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

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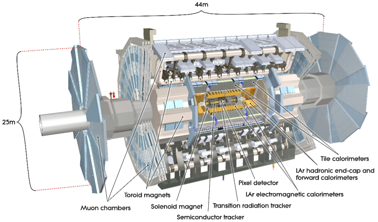
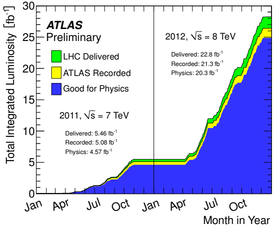
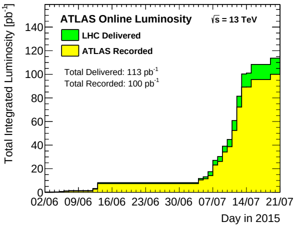
ATLAS and LHC operation

Proton-Proton physics: $\sim 5.08\ \text{fb}^{-1}$ at $\sqrt{s} = 7$ TeV, $\sim 21.3\ \text{fb}^{-1}$ at $\sqrt{s} = 8$ TeV and $\sim 100\ \text{pb}^{-1}$ at $\sqrt{s} = 13$ TeV





- Jet analysis:
  - Inclusive jet cross sections at $\sqrt{s} = 7$ TeV
  - Dijet cross sections at $\sqrt{s} = 7$ TeV
  - Three-jet cross sections at $\sqrt{s} = 7$ TeV
  - Four-jet cross sections at $\sqrt{s} = 8$ TeV
  - Jet charge in dijet events at $\sqrt{s} = 8$ TeV
  - Transverse energy-energy correlations at $\sqrt{s} = 7$ TeV
  - Inclusive jet cross sections at $\sqrt{s} = 13$ TeV
- Isolated promt photons in ATLAS:
  - Inclusive isolated prompt photon cross sections at $\sqrt{s} = 7$ TeV
  - Inclusive isolated prompt photon production at $\sqrt{s} = 13$ TeV



Jets in ATLAS

Jets can be interpreted as the fragmentation of partons produced in the scattering process.

- QCD processes are dominant in hadron colliders:
  - Background to new physics $\rightarrow$ Multijet events.
- Tests of pQCD and measurements of QCD parameters.
- Experimental constraints on proton PDFs.
- Tuning of Monte Carlo models.
- Reconstructed from topological calorimeter clusters.
  - Corrected for non-compensating response to hadrons, dead material and signal losses due to the clustering process.
- anti-k_T jet algorithm with radius parameter R=0.4 and R=0.6 (FASTJET package).
- The jet energy scale (JES) is calibrated to that of jets reconstructed from quasi-stable simulated particles. $\rightarrow$ Details in next slide

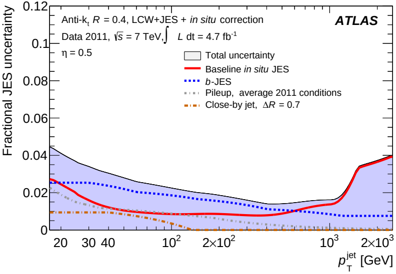
Jet energy scale

Jets are calibrated using the following procedure:

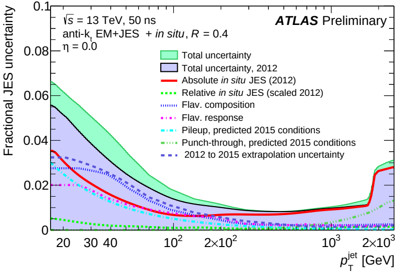
- Pileup correction: To account for the energy offset caused by pileup interactions.
- Origin correction: To make the jet point back to the primary event vertex.
- MC based correction: To account for instrumental effects.
- In situ correction: To account for residual data/MC differences.

JES uncertainty is the dominant source of systematic uncertainty in analysis involving jets.

Eur.Phys.J. C75 (2015) 17



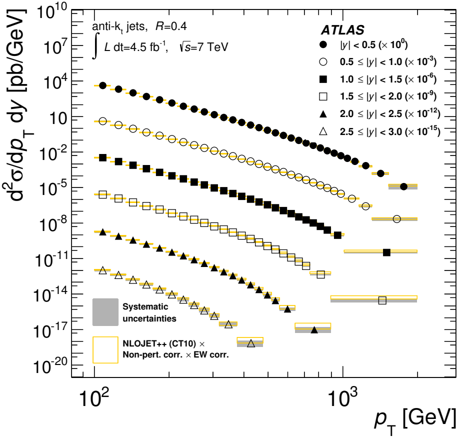
ATL-PHYS-PUB-2015-015



Inclusive jet cross sections at $\sqrt{s} = 7$ TeV.

