19 July

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

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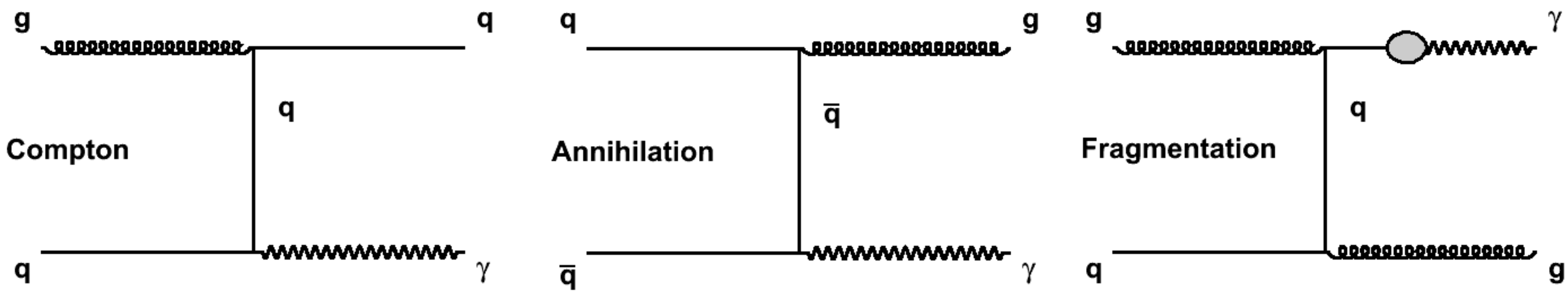
on behalf of the ATLAS collaboration

McGill

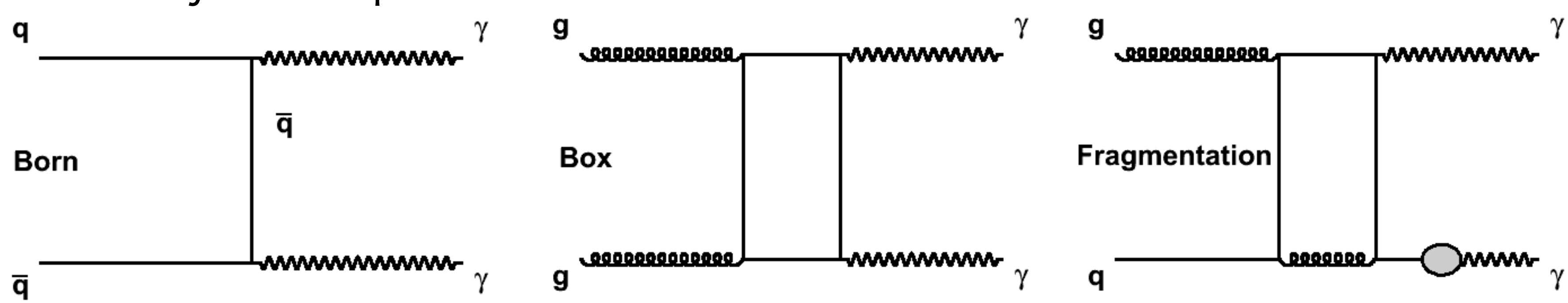
Introduction

- 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



- Similarly for di-photons:



Motivation

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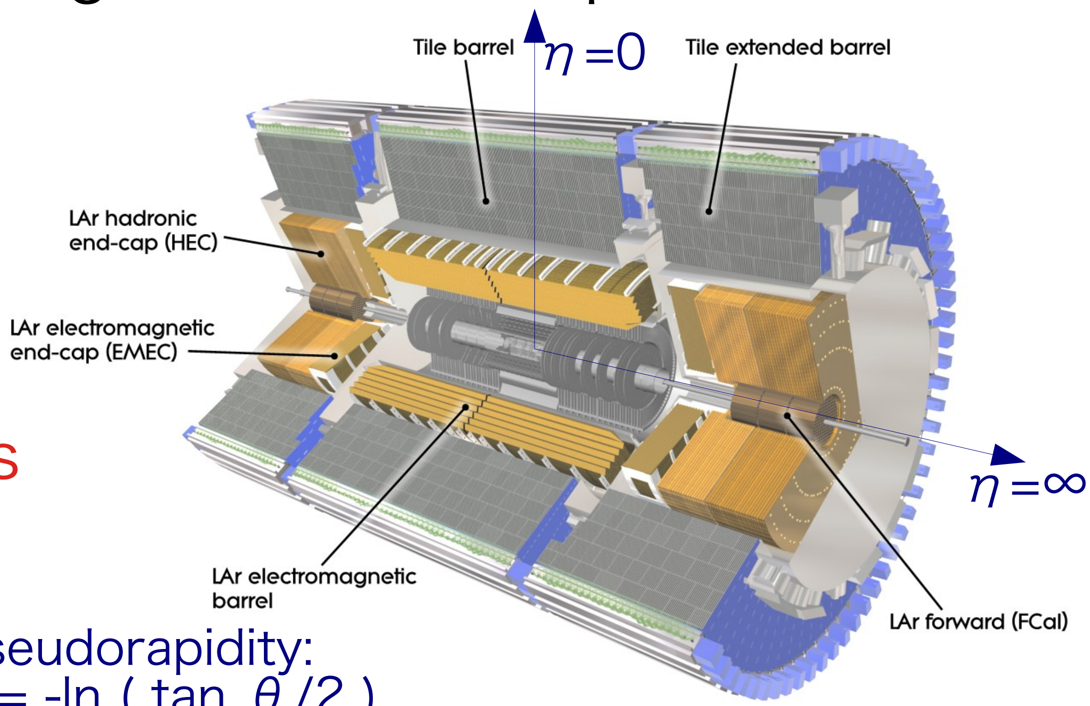
- In the new phase space of the LHC, photon measurements:
  - Test perturbative QCD
  - Probe gluon content of the proton
  - Understand photon background for Higgs and New Physics searches
- Photon-jet + di-photon measurements also improve our understanding of the fragmentation component

