Jet physics in p-p collisions at ATLAS

Pierre-Antoine Delsart
On behalf of the ATLAS collaboration

Winter Workshop on Recent QCD Advances at the LHC

Les Houches, February 13th - 18th, 2011

Laboratoire de Physique Subatomique et Corpusculaire
CNRS/IN2P3

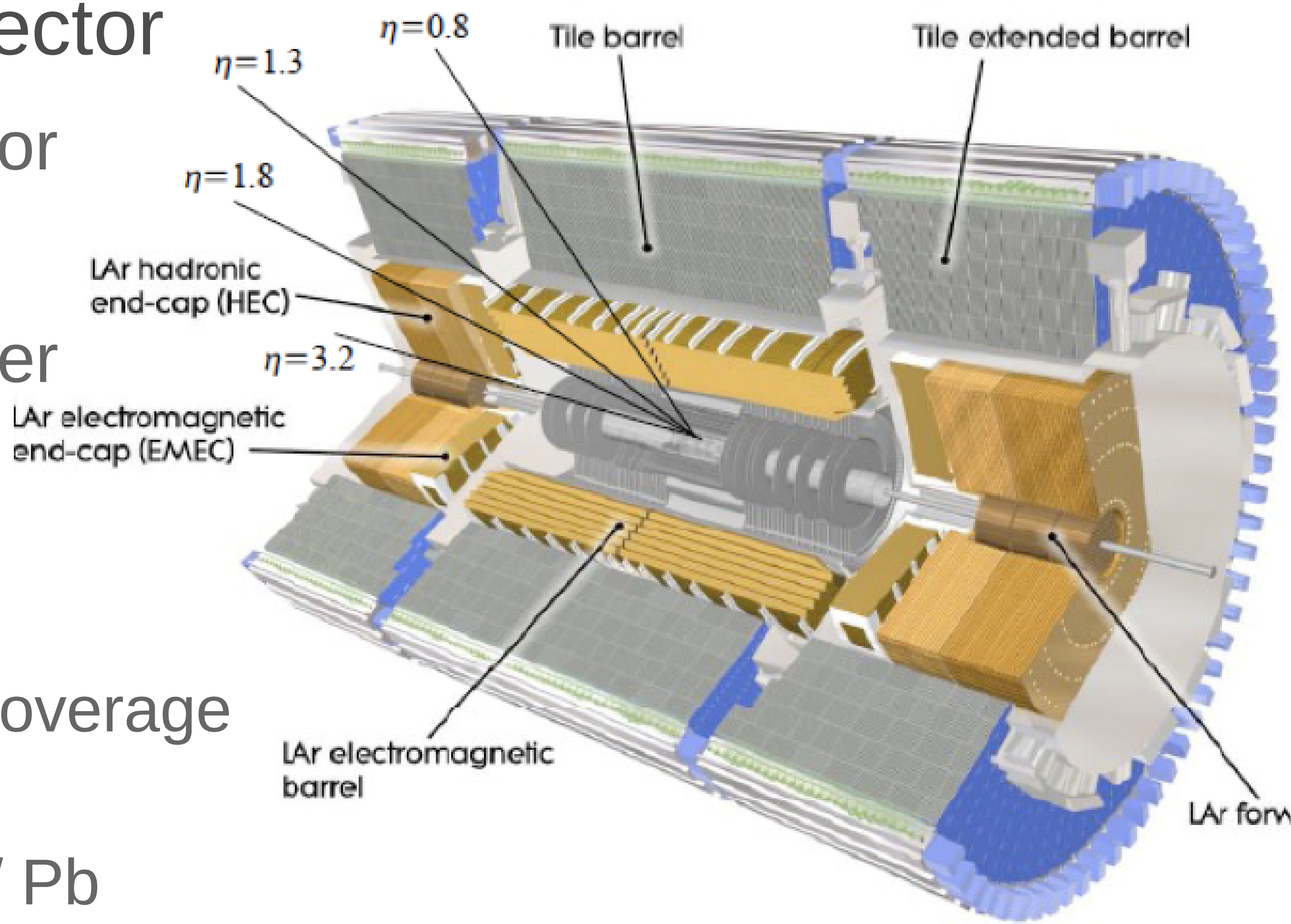
Outline

Report on high energy jet physics analysis in ATLAS

- Common ingredients
  - Detector
  - Data sample, event selection, Monte-Carlo
  - Jets reconstruction, systematics
- Physics results
  - Inclusive, di-jets, multi-jets x-sections
  - Jet shapes
  - Azimuthal decorrelation
- Conclusion, outlook

The ATLAS Detector

- Multi-purpose detector
  - Inner track detector
  - Calorimeter
  - Muon spectrometer



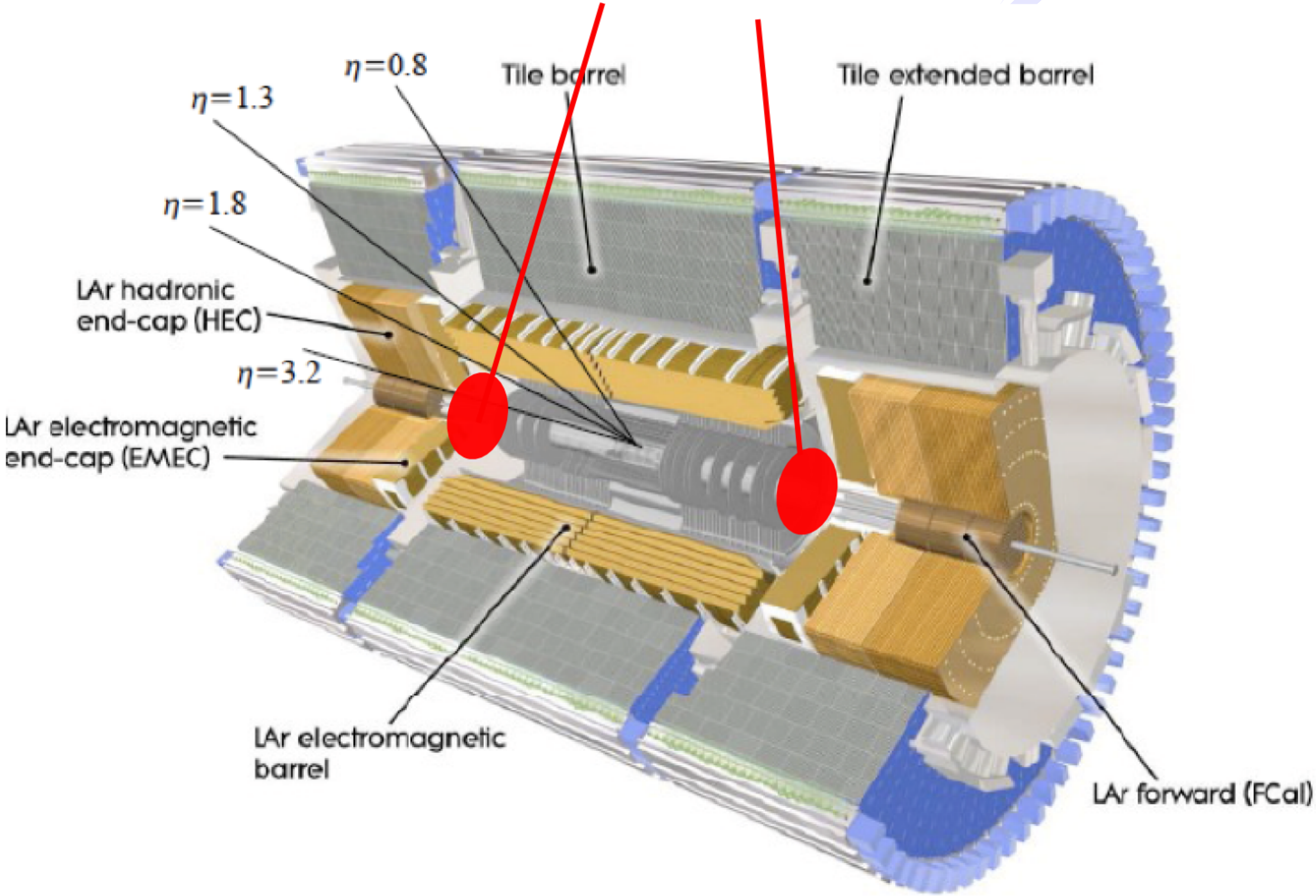
- Calorimeter
  - Good granularity, coverage (up to eta=5)
  - EM : Liquid Argon / Pb
  - Hadronic : Scintillating tiles (Barrel, end-caps) and LAr/Cu or W (end-caps)

Non-compensating calorimeter
E/h ~1.3 – 1.6
(depending on sub-calo)

Data samples and event selection

- Data samples
  - Early runs of LHC with $\sqrt{s} = 7\ \mathrm{TeV}$
  - Integrated luminosity between $17nb^{-1}$ and $3pb^{-1}$
    - ($\Delta\phi$ analysis with full 2010 data : $36pb^{-1}$)
- Trigger events with
  - MBTS

