Jet and photon measurements from ATLAS

João Gentil Mendes Saraiva
LIP Lisboa

LHCP 2013

Barcelona, Spain 13th-18th May

Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

Outline

- Introduction
- Jets Differential cross sections
  - Inclusive jets → PDFs refit
  - Di-jets
  - Multi-Jet ratios → α_s
- Photons Differential and Integrated cross sections
  - Prompt isolated photons
  - Di-photons
- Conclusions

Documents used for this talk:
Prompt photons: ATLAS-CONF-2013-022
Di-photon: arXiv:1211.1913v2
Di-jets: ATLAS-CONF-2012-021
Inc. Jet:: arXiv:1304.4739
alpha_s: ATLAS-CONF-2013-041

Introduction

- Jets and photons increase our understanding of QCD interactions:
  - Test the validity of pQCD down to shortest accessible distances
  - Sensitive to protons PDFs and measure α_s
  - Photons are colorless probes to QCD and used to constrain PDFs
  - Di-Photons e.g. are an important background for H->γγ
  - QCD with the LHC: high statistics + access larger pT scales
- In this talk:
  - Data from 2010/2011

2010	7 TeV	37 pb-1
2011	7 TeV	4.8 fb-1
2011	2.76 TeV	0.20 pb-1

  - Comparison with NLO/NNLO QCD calculations

Inclusive jets Cross Sections

$$\frac{d^2\sigma}{dp_T\,dy} \qquad 20 \leqslant p_T \leqslant 430\,GeV \quad \wedge \quad |y| < 4.4$$

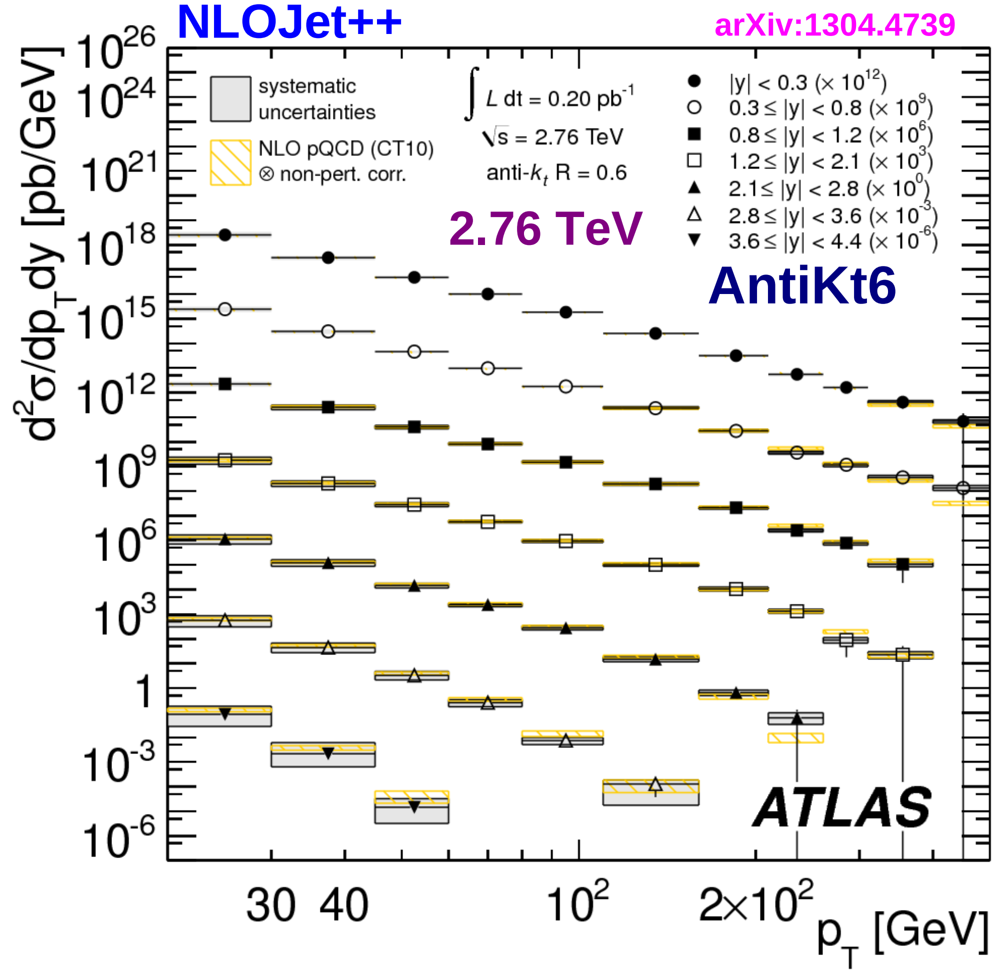
Previously @ 7 TeV

Well described by NLO pQCD x corr.
Non-perturbative effects from hadronization + underlying event (UE)

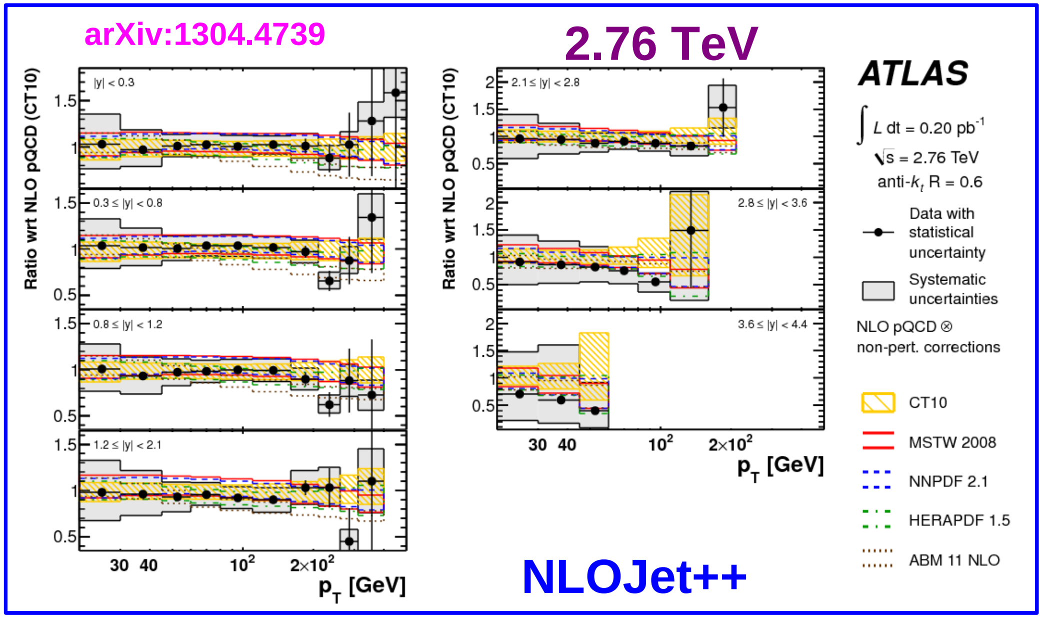
Now results for 2.76 TeV detailed

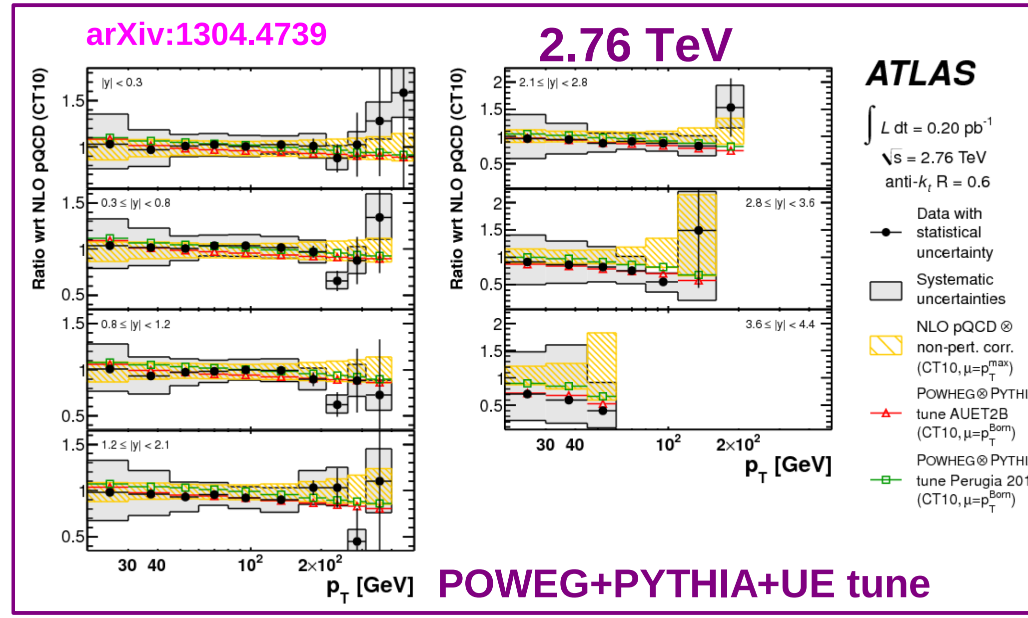
Calculation ratio of the two CS:

- $\rho(y, x_T)$ ↓ Theoretical uncertainties
- $\rho(y, p_T)$ ↓ Experimental systematic uncert.
- Explore correlations between data/theory to re-fit PDFs



Inclusive jets XS/NLO predictions





pQCD uncertainties → 5-15% **central region**, 10-80% **forward region** → **Low pt** from scale ($\mu_{R,}$ μ_F) uncert. **High pt** from PDF uncert

NLOJet++

Results consistent with theory predictions with different PDFs sets
CT10 MSTW 2008 NNPDF 2.1 HERAPDF 1.5 ABM 11
within their systematic uncertainties

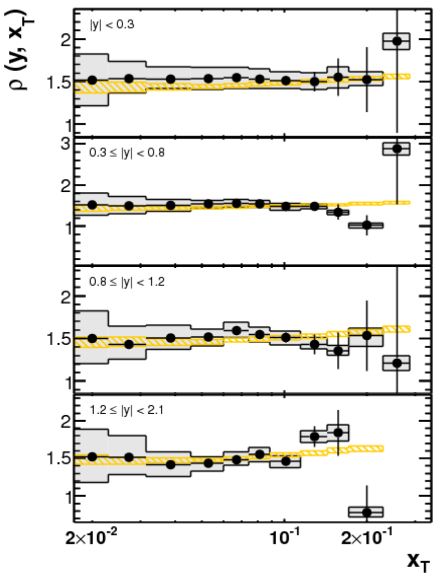
POWEG+PYTHIA+UE tune

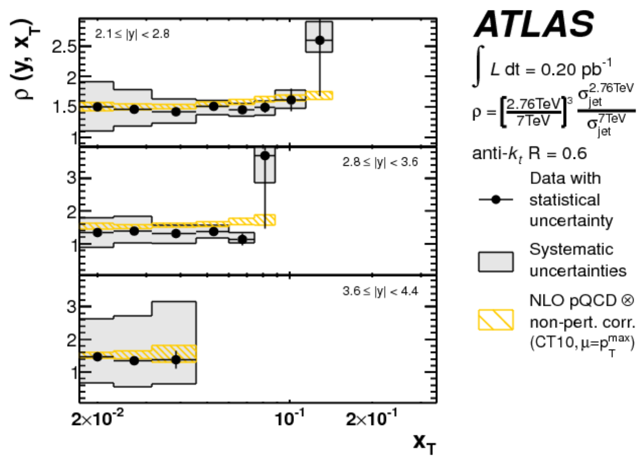
Model close to data in the forward region than central region
Perugia 2011 tune farther away **AUET2B tune** closer