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

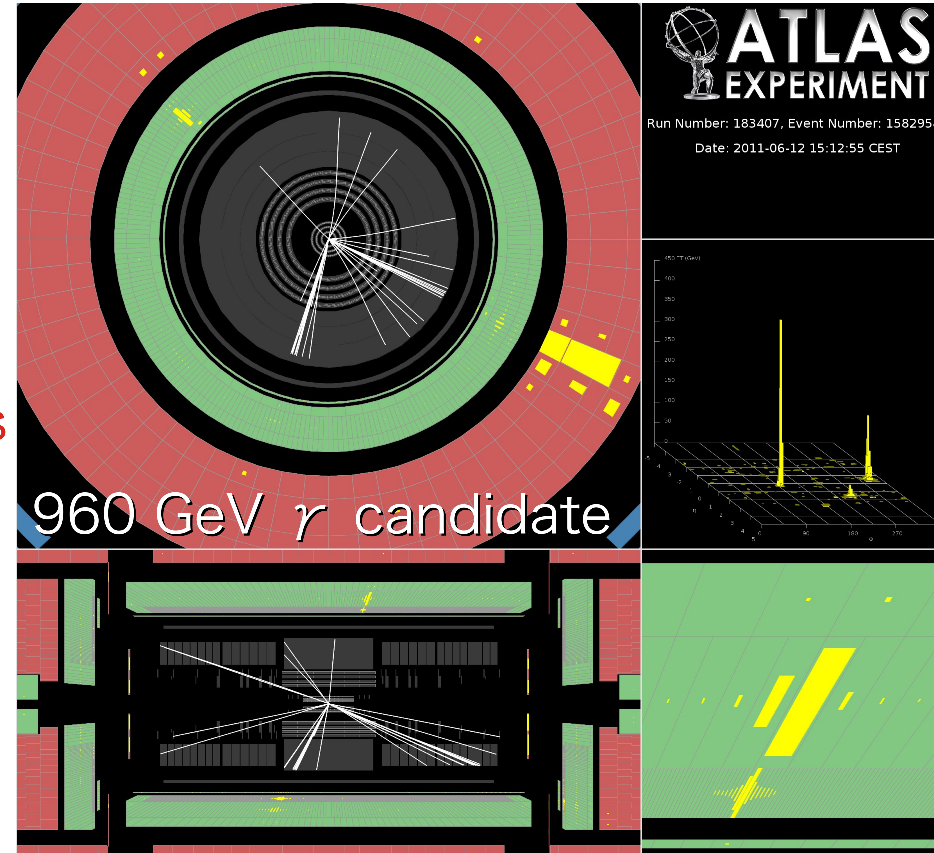


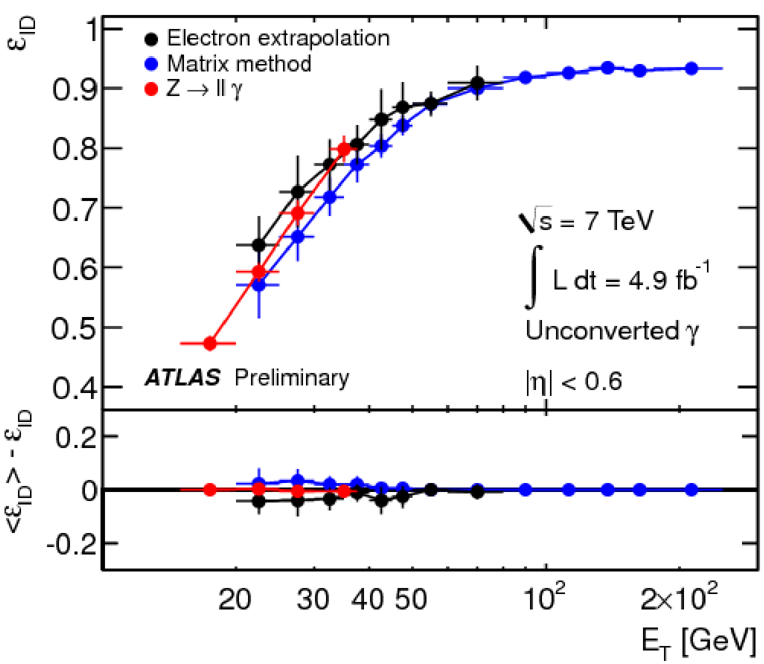
Pseudorapidity:
$\eta = -\ln(\tan\theta/2)$

Reconstruction

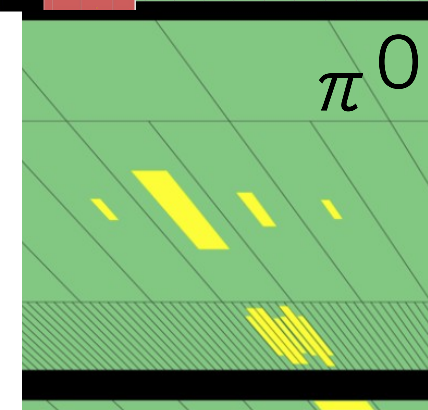
- Reconstruct photons from EM calorimeter cells
  - No track → unconverted
  - 1 or 2 track matching → converted

- Main background from π^0 in jets
- Use shower shape variables in first layer



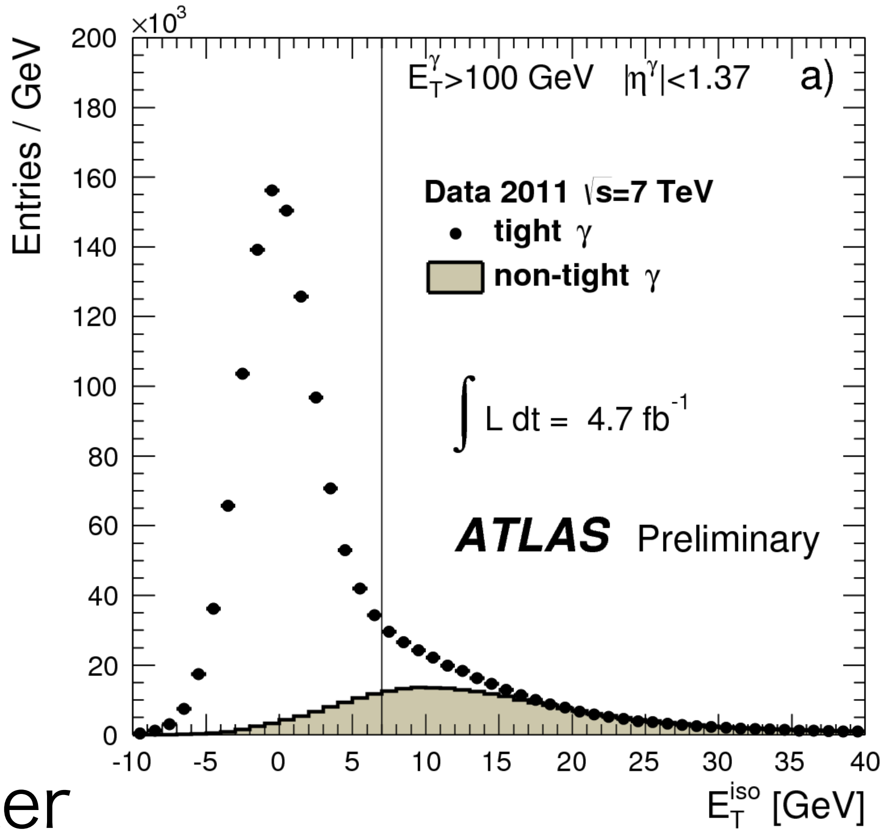


- "Tight" selection to identify signal γ
- ε_{ID} → how many reco photons pass the tight selection