Minimum Bias Trigger Scintillator



Data samples and event selection

- Data samples
  - Early runs of LHC
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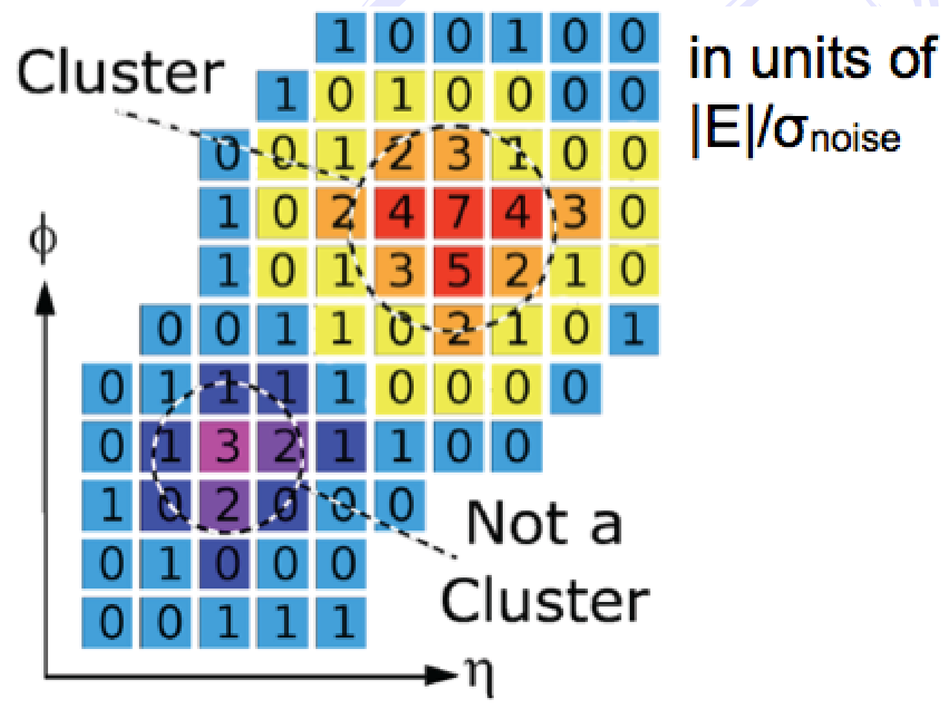
- Triggers
  - MBTS
  - L1 calorimeter ('Towers' with p_T>5, 15, 30, 55 GeV)
  - Used in their ~100% efficiency domain
- Analysis cuts (details depend on analysis)
  - 1 vertex required
  - Jets Pt ⩾ ~50GeV

Monte-Carlo Samples

- Pythia 6.241
  - PDF : MRST2007LO
  - Default parameters tune : 'Atlas MC09', based on Tevatron results
  - Other tunes : Perugia2010, DW (PDF : CTEQ5L)
- Herwig6 + Jimmy / Herwig++
  - Often used as x-check samples/ systematics estimations
- Sherpa
- Alpgen
  - For multi-jets events
  - Interfaced with Herwig & Jimmy. PDF : CTEQ61L
- NLO calculations
  - NLOJET++ 4.1.2 (with CTEQ6.6 NLO, or MSTW2008)
  - JETRAD used for cross-checks

Jet reconstruction in Atlas

- **Input** Calorimeter objects are 3D **Topological Clusters**
  - 4/2/0 algorithm based on E/sigma ratios
  - Intrinsic noise suppression
  - Use default calorimeter calibration : EM scale



Jet reconstruction in Atlas

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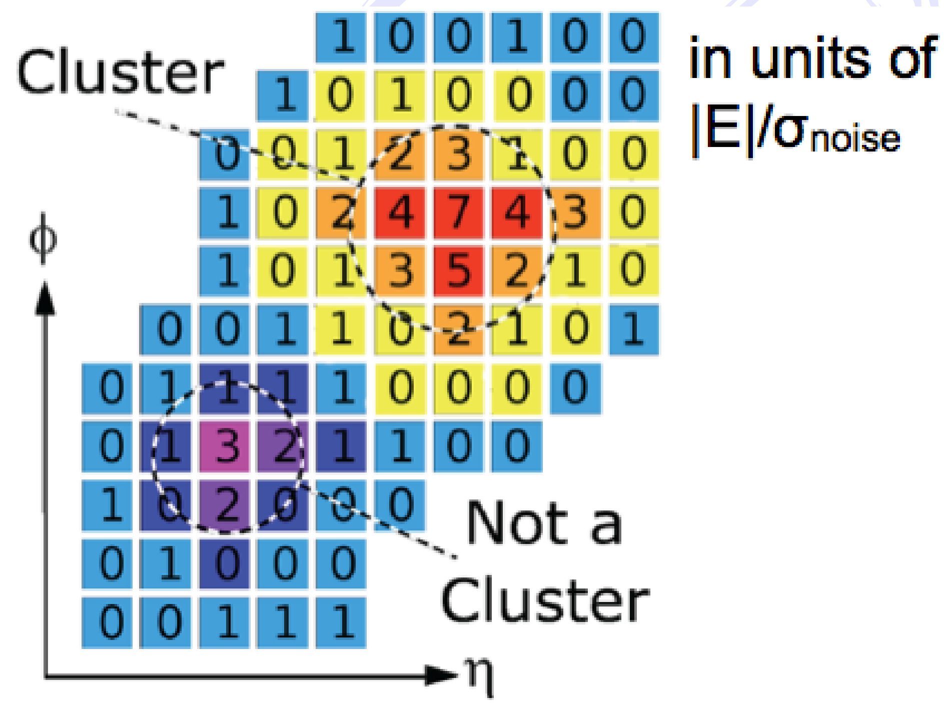
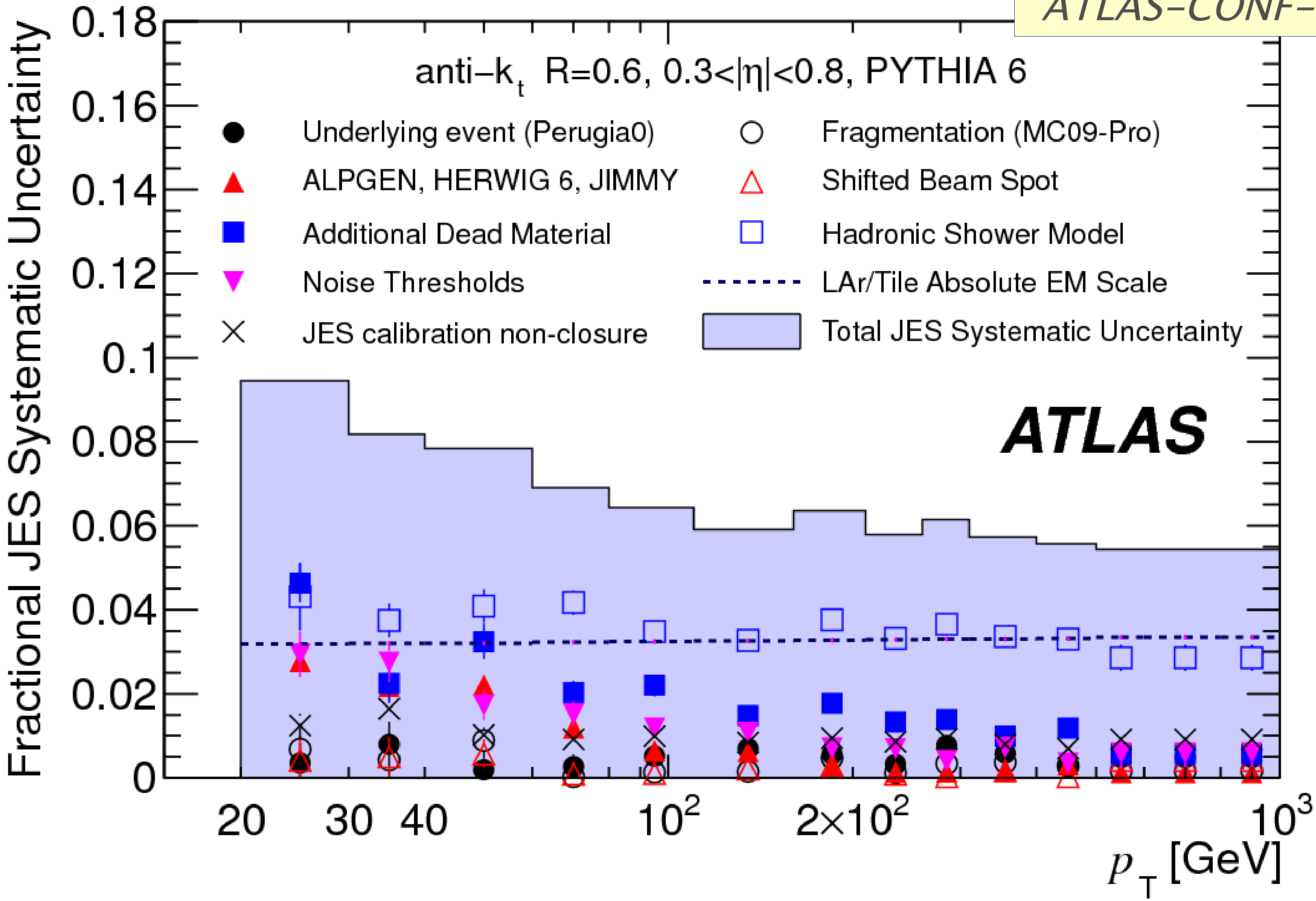


- Jets build from clusters with **AntiKt algorithm**
  - R=0.4 or **0.6** (all plots in this talk)
  - Calibration : scale factor based on Monte-Carlo Numerical Inversion

Systematic uncertainties

Dominant uncertainty in most analysis : **Jet Energy Scale** (JES)

ATLAS-CONF-2010-056



Systematic uncertainties

- Unfolding
  - Account for efficiency & resolution of trigger and detector
  - Bin-by-bin correction from simulated/generated ratios
  - Small or negligible compared to absolute JES
- Pile-up
  - Small (<2%) or negligible with early runs used here
    - Not true with full 2010 data, c.f. $\Delta\phi$ analysis
- Luminosity
  - Measured with ATLAS dedicated devices +LHC VdM scans
  - ~11%