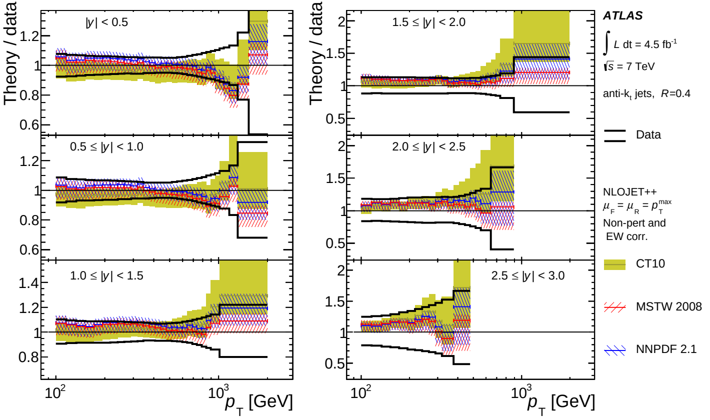
JHEP 1502 (2015) 153

- Constrain of parton distribution functions (PDF).
- $P_T^{jet} \geq 100$ GeV.
- $|y^{jet}| < 3.0$
- NLO pQCD: NLOJET++.
- Several PDF sets.
- NLO is corrected for non-perturbative and Electroweak (EW) effects .
  - Non perturbative corrections (NPC) obtained with PYTHIA/HERWIG with various tunes.
- Data unfolded to particle-level using an iterative, dynamically stabilized method (IDS).



Inclusive jet cross sections at $\sqrt{s} = 7$ TeV.

JHEP 1502 (2015) 153



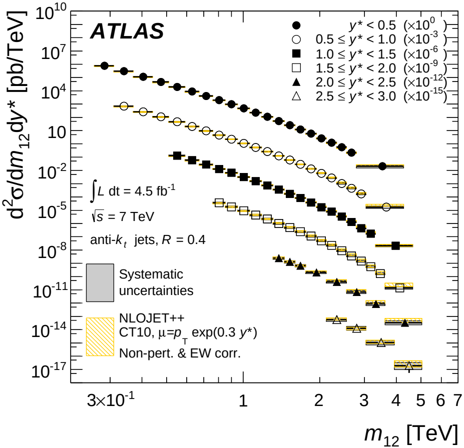
Good agreement between data and pQCD NLO calculations with several NLO PDF sets.

Predictions for $R = 0.6$ tend to be systematically lower than the data for $|y| < 1.5$, but consistent within uncertainties.

Dijet cross sections at $\sqrt{s} = 7$ TeV.

JHEP 1405 (2014) 059

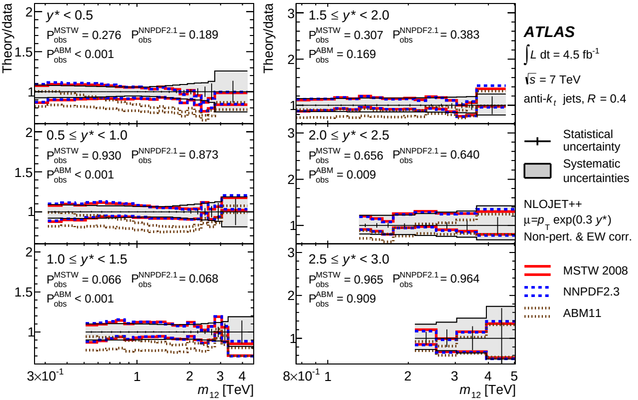
- Sensitivity to resonances (as a function of dijet mass) decaying into two jets.
- High dijet-mass region constrains gluon PDF.
- $P_T^{jet1} \geq 100$ GeV, $P_T^{jet2} \geq 50$ GeV
- $|y^{jet}| < 3.0$ and $|y^*| < 3.0$
- $y^* = |y^{jet1} - y^{jet2}|/2$
- NLO pQCD: NLOJET++.
- Several PDF sets.
- NLO is corrected for non-perturbative and EW effects.
  - NPC obtained with PYTHIA/HERWIG with various tunes.
- Data unfolded to particle-level using an IDS method.



HepData available

Dijet cross sections at $\sqrt{s} = 7$ TeV.

