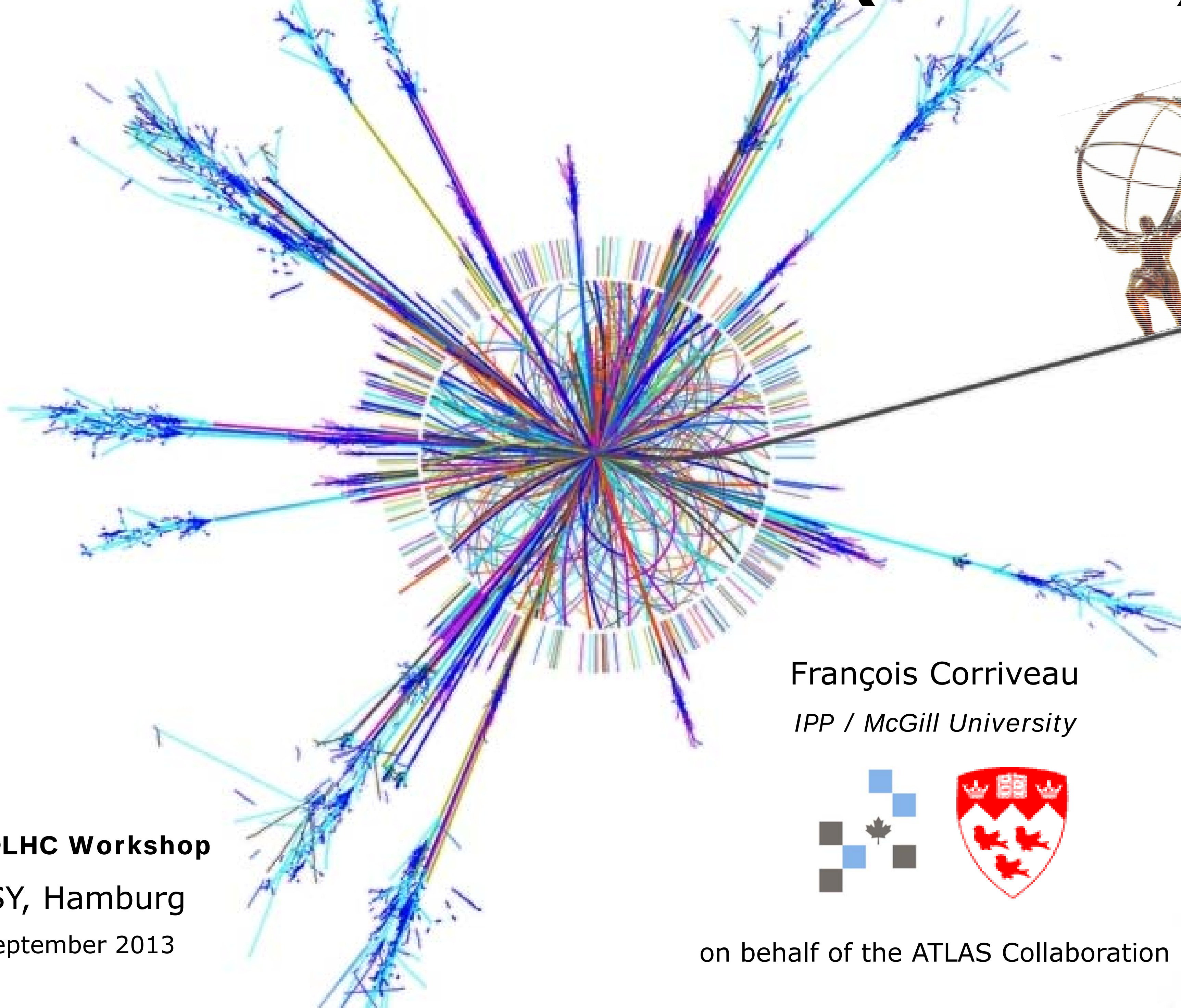
Jet Cross Sections (ATLAS)



François Corriveau

IPP / McGill University

QCD@LHC Workshop

DESY, Hamburg

3 September 2013

on behalf of the ATLAS Collaboration

Outline

Jet Physics

Theory at the Next to Leading Order (NLO)

Jet Reconstruction and Calibration

Inclusive Jet Cross Sections at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV

$\rightarrow$ use the properties of the ratios to constrain PDF's

Dijet Cross Sections at $\sqrt{s}$ = 7 TeV

Multi-Jet Cross Sections

Outlook

Publications

Measurement of inclusive jet and dijet production in pp collisions at √s = 7 TeV using the ATLAS detector.
arXiv:1112.6297, Phys.Rev. D86 (2012) 014022, 2010 data with 37 pb^{-1}

*

Measurement of the inclusive jet cross-section in *pp* collisions at √s = 2.76 TeV and comparison to the inclusive jet cross-section at √s = 7 TeV using the ATLAS detector.
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Overviews talks: K. Kousouris (QCD) 50’
A. Cooper-Sarkar (PDF) 50’
A. Ruiz-Martinez (Jets) 30’

Jet Physics

The LHC studies proton-proton interactions at very high energies.

Jets of particles are among the most frequent features observed.

They are indicative of the underlying physics of quarks and gluons produced in the scattering processes and undergoing fragmentation.

The observation of jets thus provides:

- tests of Quantum ChromoDynamics (QCD)
- measurements of the strong coupling constant α_s
- constraints on the proton Parton Distribution Functions (PDF's)
- ..

With the LHC a new kinematic domain, the TeV scale, can be probed.

Theory

NLO predictions follow two main methods:

1) **NLO Perturbative QCD (pQCD)**

NLOJET++ is used

CT10 is the default PDF set, but several others are available

3 sources of uncertainty are considered and estimated:

PDF set / factorisation and renormalisation scales / α_s

Non-perturbative corrections are applied (see later slide)

2) NLO matrix element calculations + LO parton showers

POWHEG generator for 2 $\rightarrow$ 2 partonic scattering with hardest partonic emission in the event.

PYTHIA provides the parton showers

Both packages use the CT10 PDF set

Data

	$\sqrt{s}$ = 7 TeV	$\sqrt{s}$ = 2.76 TeV	$\sqrt{s}$ = 7 TeV
Measurement	Inclusive+Dijet	Inclusive	High Mass Dijet
Data set	2010	2011	2011
Luminosity	37 pb^{-1} (17 nb^{-1} for low p_T)	0.20 pb^{-1}	4.8 fb^{-1}
Trigger Jets	minimum bias $\lvert\eta\rvert < 3.2$ $3.1 < \lvert\eta\rvert < 4.9$		$\lvert\eta\rvert < 3.2$ (pre-scaling at low E_T)
Offline Jets [GeV]	$\lvert\eta\rvert < 4.4$ $20 < p_T < 1500$	$\lvert\eta\rvert < 4.4$ $20 < p_T < 430$	$\lvert\eta\rvert < 2.8$ $p_{T1} > 100$, $p_{T2} > 50$
μ	2 - 3	0.24 *(i.e. negligible pile-up)*	4 - 20

Jet Reconstruction and Calibration

Reconstruction:

- the anti-k_t algorithm is used, with radii R=0.4 and R=0.6
- based on the calorimeter topological clusters
- jets are initially calibrated at the electromagnetic scale

Pile-up correction:

- for multiple interactions per bunch crossing
- using the minimum bias data

Geometrical correction:

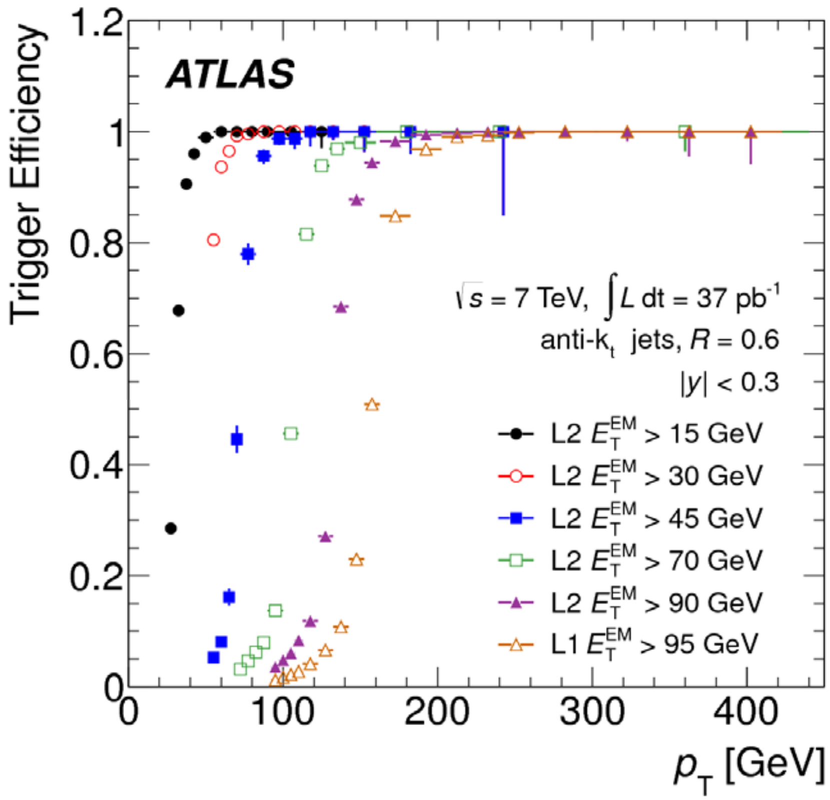
- from the interaction vertex

Jet Energy Scale (JES) correction:

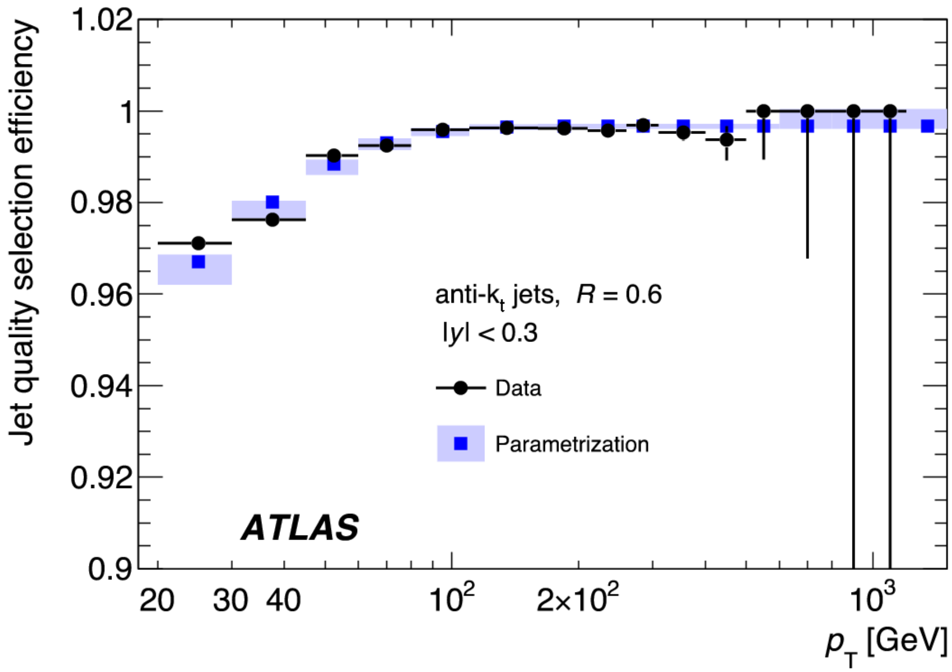
- to account for dead material and non-compensation
- based on Monte Carlo simulations and single hadron response
- this is the dominant experimental uncertainty

$|\eta|<0.8$: $<4.6\%$ for $p_T>20$ GeV
$<2.5\%$ for $p_T>60$ GeV
$|\eta|>3.8$: 11-12% for $p_T \approx 20$ GeV

Inclusive Cross Sections at √s = 7 TeV



Jet trigger efficiency as function of the reconstructed (calibrated) jet p_T in the central region.



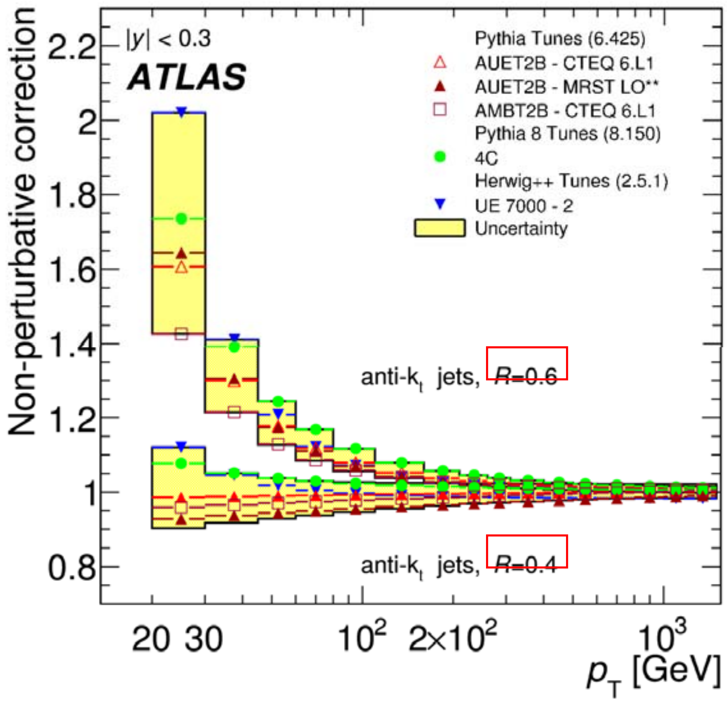
Efficiency of the jet quality selection as function of the jet p_T in the central region using a tag-probe method.

(Rejection of fake jets coming from detector noise, cosmics or other beam-related sources)

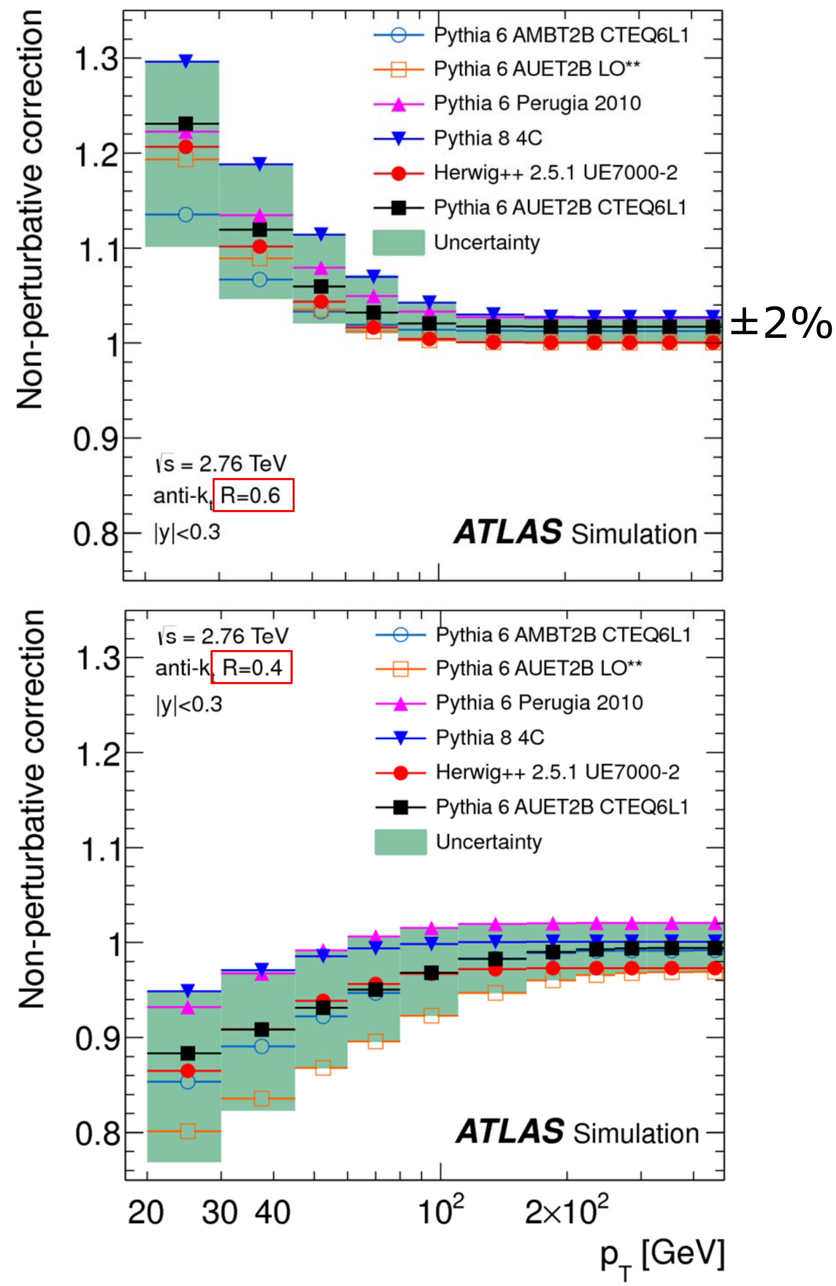
Non-perturbative correction factors

Applied on cross-section:

at √s = 7 TeV



at √s = 2.76 TeV



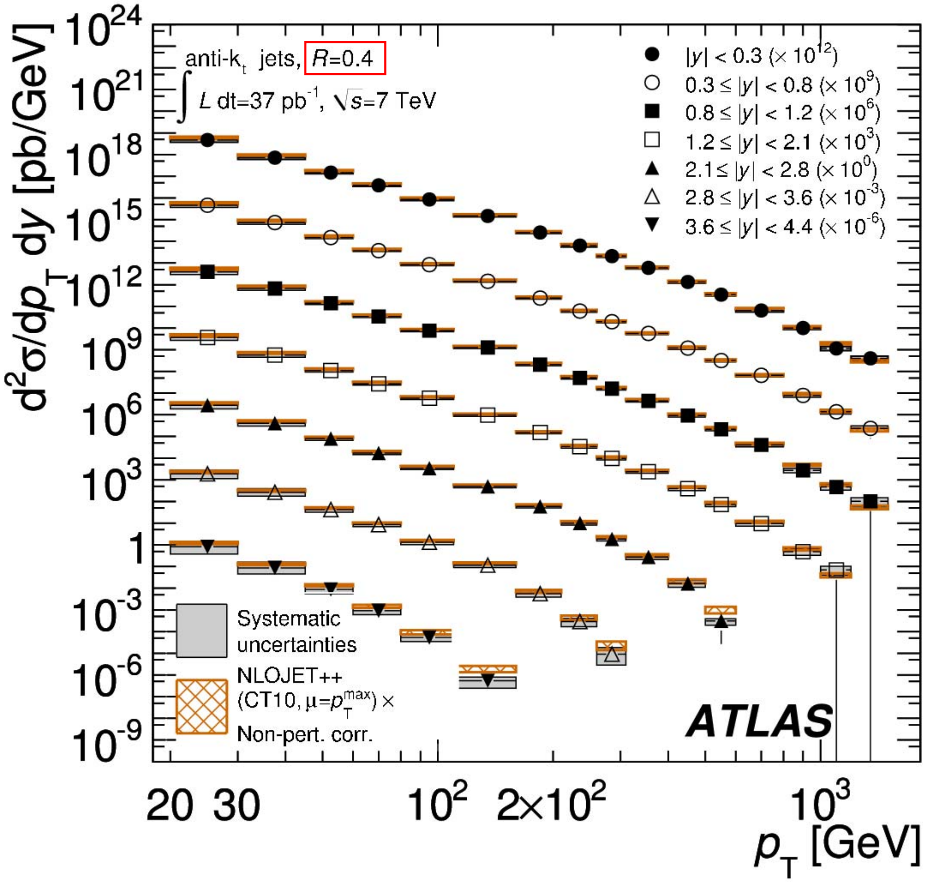
Parton shower generators (PYTHIA and HERWIG++) are used to estimate the non-perturbative effects of hadronisation and underlying event.