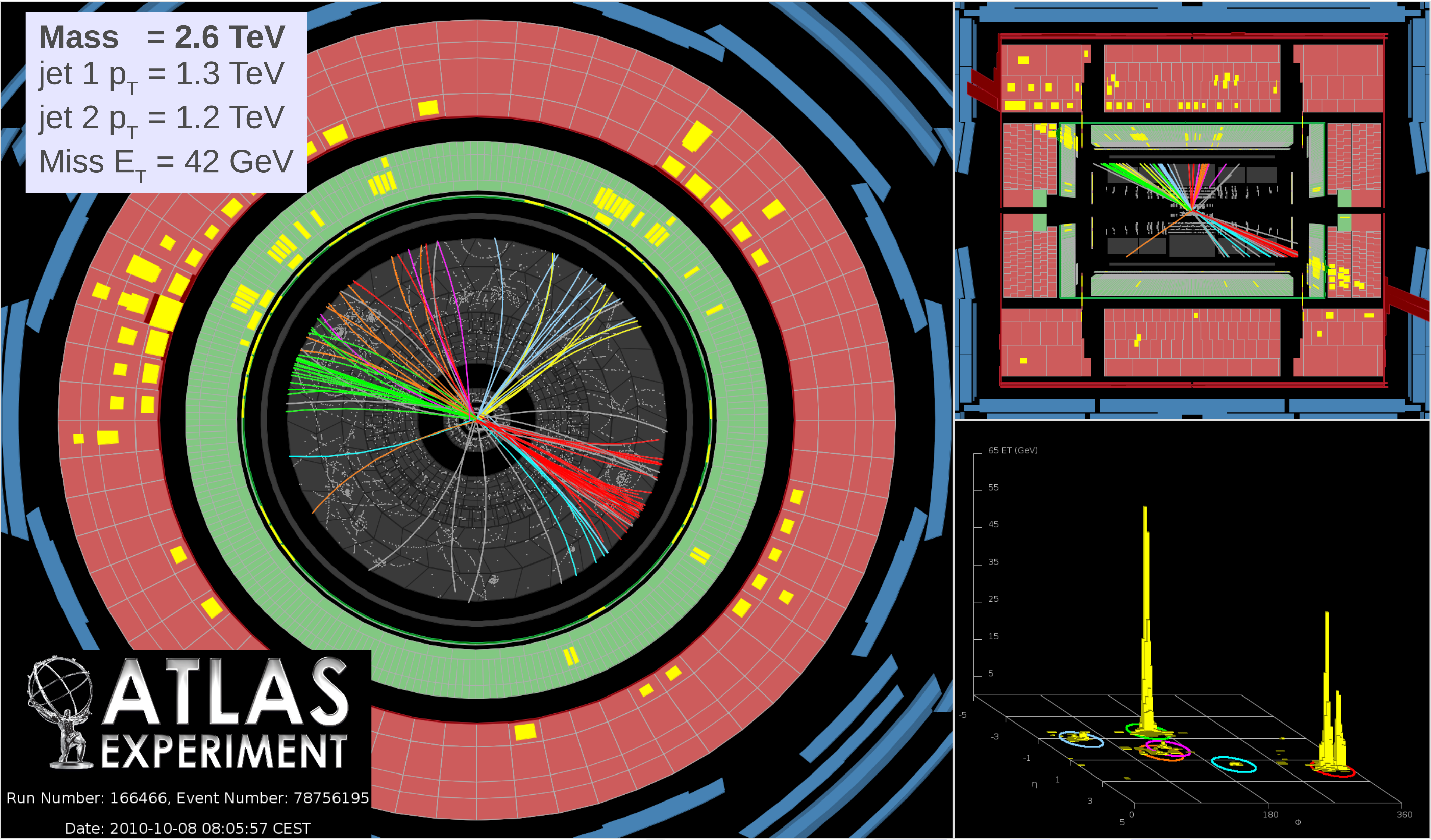
Physics Results

Single/Di-jet cross-section

Published in EPJC
s10052-010-1512-2

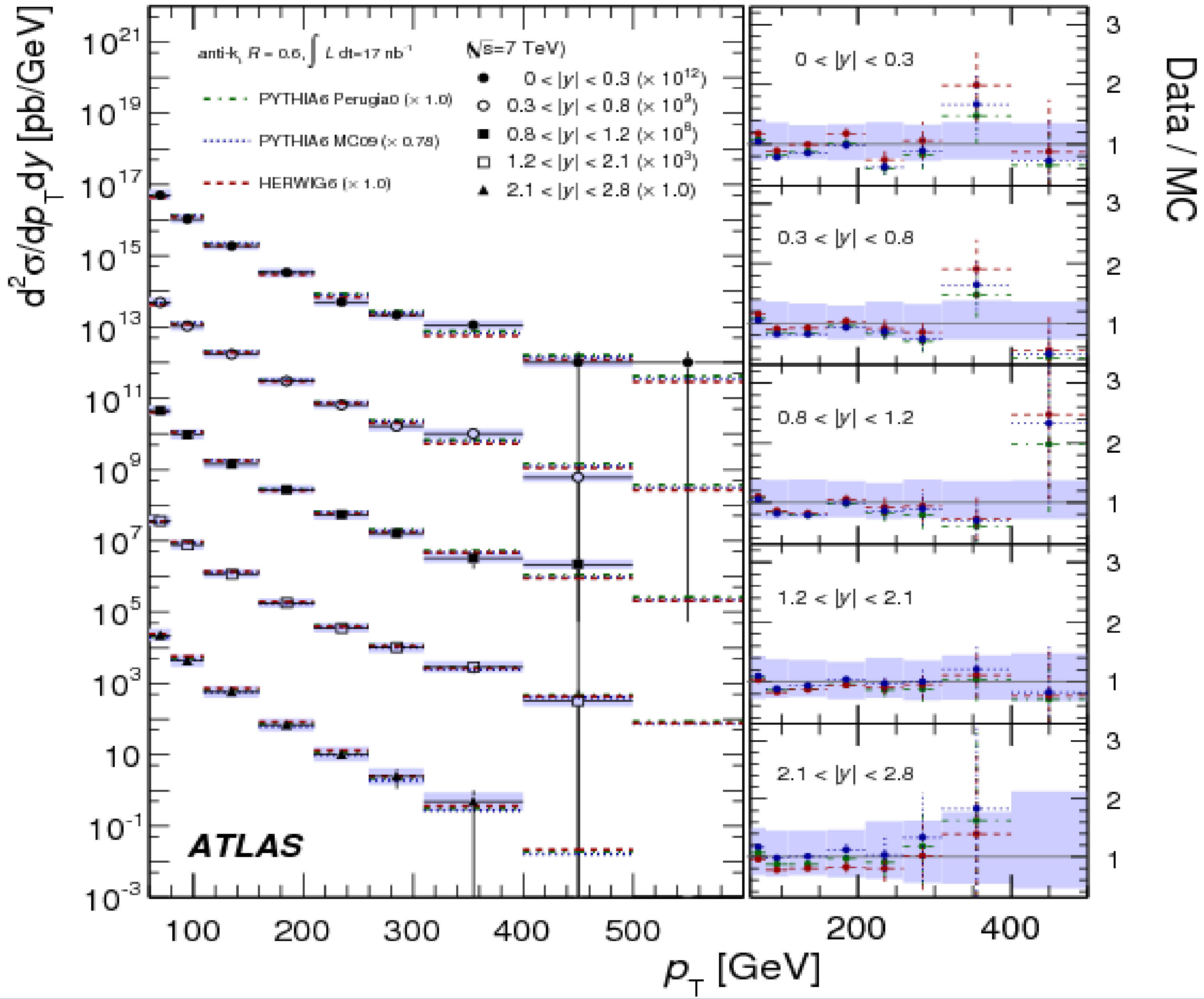
- Measured with L=17nb^{-1}
- Jet selection : p_T>60GeV, |y|<2.8
  - Require 2nd jet with pT>30 GeV in di-jet analysis
- Main systematics
  - JES
  - Luminosity
- Good agreement Data/MC

