Measurement of jet cross sections in ATLAS

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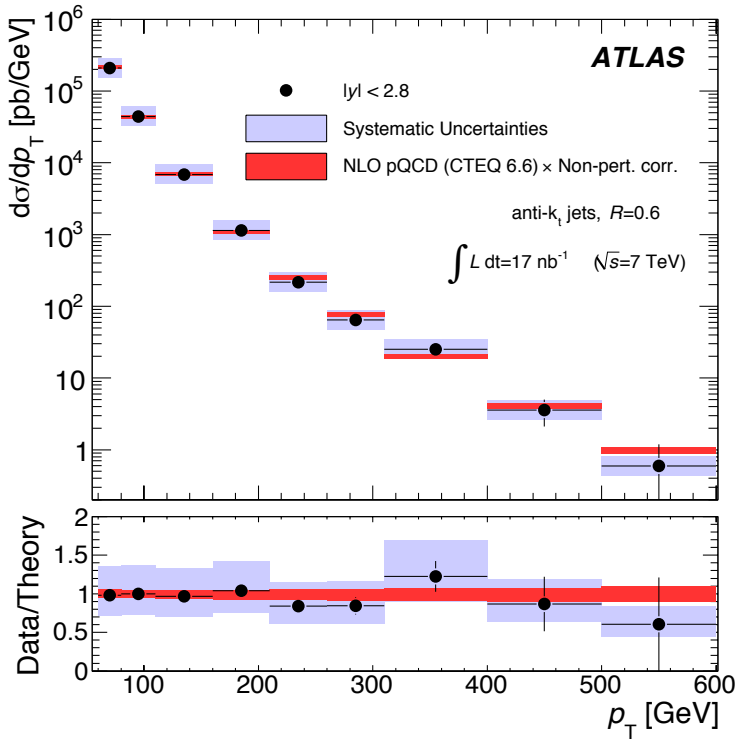
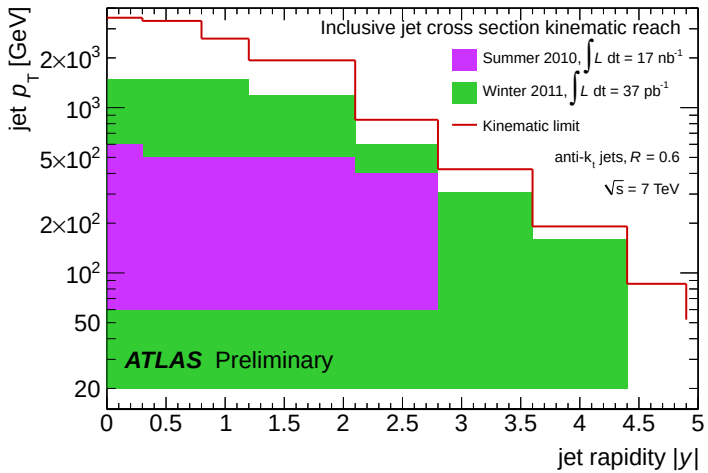
Introduction & Motivation

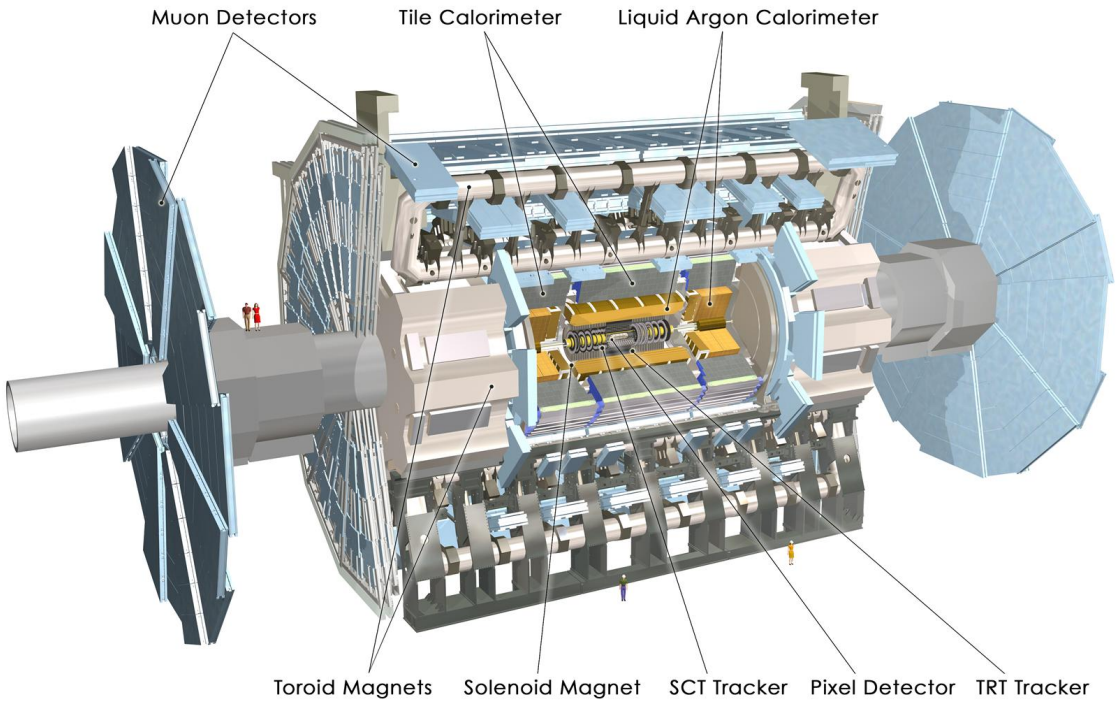
- Inclusive jet and dijet cross section measurements are one of the pillars of the Standard Model jet physics program in ATLAS:
  - Test of QCD predictions in a new kinematic regime
  - Tuning of PDFs, Monte Carlo generators, etc.
- ATLAS results with 17 nb^{-1} published: Eur. Phys. J. **C71**, 1512 (2011)
- This presentation: analysis of the whole 2010 dataset (37 pb^{-1})



- Updated kinematic range: Extension to high y, low p_T
- Improved detector understanding



The ATLAS Experiment

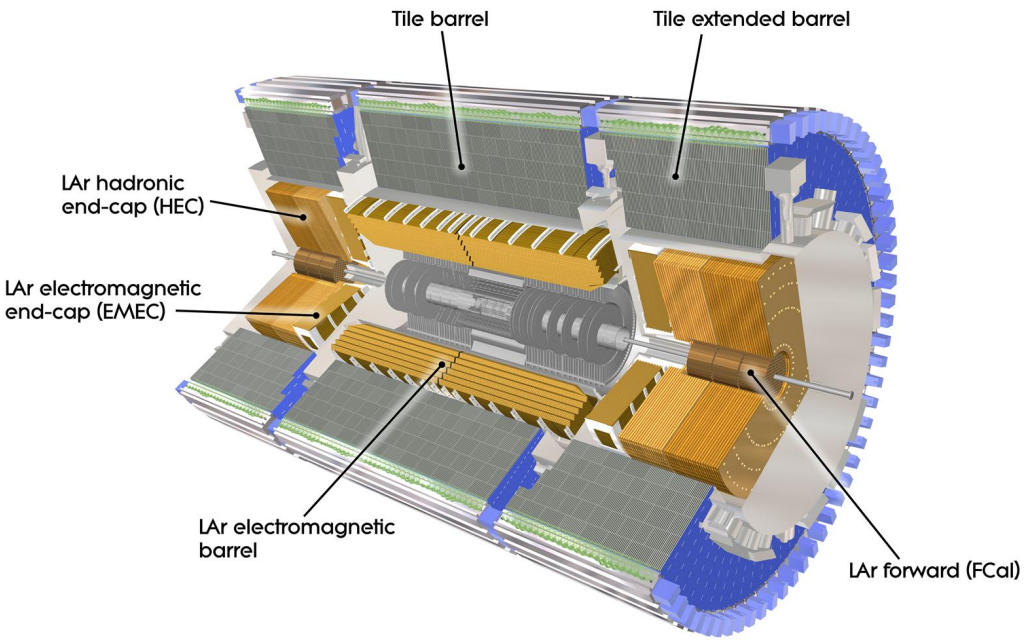


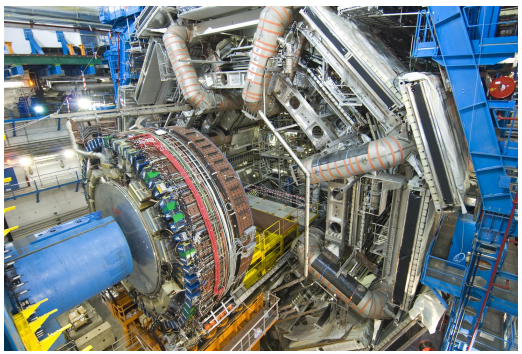
- Length: 46 m
- Diameter: 26 m
- Weight: 7000 tons
- 100×10^6 read-out channels