Inclusive XS ratios 2.76 TeV/7 TeV

arXiv:1304.4739

NLOJet++





Vs. $x_T = \frac{2 \cdot p_T}{\sqrt{s}}$

Vs x_T

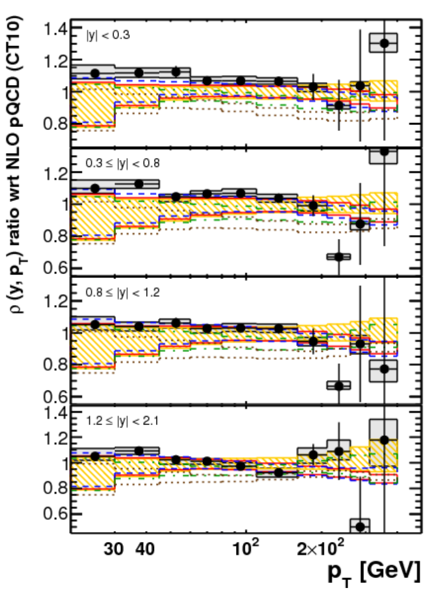
Flat response

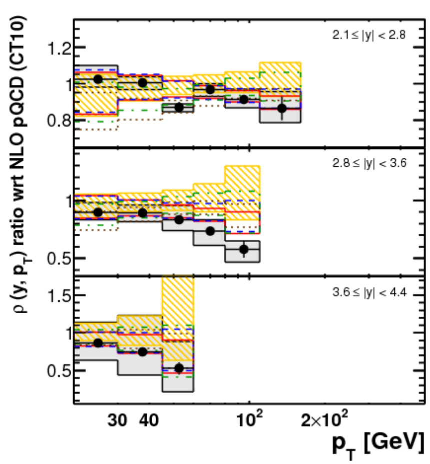
- Asymptotic freedom of QCD
- Evolution of the gluon distribution in the proton as function of the QCD scale

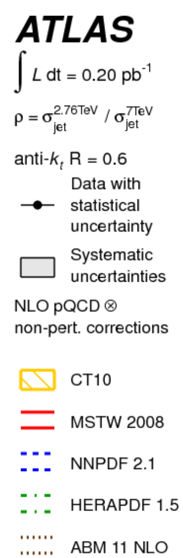
Comparison with POWEG (back-up slides)

- Agreement with data and pQCD

arXiv:1304.4739







Vs. p_T

Vs p_T

Dependence with rapidity:

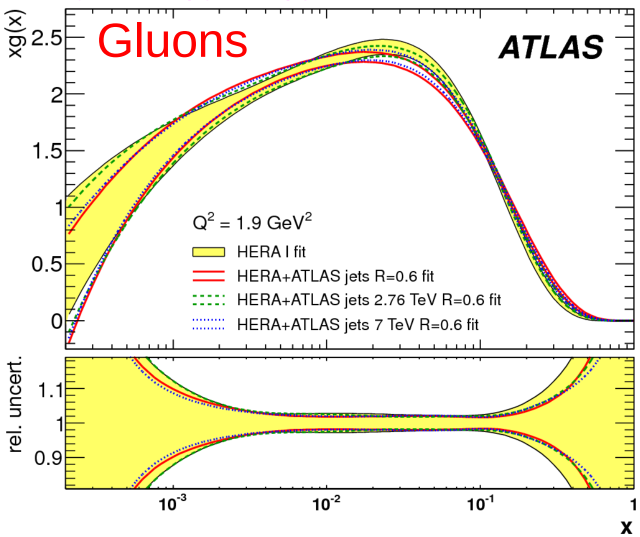
- Data higher for central region
- Data lower for forward region

Comparison with POWEG (back-up slides)

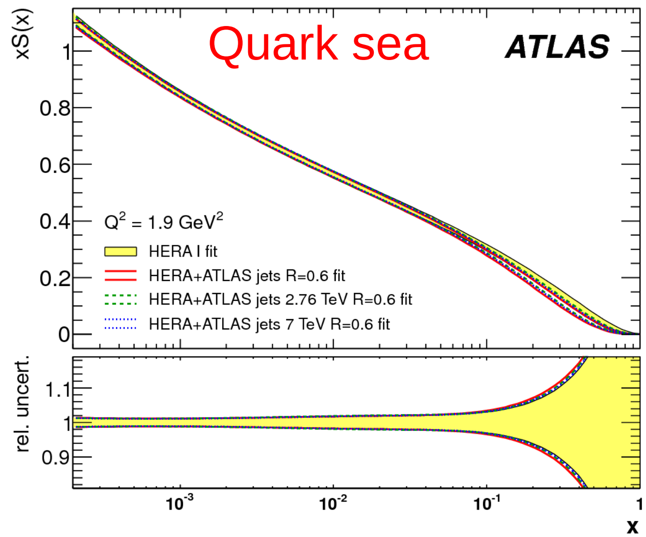
- Follows pQCD in barrel region
- Close to data in forward region

Gluon and sea parton density from inclusive jets XS

arXiv:1304.4739



arXiv:1304.4739



ATLAS data + **HERA I** data

↓

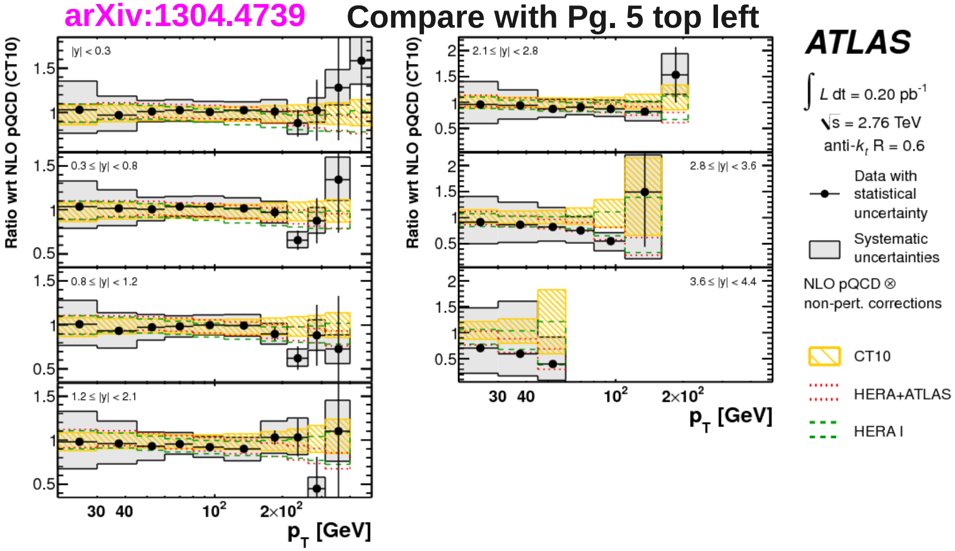
NLO pQCD analysis in the DGLAP formalism

↓

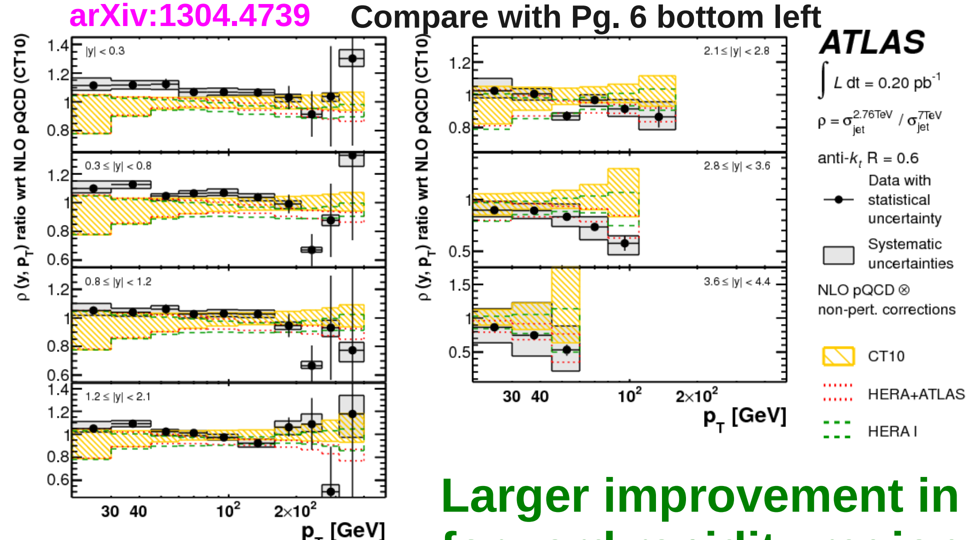
In the **HIGH** Bjorken-x region:
harder gluon distribution
softer quark sea distribution

Measured cross sections and ratios compared to predictions based on fitted PDF sets

arXiv:1304.4739 **Compare with Pg. 5 top left**



arXiv:1304.4739 **Compare with Pg. 6 bottom left**



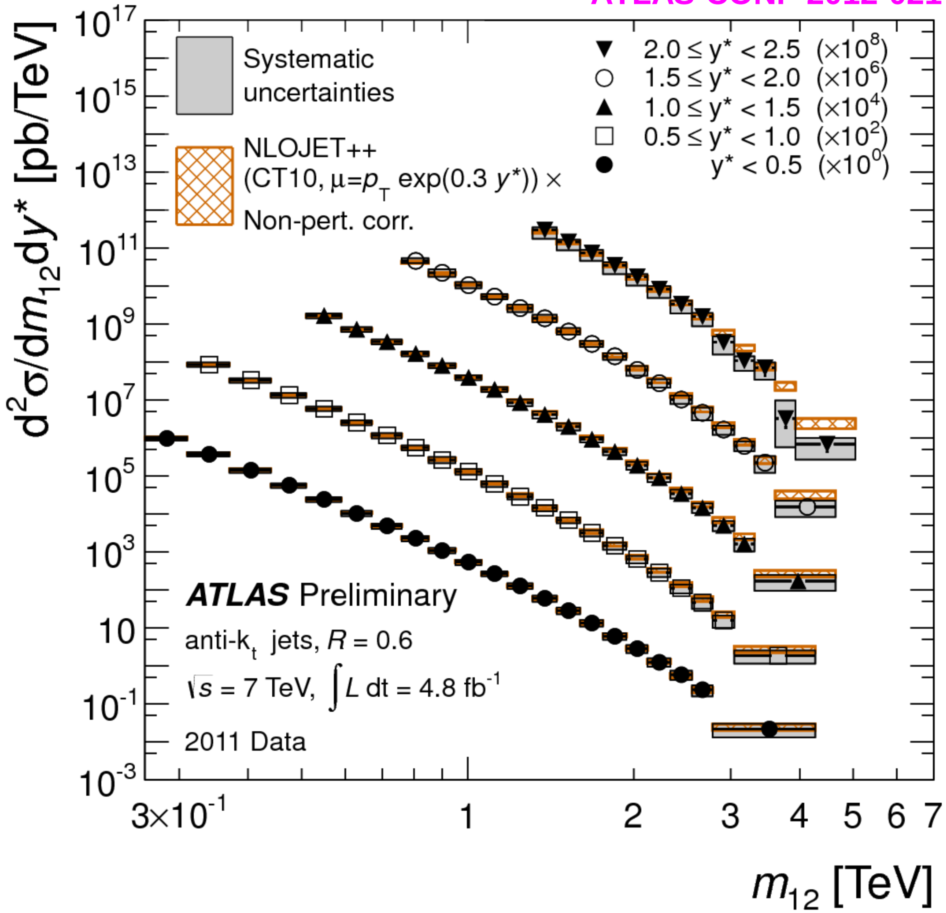
Larger improvement in forward rapidity region