Photon isolation

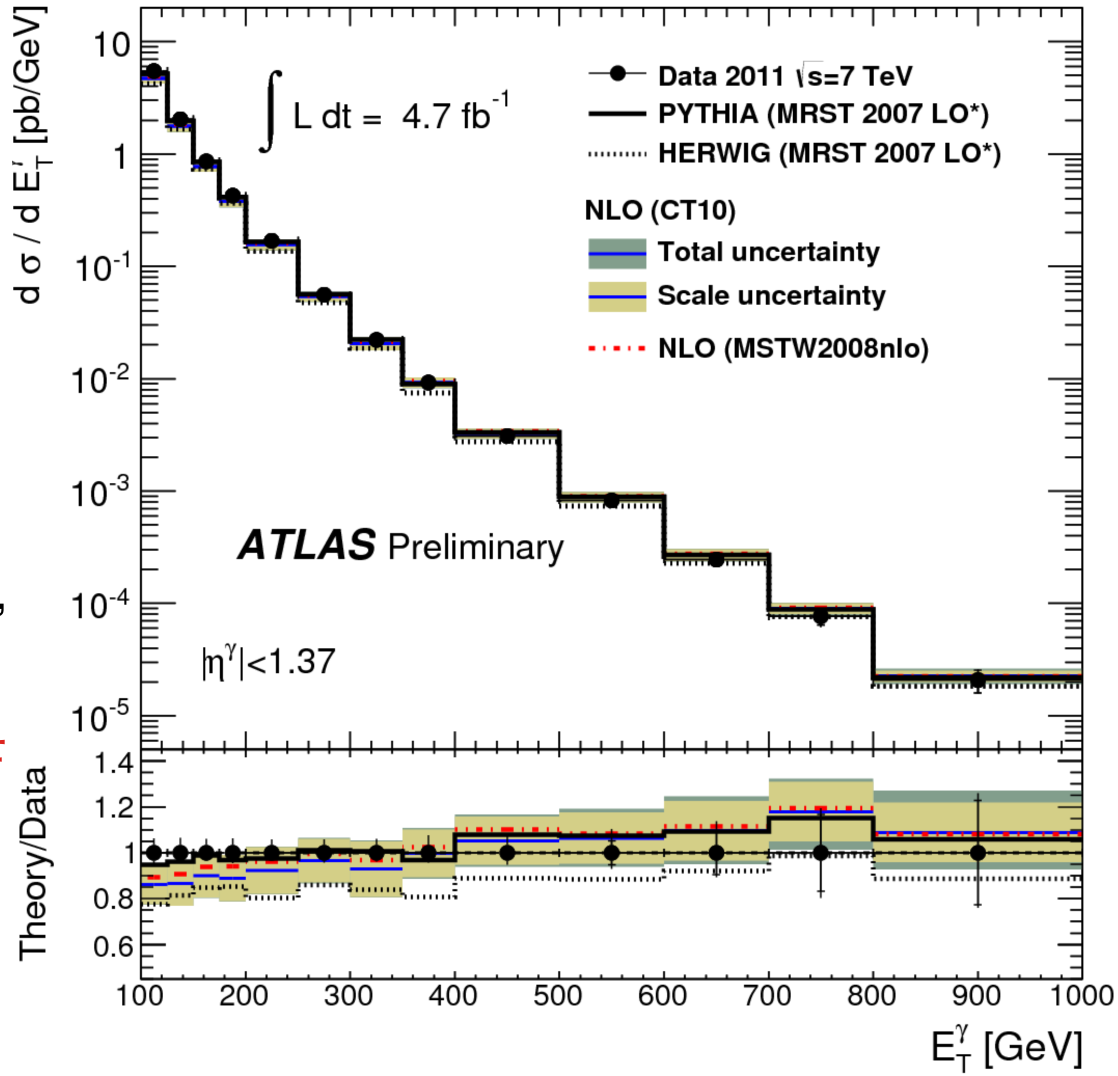
- Require the photon to be isolated:
  - E_T^{iso} is the energy in a cone of 0.4
  - NLO: all partons in the cone
  - LO: all particles in the cone
  - Experiment:
    - Remove photon cluster from the cone
    - Correct for underlying-event and pile-up effects using the "jet-area" method
      - M. Cacciari, G. P. Salam, and S. Sapeta, JHEP 04, 065 (2010)



Inclusive photon

ATLAS-CONF-2013-022

- In 2010 measurement reached 400 GeV
- 2011 reaches 1 TeV
- Apply E_T^{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



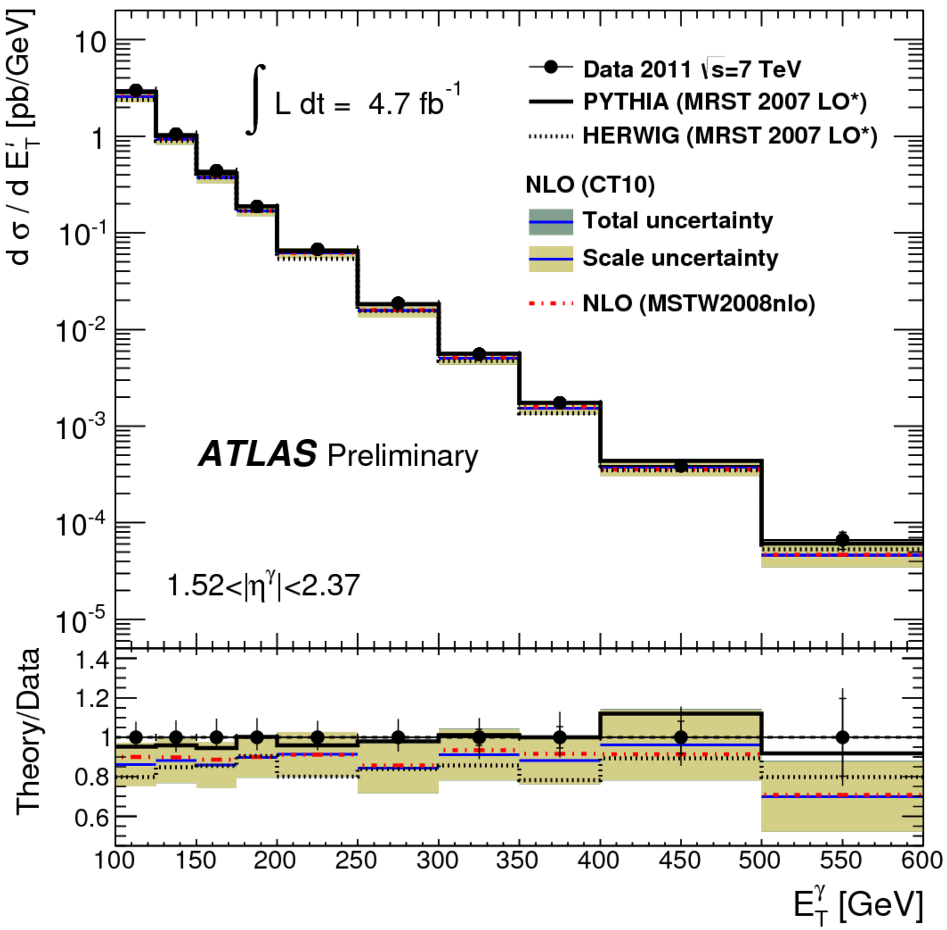
- From NLO (Jetphox) fragmentation negligible >500 GeV