Correction factors correspond to the spread of the tunes and depend strongly on the radius R.

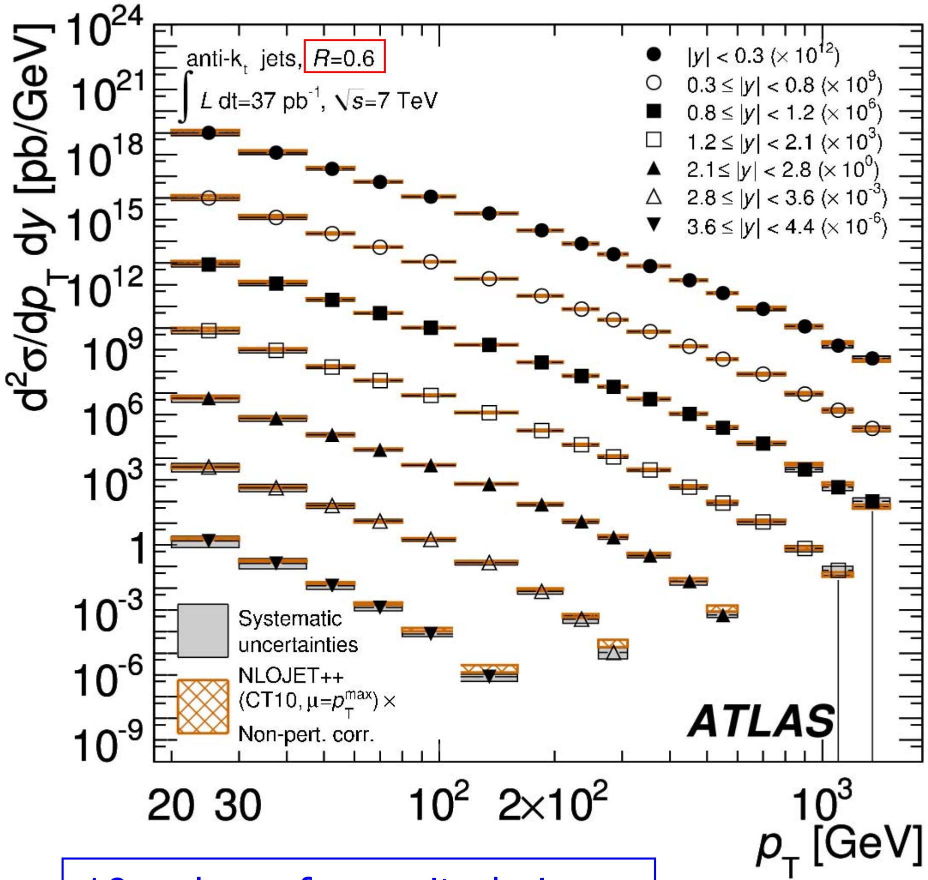
R=0.6 especially sensitive to underlying event.

Inclusive Cross Sections at √s = 7 TeV

R = 0.4



R = 0.6



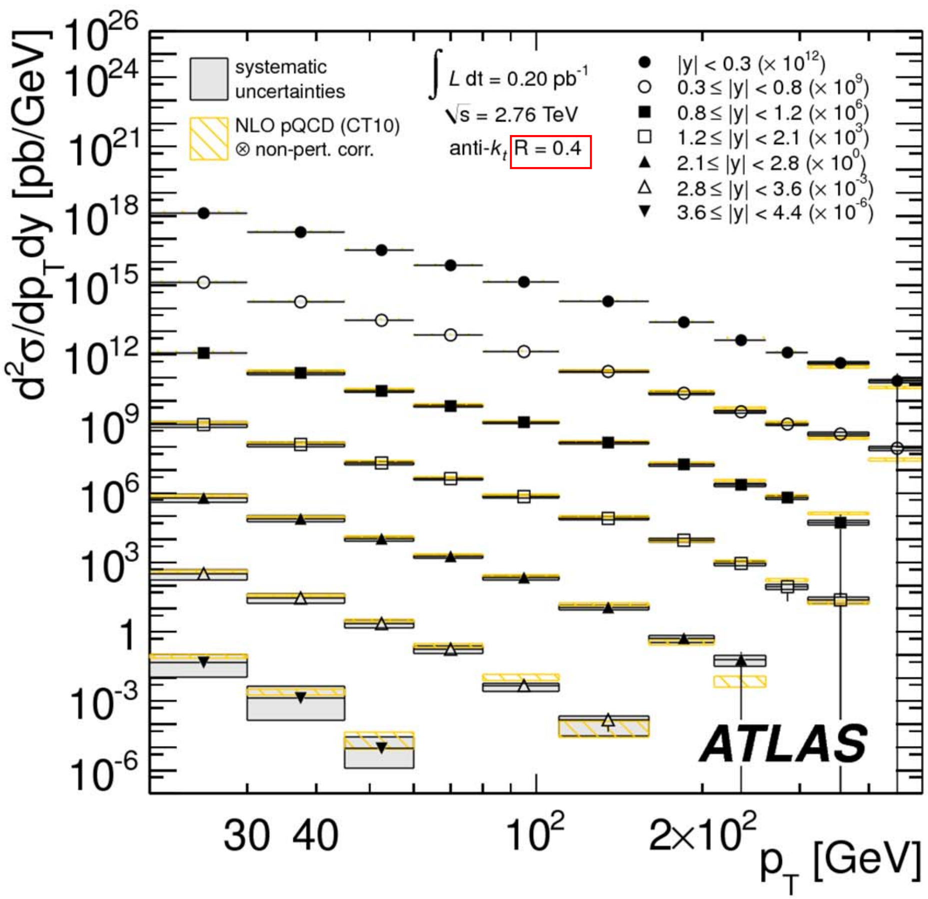
10 orders of magnitude in cross sections, 2 in p_T range.

The use of two radii constitutes a check of our understanding of non-perturbative effects.

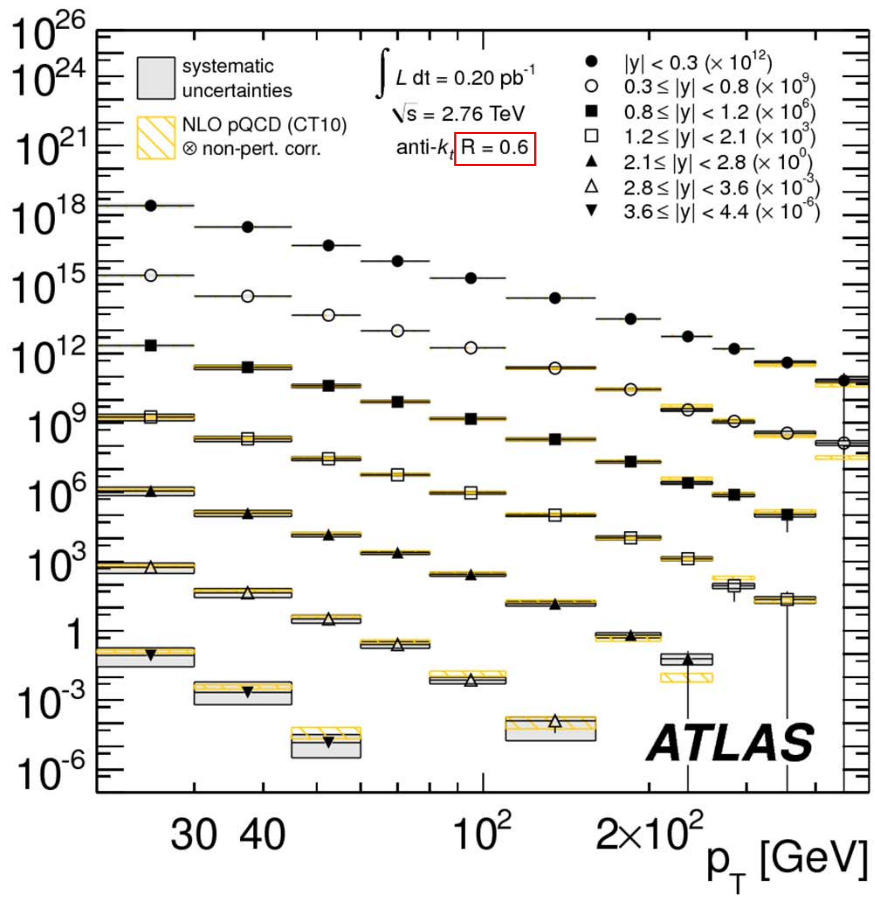
The agreement is good while discrepancies may appear in forward regions at large jet p_T.