Dijet production XS

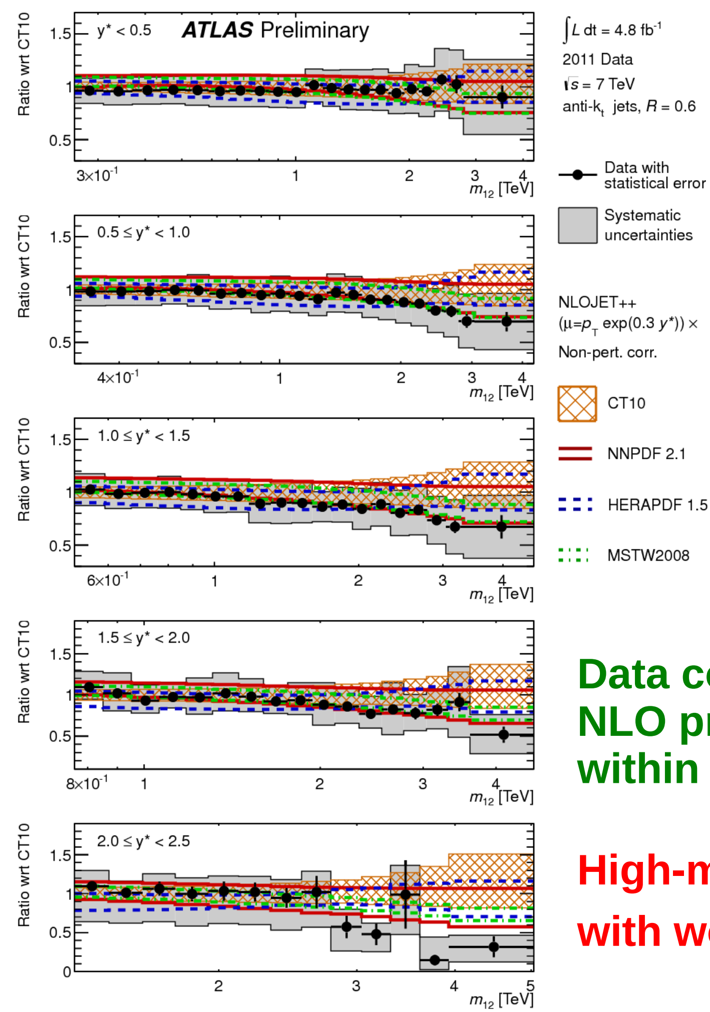
$$p_{T,1}>100\,GeV \wedge p_{T,2}>50\,GeV \wedge |y|<2.8$$

$$rapidity \quad bin \quad y^{*}=|y^{j1}-y^{j2}|/2$$

ATLAS-CONF-2012-021



ATLAS-CONF-2012-021



Data consistent with NLO predictions within errors

High-m_{12} and larger y* with worse agreement

LO MC (PYTHIA/SHERPA) have a similar behavior (back-up slides)

Multi-jets XS ratios

Two quantities sensitive to α_s

Kinematics selection:

$p_T > 40\,GeV \wedge |y| < 2.8$

$p_{T,lead} > 50\,GeV$

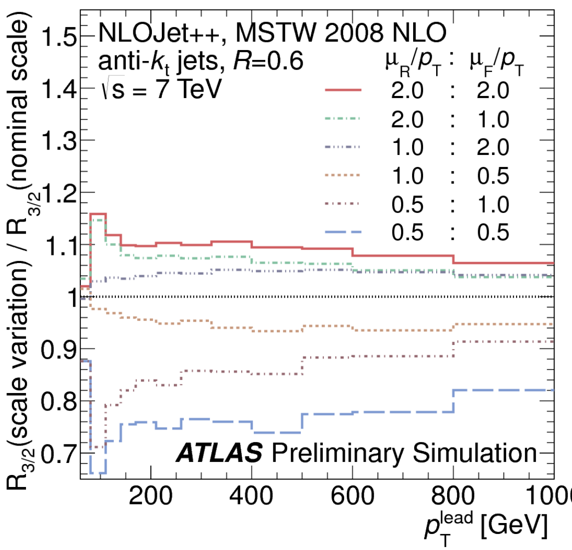
$$R_{3/2}(p_T^{\mathrm{lead}}) = \frac{d\sigma_{N_{\mathrm{jet}}\geq 3}/dp_T^{\mathrm{lead}}}{d\sigma_{N_{\mathrm{jet}}\geq 2}/dp_T^{\mathrm{lead}}}$$

$$N_{3/2}(p_T^{(\mathrm{all\,jets})}) = \frac{\sum_i^{N_{\mathrm{jet}}}\left(d\sigma_{N_{\mathrm{jet}}\geq 3}/dp_{T,i}\right)}{\sum_i^{N_{\mathrm{jet}}}\left(d\sigma_{N_{\mathrm{jet}}\geq 2}/dp_{T,i}\right)}$$

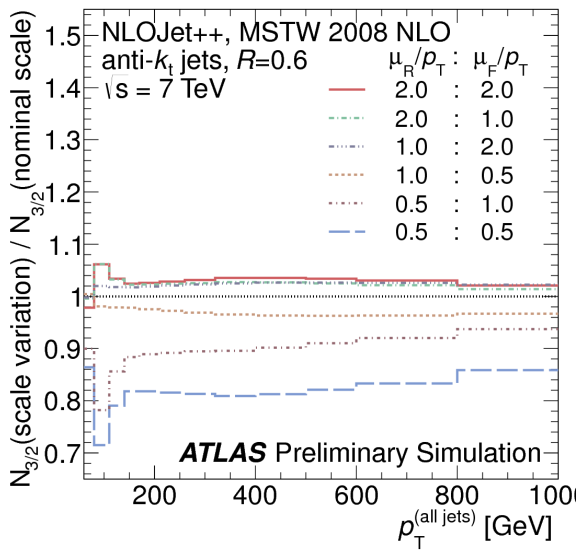
$R_{3/2}$ receives a single entry/event

$N_{3/2}$ receives all jets in a event

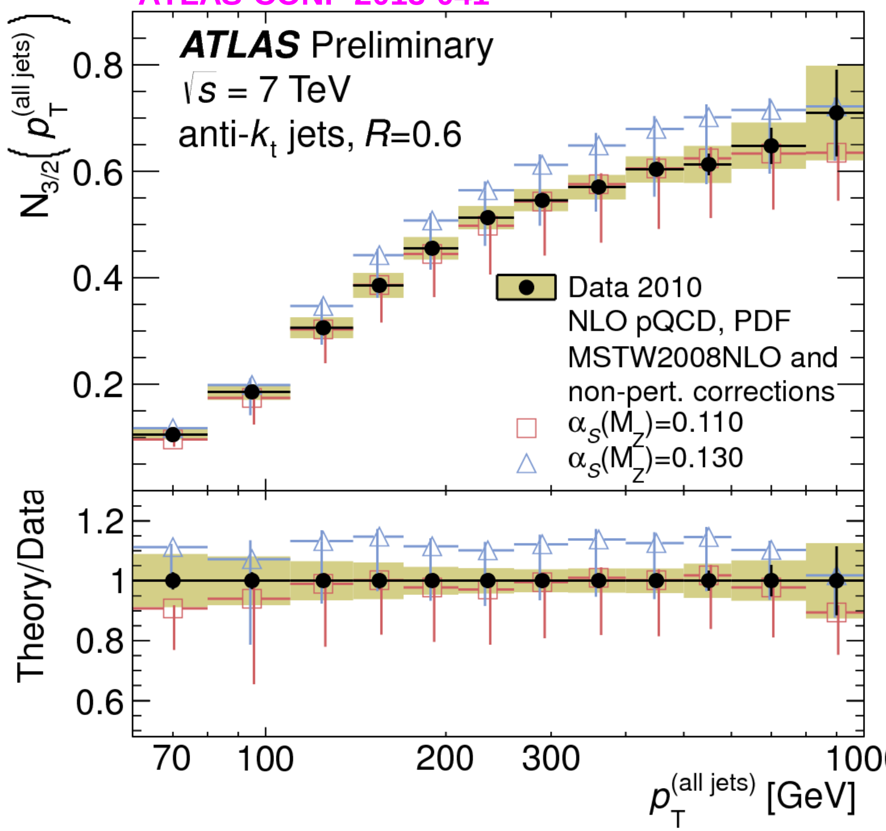
ATLAS-CONF-2013-041



ATLAS-CONF-2013-041



ATLAS-CONF-2013-041



$N_{3/2}$ less sensitive to renormalization and factorization scale variations

Use $N_{3/2}$ to extract α_s

α_s strong coupling constant

Combined fit result:

$$\alpha_s(M_Z) = 0.111 \pm 0.006(\text{exp.})\ ^{+0.016}_{-0.003}(\text{theory})$$