Highest central di-jet inv. mass



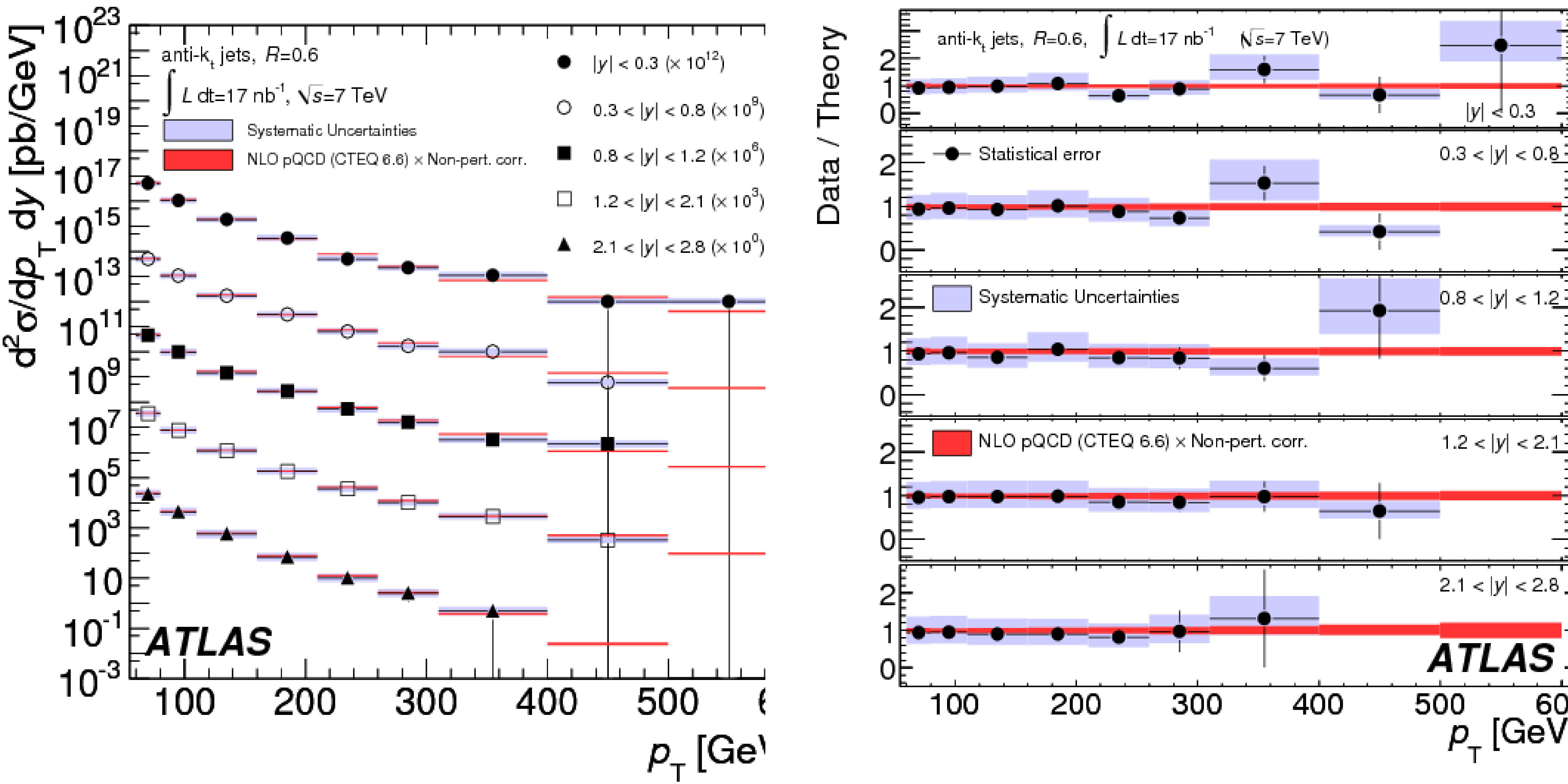
Single jet double diff cross-section

Compared to event generators



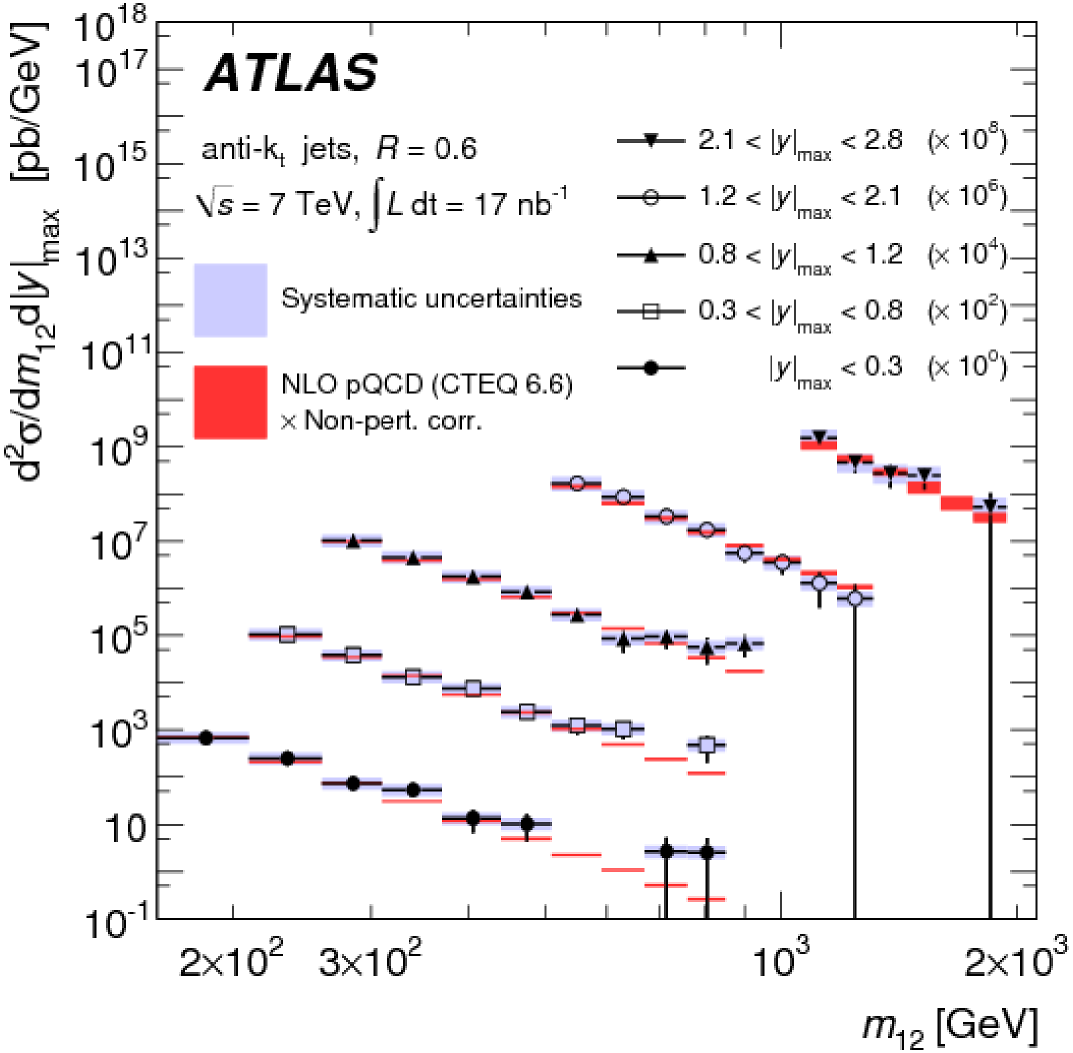
Single jet double diff cross-section

Compared to NLO pQCD calculations

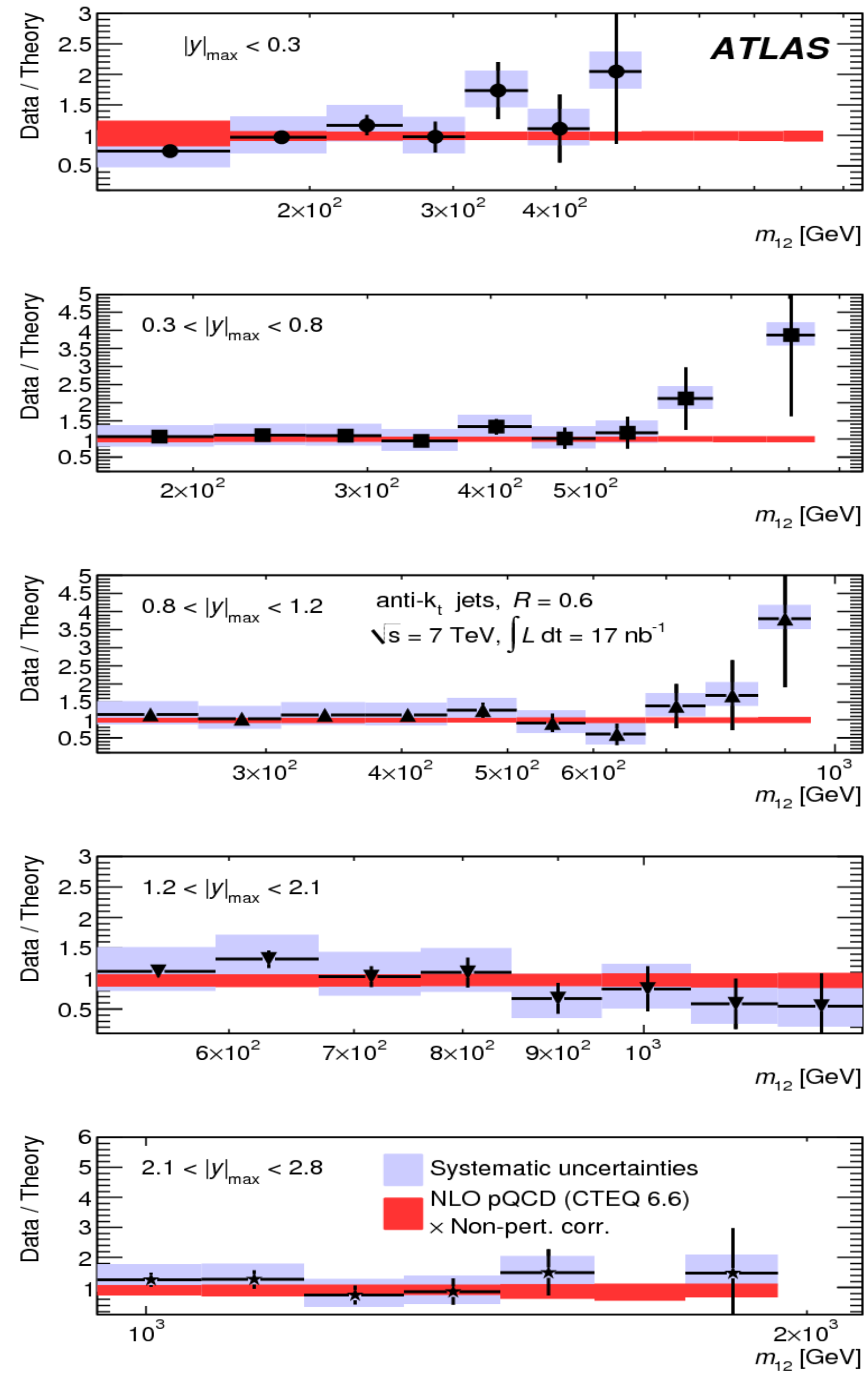


Di-jet double diff cross-section

As function of dijet inv. mass



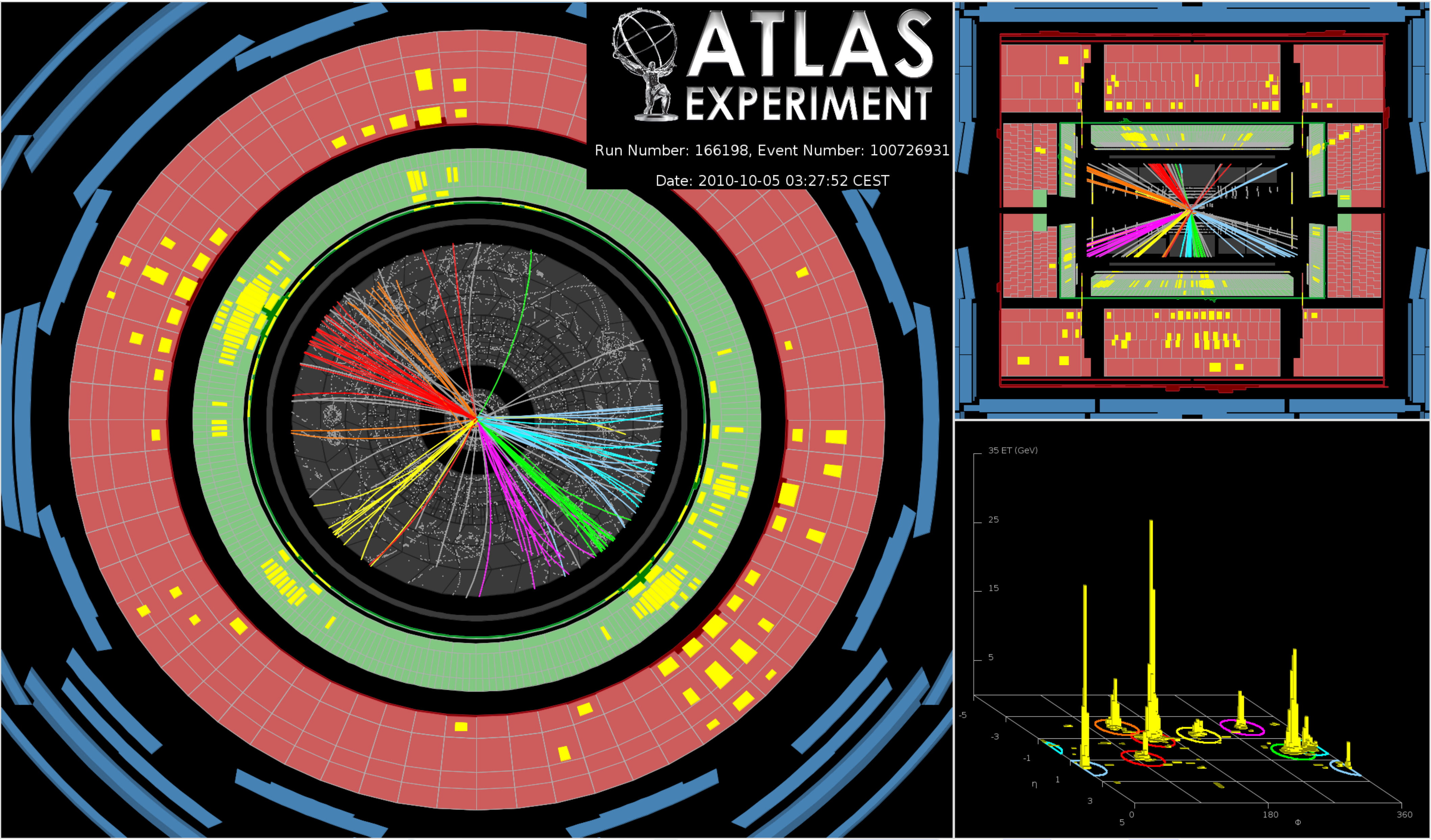
Ratio vs NLO



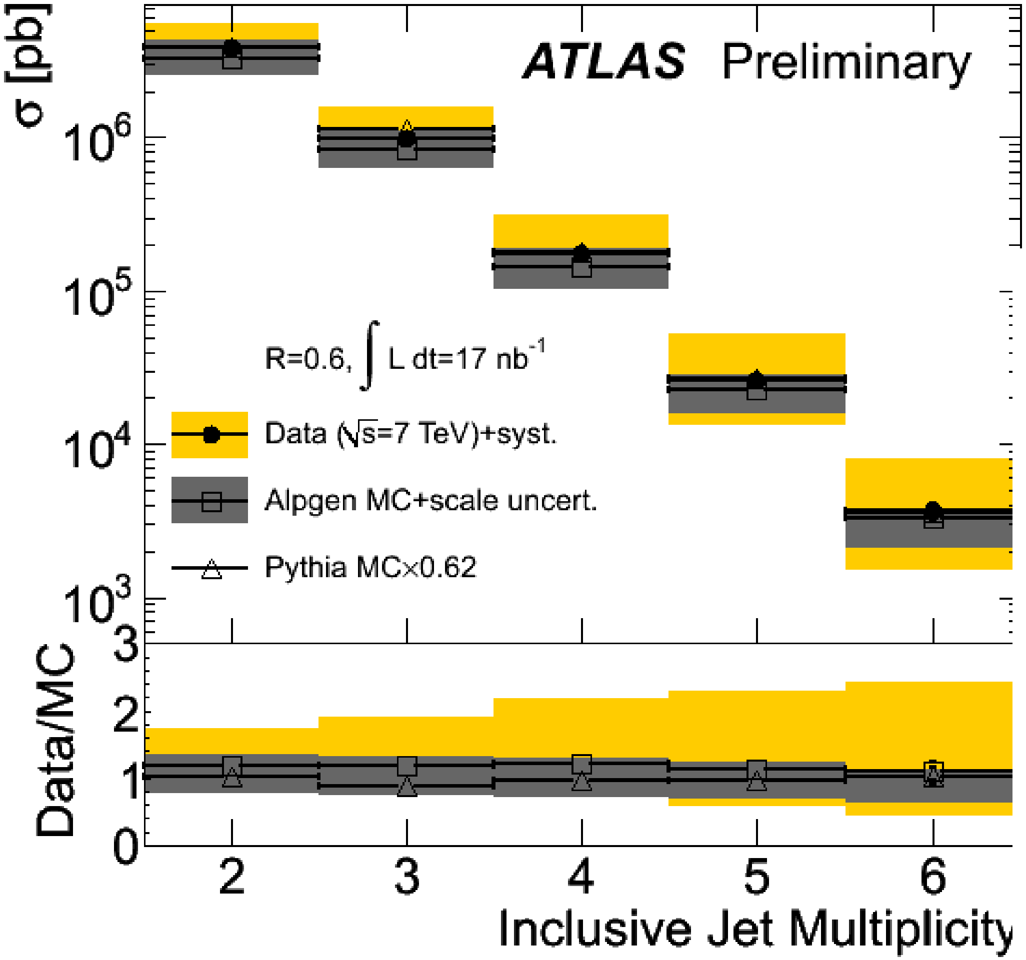
Multi-jet cross-sections

ATLAS-CONF-2010-084

