Measurements of jet and photon production properties in pp collisions with the ATLAS detector

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XXII Baldin Seminar on HEP Problems

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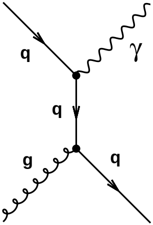
Outline

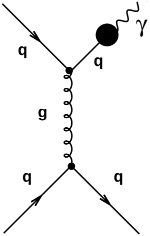
1. isolated prompt photon production at 7 TeV
2. photon $+$ jet cross sections and dynamics at 7 TeV
3. isolated diphoton cross section measurements at 7 TeV
4. dijet production at 7 TeV
5. jet asimuthal decorrelation studies at 7 TeV
6. summary

Prompt photon production

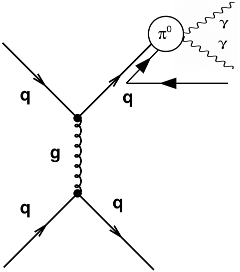
direct photon



parton fragmentation into photon

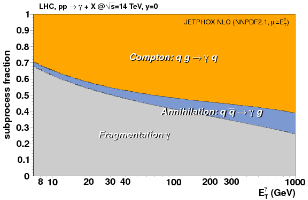


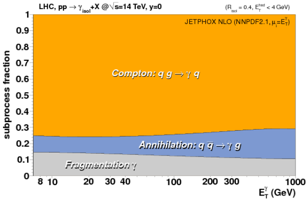
particle decay into photons



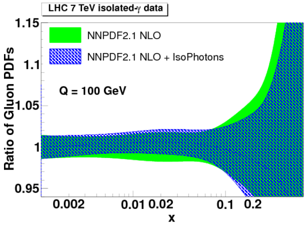
- photon+X: direct photon provides a probe of gluon density in proton
- photon+jet: measure the scattering angle $\cos\theta^{\gamma j} = \tanh\left(y^{\gamma} - y^{j}\right)$
  - quark exchange $\approx (1 - |\cos\theta^{\gamma j}|)^{-1}$
  - gluon exchange $\approx (1 - |\cos\theta^{\gamma j}|)^{-2}$

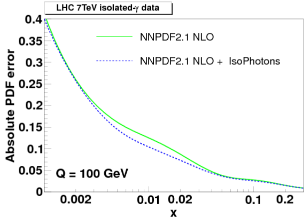
Prompt isolated photons as probe for PDF gluon density [NuclPhysB(2012)311]





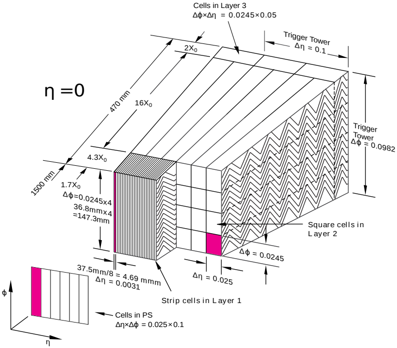
- Isolation requirement reduces fragmentation background
- s-channel gives no singularity at $\cos\theta^{\gamma j} = 1$

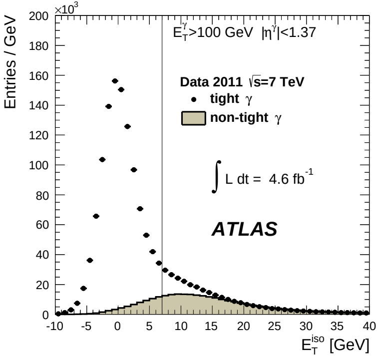




- Using $\sqrt{s} = 7\,TeV, L = 37pb^{-1}$ ATLAS and CMS 2010 data constrain PDF in $x \approx 0.002 - 0.05$ at scales $Q^2 = 10 - 10^4\,GeV^2$

