolated cross section

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

- Data 2010 \( \int L dt = 35 \text{ pb}^{-1} \)
- Luminosity uncertainty
- JETPHOX CTEQ 6.6
- \( E_T^\text{iso}(\Delta R < 0.4) < 4 \text{ GeV} \)

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

- Data 2010 \( \int L dt = 0.88 \text{ pb}^{-1} \)
- Luminosity uncertainty
- JETPHOX CTEQ 6.6
- \( E_T^\text{iso}(\Delta R < 0.4) < 4 \text{ GeV} \)

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

\[ \text{data/theory} \]

\[ 0.6 \quad 0.8 \quad 1 \quad 1.2 \quad 1.4 \]

\[ 60 \quad 100 \quad 150 \quad 200 \quad 250 \quad 300 \quad 350 \quad 400 \]

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

\[ 1.81 < |\eta| < 2.37 \]
diphoton cross section
Background estimates

2x2D-sidebands

L’ sample, leading candidate

Control region

non-TIGHT

C

D

Identification cut

Signal region

TIGHT

A

B

Control region

E_{T,1}^{iso} [GeV]

-5 0 5 10 15 20 25 30 35

A sample, sub-leading candidate

Control region

non-TIGHT

C’

D’

Identification cut

Signal region

TIGHT

A’

B’

Control region

E_{T,1}^{iso} [GeV]

-5 0 5 10 15 20 25 30 35

2D isolation template fit

ATLAS

Data 2010, \sqrt{s} = 7 TeV, \int L dt = 37 pb^{-1}

E_T > 16 GeV

γγ

γj

jγ+jj

γγ+jγ+jj

(leading photon)

events / GeV

5 10 15 20 25

ATLAS

Data 2010, \sqrt{s} = 7 TeV, \int L dt = 37 pb^{-1}

E_T > 16 GeV

γγ

γj

jγ+jj

γγ+jγ+jj

(sub-leading photon)

events / GeV

5 10 15 20 25

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photon and diphoton production at ATLAS
Background estimates

\[
\begin{pmatrix}
PP \\
PF \\
FP \\
FF
\end{pmatrix} =
\begin{pmatrix}
\epsilon_1 \epsilon_2 \\
\epsilon_1 (1 - \epsilon_2) \\
(1 - \epsilon_1) \epsilon_2 \\
(1 - \epsilon_1)(1 - \epsilon_2)
\end{pmatrix}
\begin{pmatrix}
\epsilon_1 f_2 \\
\epsilon_1 (1 - f_2) \\
(1 - \epsilon_1)(1 - f_2) \\
(1 - \epsilon_1)(1 - \epsilon_2)
\end{pmatrix}
\begin{pmatrix}
f_1 \epsilon_2 \\
f_1 (1 - \epsilon_2) \\
(1 - f_1) \epsilon_2 \\
(1 - f_1)(1 - \epsilon_2)
\end{pmatrix}
\begin{pmatrix}
f_1 f_2 \\
f_1 (1 - f_2) \\
(1 - f_1) f_2 \\
(1 - f_1)(1 - f_2)
\end{pmatrix}
\begin{pmatrix}
W_{\gamma\gamma} \\
W_{\gamma j} \\
W_{jj} \\
W_{jjj}
\end{pmatrix}
\]

Passes or Fails

\( \epsilon_i \) = probability for a \( \gamma \) to pass isolation cut (data-driven)

\( f_i \) = probability for a jet to pass isolation cut (data-driven)

Event weights

accounting for the correlation of the isolation energy of the 2 \( \gamma \) candidates

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**ATLAS**

Data 2010, \( \sqrt{s} = 7 \text{ TeV}, \int L dt = 37 \text{ pb}^{-1} \)

(TITI sample)

- event weighting
- 2D fit
- 2D-sidebands

**e\(\rightarrow\)\(\gamma\) fake rate measured from data from e\(\gamma\) pairs close to Z mass**
Isolated diphoton cross section

\[ \frac{d\sigma}{dm_{\gamma\gamma}} \text{ [pb GeV]} \]

Data 2010, $\sqrt{s} = 7$ TeV, $\int L_{\text{int}} = 37$ pb$^{-1}$

- $p_T > 16$ GeV, $E_T^{\text{iso(part)}} < 4$ GeV, $\Delta R > 0.4$
- $|\eta| < 2.37$ excluding $1.37 < |\eta| < 1.52$

- measured (stat)
- measured (stat $\oplus$ syst)
- DIPHOX
- ResBos

\[ \text{ATLAS} \]

\[ \text{DIPHOX} \]

\[ \text{ResBos} \]
Isolated diphoton cross section

\[ \text{Data 2010, } \sqrt{s} = 7 \text{ TeV, } \int Ldt = 37 \text{ pb}^{-1} \]

- $p_T > 16 \text{ GeV, } E_T^{\text{iso(part)}} < 4 \text{ GeV, } \Delta R_{\gamma\gamma} > 0.4$
- $|\eta| < 2.37$ excluding $1.37 < |\eta| < 1.52$

- measured (stat)
- measured (stat ⊕ syst)
- DIPHOX
- ResBos
More than 1 fb$^{-1}$ collected in 2011...

\[ \text{ATLAS Preliminary} \]

\[ \sqrt{s} = 7 \text{ TeV}, \int \text{Ldt} = 1.08 \text{ fb}^{-1} \]

- Data 2011 (tight, isolated $\gamma$)
  $E_T^{\text{iso}} < 5 \text{ GeV}$
Unconverted $E_{T}^{iso} < 5$ GeV
Pass tight cuts $E_{T} = 960$ GeV
Summary

• ATLAS has measured on the full \( pp \) collision data set collected in 2010 at \( \sqrt{s} = 7 \) TeV (~35 pb\(^{-1}\)) the production cross-sections for isolated photons and isolated diphotons
  ✓ Isolation energy corrected event-by-event for pileup and UE
  ✓ Data-driven background subtraction

• Results in good agreement with theoretical pQCD computation at NLO. Some differences observed:
  ✓ Inclusive photon production at low \( E_T \) (Fragmentation? \( K_T \) factorization?)
  ✓ Azimuth separation for diphoton production (Resummation?)

• ATLAS is capable to explore the photon physics in a robust way!

• Looking ahead...
  ✓ Photon + (heavy flavor) jets
  ✓ Inclusive photons at very high ET, using refined isolation prescriptions
  ✓ Diphotons at high \( m_{\gamma\gamma} \)
  ✓ Double/triple differential cross sections, cross section ratios, …