Inclusive Cross Sections at √s = 2.76 TeV

R = 0.4



R = 0.6

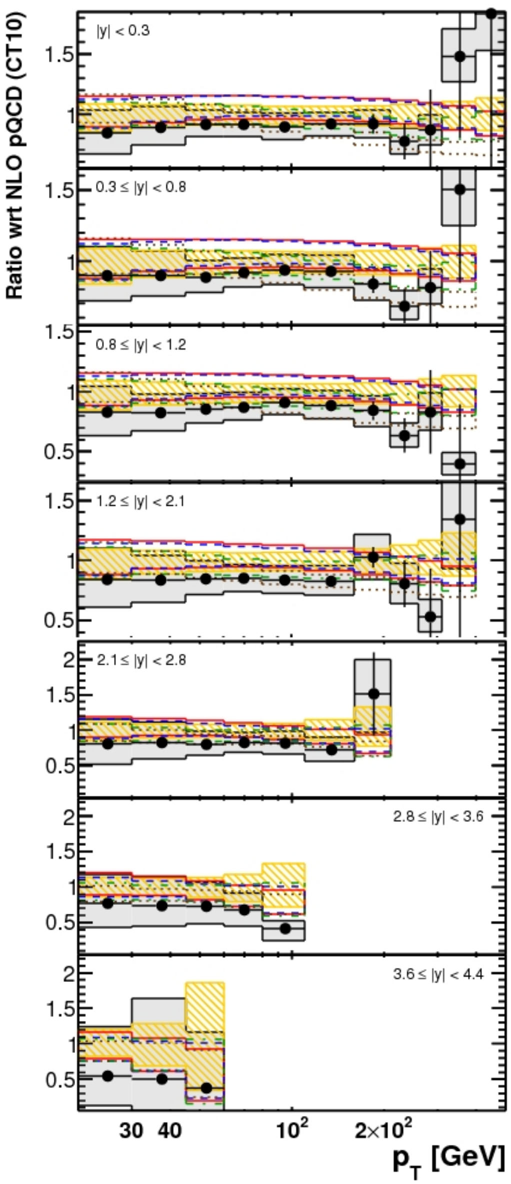


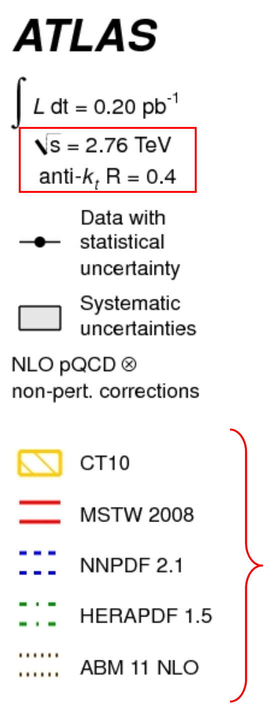
7 orders of magnitude in cross sections, 1½ in p_T range.

Also good general agreement with the predictions

Comparison with Theory Predictions

Ratio Data/NLO pQCD(NLOJET++)





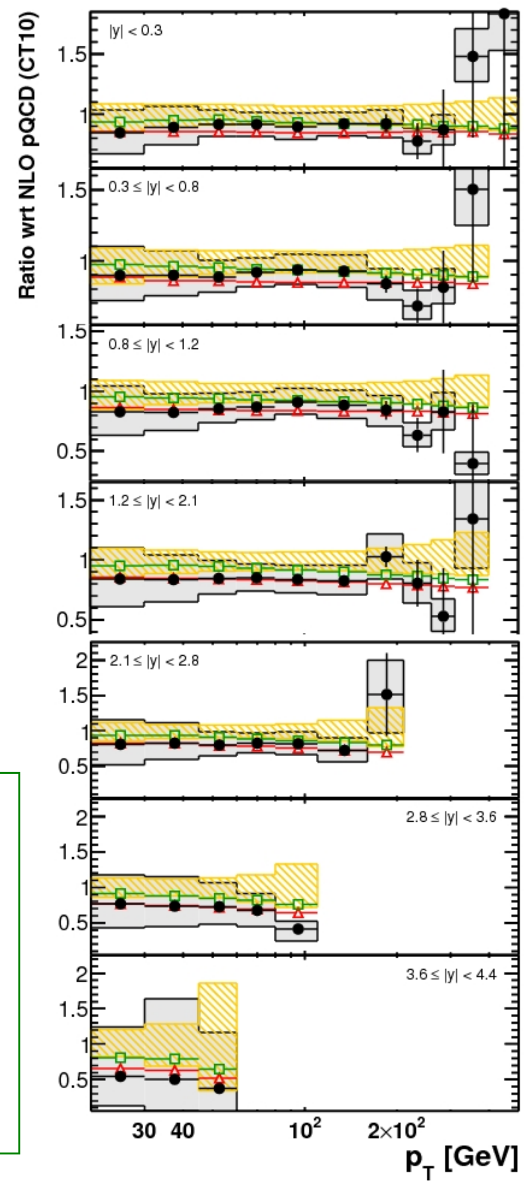
PDF's

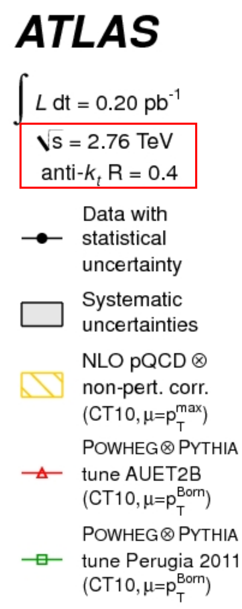
good agreement within uncertainties

data is lower, especially at large values of p_T and y

as for √s=7 TeV data

Same ratio, including POWHEG calculations





parton showers & tunes

good agreement within uncertainties

Not very sensitive to tune (yet)

similar at √s=7 TeV

Ratio of √s = 2.76 TeV to 7 TeV Data

Ratios of cross sections at different energies see some of the theoretical and experimental uncertainties much reduced, e.g. respectively the choice of factorization of renormalization scale or the experimental jet energy scale

A scaling-like variable is defined to study jet cross sections σ:

$$x_{\mathrm{T}} = 2p_{\mathrm{T}}/\sqrt{s}$$

Ratios are defined as function of p_T and x_T:

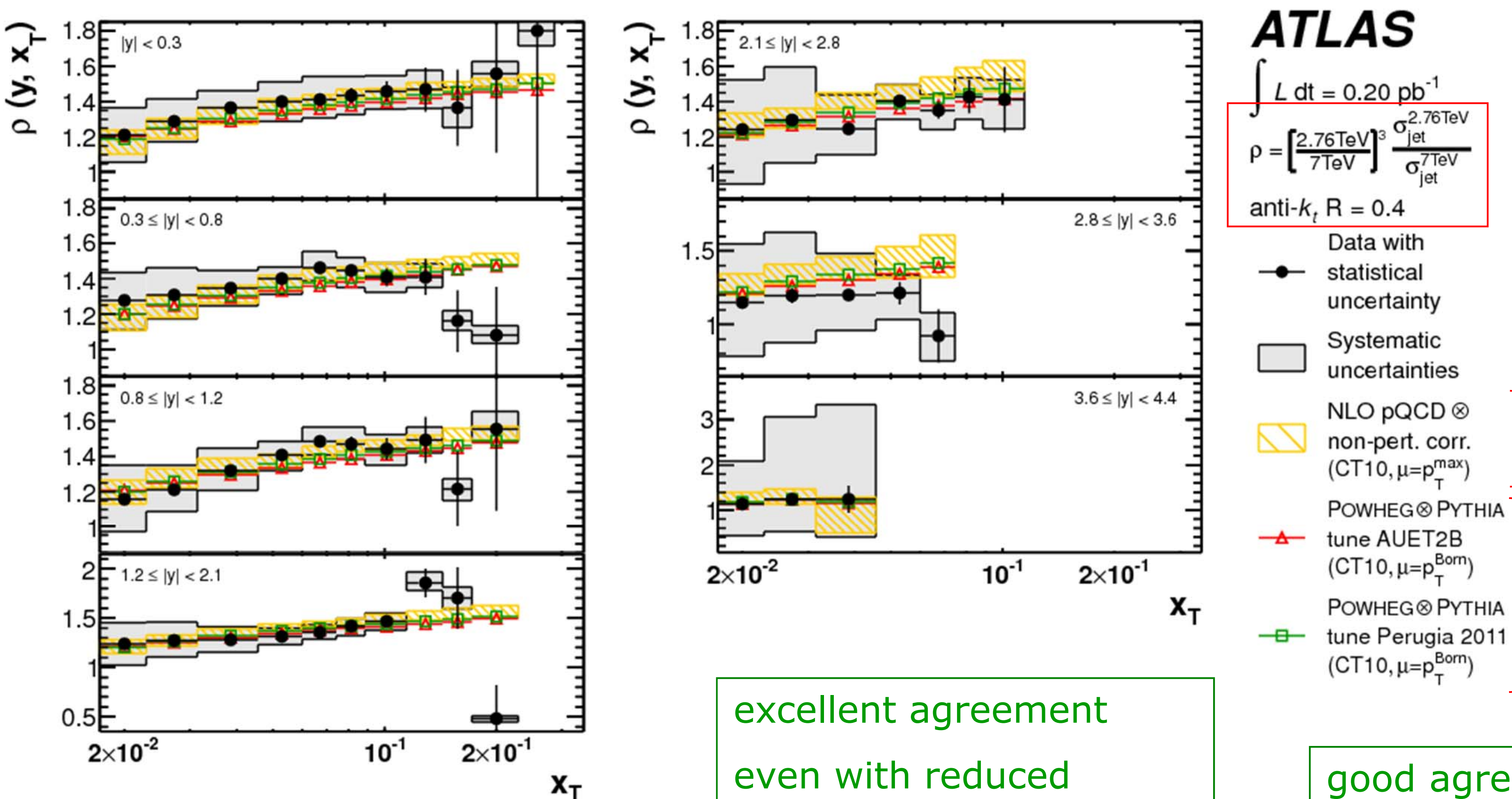
$$\rho(y, x_{\mathrm{T}}) = \left(\frac{2.76\ \mathrm{TeV}}{7\ \mathrm{TeV}}\right)^3 \cdot \frac{\sigma(y, x_{\mathrm{T}}, 2.76\ \mathrm{TeV})}{\sigma(y, x_{\mathrm{T}}, 7\ \mathrm{TeV})}$$

$$\rho(y, p_{\mathrm{T}}) = \frac{\sigma(y, p_{\mathrm{T}}, 2.76\ \mathrm{TeV})}{\sigma(y, p_{\mathrm{T}}, 7\ \mathrm{TeV})}$$

The theoretical predictions can be compared to more stringently and will lead to new constraints for the PDF's.