$\alpha_s(M_Z) = 0.1184 \pm 0.0007$ **World**

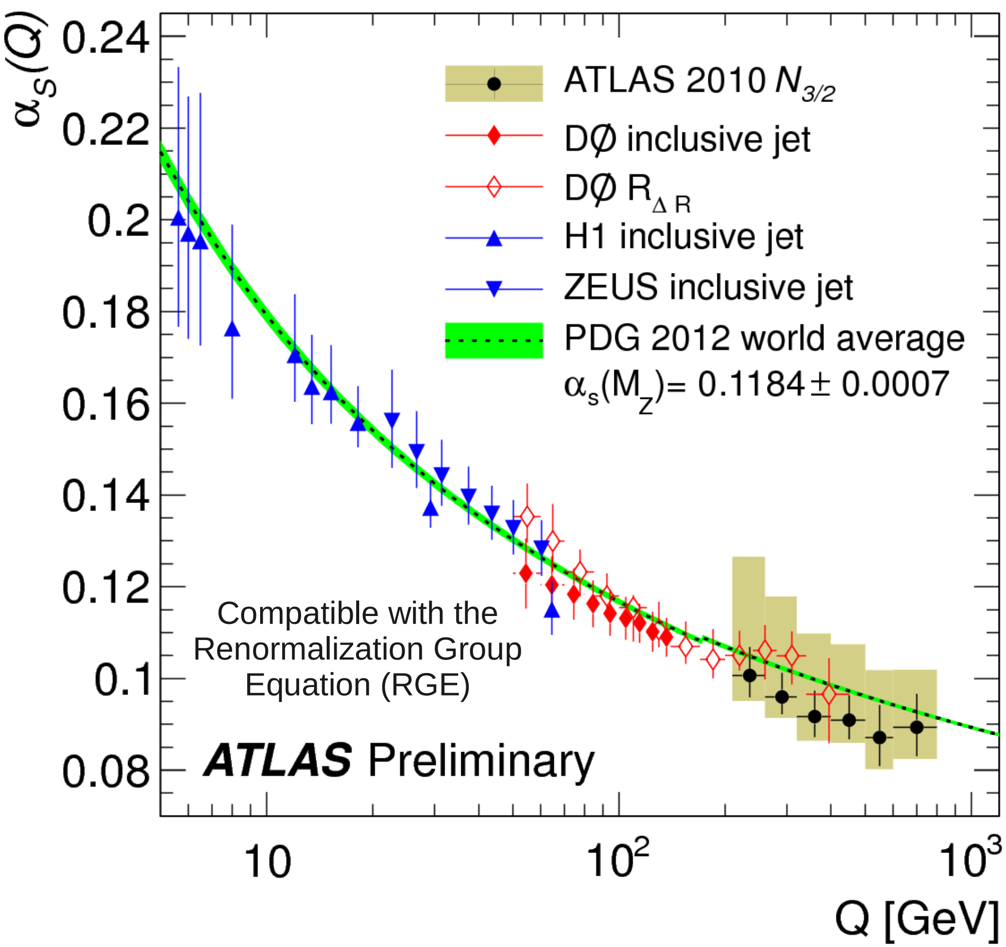
$\alpha_s(M_Z) = 0.1178 \pm 0.0001(\text{stat.})^{+0.0081}_{-0.0095}(\text{syst.})$ **CDF**

$\alpha_s(M_Z) = 0.1191^{+0.0048}_{-0.0071}$ **D0**

PDF	$\alpha_s(M_Z)$
MSTW08	0.111 ± 0.006
CT10	0.109 ± 0.006
HERAPDF 1.5	0.114 ± 0.005
ABM11	0.116 ± 0.005
NNPDF 2.3	0.112 ± 0.005

(exp.)

ATLAS-CONF-2013-041



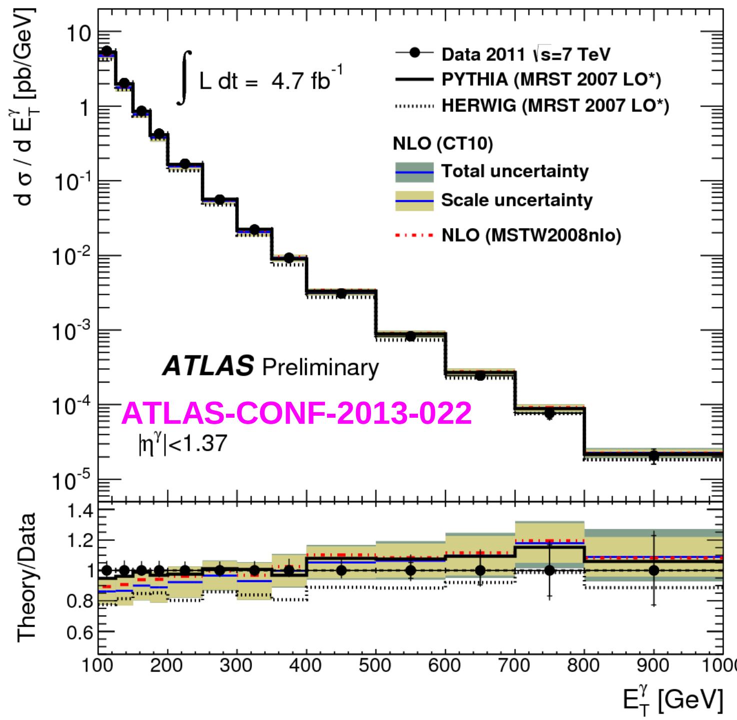
Prompt isolated photons XS

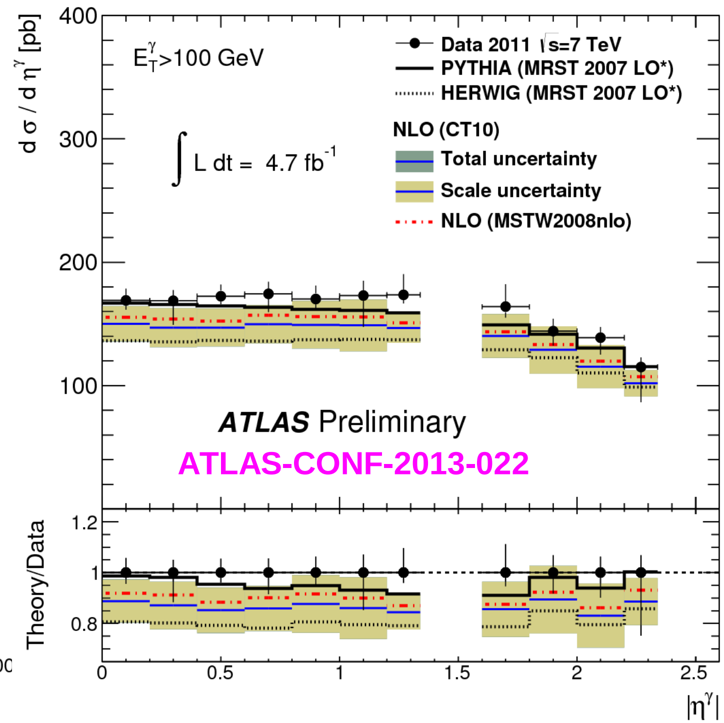
NLO calculations

JETPHOX 1.3 NLO QCD
direct and frag. contrib. +
NLO γ frag. func. BFG set II +
PDFs CT10/MSTW2008NLO

LO Simulation

PYTHIA 6.4 and HERWIG 6.5
only qg->qγ and q$\bar{q}$->qγ
PYTHIA + MRST2007LO + AMBT2
HERWIG +MRST2007LO + AUET2





Data well set within theory uncertainties

PYTHIA reproduces data

HERWIG underestimates

Shape well described by both

NLO/PYTHIA agreement

$|\eta|<1.37$ $\quad \sigma(\gamma+X)=234\pm2(stat)^{+13}_{-9}(syst)\pm4(lumi)\,pb$

PYTHIA	224 pb
HERWIG	187 pb
JETPHOX CT10	203 ± 25 *(theo.)* pb
JETPHOX MSTW2008	212 ± 24 *(theo.)* pb

$1.52\leq|\eta|<2.37$ $\quad \sigma(\gamma+X)=122\pm2(stat)^{+9}_{-7}(syst)\pm2(lumi)\,pb$

PYTHIA	118 pb
HERWIG	99 pb
JETPHOX CT10	105 ± 15 *(theo.)* pb
JETPHOX MSTW2008	109 ± 15 *(theo.)* pb

Di-photons XS vs pT, vs Δφ

Integrated exp. cross section $44.0^{+3.2}_{-4.2}$ *pb*

Theory for CS comparisons

2γNNLO 44.0^{+6}_{-5} *pb*

NNLO direct part
BUT neglecting fragmentation

DIPHOX+GAMMA2MC 39^{+7}_{-6} *pb*

NLO direct+fragmentation
GAMMA2MC NNLO to set contribution of gg->γγ to a size of NLO terms

PYTHIA*

LO di-photon ME and models high order through γ-jet and di-jet production combined with ISR and FSR