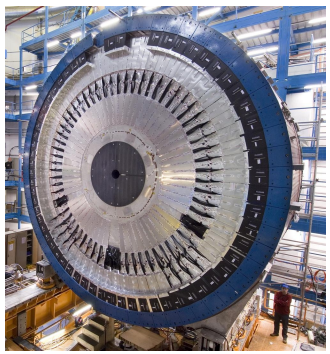
- **Magnets:** inner solenoid (2T) and 3 outer toroids (4T)
- **Inner Detector:** silicon pixels and microstip detectors, transition radiation detector
- **Calorimetry:** electromagnetic and hadronic calorimeters outside solenoid
- **Muons:** 4 different chambers technologies (precision tracking and trigger)

ATLAS Calorimetry

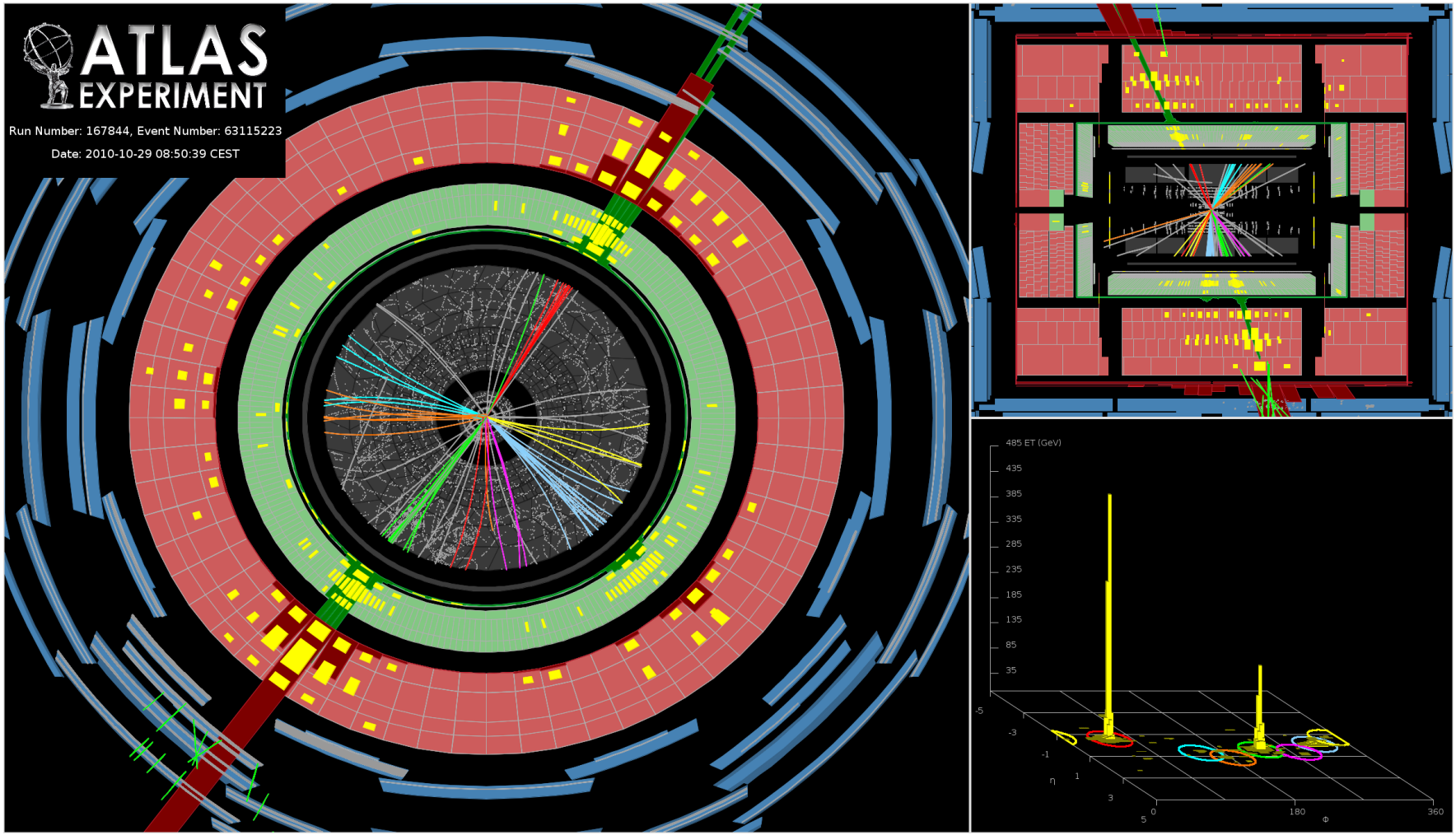
- **Electromagnetic:** $|\eta| < 3.2$
  - Lead/Liquid Argon (LAr) with accordion geometry
  - Total depth: $\gtrsim 25 x_0$
- **Hadronic:**
  - Barrel: TileCal (steel/plastic scintillator), $|\eta| < 1.7$
  - Hadronic Endcap (HEC): Cooper/LAr, $1.5 < |\eta| < 3.2$
  - Total depth: $\gtrsim 10\lambda$
- **Forward:** $3.1 < |\eta| < 4.9$
  - Both EM and hadronic
  - Cooper-Tungsten/LAr
  - Total depth: $\gtrsim 9\lambda$
- Projective read-out geometry
- $\sim 200 \times 10^3$ read-out channels