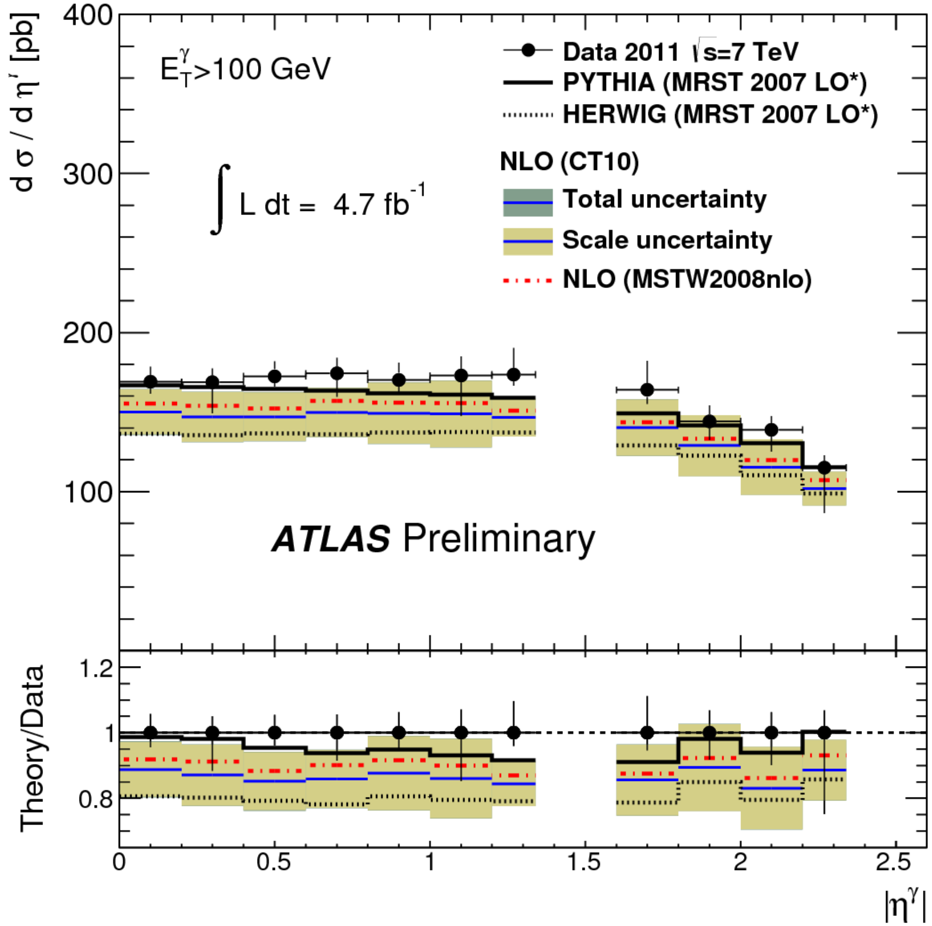
Inclusive photon

ATLAS-CONF-2013-022

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

σ(pb)	|η|<1.37	1.52<|η|<2.37
ATLAS	234±2(stat)+13-9(syst)±4(lumi)	122±2(stat)+9-7(syst)±2(lumi)
CT10	203±25	105±15
MSTW	212±24	109±15