SHERPA*

Like PYTHIA + di-photon higher order real-emission ME

(PYTHIA*, SHERPA*): 36 *pb*

SHERPA better than PYTHIA

High-order terms are included in SHERPA

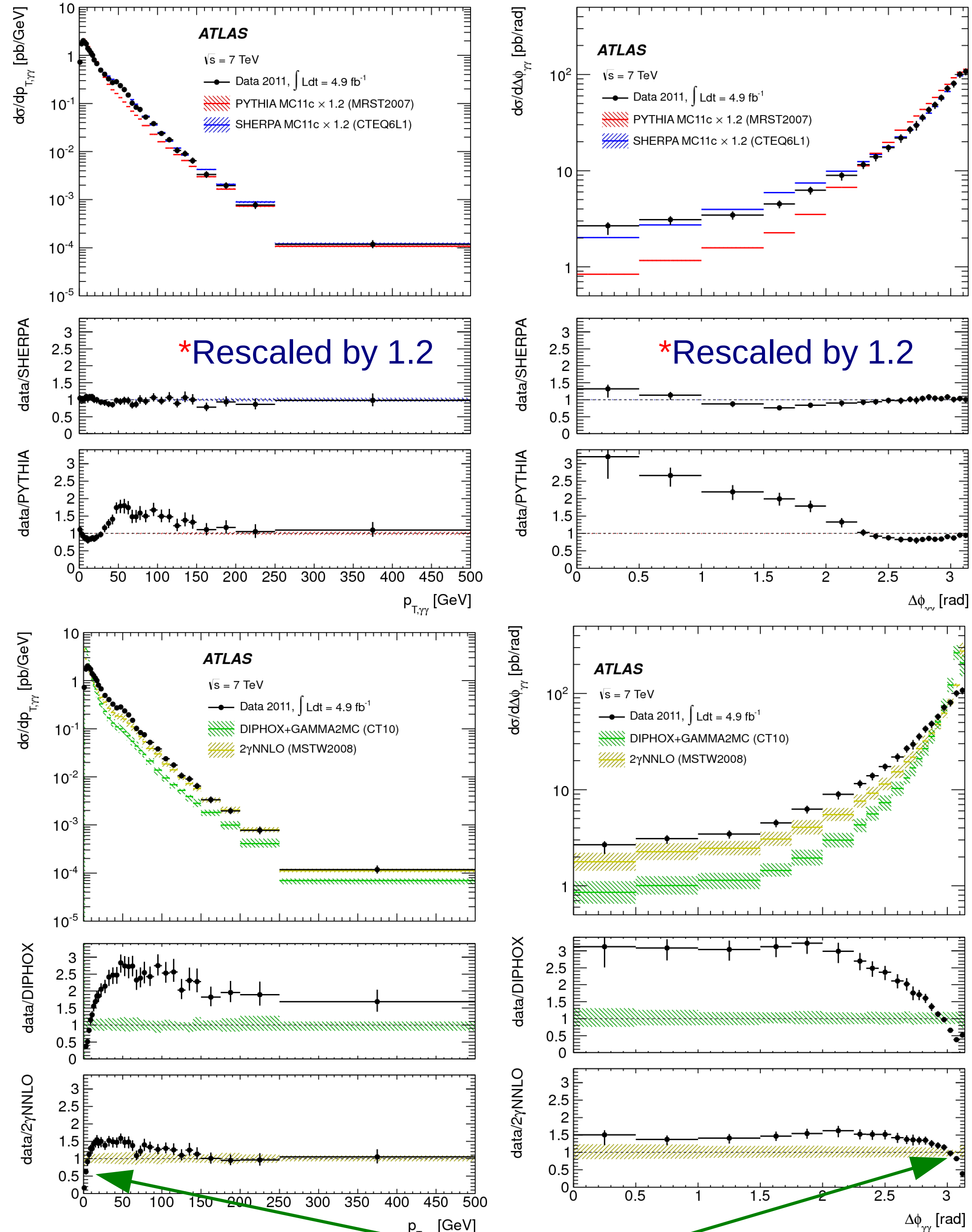
DIPHOX

Underestimates data

2γNNLO

Disagreement from lack of fragmentation component: pT [20,150] GeV and low Δφ

NNLO is closer to data



Expected for a fixed order calculation

Summary and Conclusions

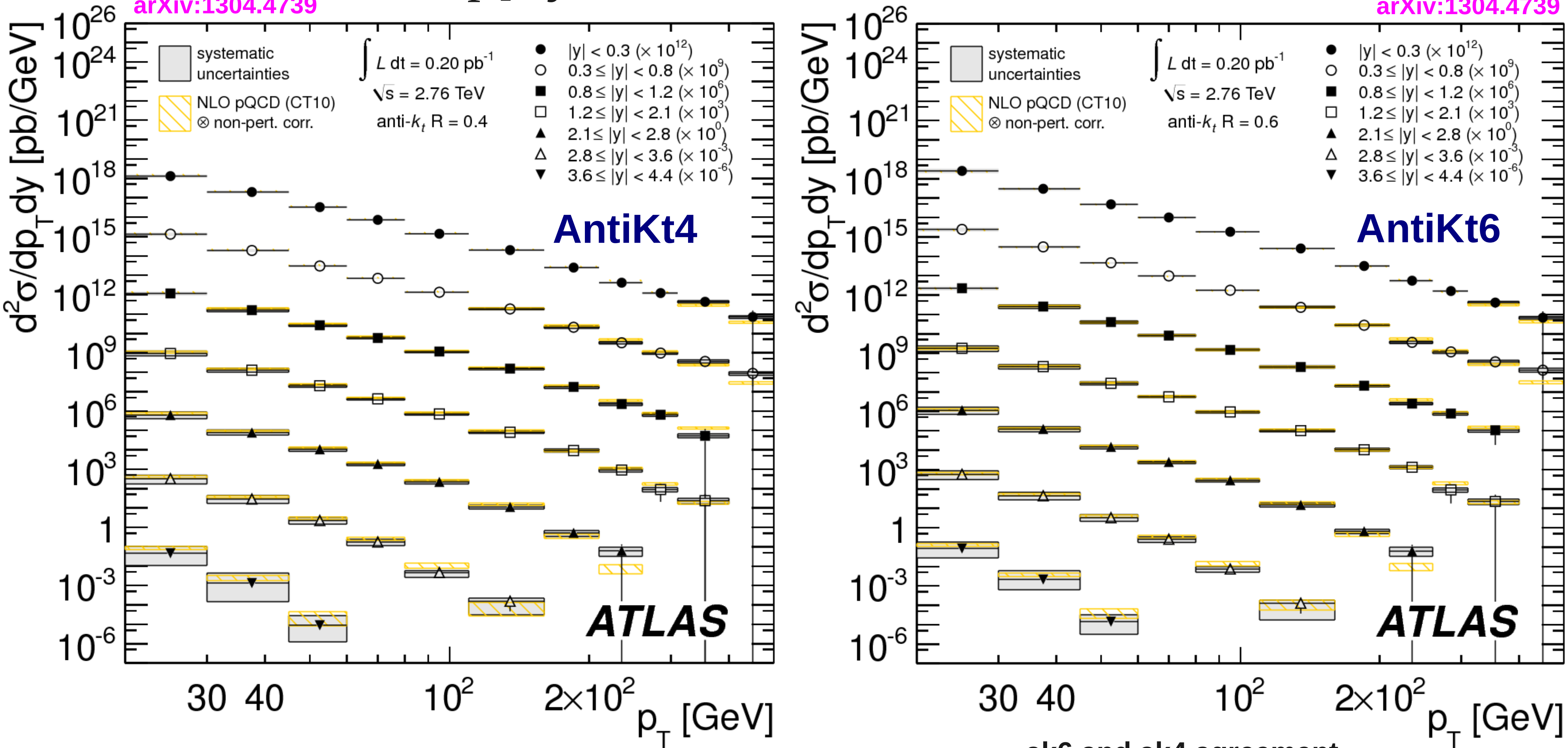
- **Globally**: a reasonable reproduction of data from NLO QCD predictions
- **Increased sensitivity** to PDFs is achieved with the 2.76 TeV and 7 TeV results correlation:
  - HERA+ATLAS : **harder gluon** and **softer sea-quark** densities at high Bjorken-x.
- A value of $\boldsymbol{\alpha_s \sim 0.111}$ compatible with previous measurements and predictions using different PDFs
  - α_s with a **running compatible** with the RGE prediction.
- Prompt photons results close to NLO pQCD predictions over a large E_T
  - **Higher order** descriptions are necessary for a **good description of data**.
- Di-photons results show that **higher order** theory predictions get a **better** agreement with data
  - 20% underestimation for LO while NNLO with an almost perfect match.

2012 data (not covered in this talk) will access an even higher kinematic range and give much more statistics

Inclusive jets CS

$$\frac{d^2\sigma}{dp_T\,dy} \qquad 20 \leqslant p_T \leqslant 430\,GeV \;\wedge\; |y| < 4.4$$

arXiv:1304.4739



arXiv:1304.4739

ak6 and ak4 agreement
focus given to akt6 for next slides
akt4 on backup slides

Inclusive jets CS ratios 2.76/7 (syst.)

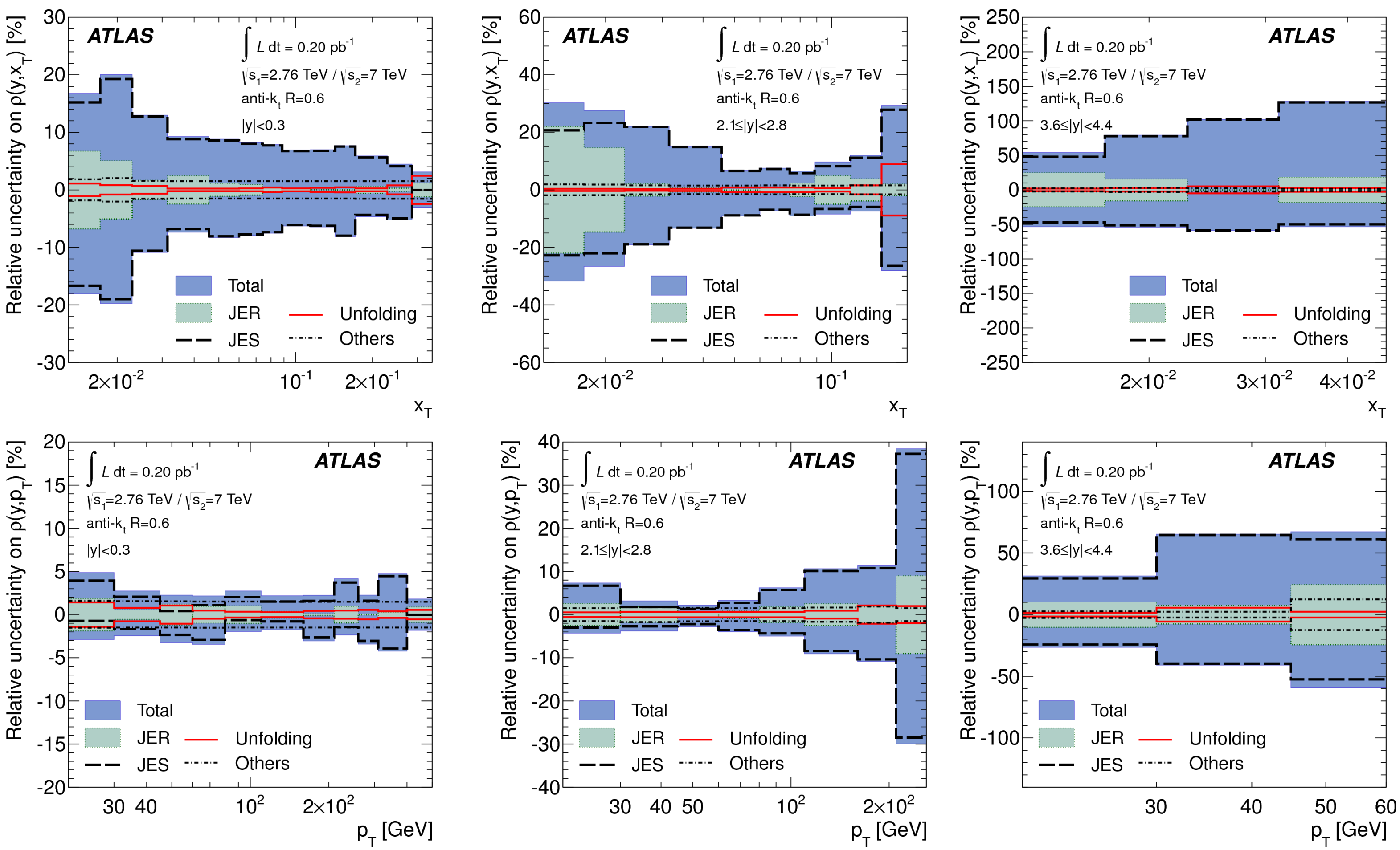
Cross section ratio uncertainties

$$\frac{\Delta\rho_{s_i}}{\rho} = \frac{1+\delta_{s_i}^{2.76\ \mathrm{TeV}}}{1+\delta_{s_i}^{7\ \mathrm{TeV}}} - 1$$

x_T Momentum fraction of the initial state partons with respect to the proton beam