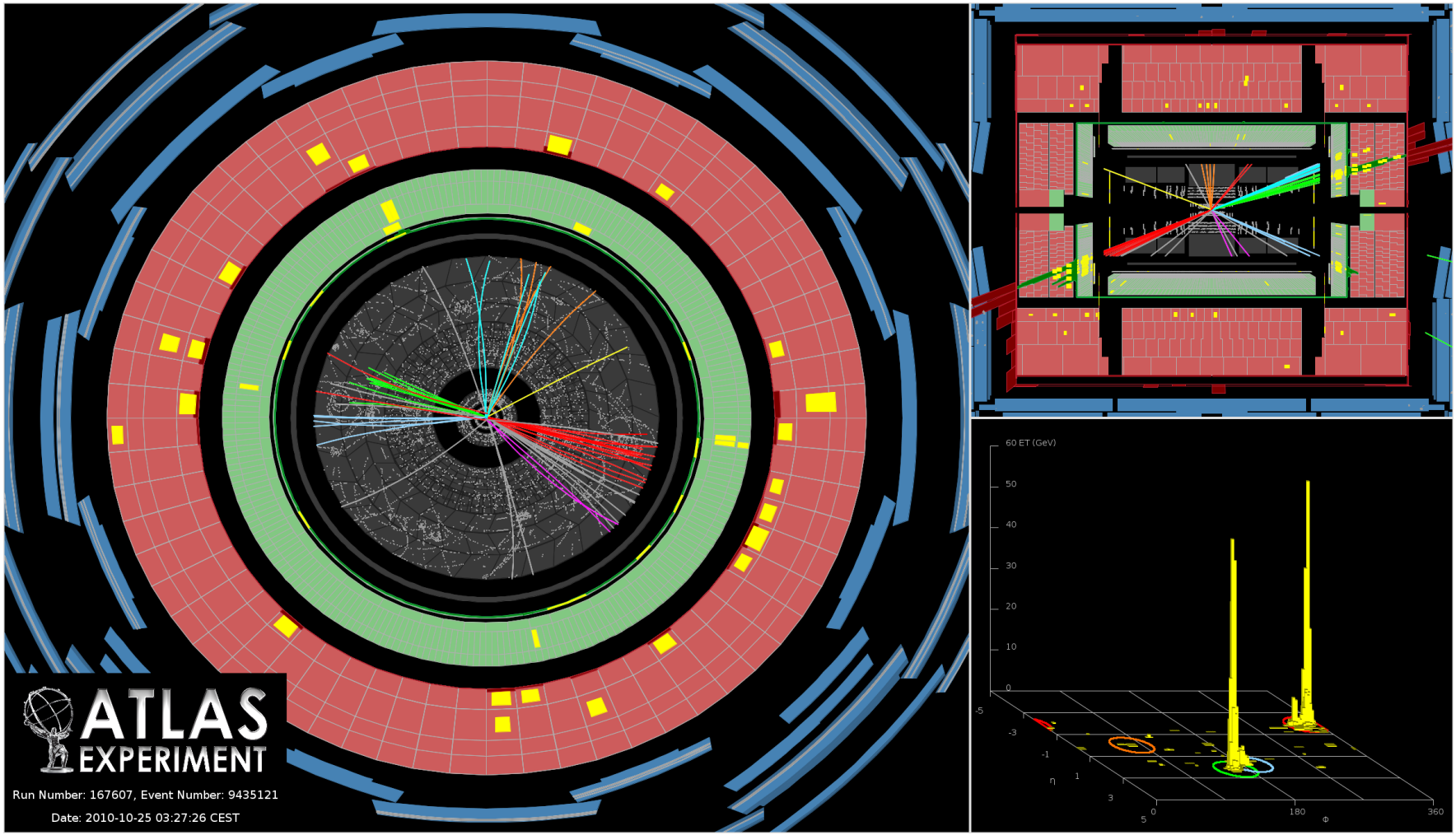




Event with Highest p_T Jet (1.5 TeV)

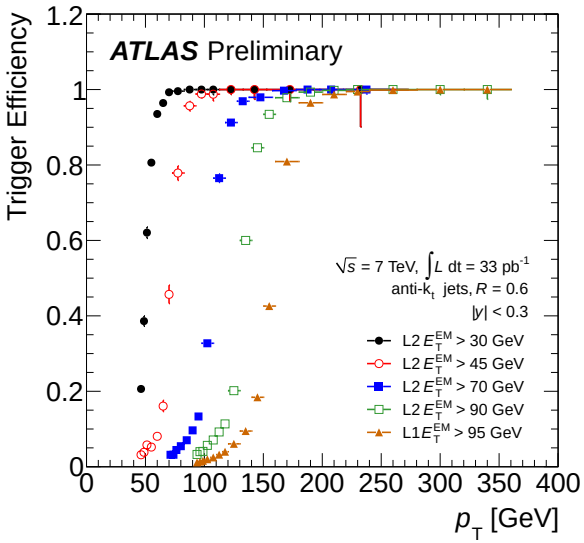


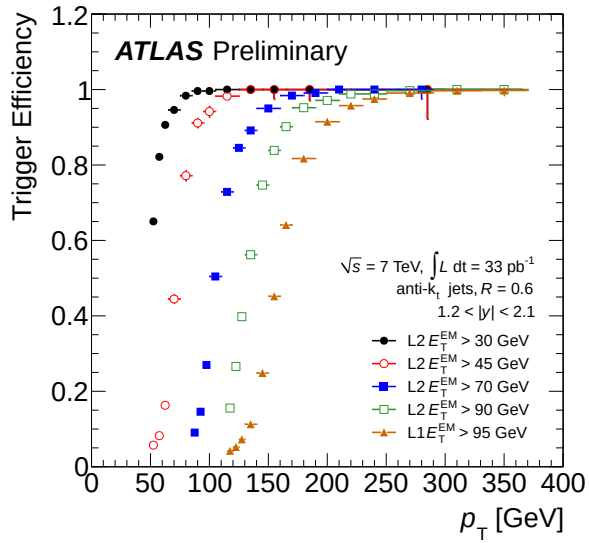
Event with Highest Dijet Invariant Mass (4.0 TeV)

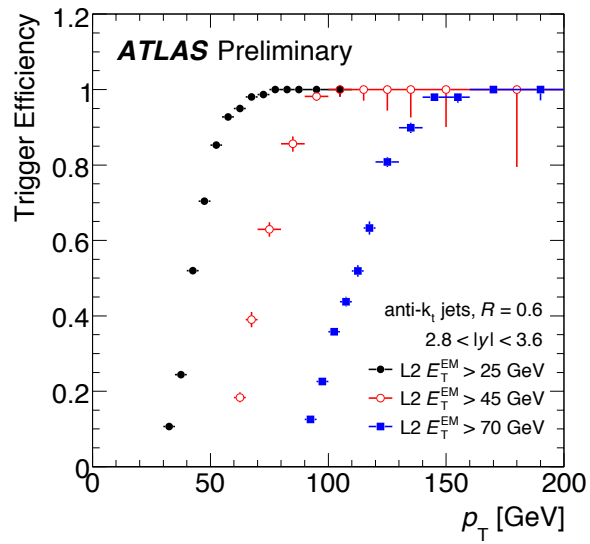


Definition of Observables

- **Inclusive single-jet double-differential cross section:** $d^2\sigma/dp_T dy$
  - Measured as a function of jet p_T and y in the region $p_T > 20$ GeV, $|y| < 4.4$
- **Dijet double-differential cross section:** $d^2\sigma/dm_{12}dy$
  - Measured as a function of the dijet invariant mass m_{12} and y
  - Jet selection: $p_T(jet_1) > 30$ GeV, $p_T(jet_2) > 20$ GeV, $|y| < 2.8$
- Jets identified with the anti-k_T algorithm with $R = 0.4$ and 0.6
- Trigger:
  - Minimum bias trigger: $20 < p_T < 60$ GeV
  - Single jet triggers: $p_T > 60$ GeV
  - For each bin in the measurement a trigger which is fully efficient is selected







Data Correction & Systematic Uncertainties

- All corrections for detector inefficiencies and resolutions are performed using a bin-by-bin correction. Correction factors were obtained from PYTHIA LO Monte Carlo reweighted using a NLO PDF
- Systematics considered in the unfolding:
  Jet energy resolution, angular resolution, cross section shape.
- Results consistent with other unfolding methods:
  - *Singular Value Decomposition* (Höcker, Kartvelishvili; NIM A **372** (1996) 469)
  - *Bayesian unfolding* (D'Agostini; NIM A **362** (1995) 487)
- Largest systematics coming from jet energy scale
- Systematic uncertainties for some representative bins:

Inclusive jet cross section

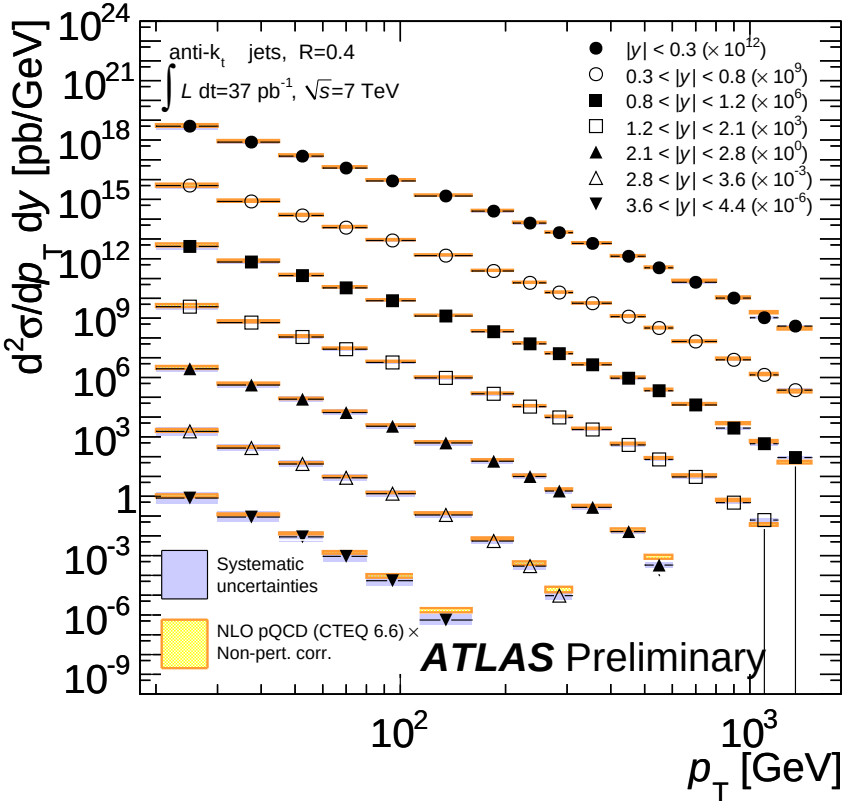
p_T [GeV]	$\|y\|$	Abs. JES	Unfolding	Cleaning	Trigger	Jet Rec.
20	2.1-2.8	$^{+40\%}_{-30\%}$	20%	0.5%	1%	2%
20	3.6-4.4	$^{+80\%}_{-50\%}$	20%	0.5%	1%	2%
100	< 0.3	10%	2%	0.5%	1%	1%