Photon + Jet

Phys. Rev. D 85 (2012) 092014

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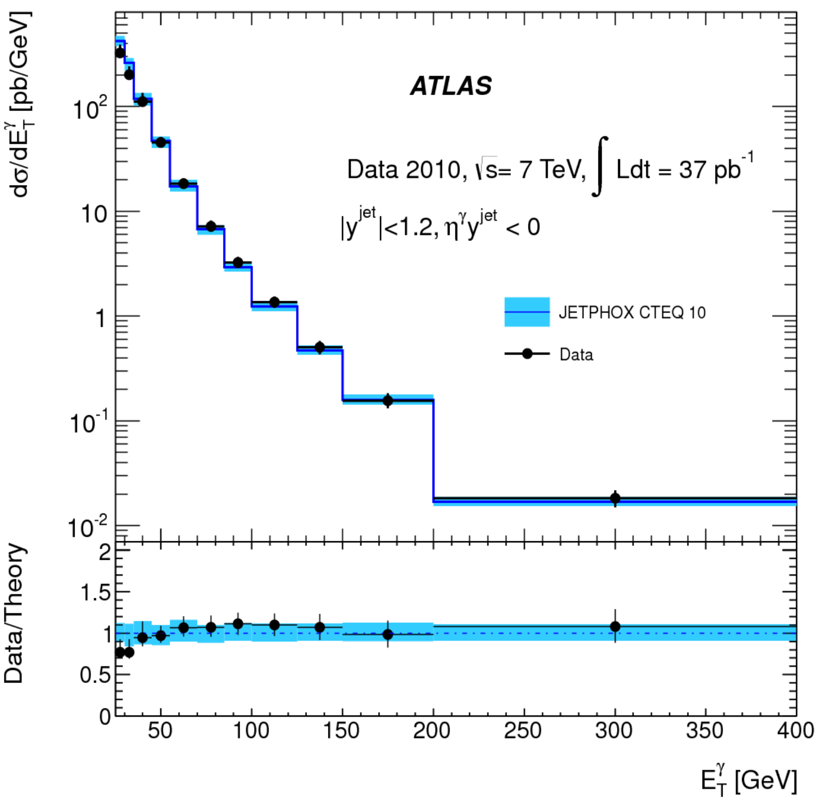
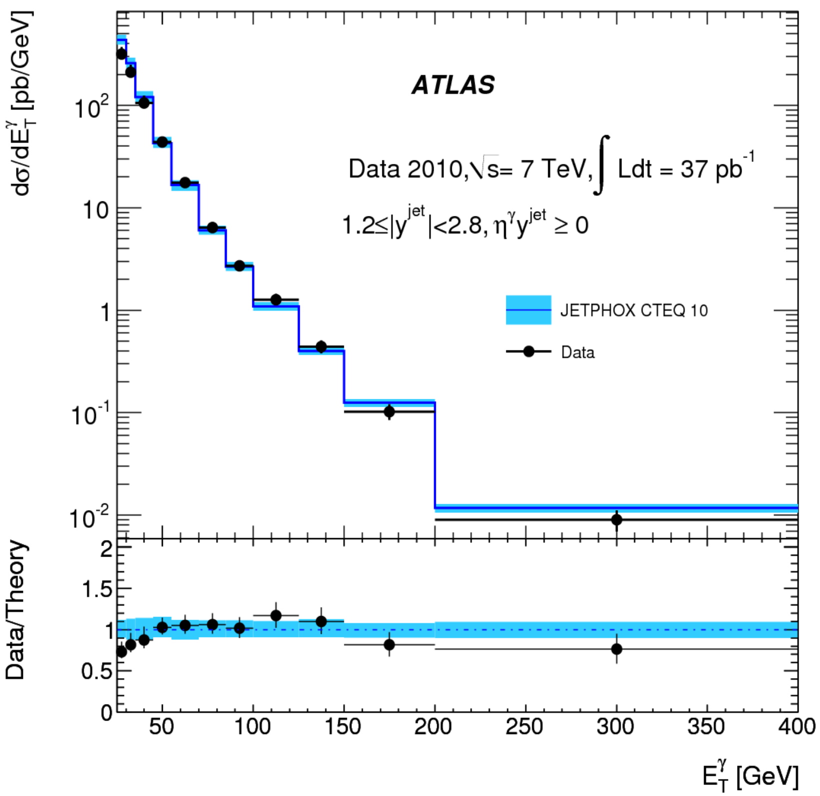
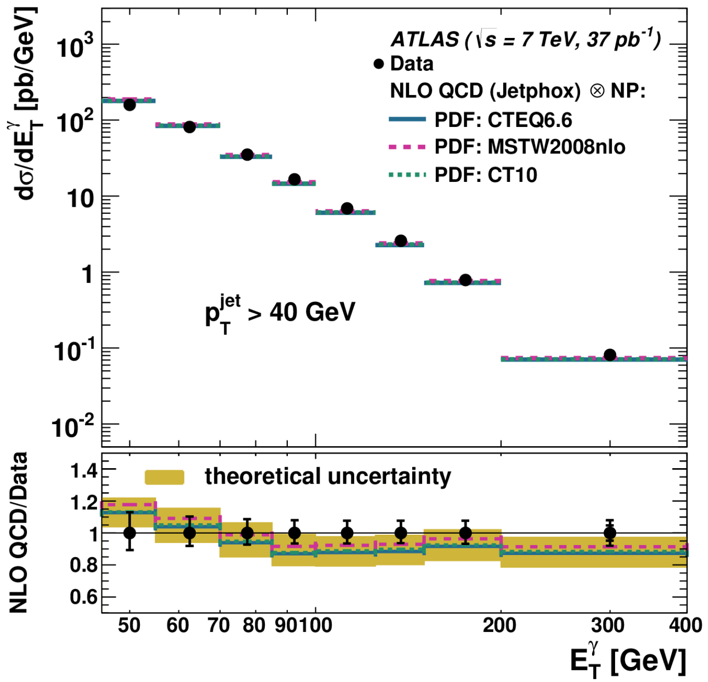
- Study photon+jet system to gain insights into size of fragmentation contribution, the likely source of disagreement with theory
- Two measurements made with 2010 data:
  - Investigating the same/opposite side nature of the photon/jet probes different fragmentation fractions
  - Calculate σ for different y^{jet} cuts and as a function of $E_T{}^{\gamma}$



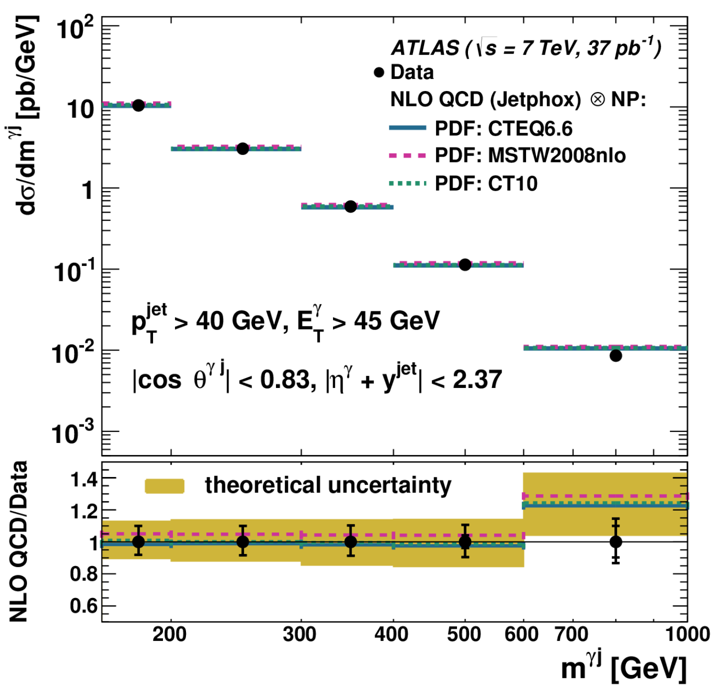


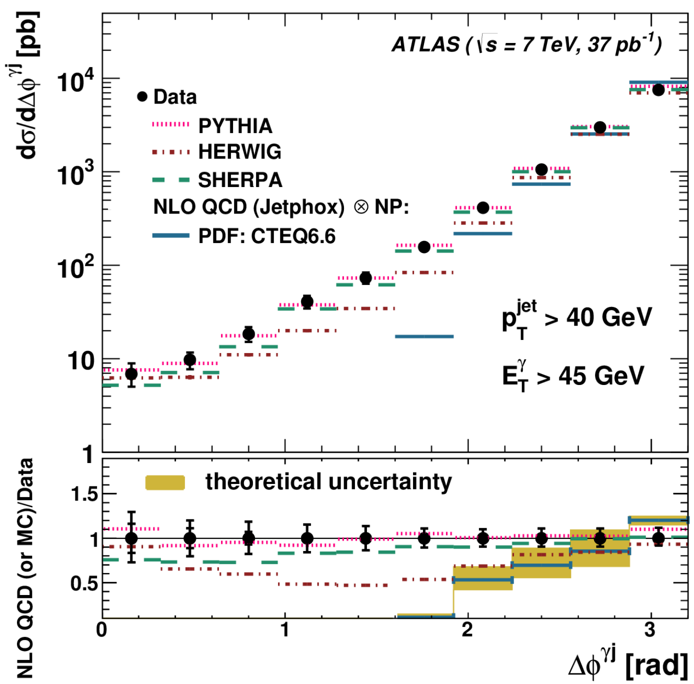


- NEW: Photon-jet dynamics (2010 data)
- Anti-kt jets R = 0.6 $|y^{jet}| < 2.37$
- E_T^{iso}<4 GeV γ-jet separation ΔR>1.0
- Measure cross section for:

E_T^{γ}, p_T^{jet}, $|y^{jet}|$, $\Delta\Phi^{\gamma j}$, $m^{\gamma j}$ and $|\cos\ \theta^{\gamma j}|$