Systematic uncertainties considered fully correlated for both $\sqrt{s}$

arXiv:1304.4739



vs. x_T

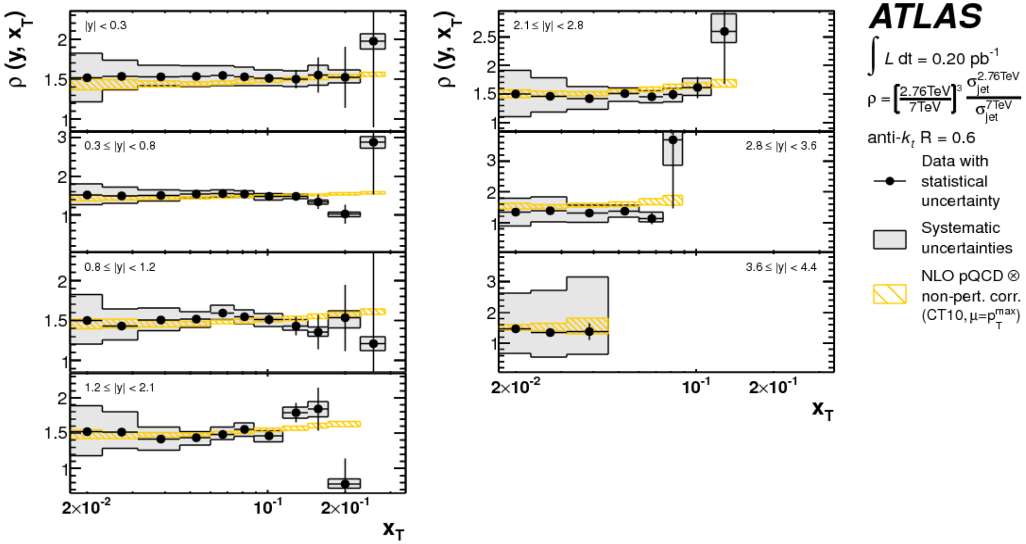
Reduction resulting from larger cancelation of JES uncertainty in pT bins

vs. p_T

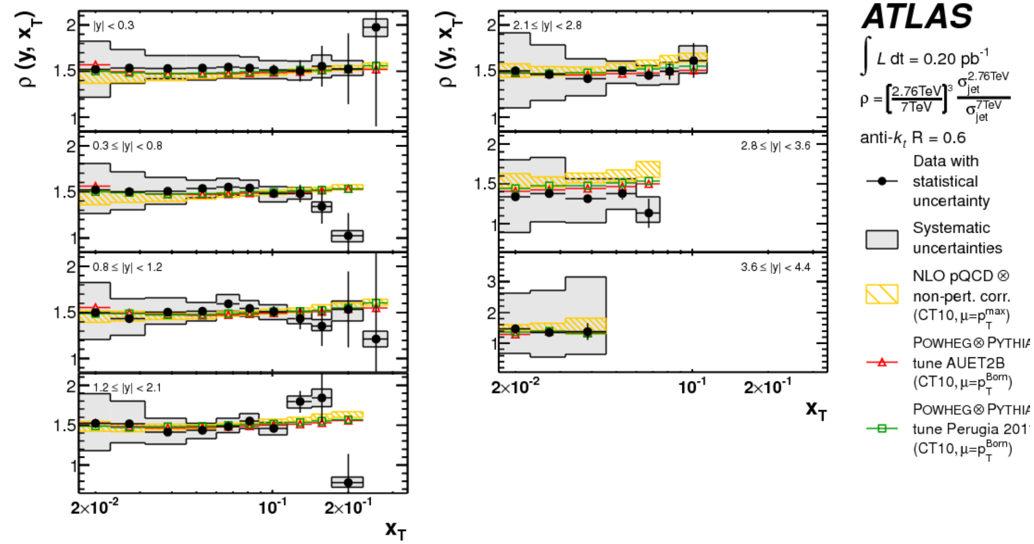
Inclusive CS ratios 2.76 TeV/7 TeV

x_T Momentum fraction of the initial state partons with respect to the proton beam

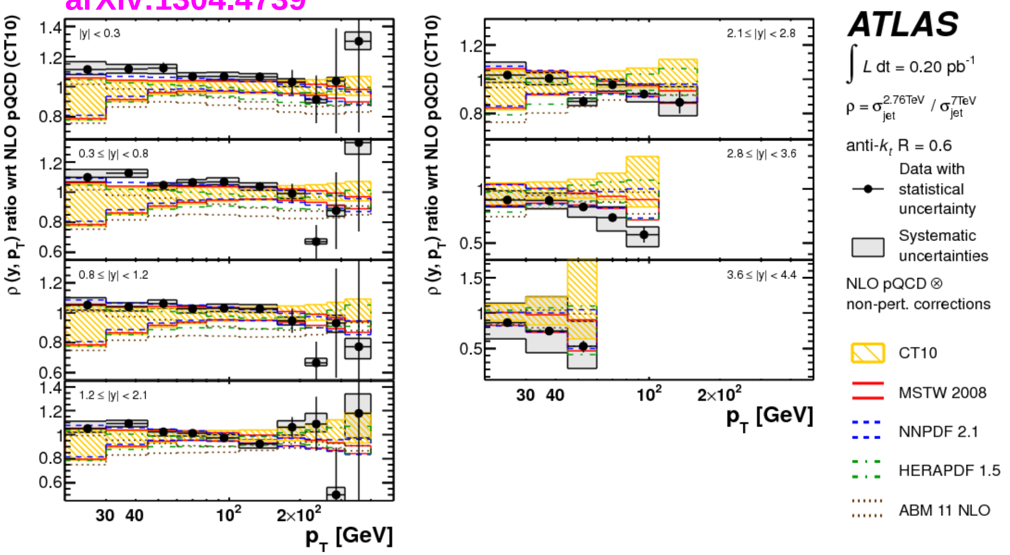
arXiv:1304.4739



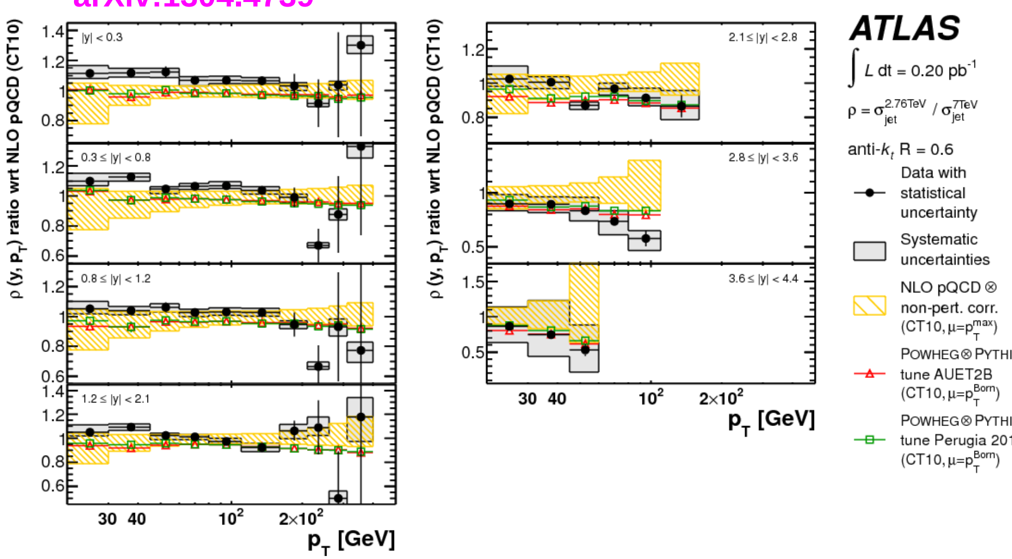
arXiv:1304.4739



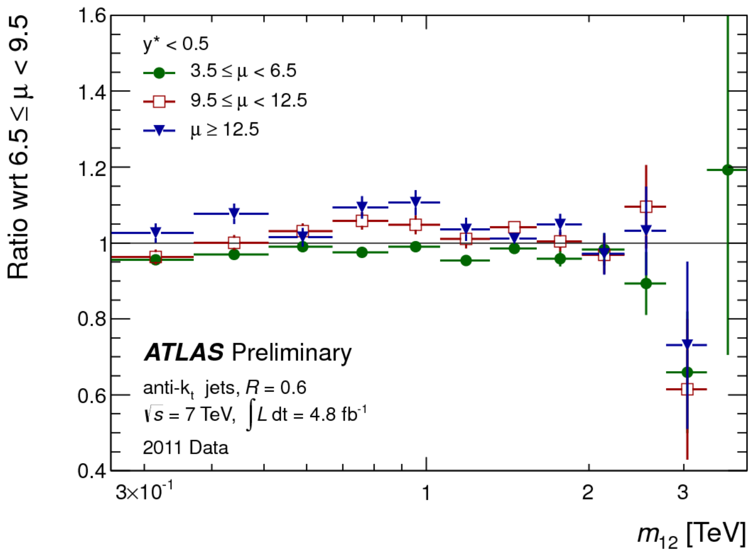
arXiv:1304.4739

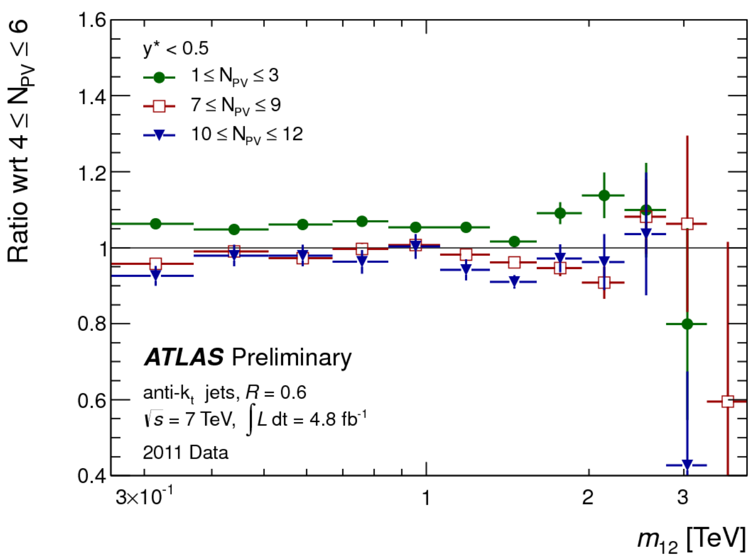


arXiv:1304.4739



Dijets



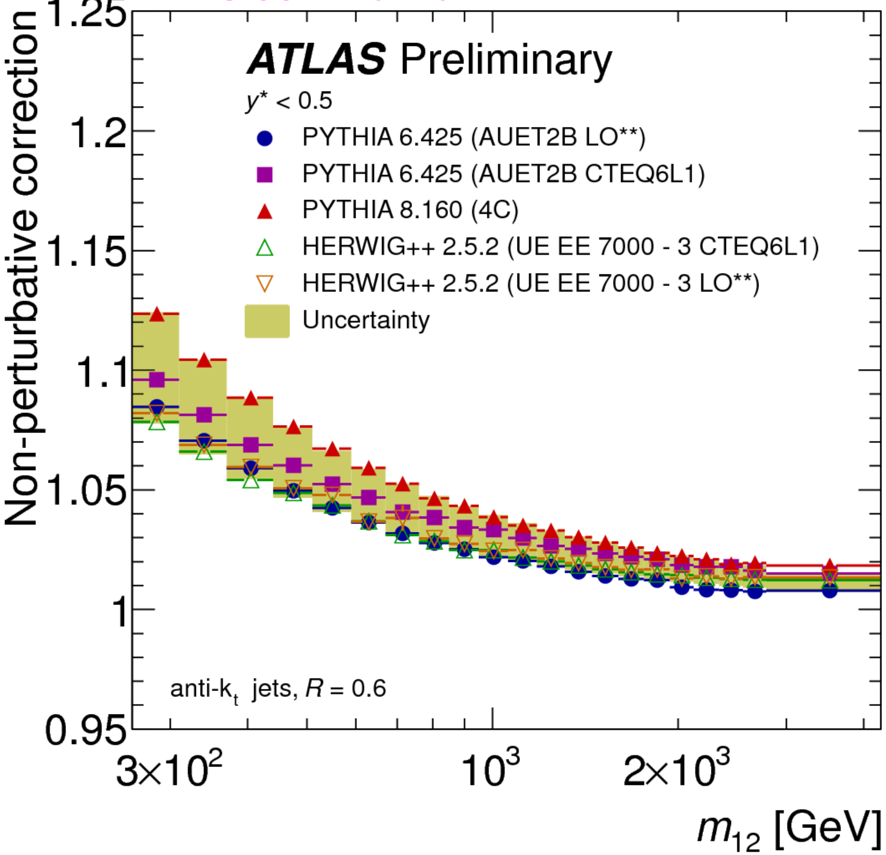


5-7%

Systematics coming from pile-up

Atlas studies resulted in a new version of POWHEG being released, to account for problems seen of low pt partons becoming high pt jets