Dijet cross section

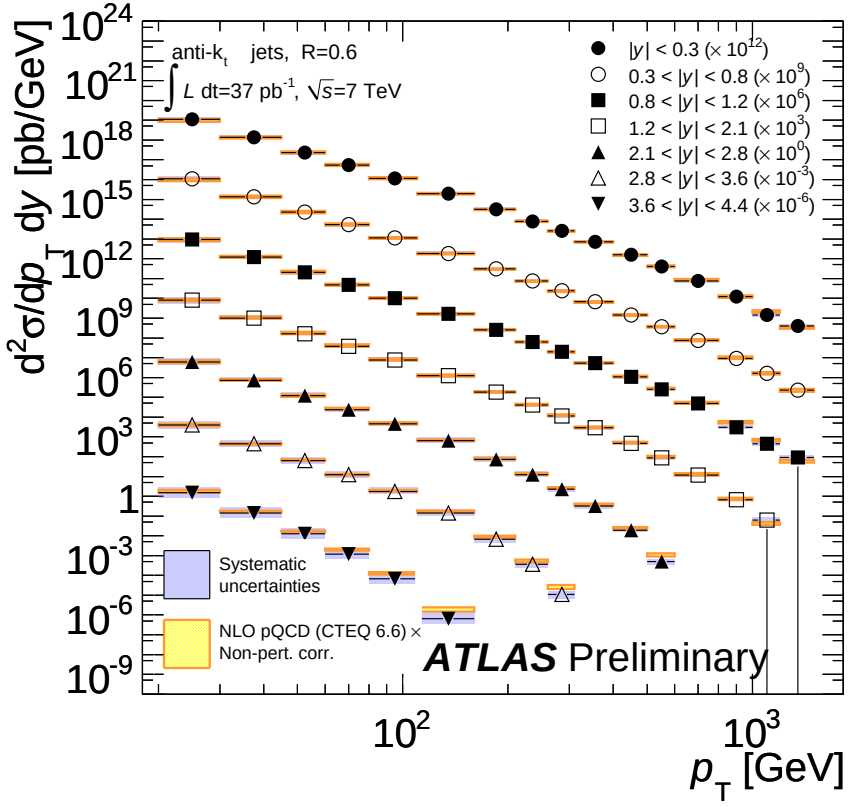
m_{12} [GeV]	$\|y\|_{\max}$	Abs. JES	Rel. JES	Unfolding	Cleaning	Trig.	Jet Rec.
60	2.1-2.8	$^{+30\%}_{-20\%}$	10%	10%	0.5%	1%	2%
200	< 0.3	10%	0%	5%	0.5%	1%	1%

Inclusive Jet Cross Section

Anti-k_T $R = 0.4$



Anti-k_T $R = 0.6$

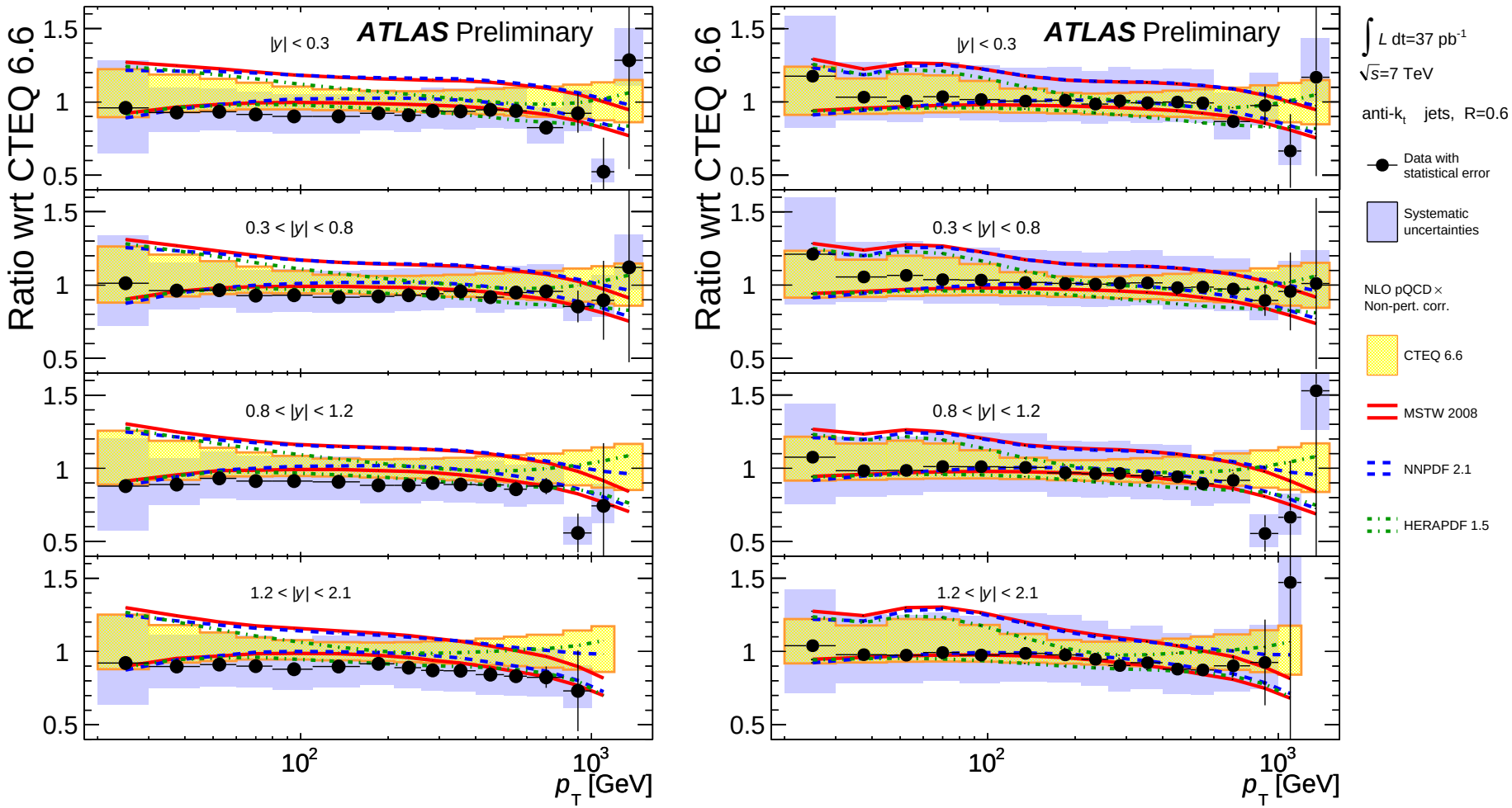


- Measurement expanding over 2 orders of magnitude in p_T and 7 orders of magnitude in cross section
- Theory: NLO pQCD using NLOJet++ with non-perturbative corrections applied
- Data and theory in good agreement

Inclusive Jet Cross Section: Comparison with pQCD

- Ratio data over theory predictions (several PDF choices shown)