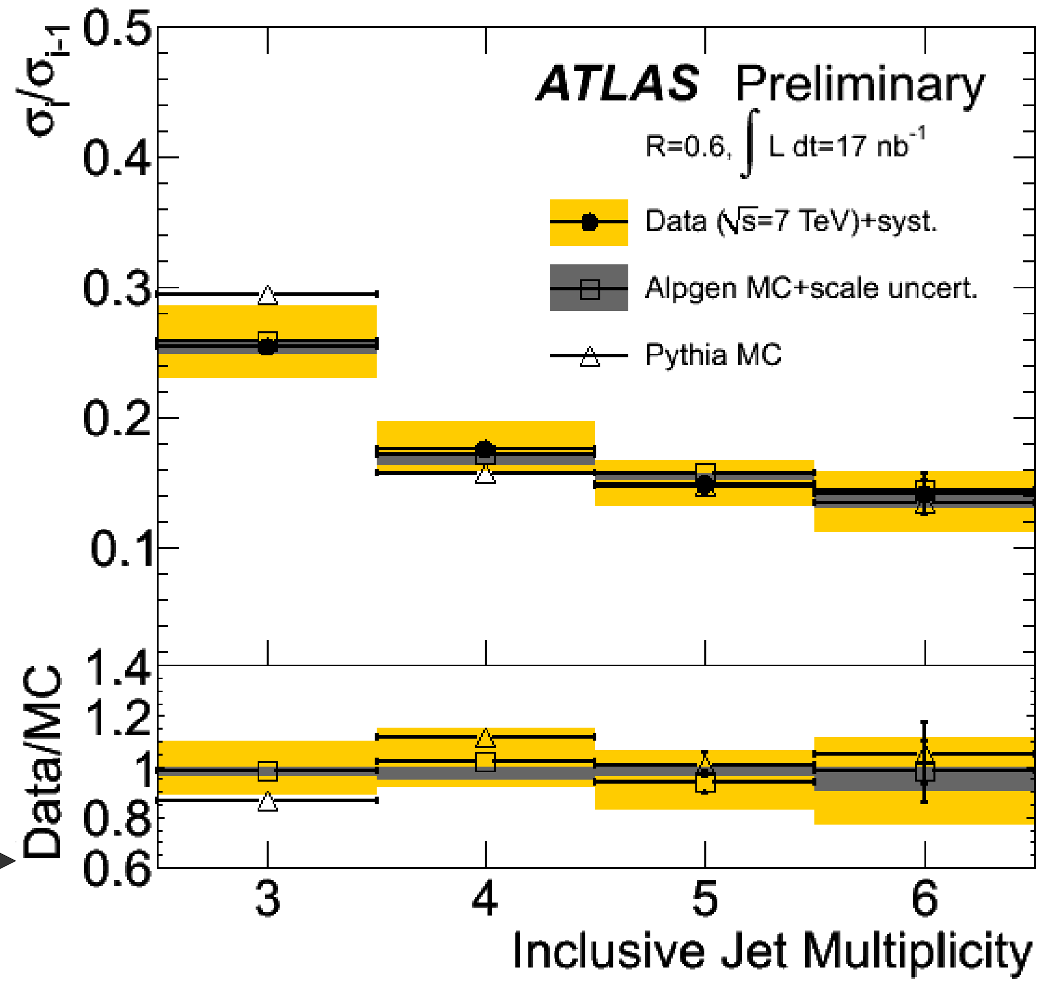
- Measured with $L=17nb^{-1}$
- Jet selection :
  - p_T > 30 GeV, |y|<2.8, at least 1jet p_T>60GeV
- Results given as function of $H_T = \sum_{\text{jets}} p_T$
- Monte-Carlo
  - ALPGEN, interfaced to Herwig/Jimmy (hadronization/UE)
- Main systematics
  - JES and '**close-by jets**' effects
  - Luminosity
- Good agreement Data/MC


ATLAS
EXPERIMENT
Run Number: 166198, Event Number: 100726931
Date: 2010-10-05 03:27:52 CEST
35 ET (GeV)
25
15
5
η
Φ
0
180
360