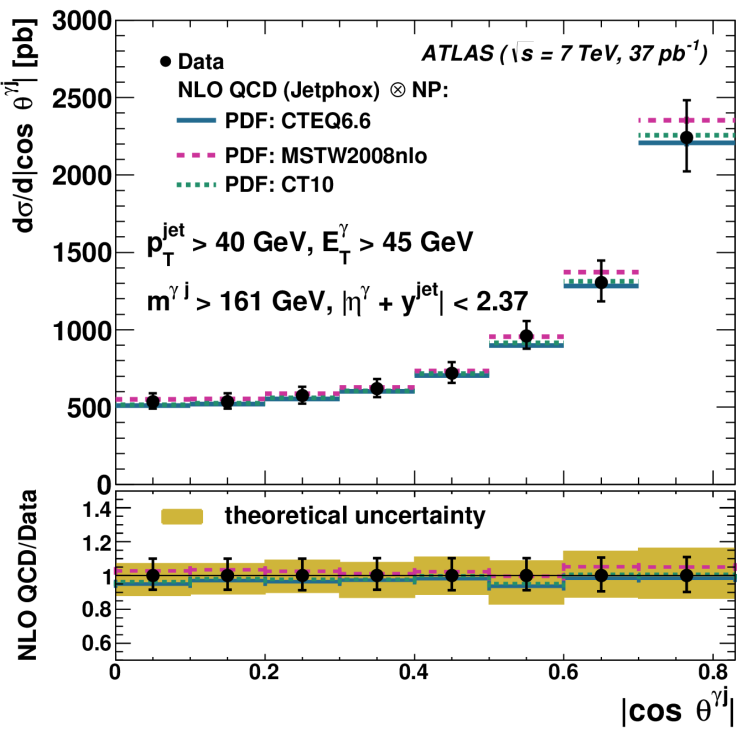
- Good agreement in most variables
  - Same E_T^{γ} difference as prev results
  - Experimental errors often smaller than theoretical
  - $\Delta\phi^{\gamma j} > \pi/2$ for NLO, Pythia and Sherpa perform better than Herwig

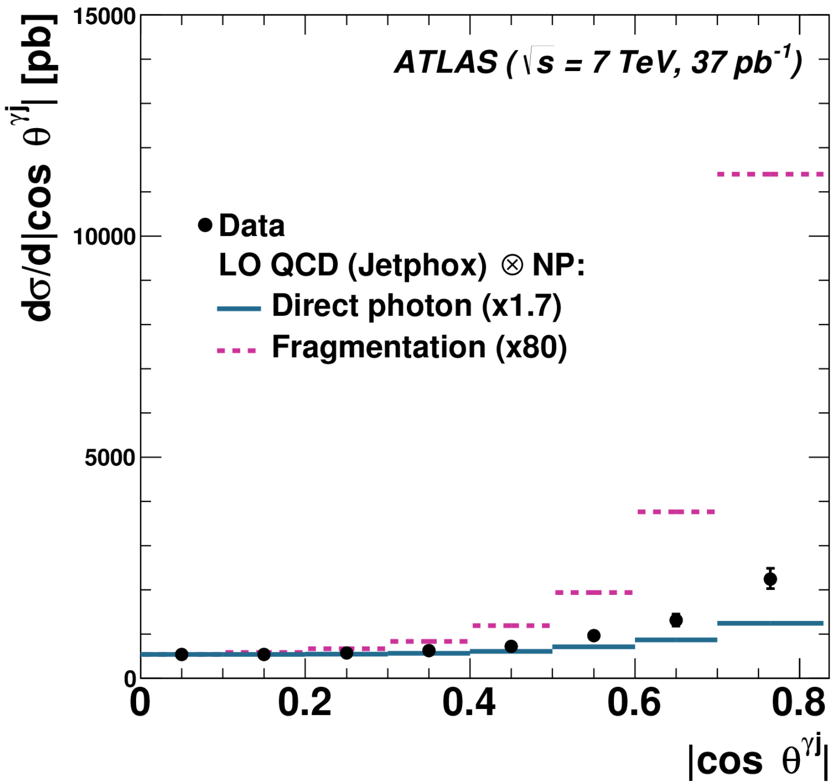




Fragmentation

- Measuring $|\cos\theta^{\gamma j}|$ shows good agreement to NLO
  - Apply extra constraints $|\eta^{\gamma}+y^{jet}|<1.185$, $m^{\gamma j}>161$GeV and $|\cos\theta^{\gamma j}|<0.83$ to remove any distortions due to the restrictions E_T^{γ}, η^{γ}, p_T^{jet}, y^{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^{γ}, p_T^{jet} and $M^{\gamma j}$



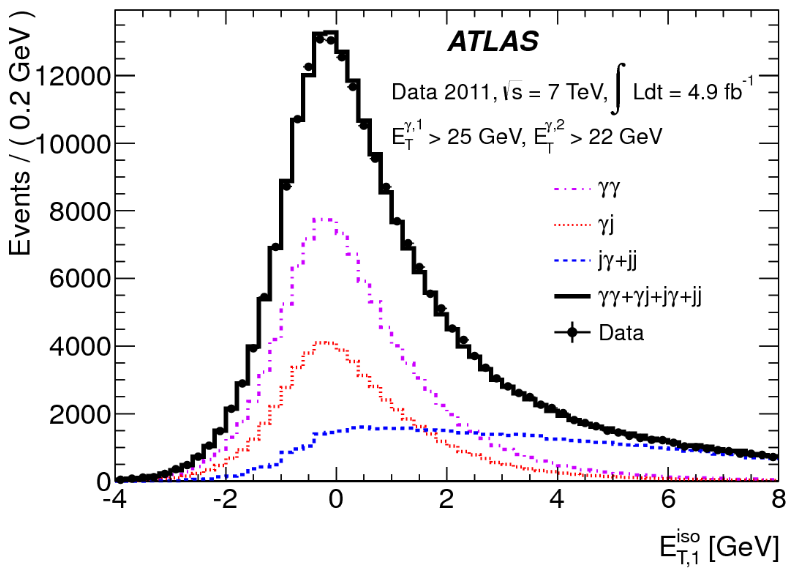


Di-photons

JHEP 1301 (2013) 086

- In 2011 data there is also an update of the di-photon σ
  - Key to understand backgrounds to di-photon searches