Anti-k_T $R = 0.4$ Anti-k_T $R = 0.6$



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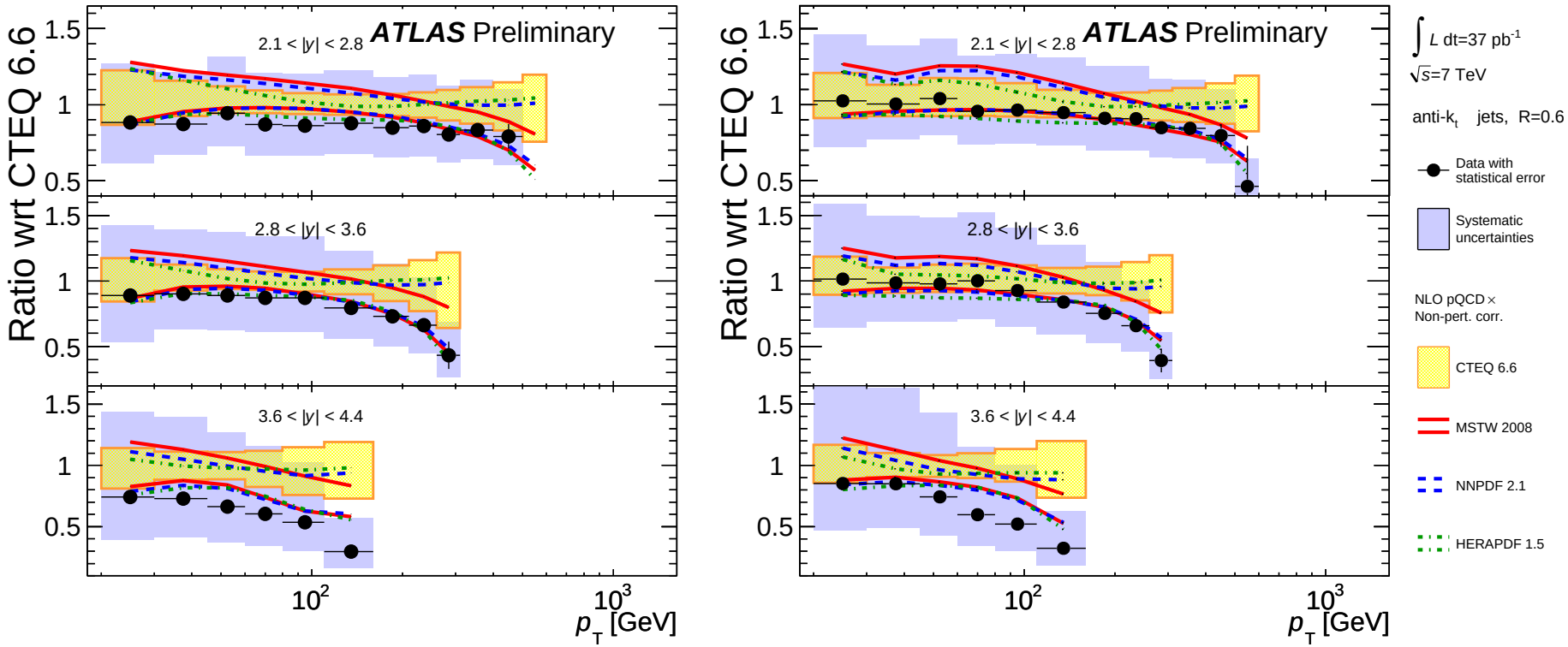
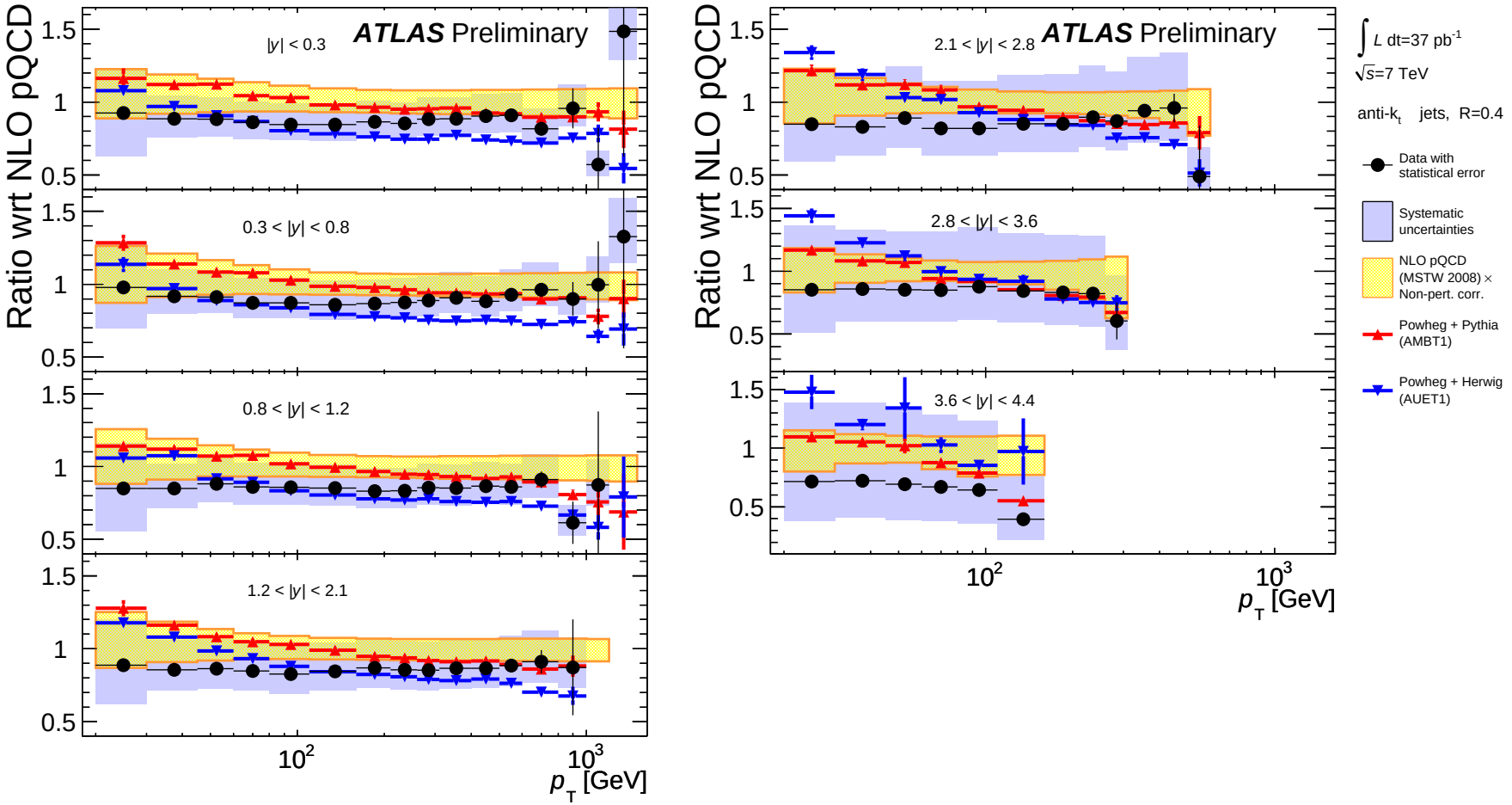


- Large rapidity region is sensitive to the choice of PDF
- CTEQ6.6 is disfavored; MSTW, NNPDF2.1 and HERAPDF 1.5 agree better with data