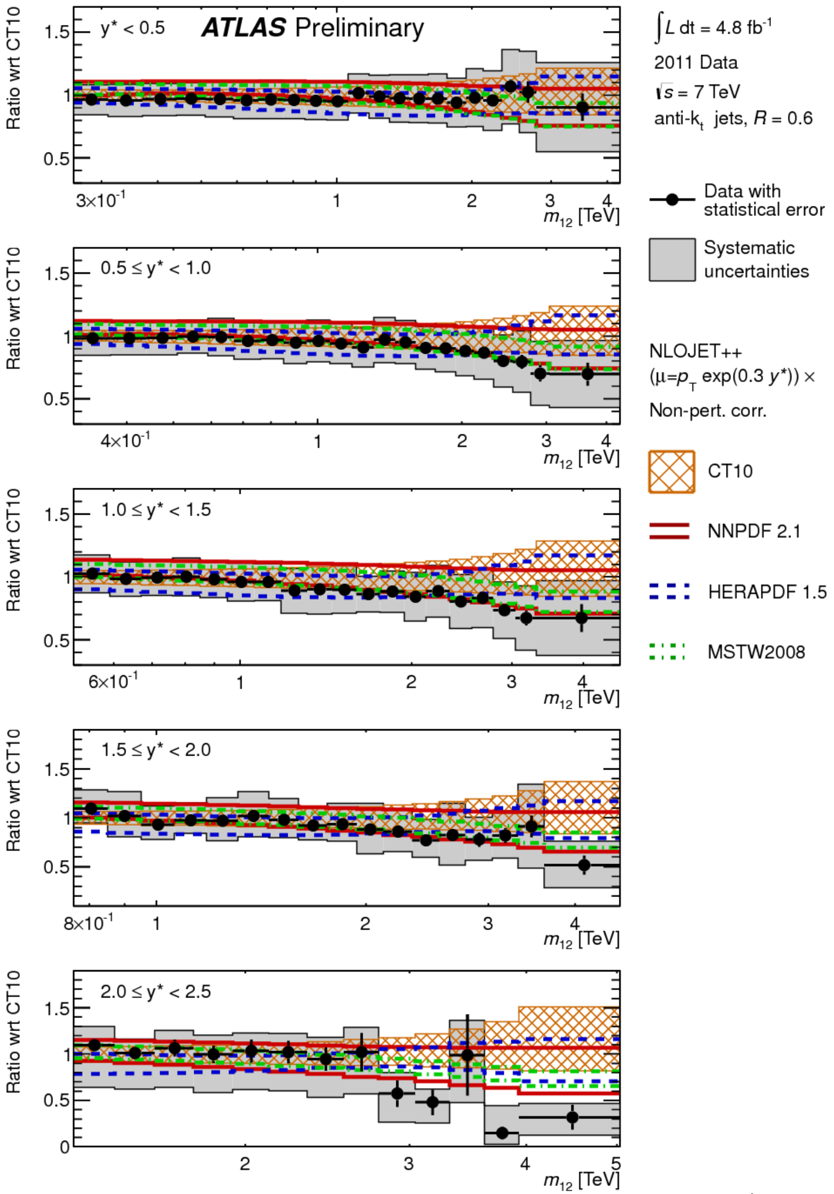
ATLAS-CONF-2012-021



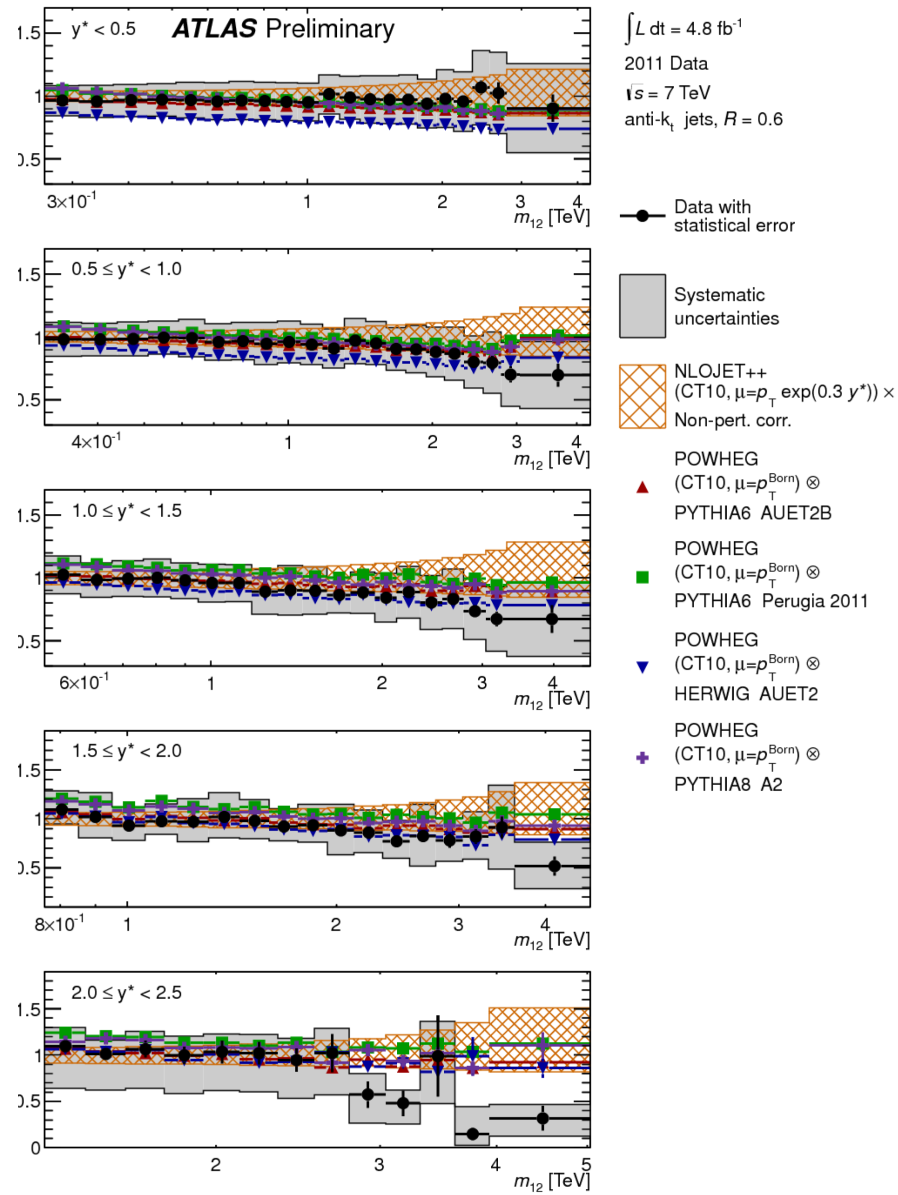
Dijets ratios Data/NLO pQCD

Data reproduced well by pQCD being set within stat. and syst. errors.

ATLAS-CONF-2012-021

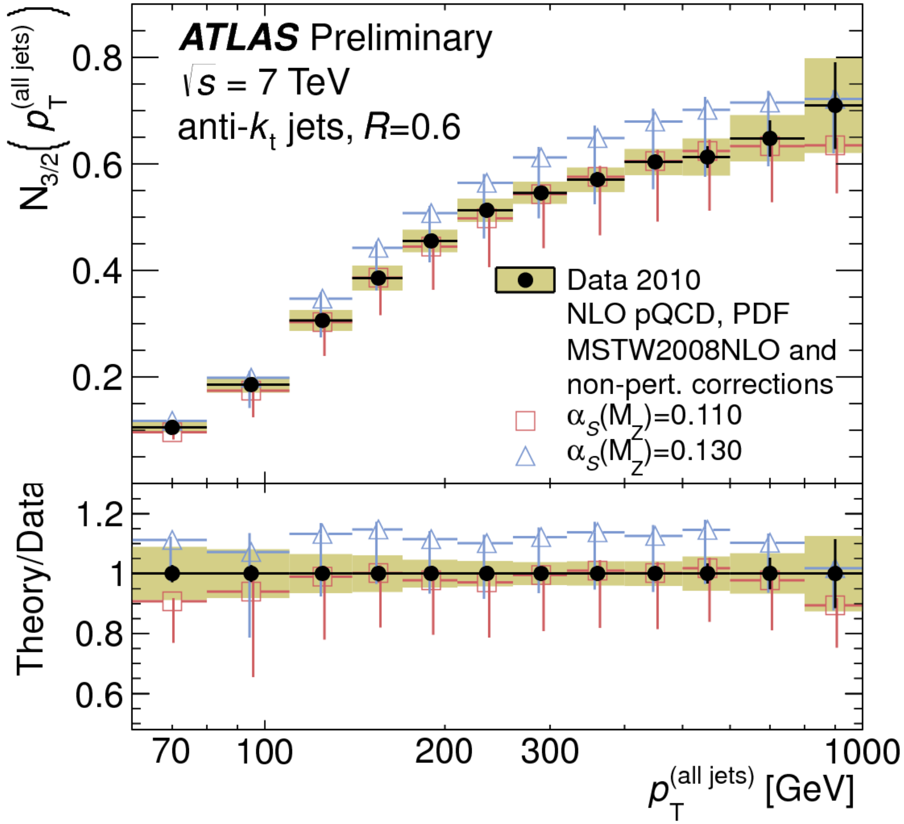


ATLAS-CONF-2012-021

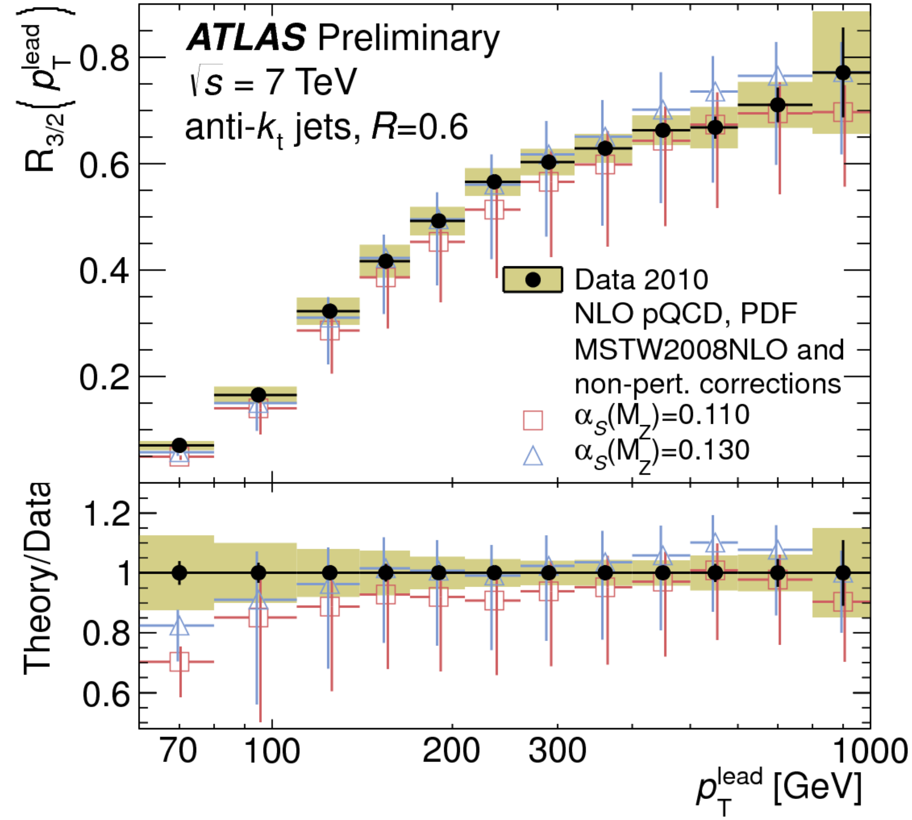


Multi-jets CS ratios

ATLAS-CONF-2013-041



ATLAS-CONF-2013-041



NLO pQCD predictions NLOjet++, corrected for non-perturbative effects:
$\alpha_s(M_Z)$ = 0.110 and 0.130

A least-squares fit is used to fit the data to the theory predictions as a function of alpha_s(MZ) for
210 GeV < p(all jets)T < 800 GeV.