Ratio $\rho(y,x_T)$

Ratio of the cross sections, compared to NLO pQCD(NLOJET++) and POWHEG calculations



PDF

parton showers & tunes

excellent agreement

even with reduced theoretical uncertainties

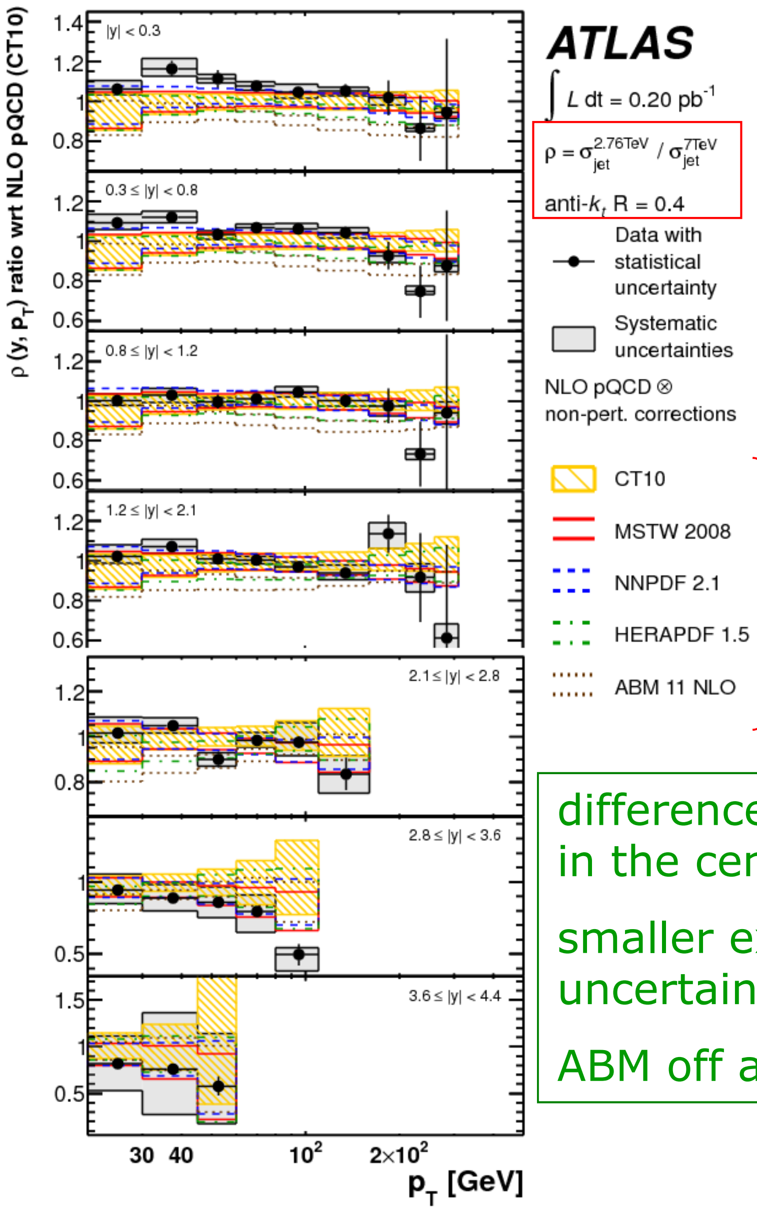
the ~flatness of the ratio confirms scaling

good agreement within uncertainties

much less sensitive to the exact tune

Ratio $\rho(y,p_T)$

Ratio of cross sections/NLO pQCD(NLOJET++)