JHEP 1405 (2014) 059



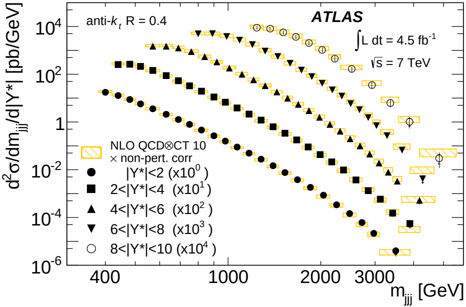
Good agreement between data and pQCD NLO calculations with several NLO PDF sets except for ABM11.

Predictions for $R = 0.6$ tend to be systematically lower than the data, but consistent within uncertainties.

Three-jet cross sections at $\sqrt{s} = 7$ TeV.

Eur.Phys.J. C75 (2015) 228

- Test of higher multiplicity calculations in pQCD.
- $P_T^{jet1} \geq 150$ GeV, $P_T^{jet2} \geq 100$ GeV, $P_T^{jet3} \geq 50$ GeV
- $|y^{jet}| < 3.0$ and $|Y^*| < 10.0$
- $Y^* = |y^{jet1} - y^{jet2}| + |y^{jet1} - y^{jet3}| + |y^{jet2} - y^{jet3}|$
- NLO pQCD: NLOJET++.
- Several PDF sets.
- NLO is corrected for non-perturbative effects.
  - NPC obtained with PYTHIA/HERWIG with various tunes.
  - EW corrections not available.
- Data unfolded to particle-level using an IDS method.



Three-jet cross sections at $\sqrt{s} = 7$ TeV

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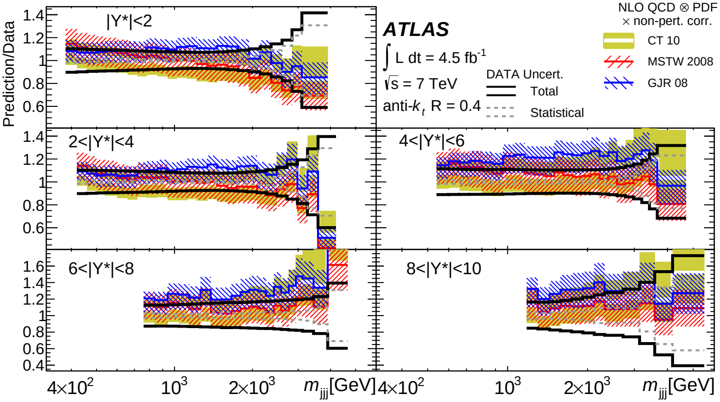


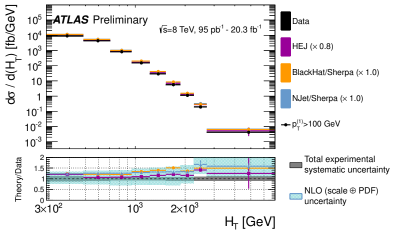
Good agreement between data and pQCD NLO calculations with several NLO PDF sets.

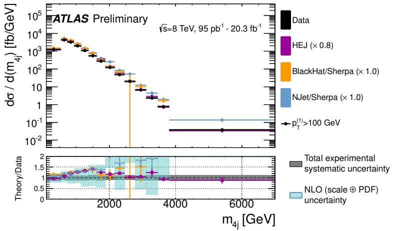
Predictions for $R = 0.6$ tend to be systematically lower than the data, but consistent within uncertainties.

Four-jet cross sections at $\sqrt{s} = 8$ TeV.

CERN-PH-EP-2015-181

- $P_T^{jet1} \geq 100$ GeV, $P_T^{jet} \geq 64$ GeV.
- $|y^{jet}| < 2.8$
- $\Delta R_{4j}^{min} > 0.65$
  - $\Delta R_{4j}^{min} = min_{i,j\in[1,4]}(\Delta R_{i,j}), i \neq j$
- Data unfolded to particle-level using a bayesian iterative method.
- LO MC: PYTHIA,HERWIG and MADGRAPH+PYTHIA.
- NLO pQCD: Blackhat/Sherpa and NJet/Sherpa.
- HEJ also used: Fully exclusive MC generator.
  - Approximates Matrix element to all orders for jet multiplicities of two or greater.
  - Approximation exact for large separation in rapidity between partons.