Photon identification and isolation at ATLAS



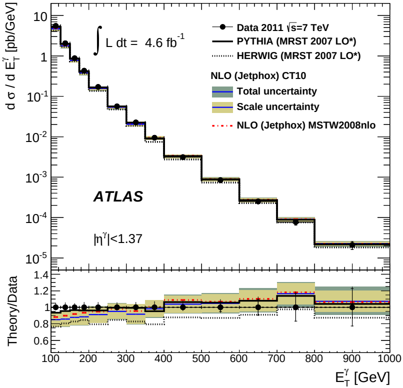


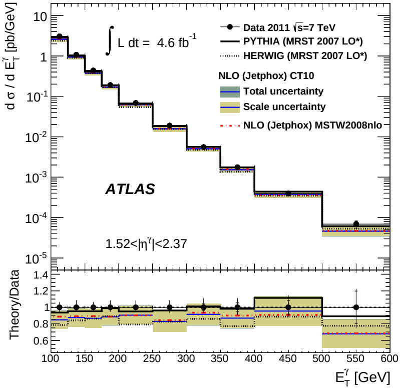
- EM shower shape variables provide tight/loose photon identification
- Fine segmentation of calorimeter first layer ($\Delta\eta x \Delta\phi = 0.003x0.025$) allows for discrimination between prompt photons and π_0, η decay photons
- Isolation: total energy in the cone of $\Delta R = 0.4$ but excluding photon core of 5x7 cells in 2nd layer EM calorimeter

$$p + p \to \gamma + X, \sqrt{s} = 7TeV, L = 4.7fb^{-1}$$

- $E_T^{\gamma} > 100GeV$, $\eta_{\gamma} < 2.37$, excluding gap $1.37 < \eta_{\gamma} < 1.52$
- tight, isolated photons $E_T^{iso} < 7GeV$
- 2D-sideband data-driven method of residual background subtraction is used
- photon distributions are corrected for detector effects

Inclusive isolated photons [PhysRevD(2014)052004], $L = 4.7 fb^{-1}$

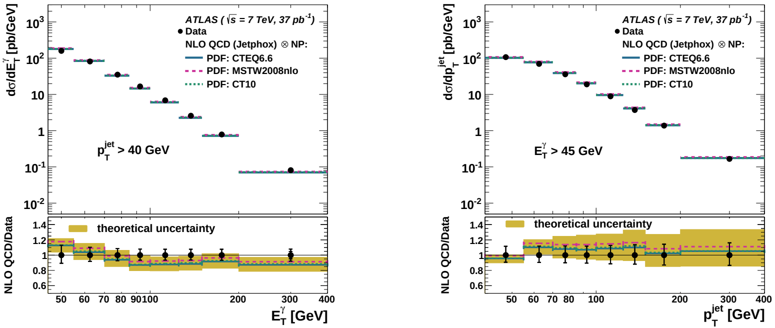




- The NLO calculations agree with data up to 1 TeV within theoretical uncertainity
- Pythia describes the data fairy well
- HERWIG underestimates fragmentation at low E_T by $\approx 10\%$

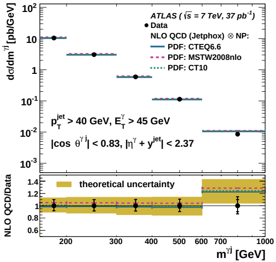
- $p + p \to \gamma + jet + X$, $\sqrt{s} = 7TeV$, $L = 37pb^{-1}$
- photon: $E_T^{\gamma} > 45GeV$, $\eta_{\gamma} < 2.37$, excluding gap $1.37 < \eta_{\gamma} < 1.52$, tight, $E_T^{iso} < 3GeV$
- jet: $p_T^{jet} > 40GeV$, $\eta_{jet} < 2.37$, discarding jets that overlap with photon in $\Delta R = 1$
- Experimental uncertanties $\approx$ 10% (dominated by JES)
- Theoretical uncertanties $\approx$ 10% (dominated by terms beyond NLO)

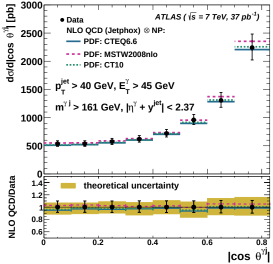
Photon + jet dynamics [NuclPhysB(2013)483], $L = 37pb^{-1}$

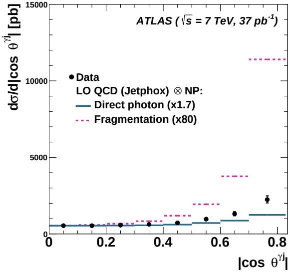


- good description by NLO pQCD for $d\sigma/dE_T^{\gamma}$ and $d\sigma/dp_T^{jet}$
- very close predictions for CTEQ6.6 and CT10 PDFs, MSTW2008nlo is 5% higher