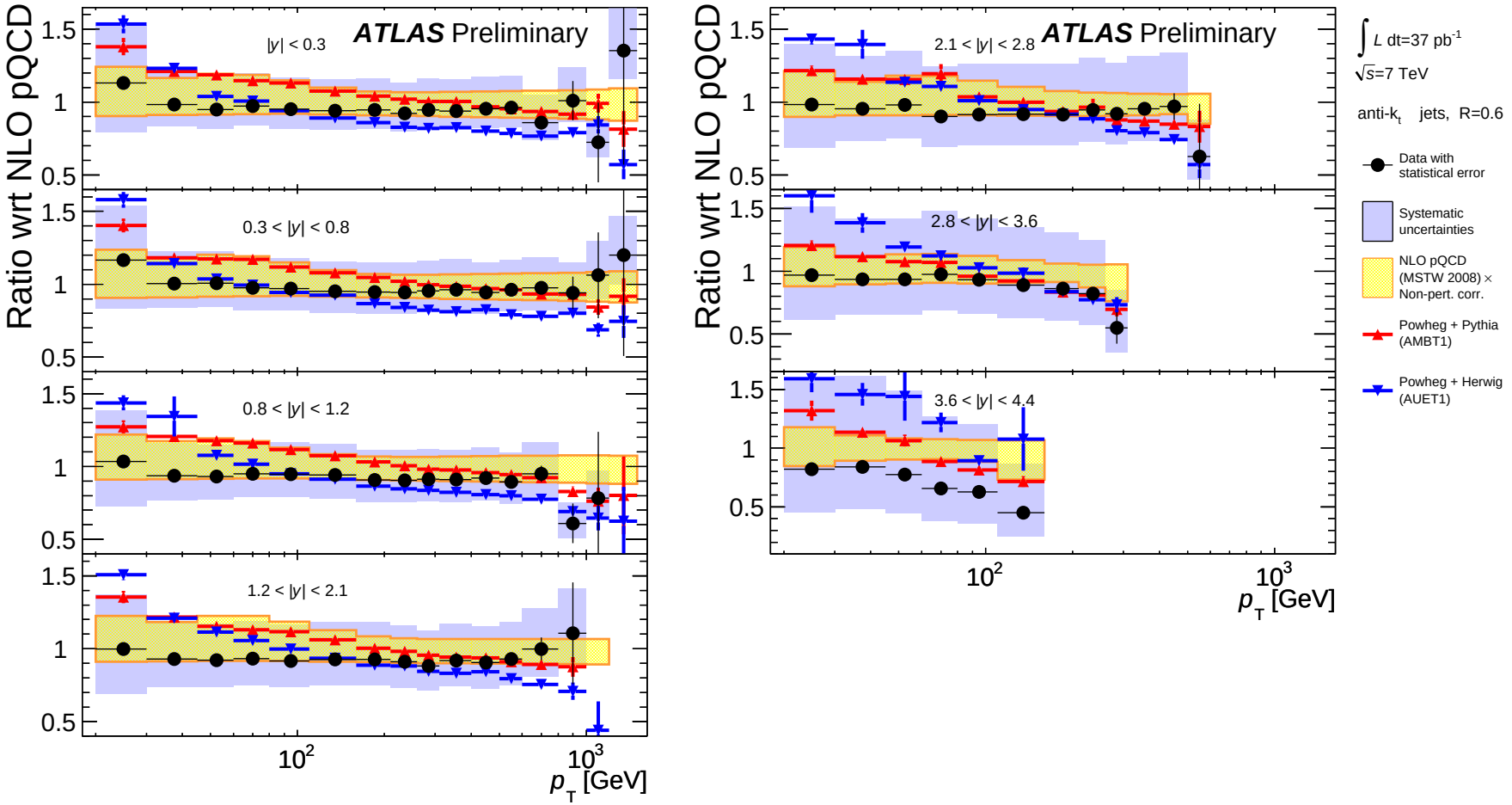
Inclusive Jet Cross Section: Comparison with NLO MC

- Powheg NLO MC prediction with parton shower MC (Pythia or Herwig) and NLO pQCD prediction (MSTW 2008 PDF). Results for Anti-k_T R=0.4
  - Low p_T: Powheg predicts larger cross sections than both data and NLOJet++
  - High p_T: Powheg closer to data but smaller cross sections than NLOJet++



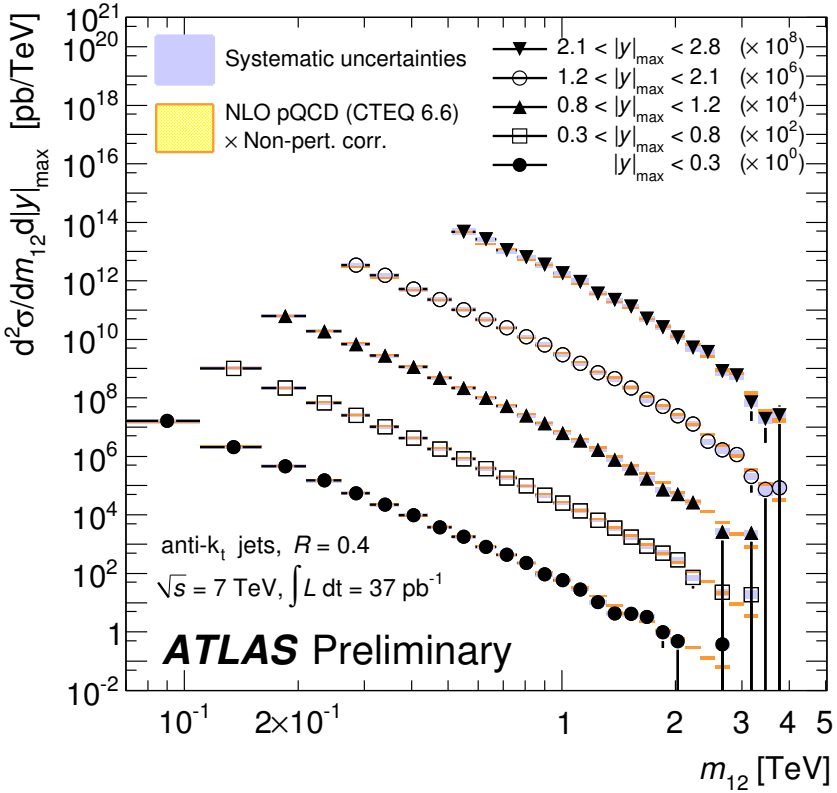
Inclusive Jet Cross Section: Comparison with NLO MC

- Powheg NLO MC prediction with parton shower MC (Pythia or Herwig) and NLO pQCD prediction (MSTW 2008 PDF). Results for Anti-k_T R=0.6
  - Low p_T: Powheg predicts larger cross sections than both data and NLOJet++
  - High p_T: Powheg closer to data but smaller cross sections than NLOJet++