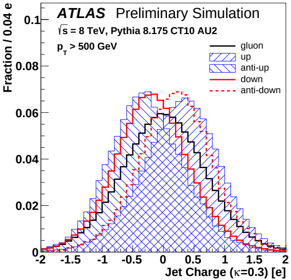
H_T well described by both NLO and HEJ. m_{4j} is well described by NLO up to 3 TeV and by HEJ at high masses. NLO uncertainties are relatively large, $O(30\%)$ at low momenta.

Jet charge in dijet events at $\sqrt{s} = 8$ TeV.

ATLAS-CONF-2015-025

$$Q_J = \frac{1}{(P_{T_J})^\kappa} \sum_{i \in Tracks} q_i \times (P_{T_i})^\kappa$$

- Jet charge is sensitive to original parton charge.
- Obtained using tracks associated to a jet.
- κ regulates the sensitivity to soft radiation. (0.3,0.5 and 0.7 considered)



- Two jets with $P_T > 50$ GeV.
- $P_T^{lead} / P_T^{sublead} < 1.5$
  - To select back-to-back topologies.
- $|y^{jet}| < 2.1$
  - To ensure all inputs are within Inner detector coverage.
- Jet with smaller $|\eta|$ is designated "More central".

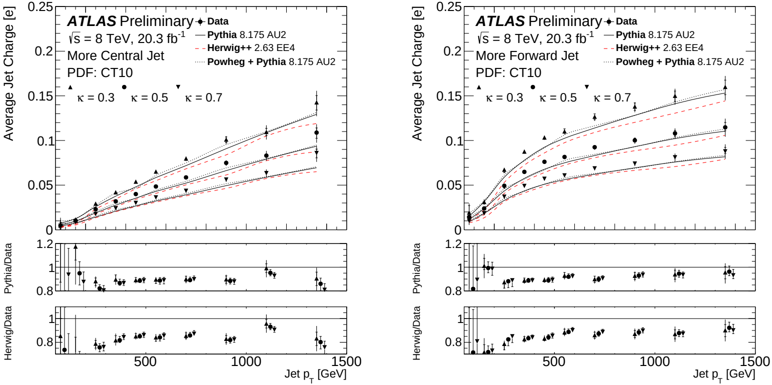
MC used for unfolding and comparison:

PYTHIA, HERWIG++ and

POWHEG+PYTHIA.

Jet charge in dijet events at $\sqrt{s} = 8$ TeV.

ATLAS-CONF-2015-025



The average jet charge increases with P_T^{jet}, as expected from the increase in final-state up-quark initiated jets. Differences between central and forward jets are due to different flavour fractions.

Differences between data and MC predictions cannot be explained solely by PDF effects.

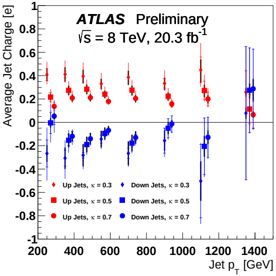
Jet charge in dijet events at $\sqrt{s} = 8$ TeV

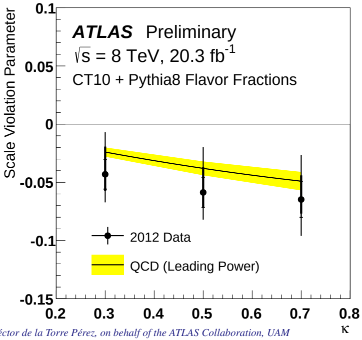
ATLAS-CONF-2015-025

$$< Q_J^{forward} >_i = (f^{forward}_{up,i} - f^{forward}_{anti\text{-}up,i})Q_i^{up} + (f^{forward}_{down,i} - f^{forward}_{anti\text{-}down,i})Q_i^{down}$$

$$< Q_J^{central} >_i = (f^{central}_{up,i} - f^{central}_{anti\text{-}up,i})Q_i^{up} + (f^{central}_{down,i} - f^{central}_{anti\text{-}down,i})Q_i^{down}$$

- Using PDF as inputs allows to obtain average jet charge for up-quark and down-quark initiated jets.
  - Fractions obtained from simulation (PYTHIA CT10 AU2).





- Scale violation parameter has also been obtained as a function of κ:

Theory: $$\frac{P_T}{< Q_\kappa >} \frac{d}{dP_T} < Q_\kappa > = \frac{\alpha_s}{\pi} \tilde{P}_{qq}(\kappa) \equiv c_\kappa$$

Data: $$< Q_i > \approx \sum_f \alpha_{f,i} \bar{Q}_f (1 + c_\kappa log(p_{T,i}/\bar{p}_T))$$

- Data supports prediction that $c_\kappa < 0$ and $\partial c_\kappa / \partial \kappa < 0$

Transverse energy-energy correlations at $\sqrt{s} = 7$ TeV.