Photon + jet dynamics [NuclPhysB(2013)483], $L = 37pb^{-1}$

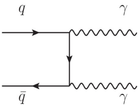




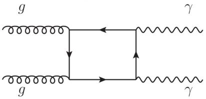


- additional phase space constraints: $|\eta^{\gamma} + \eta^{jet}| < 2.37$, $|\cos\theta^{\gamma j}| < 0.83$, $m^{\gamma j} > 161\,GeV$
- good description by NLO pQCD for $d\sigma/dm^{\gamma j}$ and $d\sigma/d\cos\theta^{\gamma j}$
- the shape of measured angular distribution is closer to that of *direct* photon than to *fragmentation* one
- fit can be used to determine the ratio of direct/fragmentation components

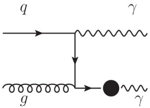
Born



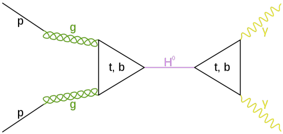
Box



fragmentation

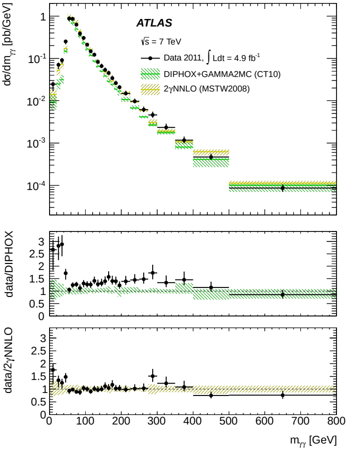


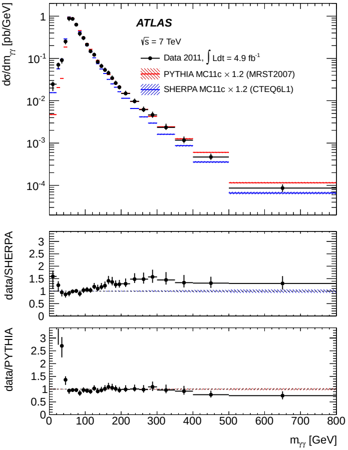
higgs to $\gamma\gamma$



- understanding irreducible background for $H \to \gamma\gamma$ and new physics
- event selection:
  - leading photon $E_T^{\gamma} > 25GeV$, subleading photon $E_T^{\gamma} > 22GeV$
  - $|\eta_\gamma| < 2.37$ excluding the gap region $1.37 < |\eta_\gamma| < 1.52$
  - isolation requirement $E_T^{iso} < 4GeV$, photon separation $\Delta R_{\gamma\gamma} > 0.4$
- two alternative methods applied to subtract the jet background of γj, $j\gamma$, jj events
  - 2x2D-sideband method
  - 2D-template fit method for isolation distribution with applied leakage corrections
  - the difference of $\approx 1.5\%$ is included as systematic uncertainity for isolation
- corrected for electron (misidentified as gamma) background from Z and W decays
- final measurements are corrected for detector and resolution effects

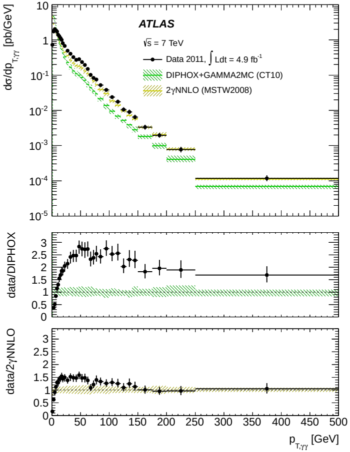
Diphoton $\frac{d\sigma}{dm_{\gamma\gamma}}$ [JHEP01(2013)086], $L = 4.9fb^{-1}$