The least-squares fit is performed both individually in each p_T bin and combining all p_T bins

α_s determination

prompt isolated photons

Colorless probe to hard scattering process → Precise tests of pQCD predictions

Sensitive to the gluon content through qg→qγ use to constrain PDFs

Isolation **(excluding 0.125x 0.175 ηxφ)**

Isolation Energy (energy in a isolation cone ΔR=0.4)

$E_T^{iso} < 7\ GeV$

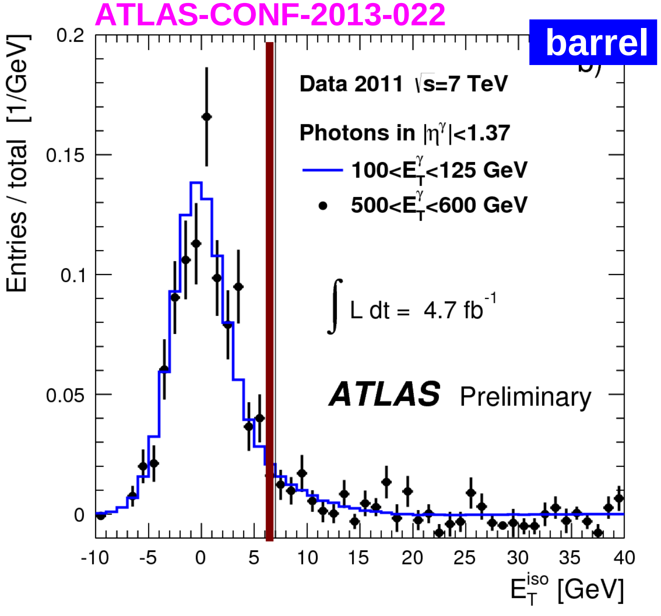
Kinematic selection:

$100 \leq E_T^{\gamma} \leq 1000\, GeV$

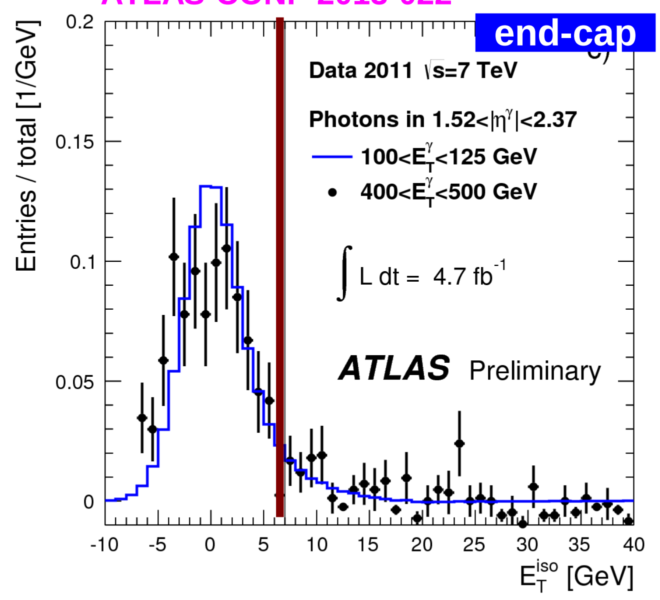
$|\eta^{\gamma}| < 1.37 \wedge 1.52 \leq |\eta^{\gamma}| \leq 2.37$

High eta granularity

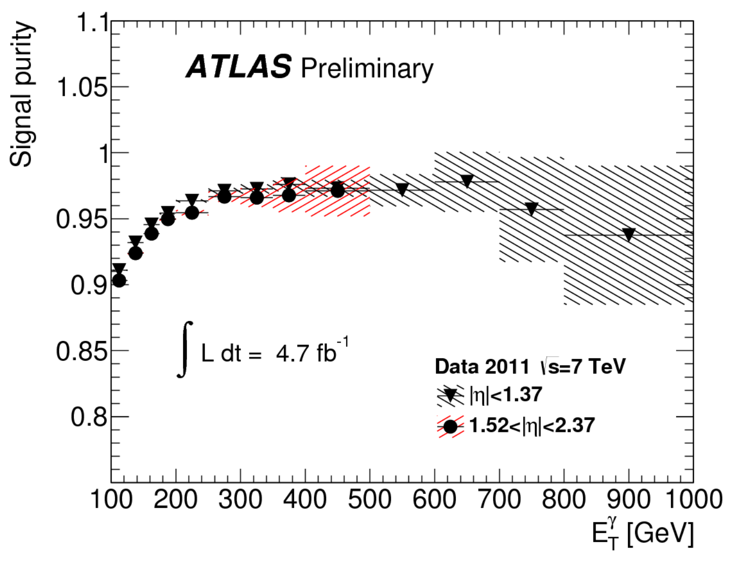
ATLAS-CONF-2013-022



ATLAS-CONF-2013-022



ATLAS-CONF-2013-022



Background subtraction from **dominant** π^0 decays and **residual** fake photons

Di-photons selection and purity

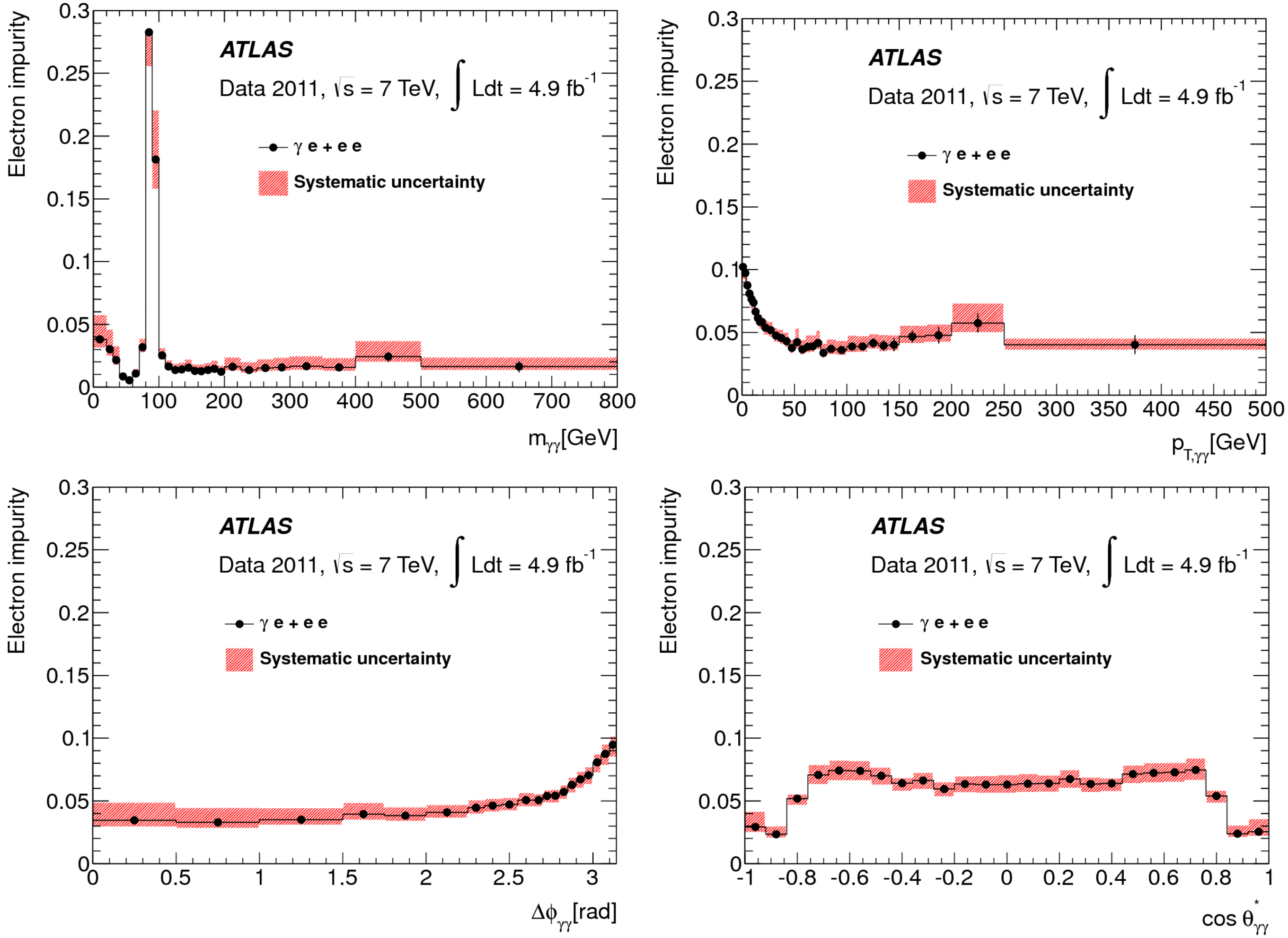
Probe pQCD + Understand the irreducible background for processes with 2 photons in the final state

Kinematic selection

$$E_T^{\gamma,1} > 25\,GeV \wedge E_T^{\gamma,2} > 22\,GeV \wedge \Delta R < 0.4$$

$$|\eta| < 1.37 \wedge 1.52 \leq |\eta| \leq 2.37$$

arXiv:1211.1913v2



Irreducible backgrounds may come from boson and di-boson decays resulting from electrons that fake photons

Electron background

Enhancements due to Z boson $m_{\gamma\gamma} \sim m_Z$, low $p_{T,\gamma\gamma}$ and $\Delta\varphi_{\gamma\gamma} \sim \pi$

$\Delta\varphi_{\gamma\gamma}$
Sensitive to the fragmentation model (both photons originate from fragmentation)
= π and small transverse momentum: sensitive to soft gluons emission not well described by fixed-order perturbation theory

Di-photons

vs m12, vs cos θ*