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

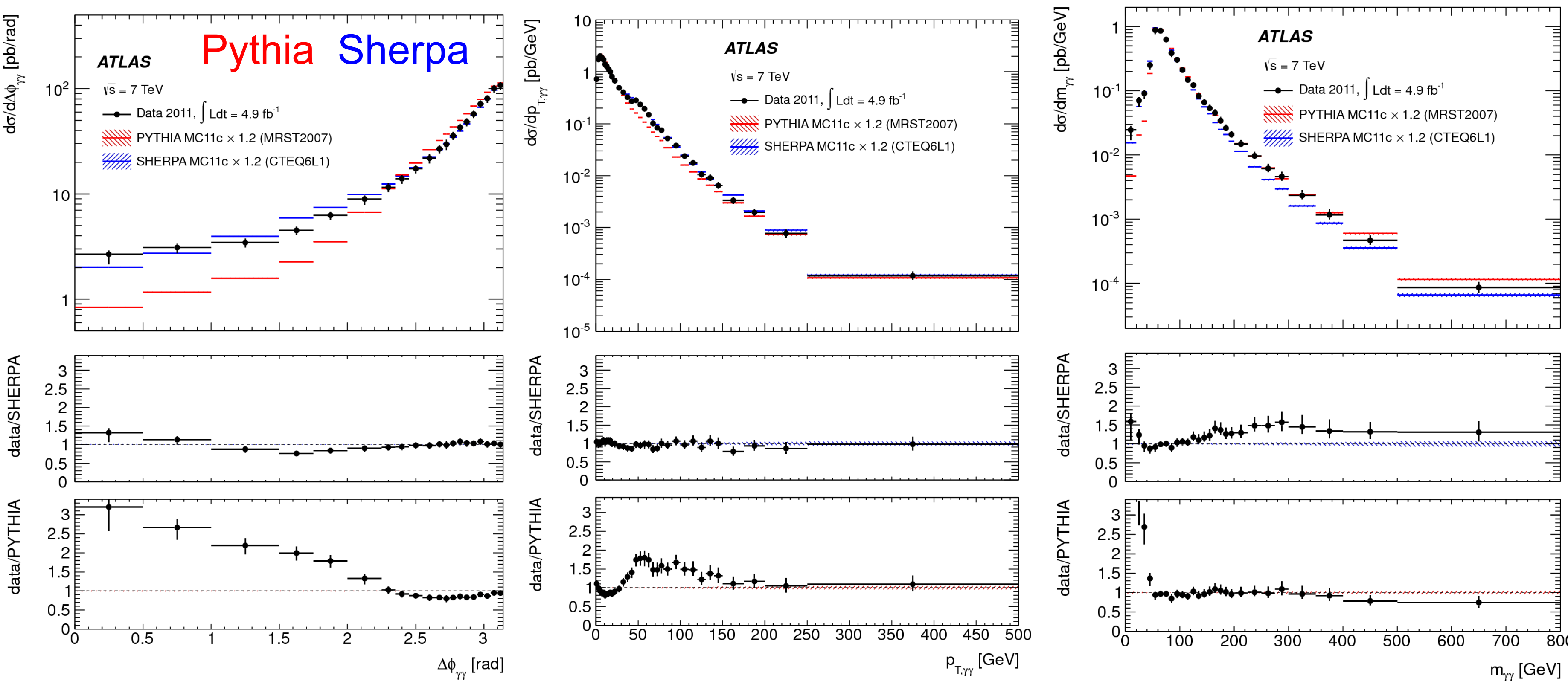


- Photon selection:
  - Two isolated (<4 GeV) photons E_T> 25, 22 GeV
  - Separated by $\Delta R > 0.4$

Di-photons

JHEP 1301 (2013) 086

- Variables for σ: $m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ 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 $\cos\theta^*_{\gamma\gamma}$



Di-photons

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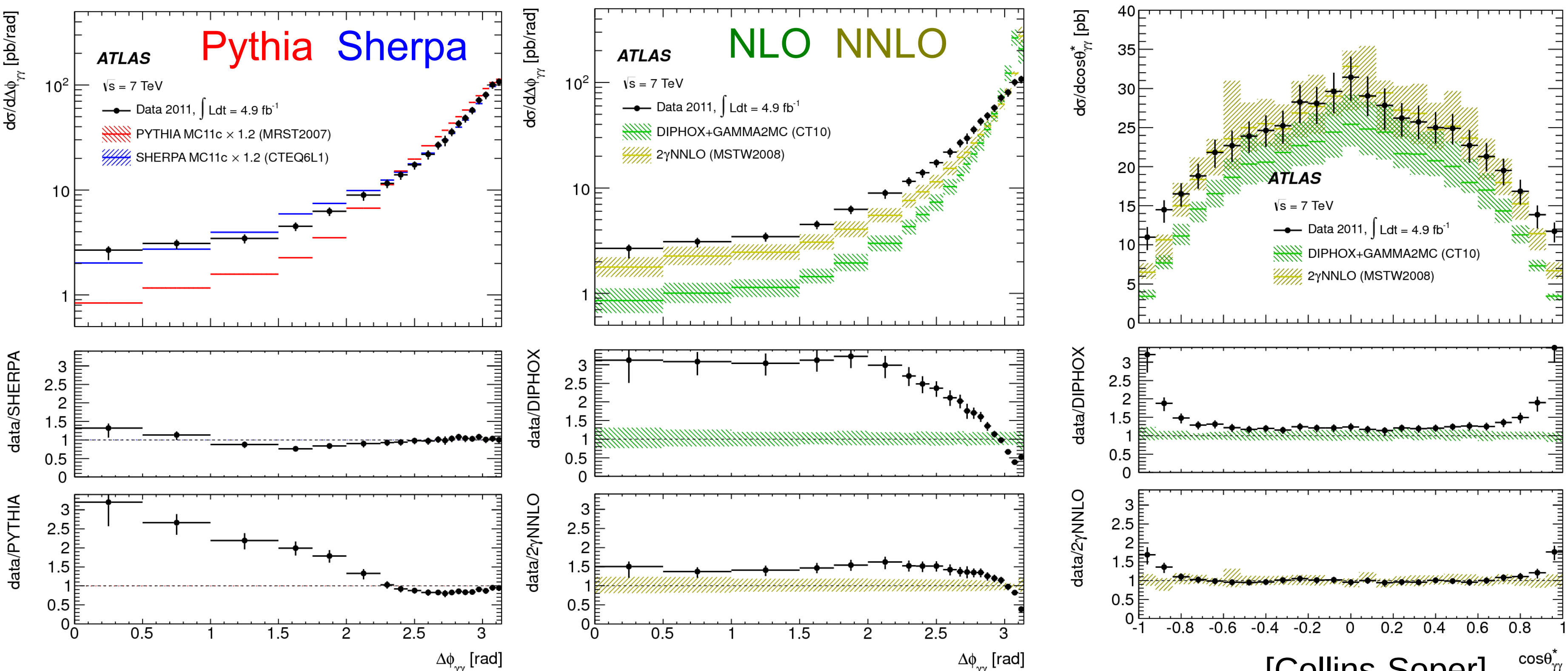
- Variables for σ: $m_{\gamma\gamma}$, $p_{T,\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$ and $\cos\theta^*_{\gamma\gamma}$
- Sherpa does better at modelling the shape than Pythia
- NNLO does better than NLO
  - Without soft gluon resummation see excess at $\Delta\phi_{\gamma\gamma} \approx \pi$
  - NNLO lacks the fragmentation contribution, see high $|\cos\theta^*|$