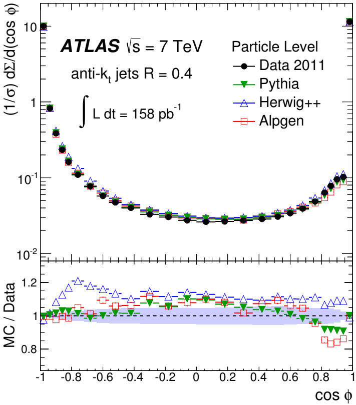
arXiv:1508.01579

- The transverse energy-energy correlation function (TEEC) exhibits a quadratic dependence on α_s.
  - Its asymmetry (ATEEC) has also been studied, results not shown in this talk.
- At least two jets with $P_T > 50$ GeV.
- $P_T^{jet1} + P_T^{jet2} > 500$ GeV.
- $|\eta^{jet}| < 2.5$
- LO MC samples: PYTHIA, HERWIG++, ALPGEN.
- NLO pQCD: NLOJET++
  - Several PDF considered, CT10 used for final results.
  - Corrected for non-perturbative effects.
- $\alpha_s(m_Z)$ extraction: χ^2 fit of NLO predictions to data.
  - Taking into account correlations between systematic uncertainties.
  - Analytical NLO parametrisation: 2nd order polynomial in $\alpha_s(m_Z)$ fitted to NLO calculations bin-by-bin

$$\frac{d\Sigma}{\sigma d\cos\phi} = \frac{1}{N\Delta\cos\phi}\sum^{N_{events}}\sum_{ij}^{N_{jets}}\frac{E_T^i E_T^j}{\left(\sum_k^{N_{jets}} E_T^k\right)^2}\delta(\cos\phi - \cos\phi_{ij})$$

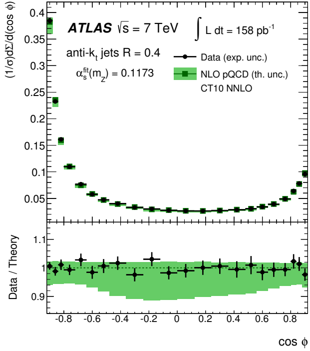
All jets with $P_T > 50$ GeV.

ϕ_{ij}: azimuthal separation between jets i and j.

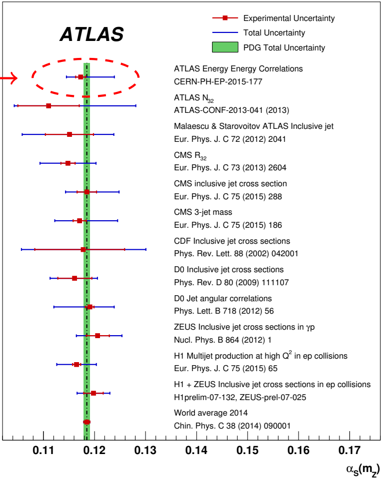


Transverse energy-energy correlations at $\sqrt{s} = 7$ TeV

arXiv:1508.01579



This analysis

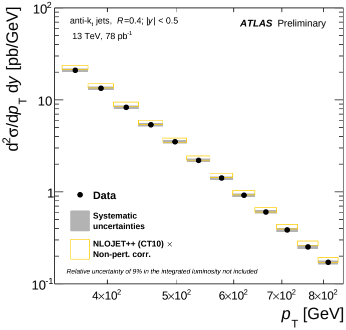


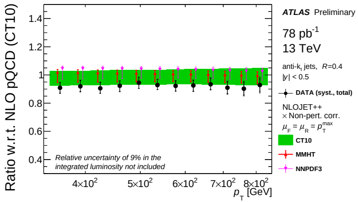
- Good agreement with NLO pQCD.
- Very good experimental precision.
- Theoretical uncertainty (scale) is dominant.
- Results compatible with world average.

$$\alpha_s(m_Z) = 0.1173 \pm 0.0010(exp.)^{+0.0063}_{-0.0020}(scale) \pm 0.0017(PDF) \pm 0.0002(NPC)$$