Multi-jet cross-sections

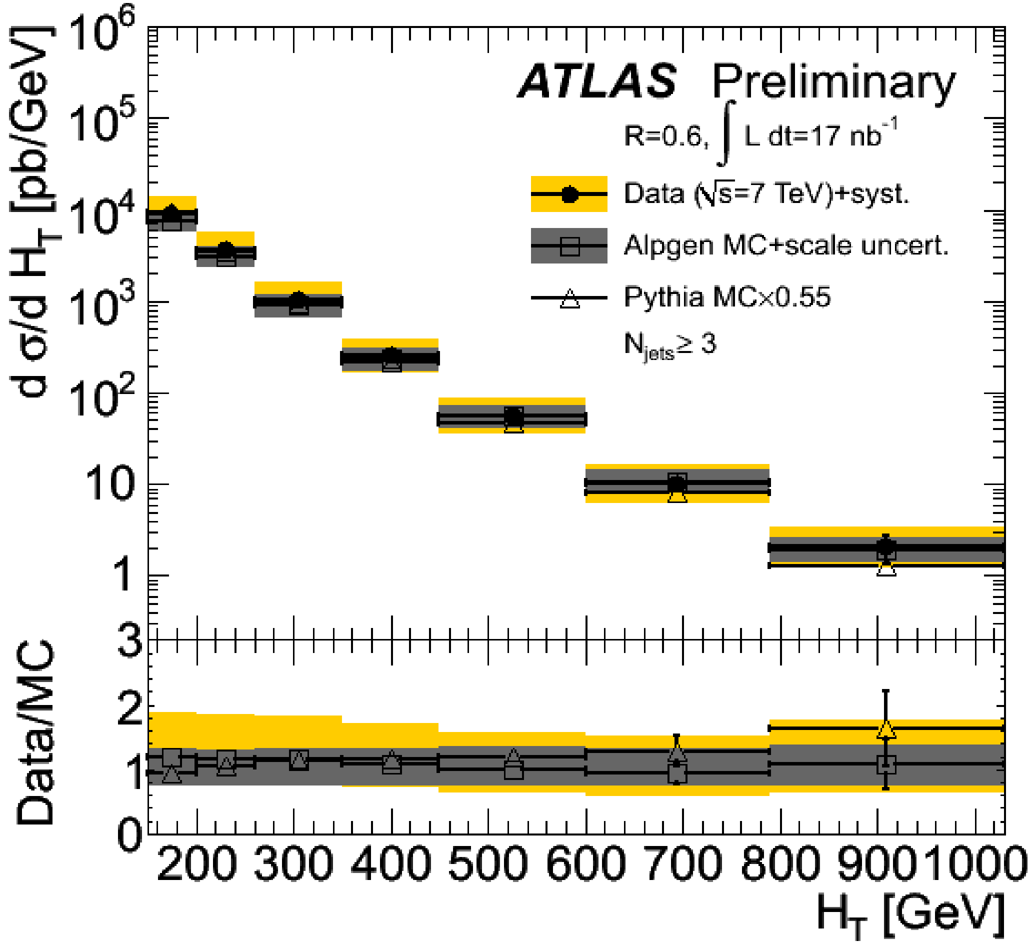


Inclusive cross-sections

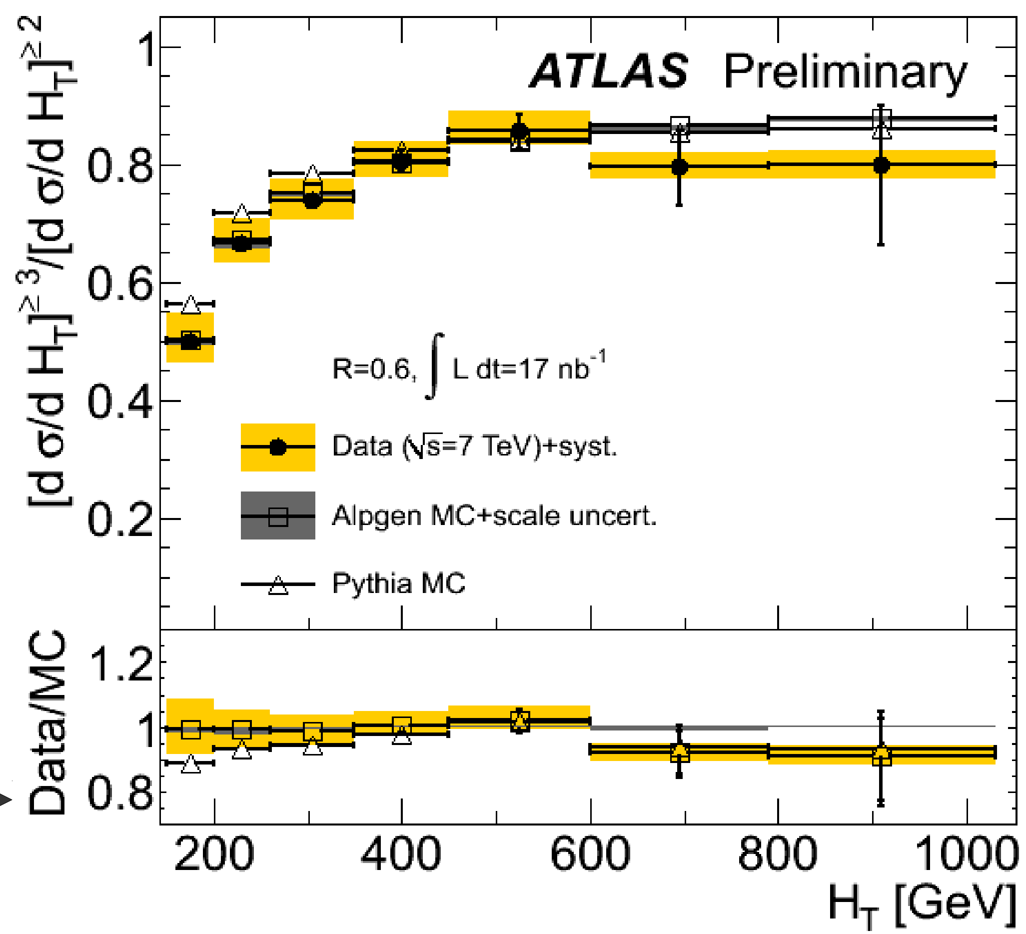


Ratios $\sigma(N)/\sigma(N-1)$
(much better uncertainties)

Multi-jet cross-sections



Diff. cross-sections vs HT for N≥3jets



Ratios σ(3jets)/σ(2jets) (much better uncertainties)

Jet shapes

arXiv:1101.0070 [hep-ex]
accepted by PRD

- Measure radial p_T distribution inside jets :

$$\rho(r) = \frac{1}{\Delta r N_{\mathrm{jet}}} \sum_{\mathrm{jets}} \frac{p_{\mathrm{T}}\,(r \pm \Delta r/2)}{p_{\mathrm{T}}\,(0, R)}$$

$$\Psi(r) = \frac{1}{N_{\mathrm{jet}}} \sum_{\mathrm{jets}} \frac{p_{\mathrm{T}}\,(0, r)}{p_{\mathrm{T}}\,(0, R)} \quad \leftarrow \text{Integrated shape}$$

- Select jets with p_T>30GeV in selected events
- Main systematics :
  - Cluster Energy Scale (separated from JES) : 5 to 15%
  - Unfolding : 2 to 10%
  - Overall uncertainty on rho(r) : from 2 to 27% depending on p_T and r bins

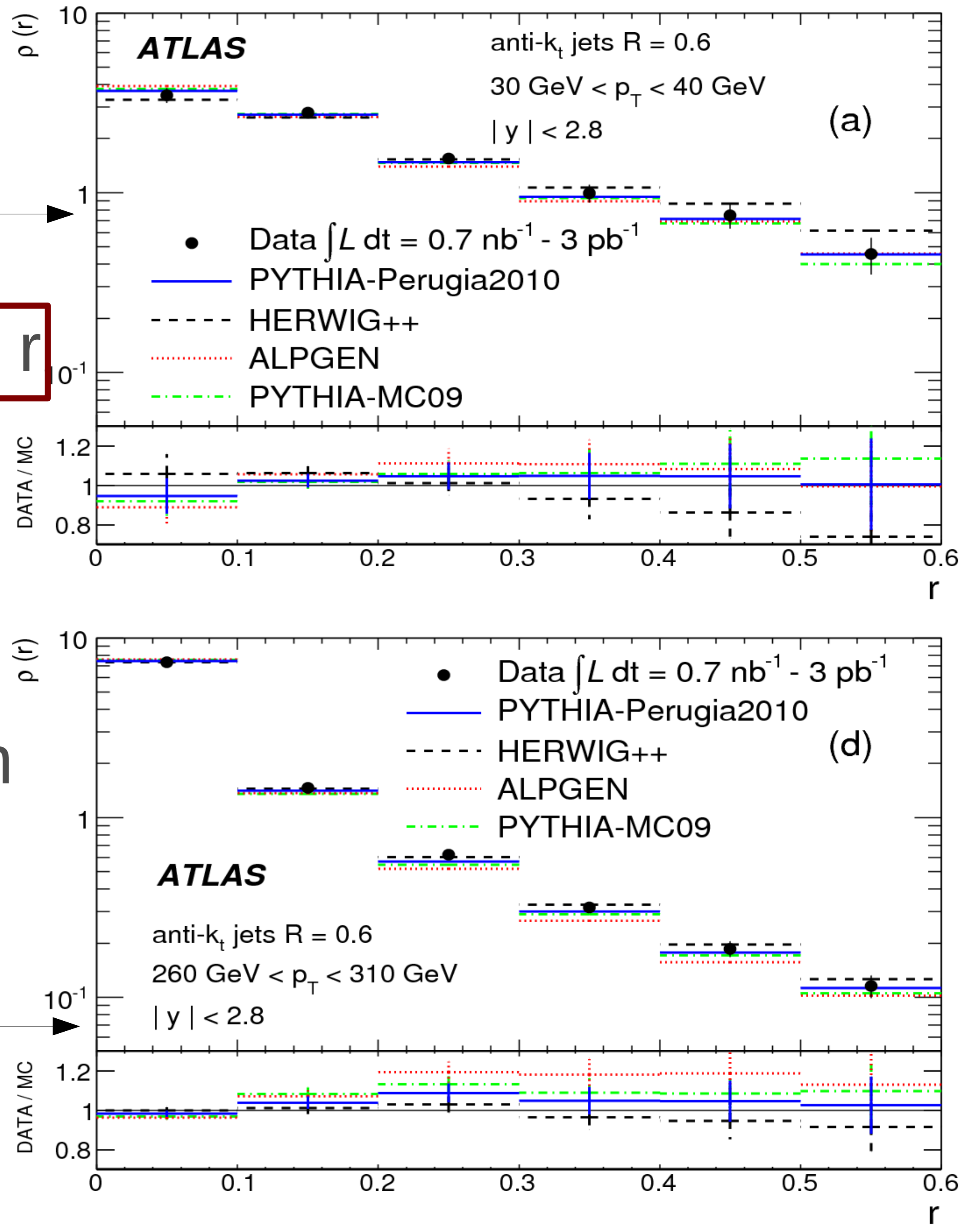
Jet shapes

Low p_T bin

Differential jet shape vs r

- Shape correctly reproduced with default Pythia tune
- Best agreement with Pythia-Perugia2010