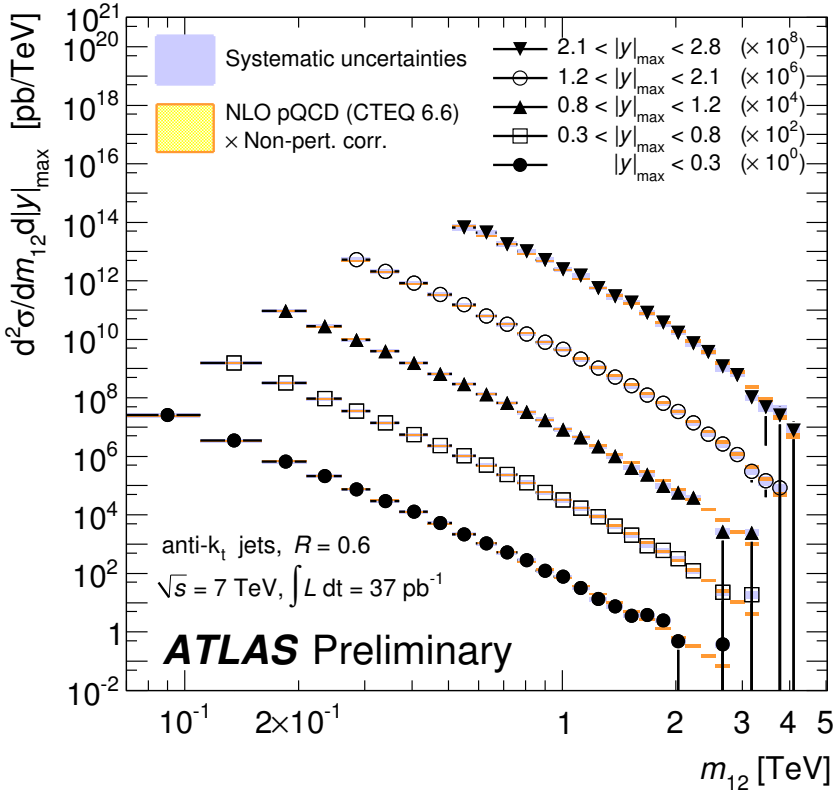


Dijet Cross Section

Anti-k_T $R = 0.4$



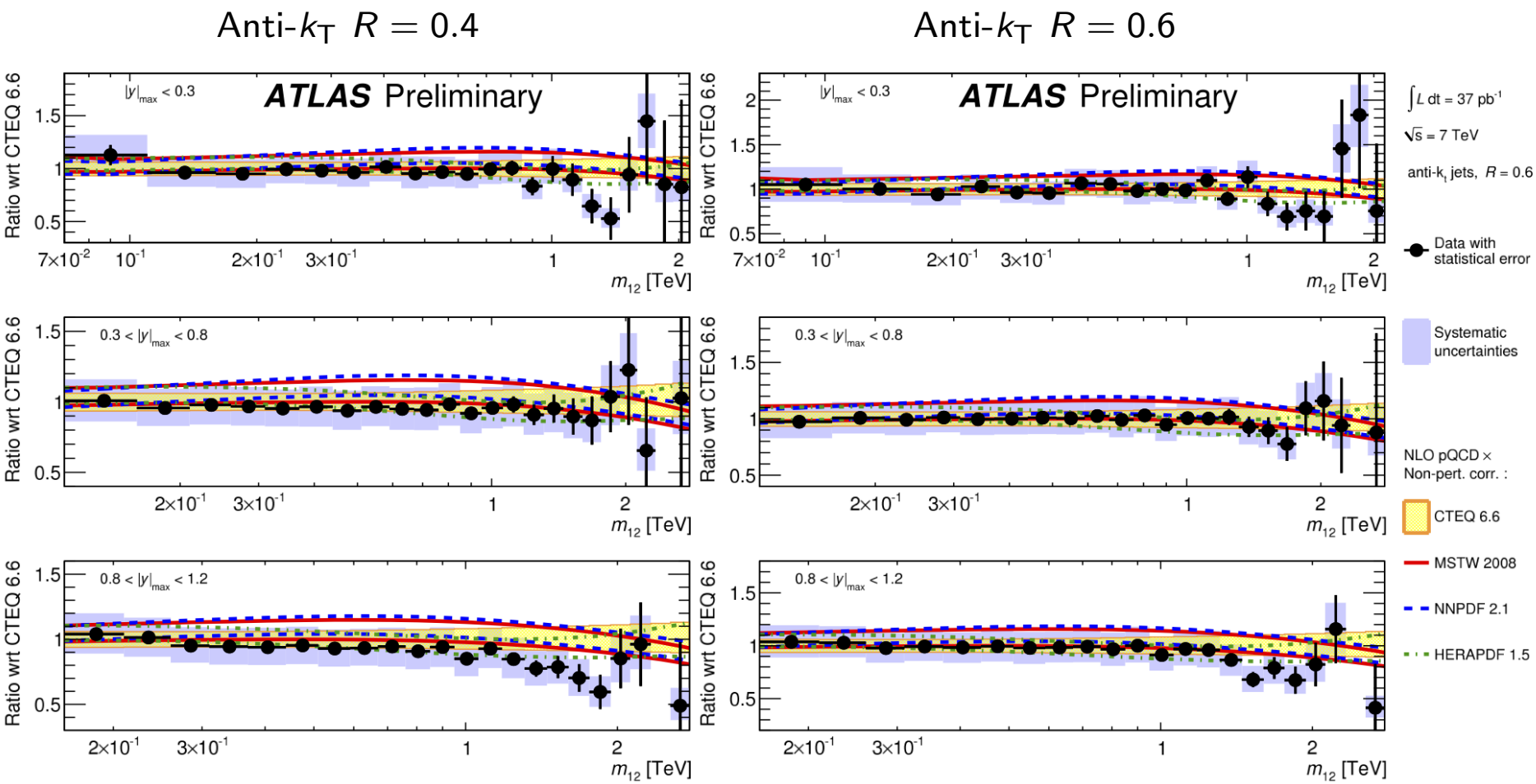
Anti-k_T $R = 0.6$



- Measurement expanding over 6 orders of magnitude in cross section
- Good agreement between data and NLO pQCD predictions

Dijet Cross Section: Comparison with pQCD

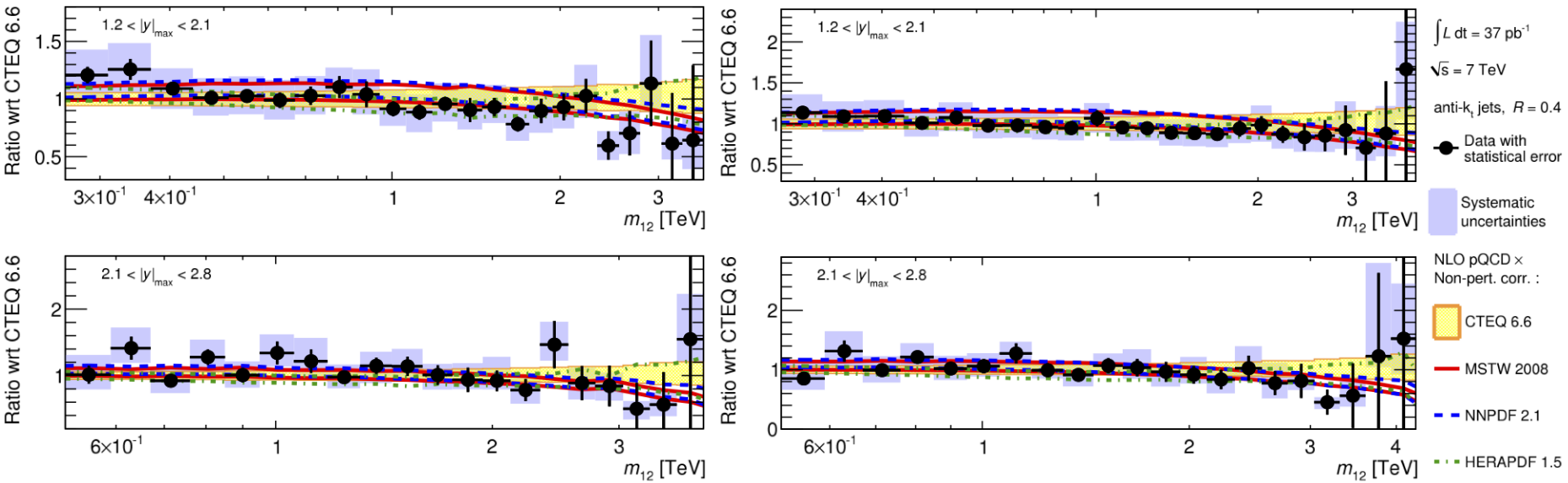
- Ratio data over theory predictions (several PDF choices shown)



Dijet Cross Section: Comparison with pQCD

- Ratio data over theory predictions (several PDF choices shown)

Anti-k_T $R = 0.4$ Anti-k_T $R = 0.6$



- Data in good agreement with theory within uncertainties
- Best agreement with data is obtained using HERAPDF 1.5, followed by the CTEQ 6.6