[Collins-Soper]

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

Backup

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ATLAS Measurements

- Inclusive photons
  - [2010*] 15-100GeV: Phys. Rev. D 83 (2011) 052005
  - [2010] 45-400GeV: Phys. Lett. B 706 (2011) 150-167
  - [2011] 400-1000GeV: ATLAS-CONF-2013-022
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-022/
- Photon+jet
  - [2010] same/opp side: Phys. Rev. D 85 (2012) 092014
  - [2010] dynamics:
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-18/
    - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2013-023/
- Diphotons
  - [2010] Phys. Rev. D 85 (2012) 012003
  - [2011] JHEP 1301 (2013) 086
    - http://link.springer.com/article/10.1007%2FJHEP01%282013%29086
- [dataset analysed] *=sub-set of full dataset (880nb^{-1})
- Latest results in red

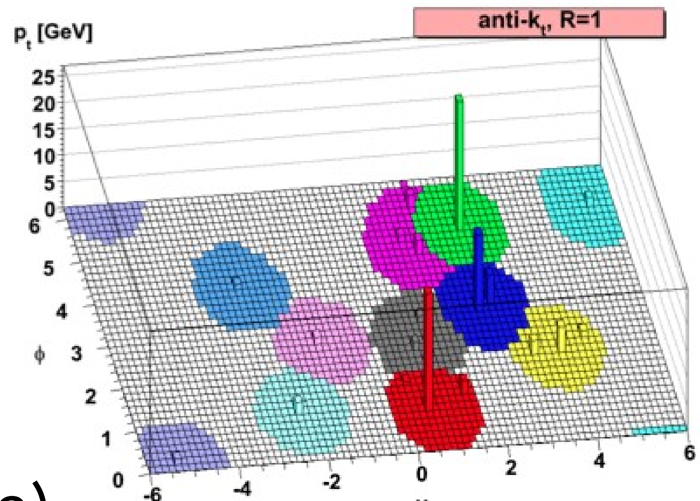
Anti-kt

M. Cacciari, G. P. Salam, and G. Soyez, JHEP 04, 063 (2008)

- 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

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



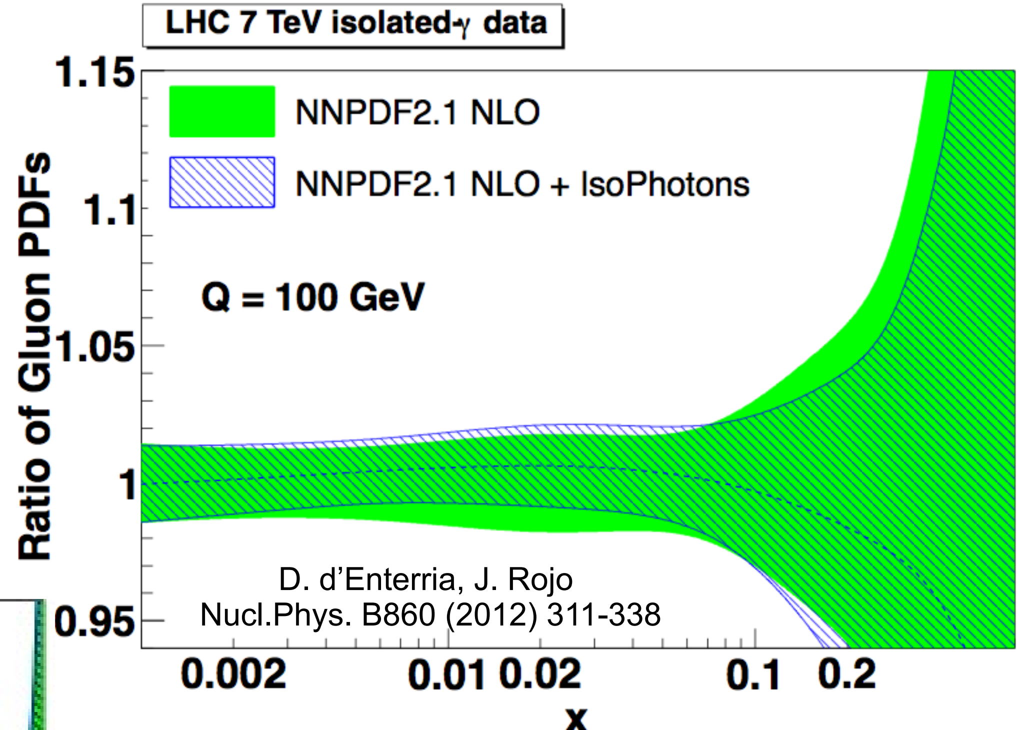
- Jets are formed from clusters of energy (for noise suppression)

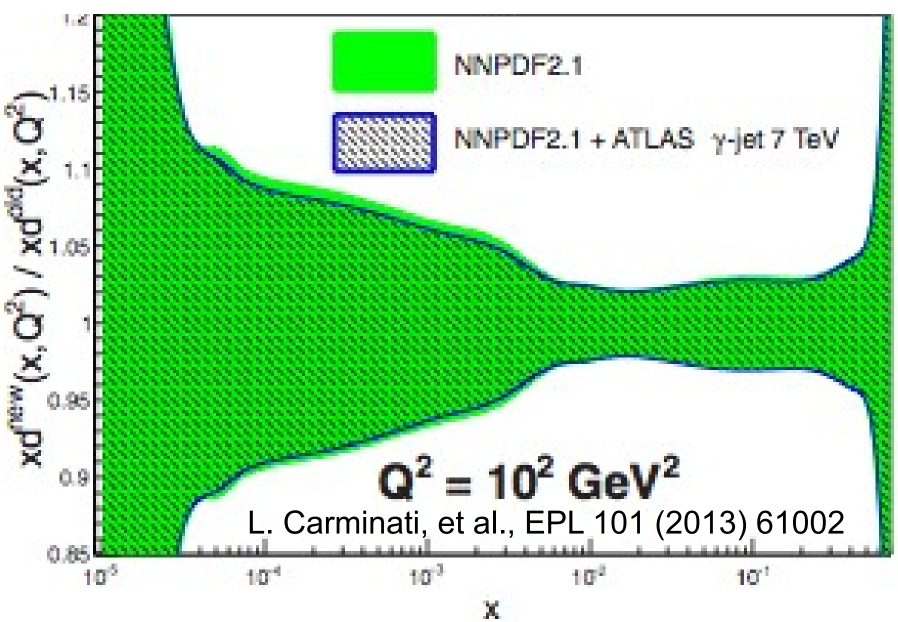
- Jets are calibrated to correct the calorimeter energy response and restore the Jet Energy Scale
  - Non-compensation
  - Dead material
  - Out of cone effects

PDFs

D. d'Enterria, J. Rojo Nucl.Phys. B860 (2012) 311-338
L. Carminati, et al., EPL 101 (2013) 61002

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





- 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