High p_T bin



Jet shapes

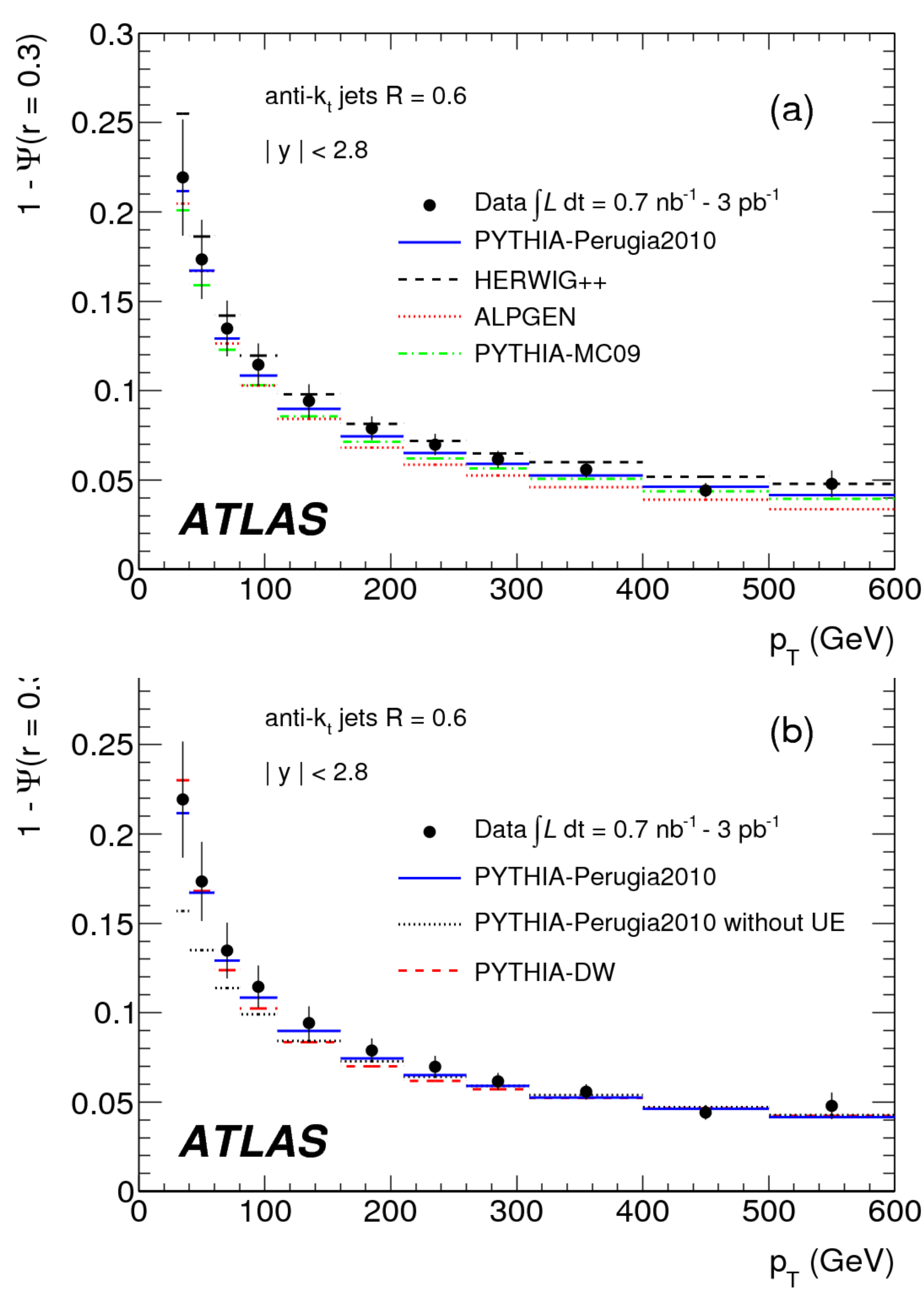
- Check 'Narrowness' of jets

Fraction of p_T outside 0.3R

=

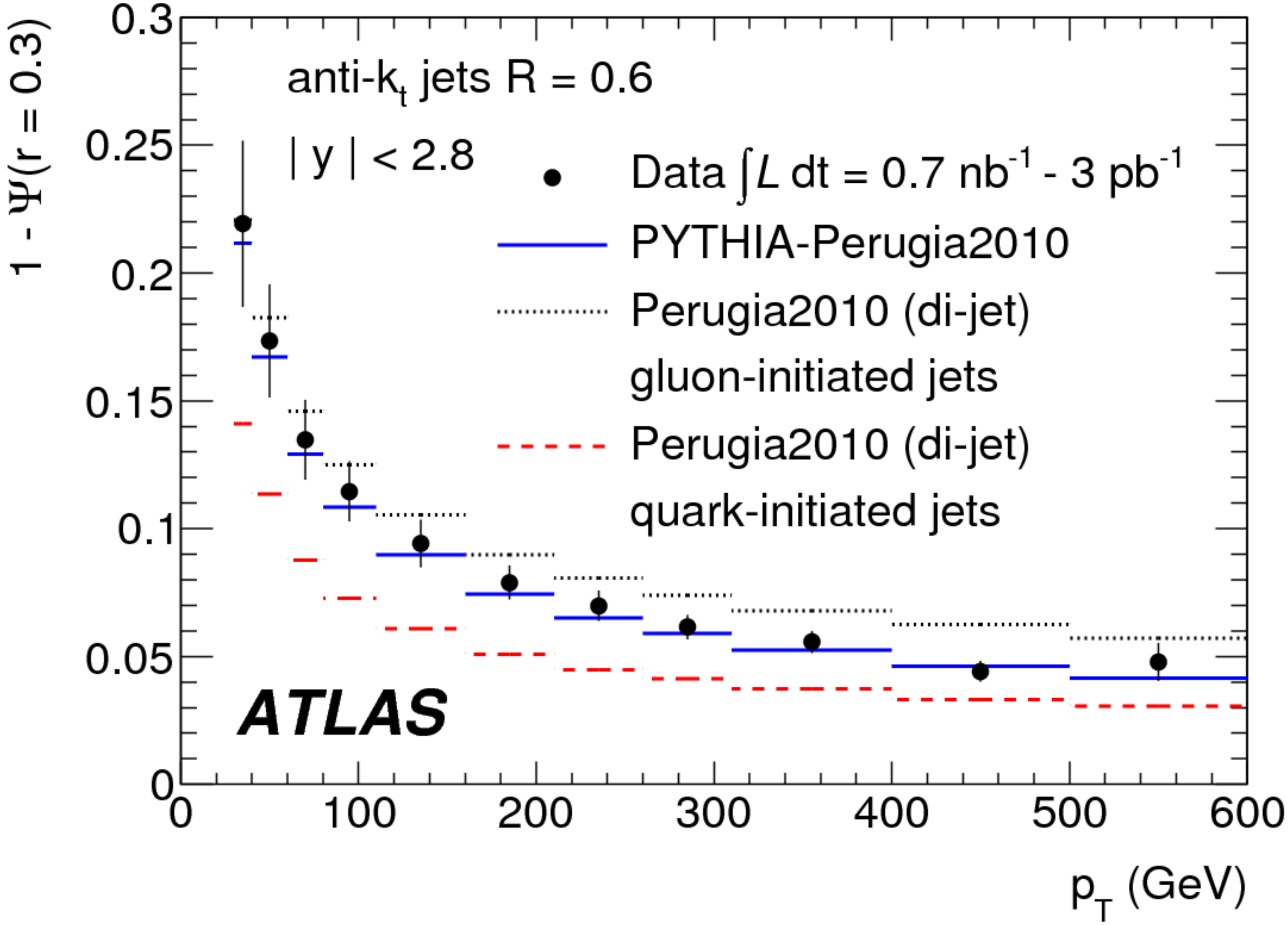
$1-\Psi(r=0.3)$

- Also compare different Pythia tunes



Jet shapes

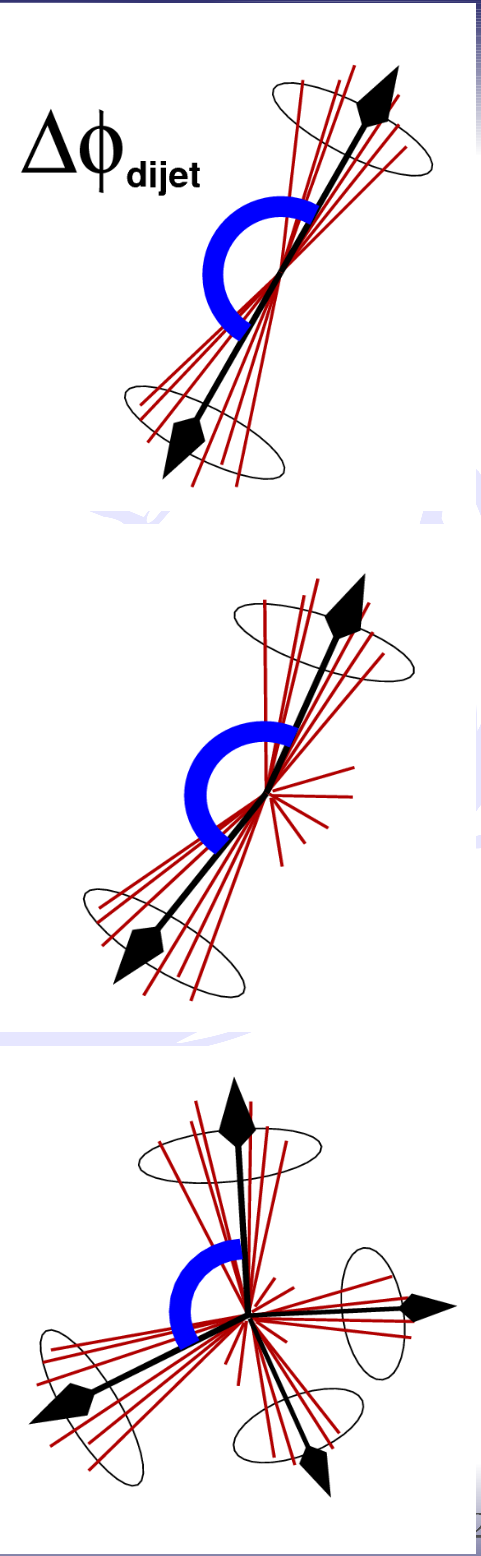
- Separate MC predictions for quark/gluon jets



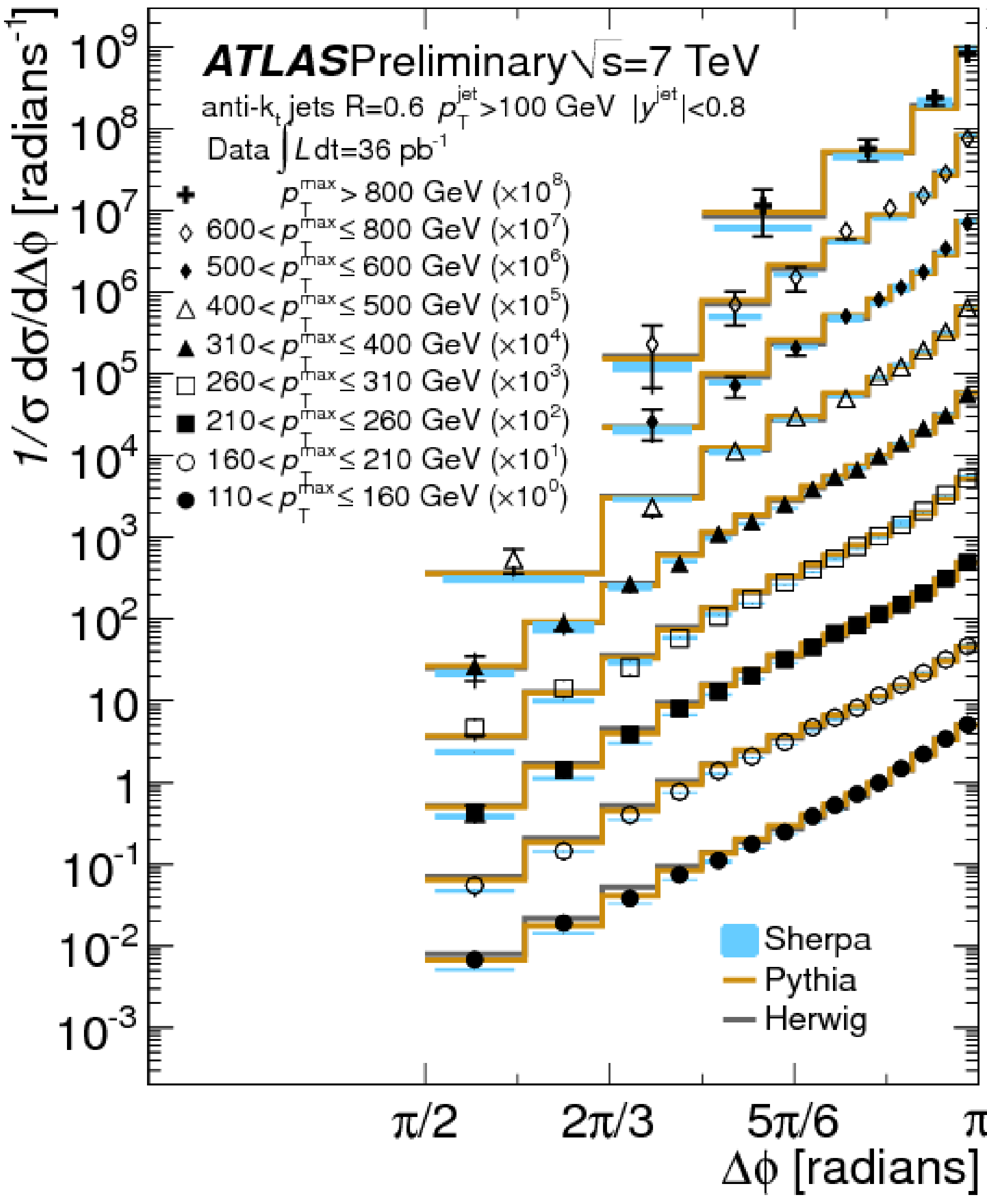
Azimuthal decorrelation

[hep-ex]1102.2696
(submitted to PRL)