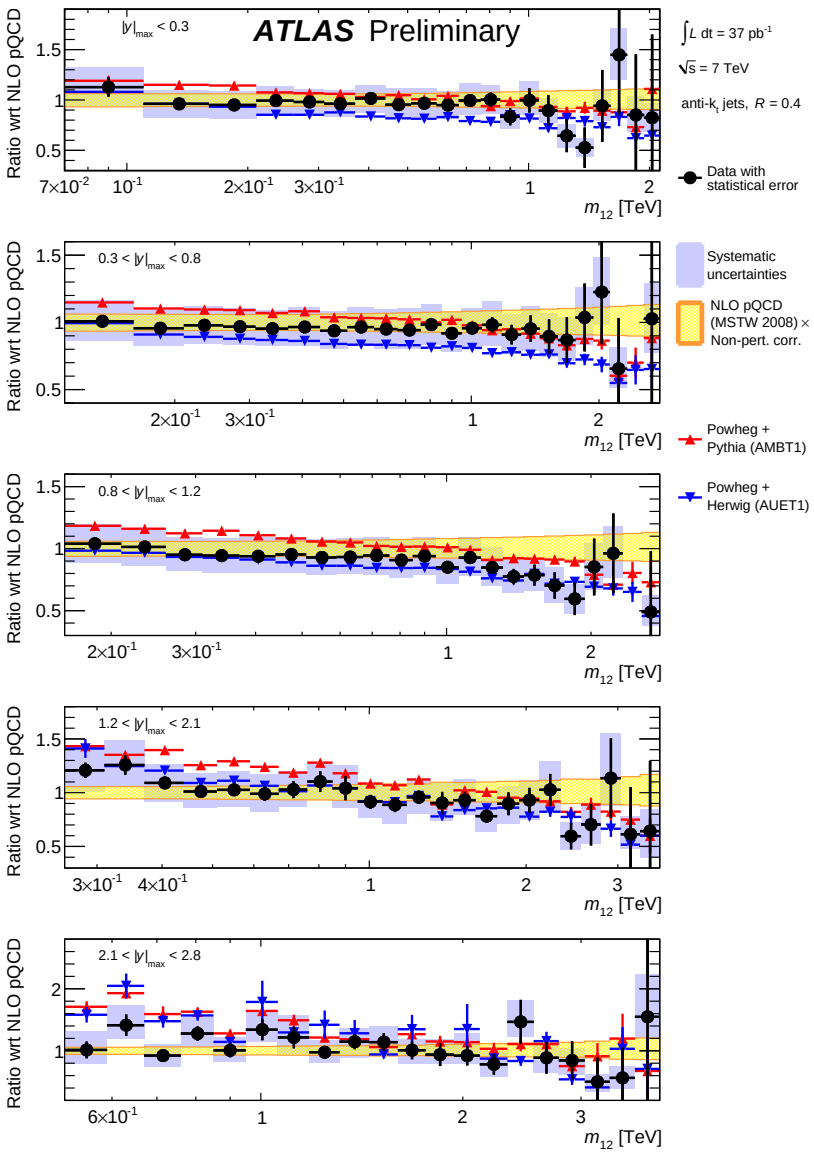
Summary

- Measurement of the inclusive jet and dijet production cross section performed with the full 2010 ATLAS data set
- Important extension from the previous published results:
  - Inclusive jet p_T measurement extended to 1.5 TeV
  - Dijet mass extended to 4.1 TeV
  - Extended coverage to low-p_T and high-rapidity regions
- Improved understanding of the ATLAS detector reduced some of the systematic uncertainties affecting this analysis
- Measurement from data compared to NLO perturbative QCD:
  - Agreement between data and theory over several orders of magnitude
  - Trend that measured cross sections are smaller than theory at large p_T and dijet mass
  - Comparison with several PDFs performed
- Comparisons with Powheg NLO MC also performed
- **Validation of the theory in a new kinematic regime**
- **ATLAS started providing sensitivity to PDFs in regions currently poorly constrained**

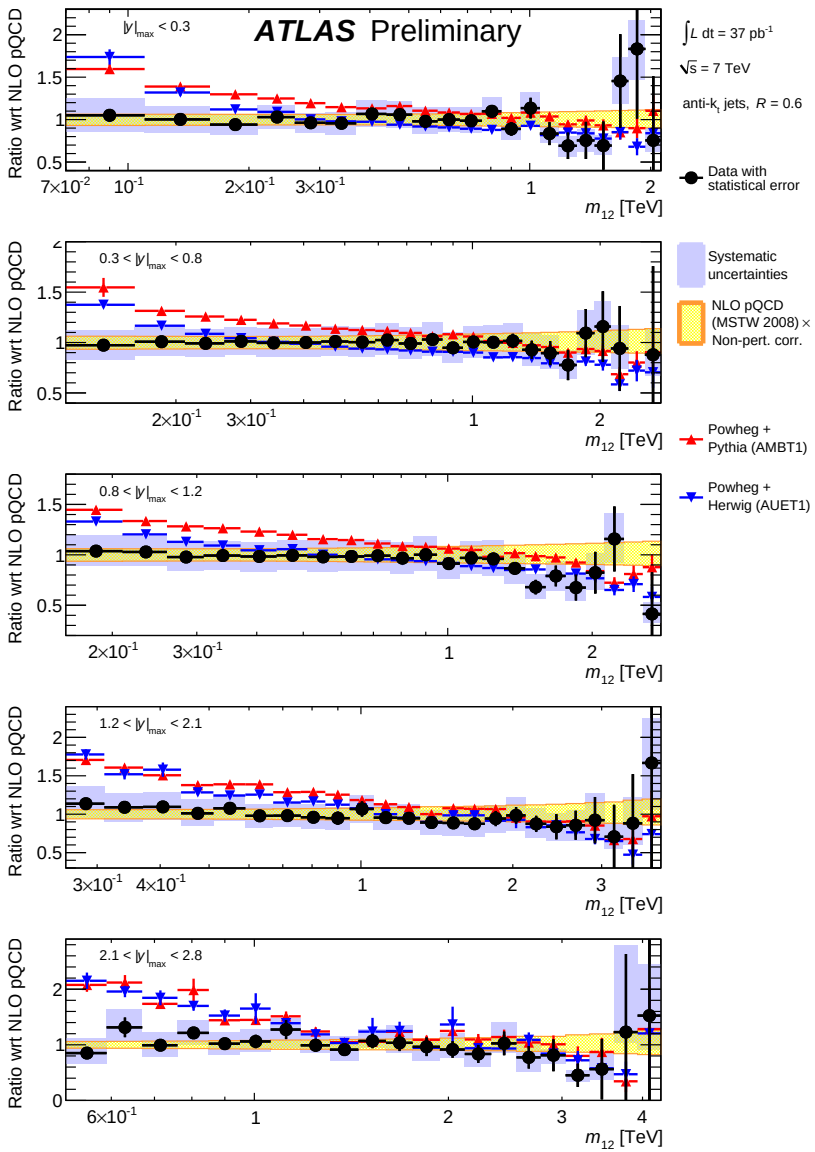
BACKUP

Dijet Cross Section: Comparison with NLO MC

Anti-k_T $R = 0.4$

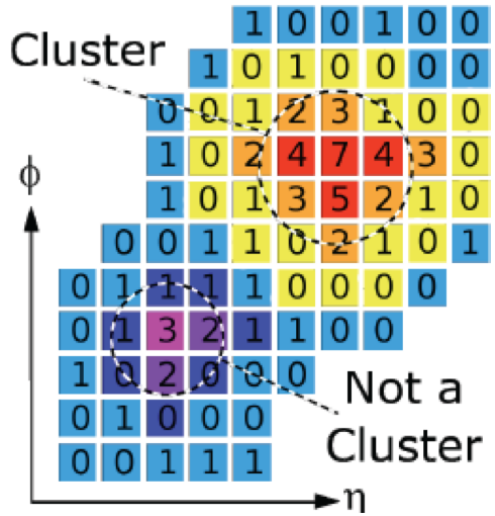
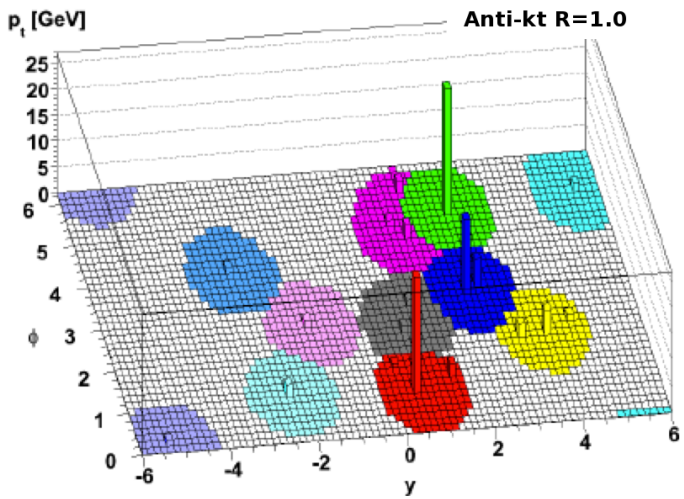


Anti-k_T $R = 0.6$



Theory Predictions

- Measured jet cross sections are compared to NLO pQCD predictions with corrections for non-perturbative effects
- **Fixed Order NLO pQCD**
  - NLOJet++ with the CTEQ 6.6 NLO PDF is used for baseline calculations
  - Results are also compared with predictions obtained using other PDFs (MSTW 2008, NNPDF 2.1, HERAPDF 1.5 and GJR08)
- **Non-Perturbative Corrections**
  - Fixed-order NLO calculations predict parton-level cross sections $\longrightarrow$ Need to correct for non-perturbative effects
  - Done by using leading-logarithmic parton shower generators (Pythia) to evaluate the ratio of cross sections with and without hadronisation and underlying event
  - Multiply bin-by-bin the parton-level cross sections by this ratio
- **NLO Matrix Element + Parton Shower**
  - NLO parton shower Monte Carlo prediction for inclusive jet and dijets recently available with Powheg
  - Use either Pythia or Herwig to shower and hadronise the partons and model the underlying event

Jet Reconstruction in ATLAS

- Topological clusters of calorimeter cells:
  - Reduce effects of noise, follow shower development
  - Seeded by cells with $|E| > 4\sigma_{noise}$
  - Neighbouring cells in (η, ϕ, r) with $|E| > 2\sigma_{noise}$ are added iteratively
  - Add neighbouring cells with $|E| > 0$
- Anti-k_T jet algorithm:
  - Proposed by M. Cacciari and G. P. Salam in Phys. Lett. B **641** (2006) 57
  - Infrared and collinear safe algorithm
  - Produces geometrically cone-like jets
- Results shown only for topo cluster jets, but also tracks or noise-suppressed towers also used in ATLAS