Inclusive jet cross sections at $\sqrt{s} = 13$ TeV. ATLAS-CONF-2015-029

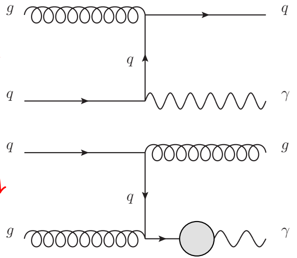
- $346 \leq P_T^{jet} \leq 838$ GeV and $|y| < 0.5$.
  - Performance of high-P_T jets under study.
  - Only jets in the central region considered.
- JES based on $\sqrt{s} = 8$ TeV calibration with updated MC-derived factors for 2015 data conditions
- NLO pQCD: NLOJET++ with various PDF sets.
- NLO is corrected for non-perturbative effects.
  - NPC obtained with PYTHIA with various tunes.
- Data unfolded to particle-level using an IDS method.
- NLO pQCD predictions are consistent with the data

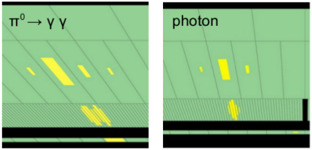




Isolated prompt photons in ATLAS.

- Three sources of photons in pp collisions
  - From the hard parton scattering (Direct).
  - From parton fragmentation (Fragmentation).
  - From hadron and tau decays (Background).
- Tests of pQCD in a cleaner reaction than jet production.
- Constraints on gluon PDFs ($qg \to q\gamma$ dominant).
- Tuning of Monte Carlo models.
- Reconstruction seeded by fixed-size clusters in the electromagnetic calorimeter.
- Calibrated to account for upstream energy loss, lateral leakage and longitudinal leakage.
- Prompt photons: expected to be more isolated than background:
  - E_T^{iso}: Calorimeter deposits in a cone of $\Delta R = 0.4$.
- Photon identification: Lateral and longitudinal energy profiles of the shower.

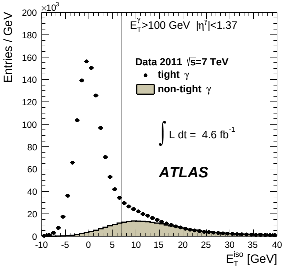




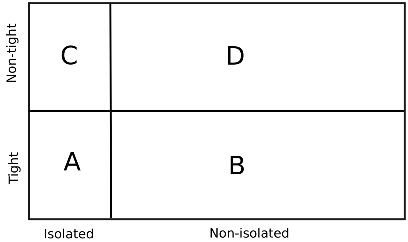
Inclusive isolated prompt photon production at $\sqrt{s} = 7$ TeV.

Phys.Rev. D89 (2014) 052004

- $E_T^{\gamma} > 100$ GeV
- $|\eta^{\gamma}| < 1.37$ or $1.52 < |\eta^{\gamma}| < 2.37$
- $E_T^{iso} < 7$ GeV and "Tight" ID criteria.
- MC LO: PYTHIA and HERWIG (MRST2007).
- NLO: JETPHOX (MSTW2008nlo and CT10).
- NLO corrected for hadronisation and underlying event effects.
  - Obtained using PYTHIA and HERWIG with various tunes.



Data-based background subtraction method

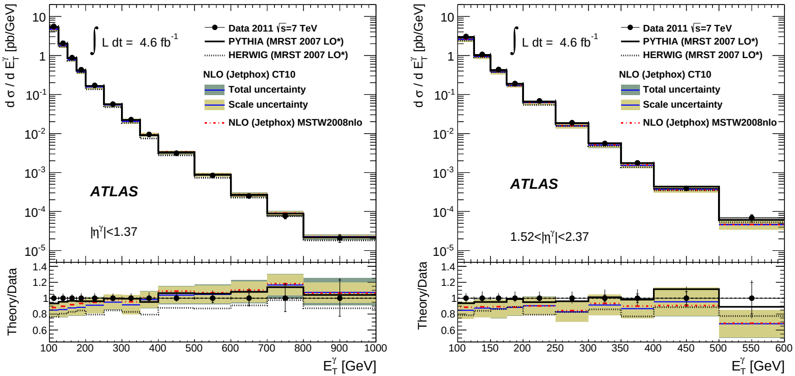


$$N_S^A = N^A - R_{BKG}\frac{(N^B - c_B N_S^A)(N^C - c_C N_S^A)}{(N_D - c_D N_S^A)}$$

$$c_k = N_s^k / N_S^A \text{ and } R_{BKG} = \frac{N_{BKG}^A N_{BKG}^D}{N_{BKG}^B N_{BKG}^C}$$

Inclusive isolated prompt photon cross sections at $\sqrt{s} = 7$ TeV.