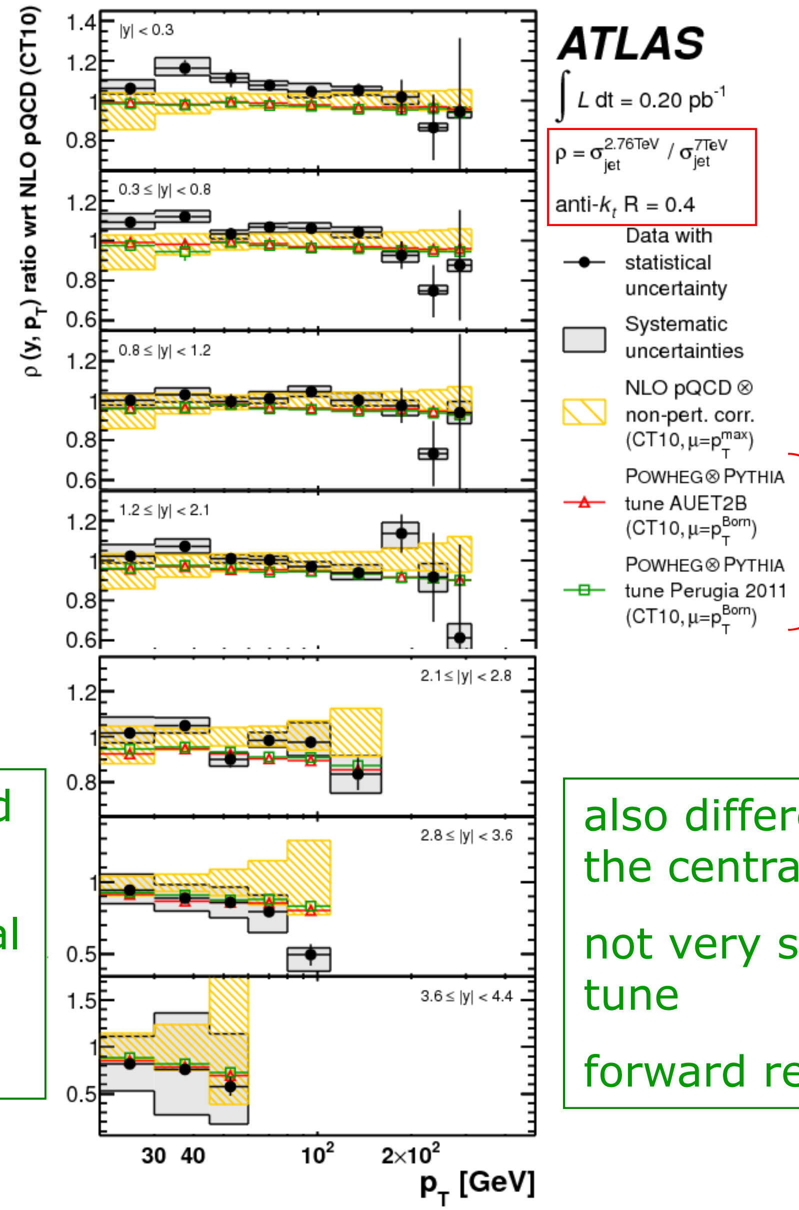
PDF's

differences observed in the central region

smaller experimental uncertainties

ABM off at low y's

.. same, including POWHEG calculations



parton showers & tunes

also differences in the central region

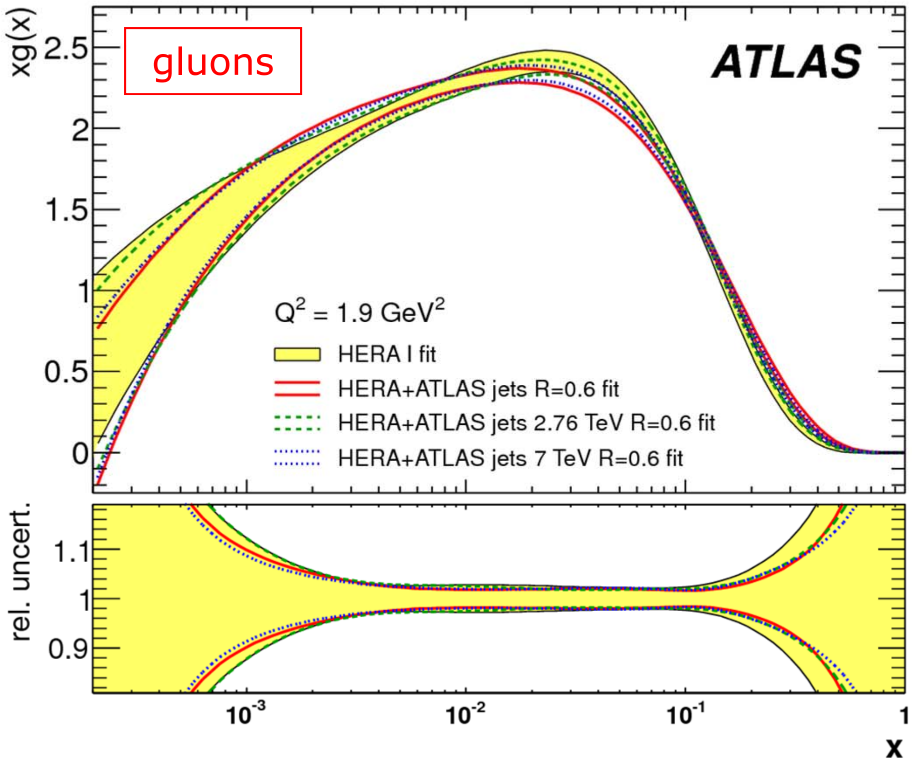
not very sensitive to tune

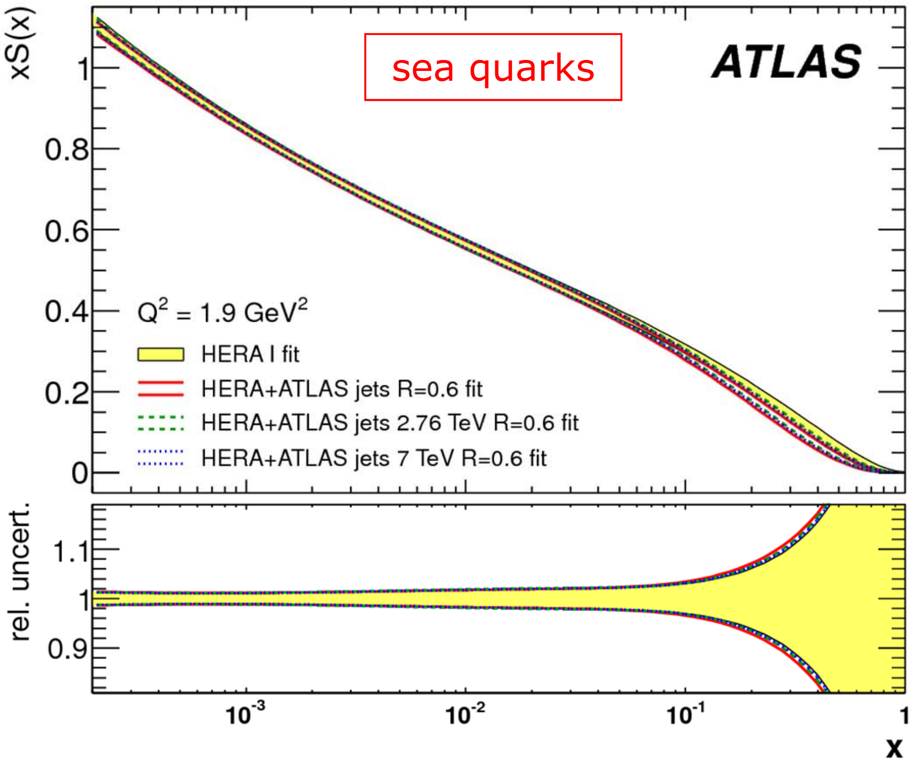
forward regions ok

Constraining the PDF's

The experimental uncertainties at $\sqrt{s}$=7 TeV and $\sqrt{s}$=2.76 TeV are strongly correlated. Their contributions thus become smaller in the cross section ratios and also then smaller than the theory uncertainties.

Increased sensitivity to the PDF's is therefore expected when both cross section data sets are analysed together. The **HERAFitter** package is used. *Please see the presentation by Amanda Cooper-Sarkar, Monday Sept. 2nd, 15:00.*





The gluon distribution becomes harder with the addition of both ATLAS jet data sets.

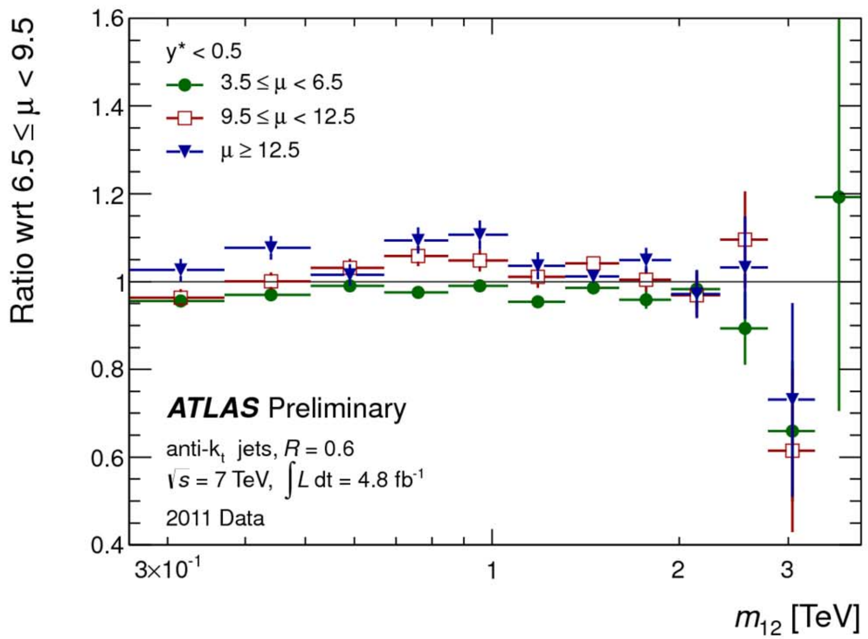
Dijet Cross Sections at √s = 7 TeV

Event selection: leading jet with p_T>100 GeV, sub-leading jet with p_T>50 GeV

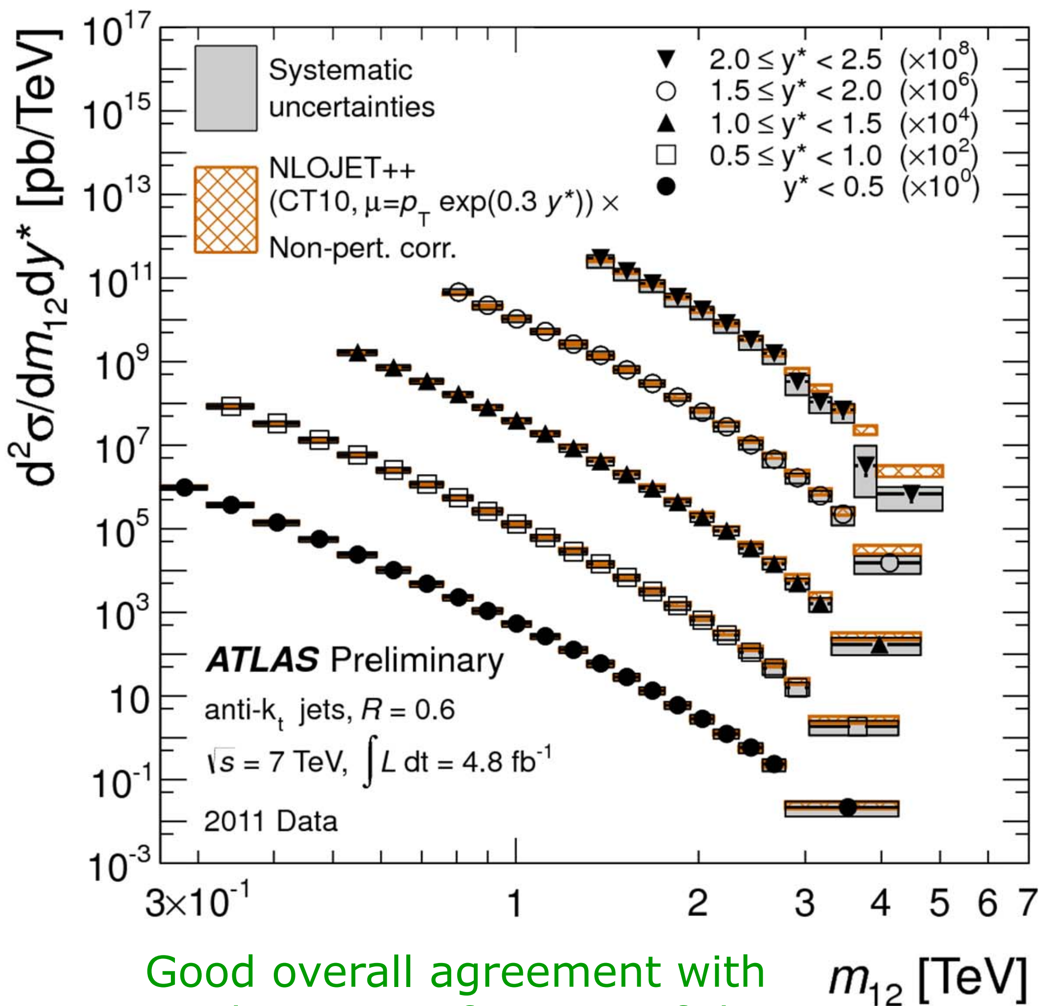
both in the central region with |y|<2.8

$y^* = ½|y_1-y_2|$

Since the average number of interactions per bunch crossing μ is large, it is important to check the applied correction through the ratio of cross sections:



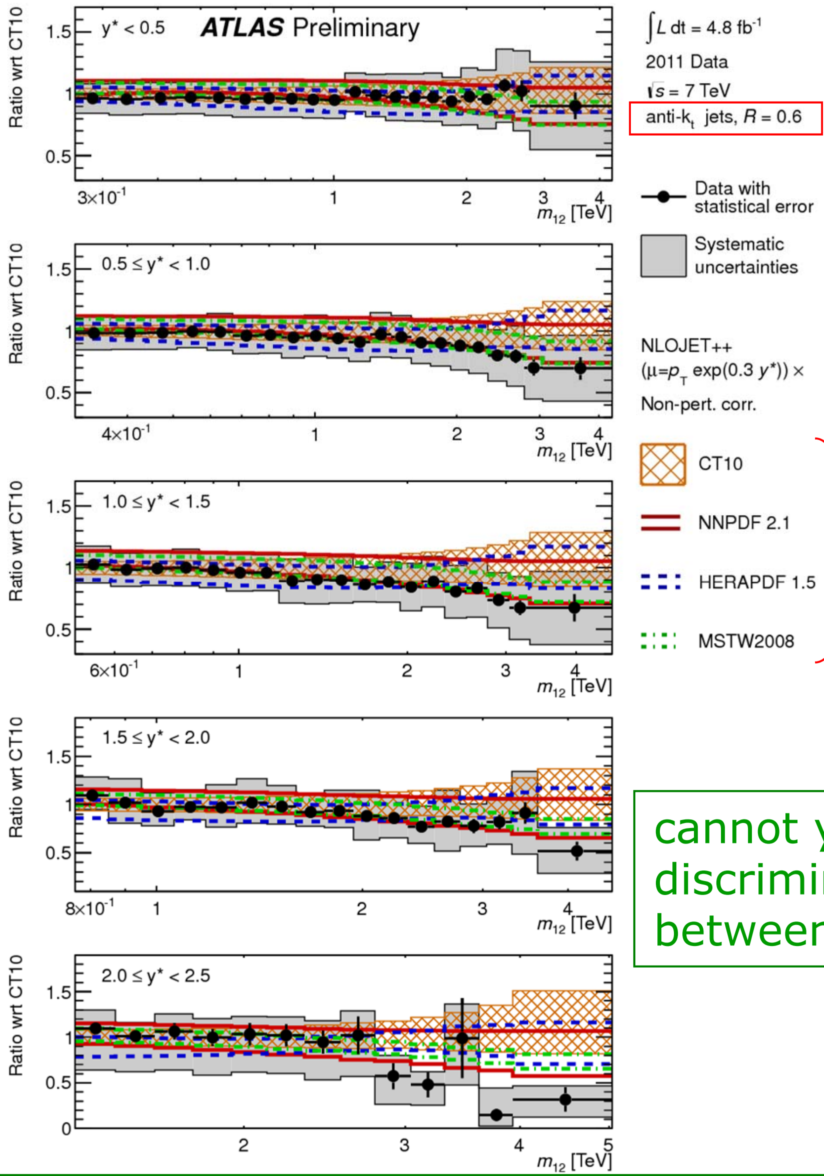
5-7% consistent between various μ ranges.



Good overall agreement with predictions as function of the invariant mass up to **~4 TeV**

Dijet Cross Sections at √s = 7 TeV

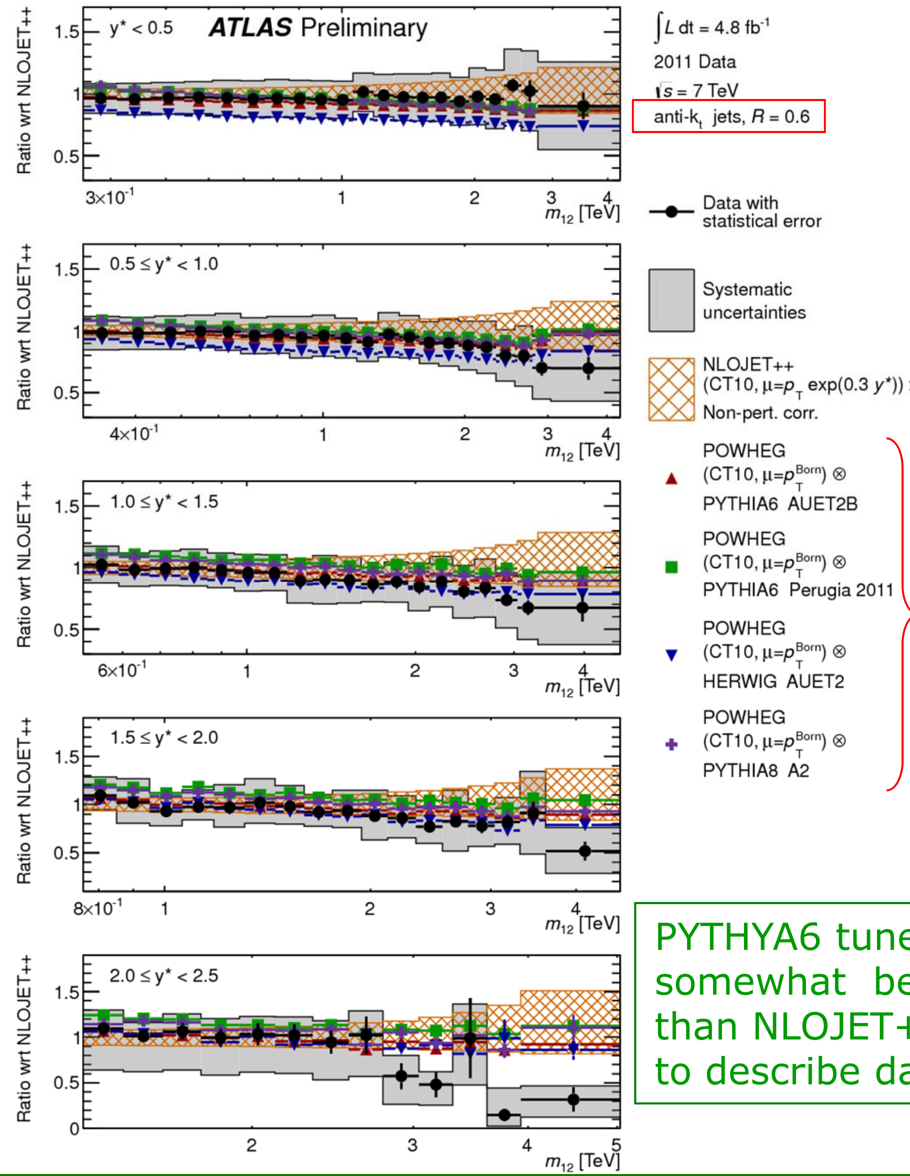
Ratio Data/NLO pQCD(NLOJET++)



PDF's

cannot yet discriminate between PDF's

Same ratio, including POWHEG calculations

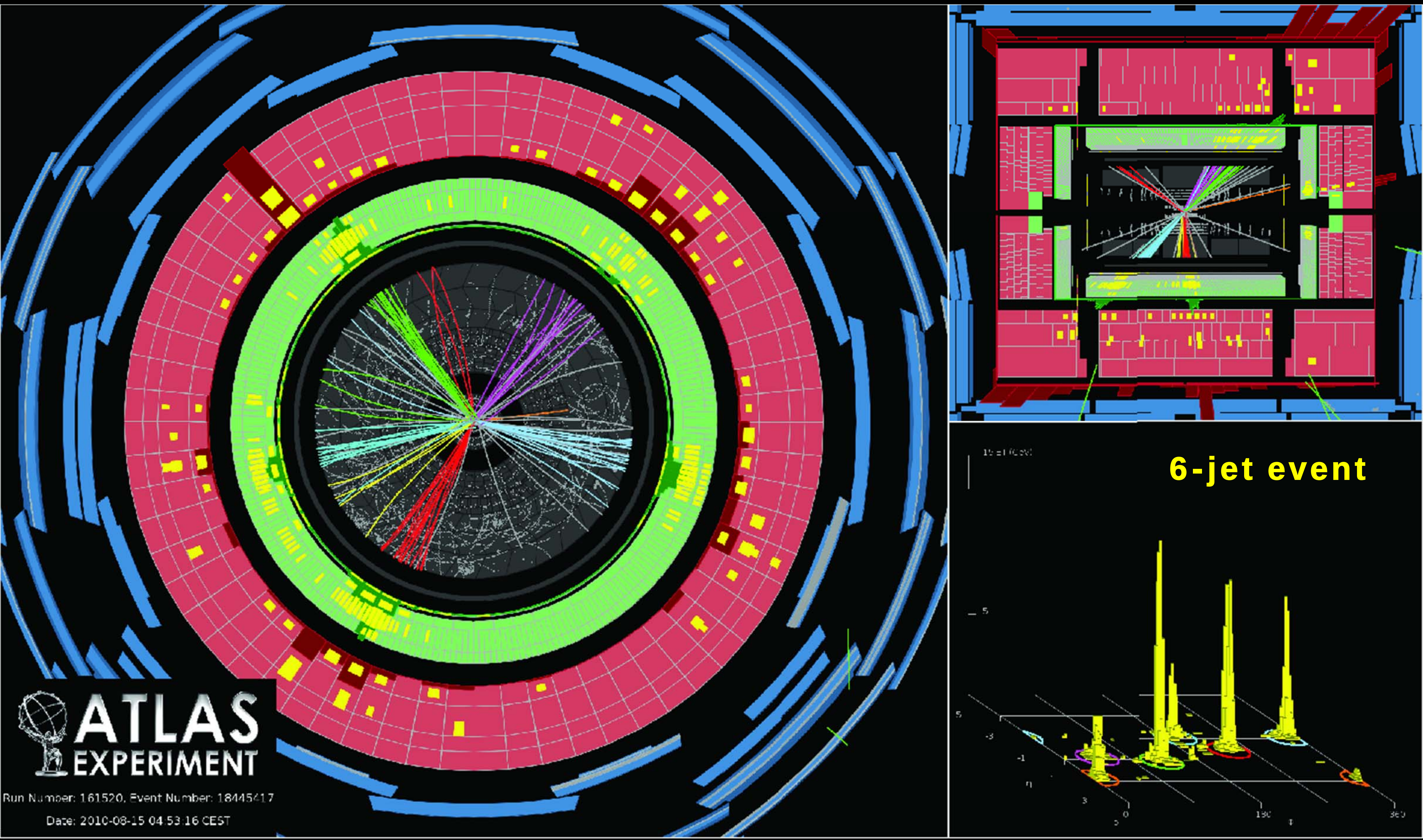


parton showers & tunes

PYTHYA6 tunes somewhat better than NLOJET++ to describe data

Agreement except at large mass and large y* where up to 40% discrepancy is observed.

