Photon, di-photon and photon+jet production measured with the ATLAS detector

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Today's talk will concentrate on the recent photon cross section results from ATLAS:
- Inclusive photons
- Photon+jet dynamics
- Di-photons

For single photon production there are three key processes:

- Compton
- Annihilation
- Fragmentation

Similarly for di-photons:

- Born
- Box
- Fragmentation
Motivation

- In the new phase space of the LHC, photon measurements:
  - Test perturbative QCD
  - Probe gluon content of the proton
  - Understand photon background for Higgs and New Physics searches
- Photon-jet + di-photon measurements also improve our understanding of the fragmentation component

- High luminosity  →  High statistics
- Precise detectors  →  Low systematics
- Reduced uncertainties  →  more stringent tests of existing models

Pseudorapidity: \( \eta = -\ln \left( \tan \frac{\theta}{2} \right) \)
Reconstruction

- Reconstruct photons from EM calorimeter cells
  - No track → unconverted
  - 1 or 2 track matching → converted
- Main background from $\pi^0$ in jets
- Use shower shape variables in first layer

- "Tight" selection to identify signal $\gamma$
- $\varepsilon_{ID} \rightarrow$ how many reco photons pass the tight selection
• Require the photon to be isolated:
  • $E_T^{iso}$ is the energy in a cone of 0.4
• NLO: all partons in the cone
• LO: all particles in the cone

• Experiment:
  • Remove photon cluster from the cone
  • Correct for underlying-event and pile-up effects using the "jet-area" method
In 2010 measurement reached 400 GeV
2011 reaches 1 TeV

Apply $E_T^{\text{iso}} < 7$ GeV
- 4 GeV in 2010

Highest disagreement to NLO at low $E_T$

LO MC's match shape well, but differ in normalisation

Above 700 GeV: large PDF (gluon) uncertainties

At low $E_T$ 5% difference between CT10 and MSTW2008

From NLO (Jetphox) fragmentation negligible >500 GeV
Inclusive photon

Also measured:
- For $1.52 < |\eta| < 2.37$
- As a function of $\eta$
- Total cross sections

| $\sigma$(pb) | $|\eta|<1.37$ | $1.52<|\eta|<2.37$ |
|-------------|-----------------|---------------------|
| ATLAS       | $234\pm2$(stat)$+13-9$(syst)$\pm4$(lumi) | $122\pm2$(stat)$+9-7$(syst)$\pm2$(lumi) |
| CT10        | $203\pm25$      | $105\pm15$          |
| MSTW        | $212\pm24$      | $109\pm15$          |

ATLAS Preliminary

$\int L dt = 4.7 \text{ fb}^{-1}$

$E_T^* > 100 \text{ GeV}$

ATLAS Preliminary
• Study photon+jet system to gain insights into size of fragmentation contribution, the likely source of disagreement with theory

• Two measurements made with 2010 data:
  • Investigating the same/opposite side nature of the photon/jet probes different fragmentation fractions
  • Calculate $\sigma$ for different $y_{\text{jet}}$ cuts and as a function of $E_T^{\gamma}$
STDM-2012-18

- **NEW**: Photon-jet dynamics (2010 data)
- Anti-kt jets $R = 0.6 \ |y^{jet}| < 2.37$
- $E_T^{iso} < 4 \text{ GeV} \ \gamma$ - jet separation $\Delta R > 1.0$
- Measure cross section for: $E_T^\gamma, p_T^{jet}, |y^{jet}|, \Delta \phi^{\gamma j}, m^{\gamma j}$ and $|\cos \theta^{\gamma j}|$
- Good agreement in most variables

- Same $E_T^\gamma$ difference as prev results
- Experimental errors often smaller than theoretical
- $\Delta \phi^{\gamma j} > \pi/2$ for NLO, Pythia and Sherpa perform better than Herwig
- Measuring $|\cos \theta^{\gamma j}|$ shows good agreement to NLO
  - Apply extra constraints $|\eta^{\gamma} + y^{\text{jet}}| < 1.185$, $m^{\gamma j} > 161 \text{GeV}$ and $|\cos \theta^{\gamma j}| < 0.83$ to remove any distortions due to the restrictions $E_T^{\gamma}$, $\eta^{\gamma}$, $p_T^{\text{jet}}$, $y^{\text{jet}}$

- Region at high $|\cos \theta^{\gamma j}|$ most sensitive to fragmentation
  - Shape much closer to direct contribution (differ due to spin of exchanged particle)
  - Also can be investigated at low $E_T^{\gamma}$, $p_T^{\text{jet}}$ and $M^{\gamma j}$
In 2011 data there is also an update of the di-photon $\sigma$
  - Key to understand backgrounds to di-photon searches

Need to remove jet-jet and $\gamma$-jet background events
Use 2 subtraction techniques:
  - 2D Template Fit with leakage correction
  - 2x2D Sidebands, used previously

Photon selection:
  - Two isolated ($<4$ GeV) photons $E_T > 25, 22$ GeV
  - Separated by $\Delta R > 0.4$
Di-photon

Variables for $\sigma$: $m_{\gamma\gamma}$, $p_T$, $\Delta\phi_{\gamma\gamma}$, and $\cos\theta^*_{\gamma\gamma}$

- **Sherpa** does better at modelling the shape than **Pythia**
  - Both are rescaled by a factor of 1.2
  - Sherpa has additional NLO contributions to help model $p_T$, $\gamma\gamma$
  - Sherpa different to data at large $m_{\gamma\gamma}$ and $\cos\theta^*_{\gamma\gamma}$
• Variables for $\sigma$: $m_{\gamma\gamma}$, $p_T$, $\Delta \phi_{\gamma\gamma}$ and $\cos \theta^*_{\gamma\gamma}$

• **Sherpa** does better at modelling the shape than **Pythia**

• **NNLO** does better than **NLO**
  • Without soft gluon resummation see excess at $\Delta \phi_{\gamma\gamma} \approx \pi$
  • NNLO lacks the fragmentation contribution, see high $|\cos \theta^*|$
Summary

- New results on inclusive, photon+jet and di-photon cross sections have been presented.
- In general, all are in good agreement with MC.
  - As before highest disagreement at low $E_T$.
- Measurements of photon+jet and di-photon systems show the impact of the fragmentation contribution.
  - Shows the importance of NNLO calculations.
ATLAS Measurements

- Inclusive photons

- Photon+jet
  - [2010] dynamics:

- Diphotons
    - http://link.springer.com/article/10.1007%2FJHEP01%282013%29086

- [dataset analysed] *=sub-set of full dataset (880nb⁻¹)
- Latest results in red
- Jet algorithm used by ATLAS with R=0.4 and 0.6
- Infrared/collinear safe
- Regular cone-like jets
- Clustering for $d_{ij} <$ jet radius R

$$d_{ij} = \min \left\{ K_{t_i}^{-2}, K_{t_j}^{-2} \right\} \times \frac{(\Delta \Phi_{ij}^2 + \Delta \eta_{ij}^2)}{R^2}$$

- Jets are formed from clusters of energy (for noise suppression)
- Jets are calibrated to correct the calorimeter energy response and restore the Jet Energy Scale
  - Non-compensation
  - Dead material
  - Out of cone effects

• Taking the inclusive photon results from both ATLAS and CMS it was shown that the gluon PDF uncertainty can be reduced by 20%.

L. Carminati, et al., EPL 101 (2013) 61002

• Similar studies of the ATLAS photon+jet results show improvements in the quark PDFs too.

• With full error correlations the PDF impact could be even more significant.