Phys.Rev. D89 (2014) 052004



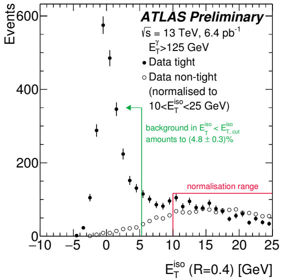
Both PYTHIA and HERWIG describe the shapes of the differential cross sections. NLO predictions agree with data up to $E_T^{\gamma} \sim 1$ TeV .

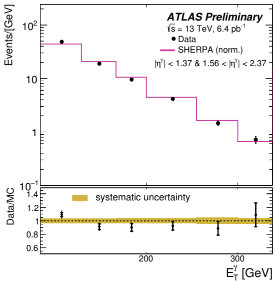
HepData available

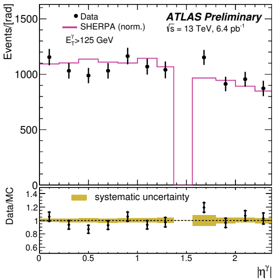
Inclusive isolated prompt photon production at $\sqrt{s} = 13$ *TeV.*

ATL-PHYS-PUB-2015-016

- $E_T^\gamma > 125$ GeV
- $|\eta^\gamma| < 1.37$ or $1.56 < |\eta^\gamma| < 2.37$
- $E_T^{iso} < 4.8$ GeV$+4.2 \cdot 10^{-3} \cdot E_T^\gamma$ and "tight" ID criteria.
- MC LO: SHERPA
- Background estimated from E_T^{iso} distributions ($\sim 5\%$).
  - Different shapes of "tight" and "non-tight" candidates.







Shape of distributions well described by SHERPA. Clear signal of inclusive isolated photons at $\sqrt{s} = 13$ TeV

Summary

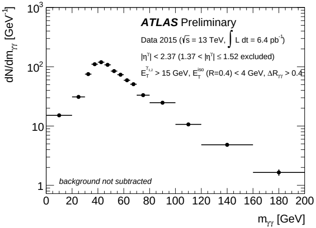
- Cross sections have been measured for inclusive jet, dijet, three and four-jets. NLO pQCD calculations are compatible with data.
- Jet Charge analysis allows the extraction of jet charge values for different quark flavours and of the scale violation parameter.
- Transverse energy-energy correlations have been measured and have been used to extract a value of $\alpha_s \to$ good experimental precision and compatible with the world average.
- Prompt photon isolation cross sections have been measured with results compatible with NLO pQCD calculations.
- First results have been obtained for inclusive jet and isolated prompt photon production in pp collisions at $\sqrt{s} = 13$ TeV.

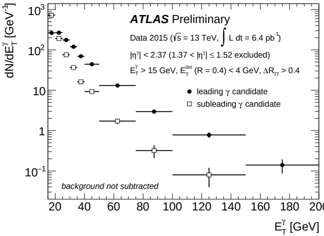
BACKUP

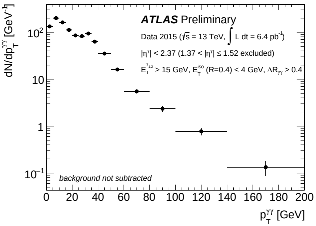
Inclusive isolated di-photon candidates at $\sqrt{s} = 13$ TeV.

ATL-PHYS-PUB-2015-020

- At least two photons with $E_T^{\gamma} > 15\ GeV$
- $|\eta^{\gamma}| < 1.37$ or $1.52 < |\eta^{\gamma}| < 2.37$
- $E_T^{iso} < 4$ GeV and "tight" ID criteria.
- $\Delta R_{\gamma\gamma} > 0.4$.
  - Avoid energy deposits in isolation cone of the other photon.