Multi-Jets


ATLAS
EXPERIMENT
Run Number: 161520, Event Number: 18445417
Date: 2010-08-15 04:53:16 CEST
6-jet event

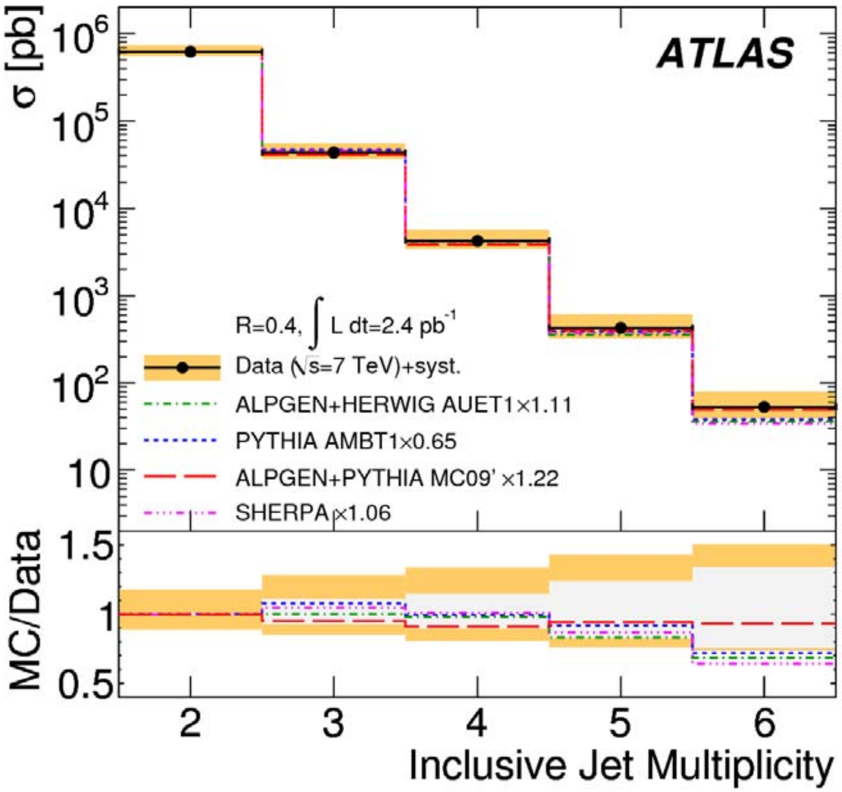
Multi-Jet Cross Sections

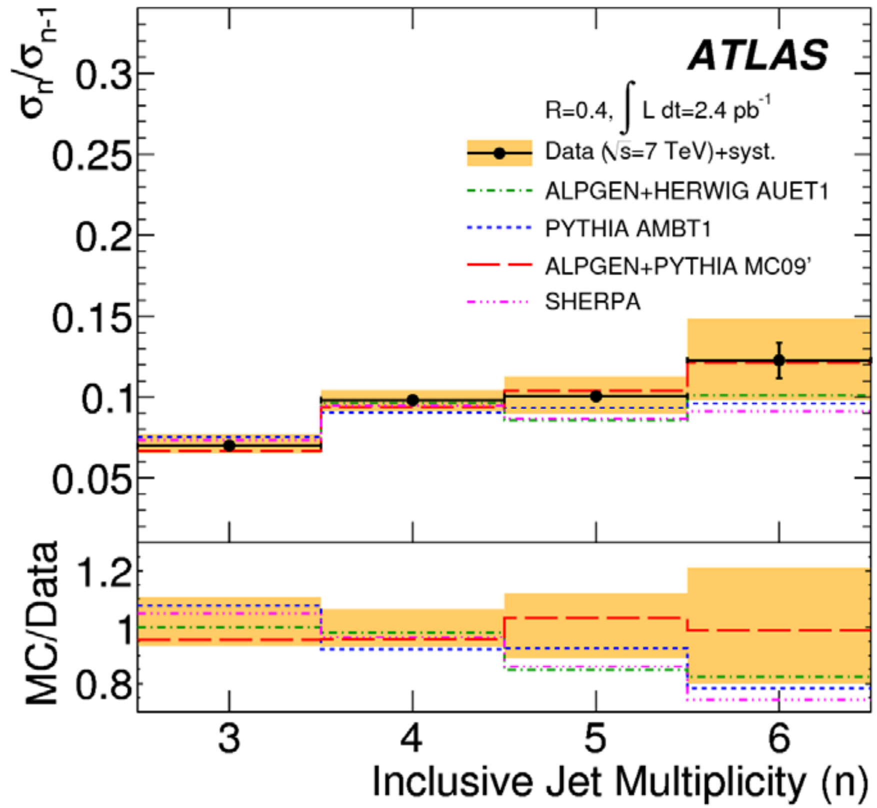
Older analysis with the 2010 data set, at $\sqrt{s}$ = 7 TeV and 2.4 pb^{-1}

LO Predictions: ALPGEN(2→6)[+HERWIG or PYTHIA], SHERPA(2→6) and PYTHIA(2→2),

They are normalised to measured inclusive two jet cross section

Jet selection: p_T>80 GeV for leading, p_T>60 GeV for the others, |y| < 2.8 for all





uncertainties dominated by JES → reduced in the ratio of cross-sections

With NLO pQCD calculations → e.g. determination of α_s. *See C. Bélanger-Champagne talk!*

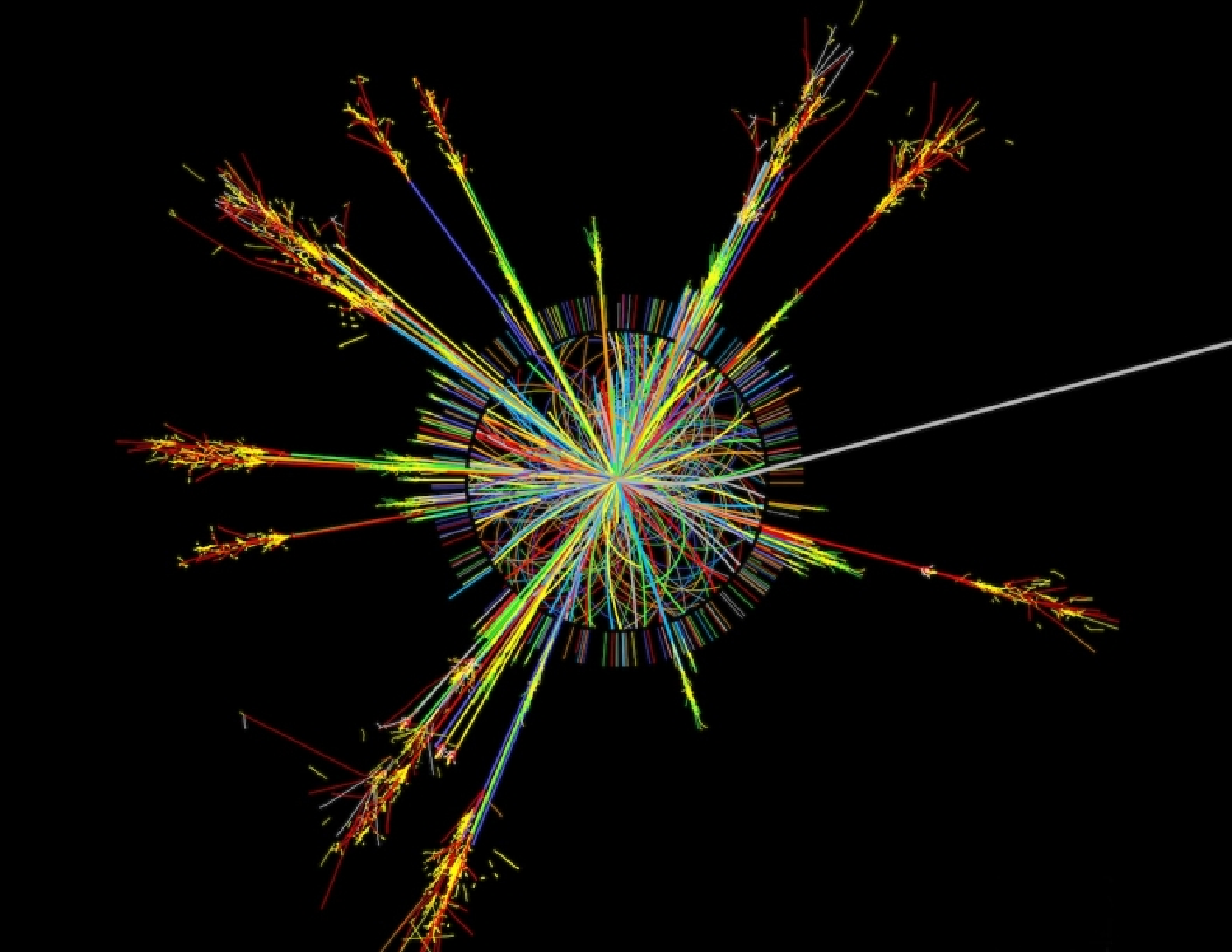
Outlook

The ATLAS collaboration has performed several studies of **jet cross sections**

Inclusive jet cross sections at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 2.76 TeV are in good agreement with the theoretical predictions and can be used to constrain the parton distribution functions

Dijet cross sections at $\sqrt{s}$ = 7 TeV generally agree but discrepancies up to 40% were observed at high values of jet momentum and rapidity.

Newer data sets needed



Backup Slides

Abstract

Jet cross sections (ATLAS)

The Large Hadron Collider at CERN studies proton-proton interactions at very high energies. Jets of particles are among the most frequent signals observed and are indicative of the underlying physics. Physics of the Standard Model and beyond is thus tested. Results of the measurements of the jet cross sections will be presented as well as their sensitivity to the parton distribution functions within the proton.

The ATLAS Calorimeters