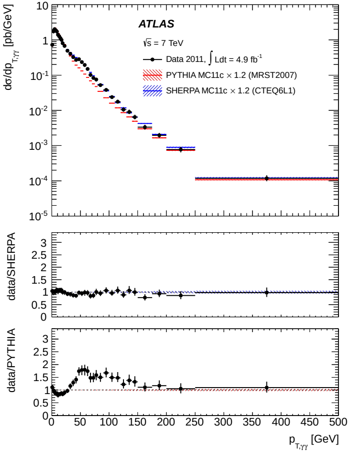




- overall good agreement with 2γ*NNLO*, DIPHOX is missing NNLO contribution
- low $m_{\gamma\gamma}$: SHERPA (includes 2 $\rightarrow$ 4 processes) is better than Pythia; intermediate $m_{\gamma\gamma}$: better description by Pythia

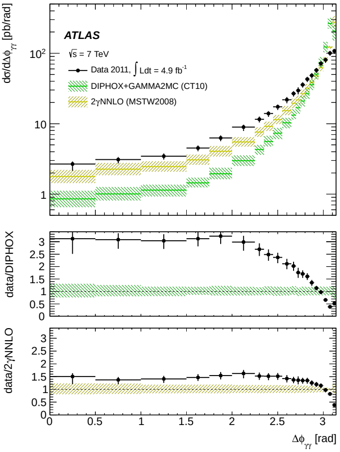
Diphoton $\frac{d\sigma}{dp_{T,\gamma\gamma}}$ [JHEP01(2013)086], $L = 4.9 fb^{-1}$

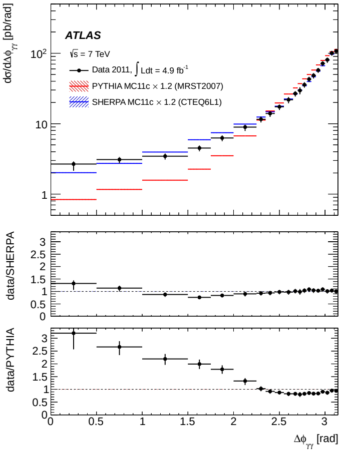




- DIPHOX and 2γ*NNLO* fail at low p_T due to initial state soft-gluon radiation divergency
- good agreement with SHERPA and at high p_T with 2γ*NNLO*

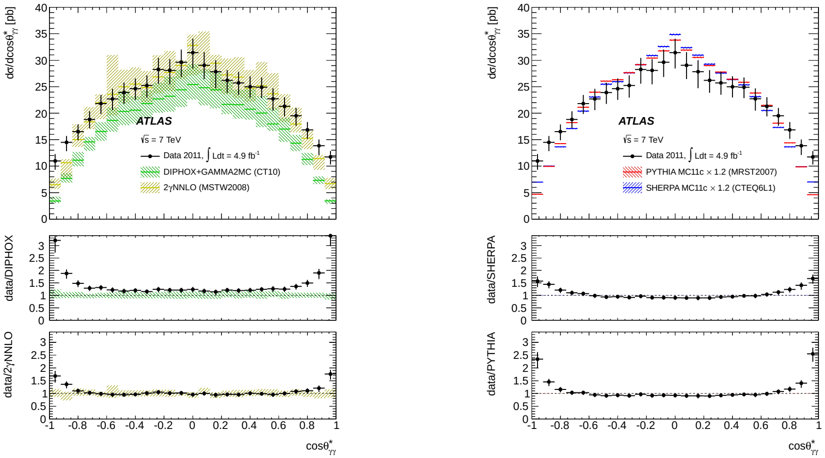
Diphoton $\frac{d\sigma}{d\Delta\phi_{\gamma\gamma}}$ [JHEP01(2013)086], $L = 4.9 fb^{-1}$





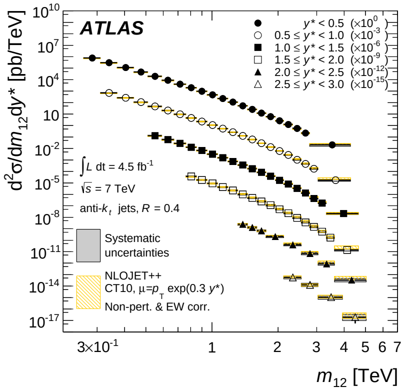
- good agreement with SHERPA and $2\gamma NNLO$
- high $\Delta\phi_{\gamma\gamma}$ region sensitive to initial state soft-gluon radiation:
  DIPHOX and $2\gamma NNLO$ overestimate data