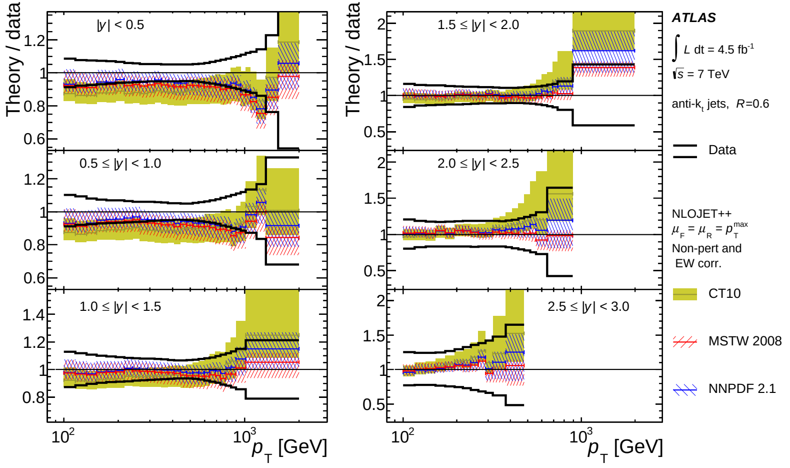




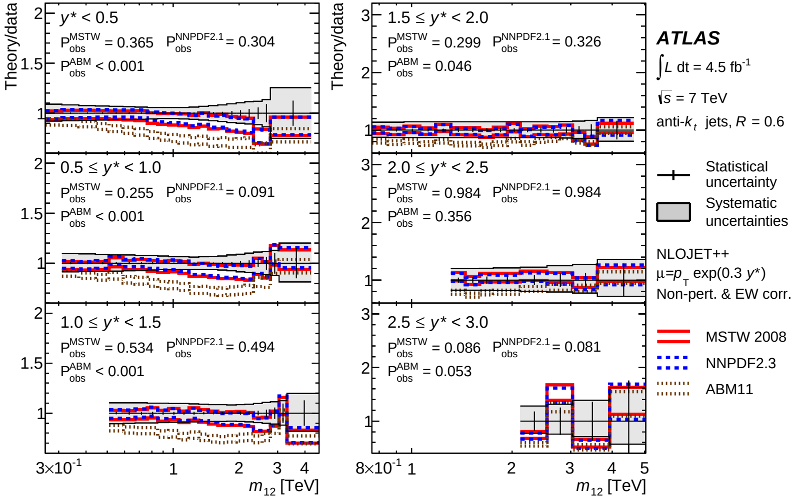


Enhancement in $P_T^{\gamma\gamma}$ between 20 GeV and 40 GeV expected from beyond leading-order contributions.

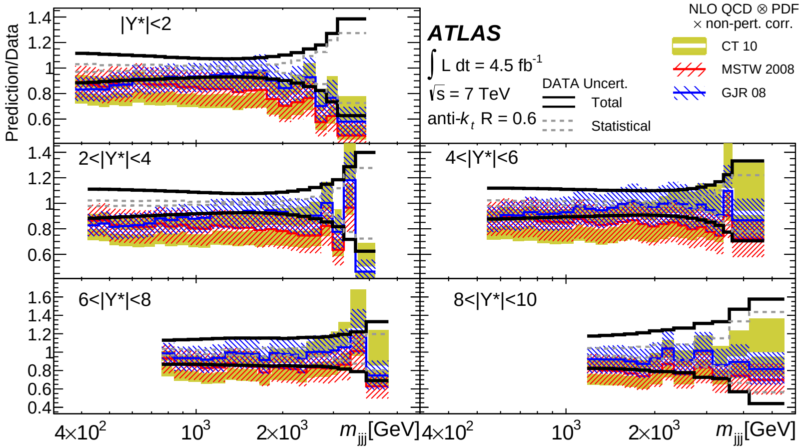
Additional results inclusive jets (R=0.6)



Additional results dijet (R=0.6)

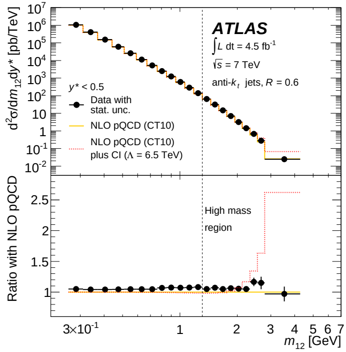


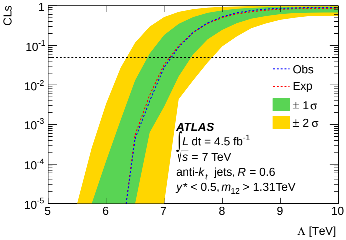
Additional results three-jets (R=0.6)



Exclusion of contact interactions (dijet)

- Search for BSM physics using cross sections at high m_{12} and $|y^*| < 0.5$
  - Tested with contact interactions.
- CLs method using generalised χ^2 to account for correlations.





Exclusion of compositeness scales $\Lambda < 6.9\text{-}7.7$ TeV