Diphoton $\frac{d\sigma}{d\cos\theta^*_{\gamma\gamma}}$ [JHEP01(2013)086], $L = 4.9 fb^{-1}$



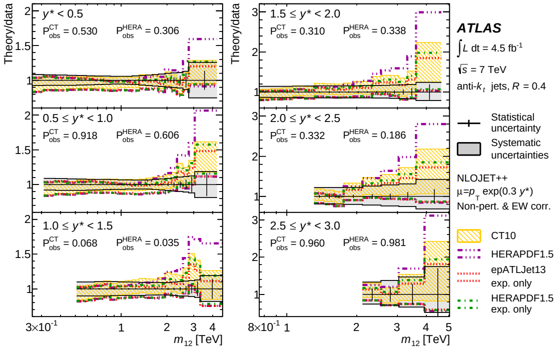
- overall good agreement except for large $cos\theta^*_{\gamma\gamma}$ dominated by fragmentation

Dijet cross section [JHEP05(2014)059], $\sqrt{s} = 7TeV$, $L = 4.5fb^{-1}$

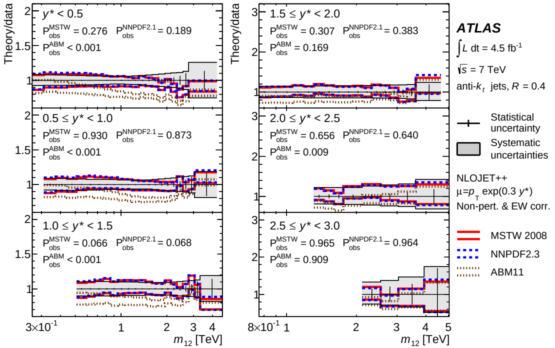


- Jet challenge: QCD processes are dominant at hadron colliders
  - probes highest energy transfers up to 5 TeV in m_{12} for $\sqrt{s} = 7TeV$
  - experimental constraints on proton PDFs (especially for gluon density at high x)
  - background to the new physics (multijet topologies)
  - tuning of Monte-Carlo
- Di-jet selection:
  - anti-k_t jet alrogithm
  - all measurements done for two cone sizes $\Delta R = 0.4$ and $\Delta R = 0.6$
  - leading jet $p_T > 100GeV$, subleading $p_T > 50GeV$, $|y_{jet}| < 3$
  - double differential cross section is measured as function of m_{12} for several $y^* = |y_1 - y_2|$ bins

- Good agreement between data and MC, tested for stability against pile-up
- Experimental uncertainties 10% for low m_{12}, up to 25% at high m_{12}, out of them jet-energy calibration gives $\approx 1\% - 2\%$



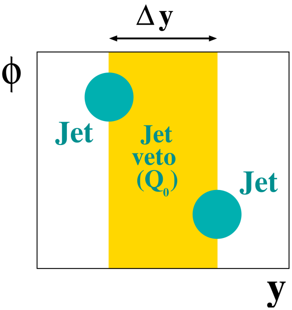
- CT10 describes well the measurements for both jet radii
- HERAPDF1.5 has disagreement at some m_{12} at certain y^*
- Using the p-value to compare the degree of agreement between data and NLO calculations with different PDFs



- MSTW2008, NNPDF2.3 describe well the measurements for both jet radii
- ABM11 has disagreement at some regions of m_{12}
- experimental input for further constraints on PDFs

Jet asimuthal decorrelations [submitted to EPJC], $\sqrt{s} = 7TeV$, $L = 36.1pb^{-1}$ and $L = 4.5fb^{-1}$

No extra jets with $p_T > Q_0$ between j_1 and j_2

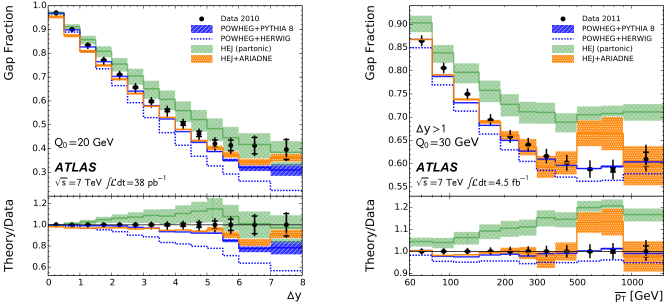


- Fixed order QCD predictions expect to perform poorly when HO are important
  - large rapidity separation Δy
  - when jet veto above Q_0 applied
- Improved results expected if HO resummed in terms of $ln(1/x)$ (BFKL approach) or in terms of $ln(Q^2)$ (DGLAP approach).
- Measuring the gap fraction $f(Q_0) = \frac{\sigma_{jj}(Q_0)}{\sigma_{jj}}$
- Gap fraction distribution is sensitive to BFKL at large Δy
- When average transverse momentum of the jets $\overline{p_T} \gg Q_0$ wide-angle soft gluon radiation may become important

- Selection: jets reconstructed with anti-k_t jet $\Delta R = 0.6$ alrogithm
  - Leading jet $p_T^{jet} > 60GeV$, sub-leading jet $p_T^{jet} > 50GeV$
  - 2010: $|y_{jet}| < 4.4$, gap fraction with veto scale $Q_0 = 20GeV$
  - 2011: $|y_{jet}| < 2.4$, gap fraction with veto scale $Q_0 = 30GeV$

ATLAS EXPERIMENT

Jet asimuthal decorrelations [submitted to EPJC], $\sqrt{s} = 7TeV, L = 36.1pb^{-1}$ and $L = 4.5fb^{-1}$



- HEJ+ARIADNE describes the gap fraction for low and medium Δy and $\overline{p_T}$
- POWHEG describes the gap fraction for low Δy and for all $\overline{p_T}$

Summary

- Inclusive photon production
  - tests of pQCD in a clean environment
  - sensivity to the gluon component of proton PDF
- Photon $+$ jet production
  - tests of color dynamics with an accuracy of $\approx$ 10%
  - dynamics of photon+jet production has good description at the order of $O(\alpha\alpha_s^2)$
- Diphoton production
  - irreducible background to $H \rightarrow \gamma\gamma$
  - improved calculations are required to provide a better descriprion at high orders
- Dijet production with and without veto
  - good description of dijet data by pQCD at the highest energy transfer
  - jet-veto measurements have no consistent description over the full phase space with DGLAP and BFKL approaches
- coming soon: inclusive jets and three-jet measurements at 7 TeV

Additional Slides

References: I

[1] Quantitative constraints on the gluon distribution function in the proton from collider isolated-photon data
D.d'Enteria, J.Roho, Nucl. Phys. B860,(2012) 311-338

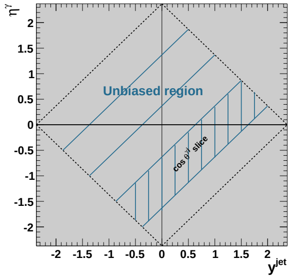
[2] Measurement of the inclusive isolated prompt photon cross section in pp collisions at $sqrt(s) = 7TeV$ *with the ATLAS detector using* $4.6fb - 1$
ATLAS Collaboration, Phys. Rev. D 89, 052004 (2014)

[3] Dynamics of isolated-photon and jet production in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector
ATLAS Collaboration, Nucl. Phys, B 875 (2013) 483-535

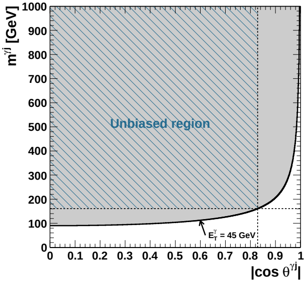
[4] Measurement of isolated-photon pair production in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector
ATLAS Collaboration, JHEP01(2013)086

[5] Measurement of dijet cross sections in pp collisions at $7TeV$ *centre-of-mass energy using the ATLAS detector*
ATLAS Collaboration, JHEP05(2014)059

[6] Measurements of jet vetoes and azimuthal decorrelations in dijet events produced in pp collisions at $sqrt(s) = 7TeV$ *using the ATLAS detector*
ATLAS Collaboration, submitted to EPJC



η^{γ}
y^{jet}
Unbiased region
$\cos\theta^{\gamma j}$ slice



$m^{\gamma j}$ [GeV]
$|\cos\theta^{\gamma j}|$
Unbiased region
E_T^{γ} = 45 GeV