- Measured with all 2010 data, L=36pb^{-1}
- Measure $\Delta\phi$ between 2 leading jets
- $\Delta\phi$ distributions depends on jet multiplicity
- Good handle on pQCD predictions
- Jets selections
  - Leading jets : p_{T1} > 110GeV , $|y_1|,|y_2|<0.8$
  - Others : p_T>100GeV, $|y|<2.8$
- Main systematics (depending on $\Delta\phi$ bin)
  - JES : 2 to 17%
  - Unfolding : 1 to 19%
  - Pile-up : 0.8% max

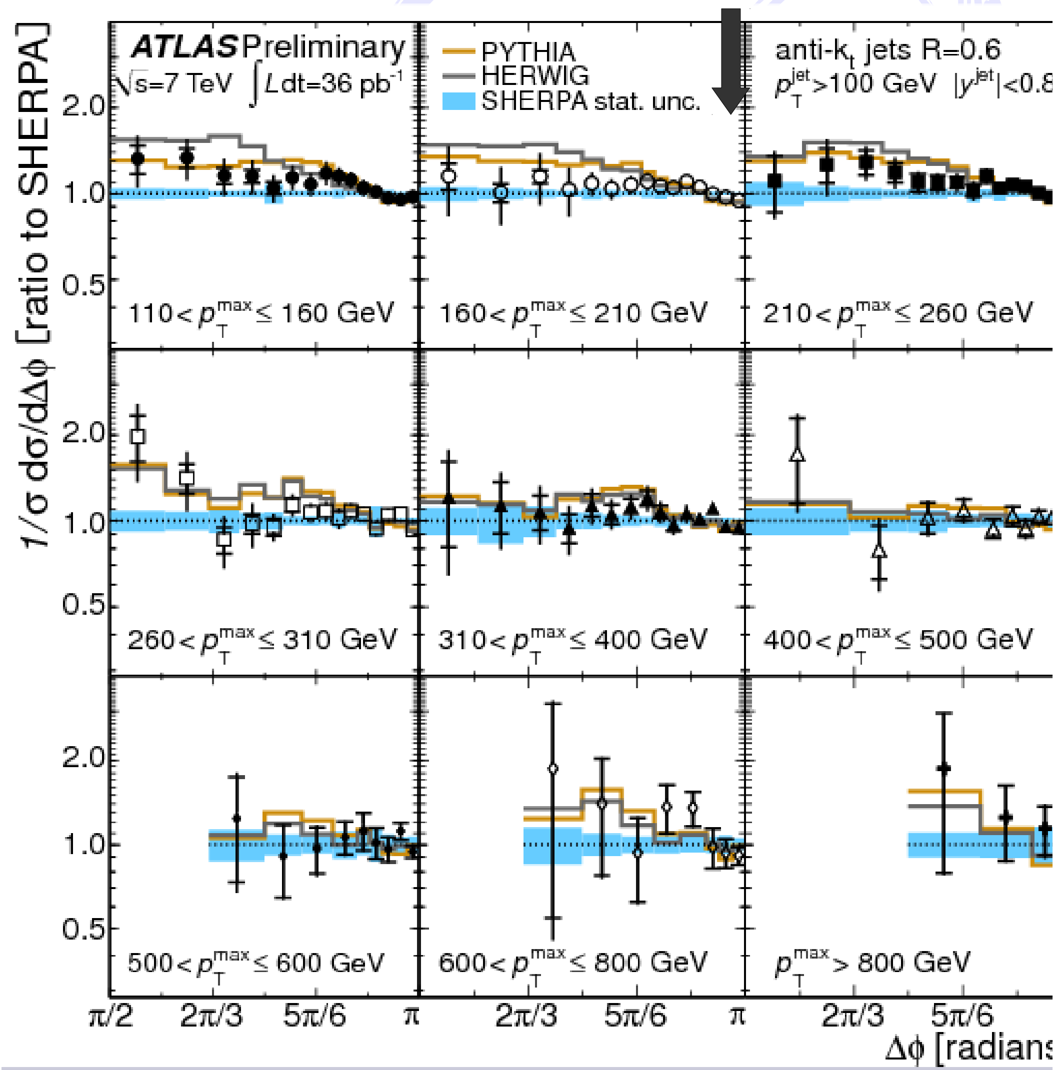


Azimuthal decorrelation

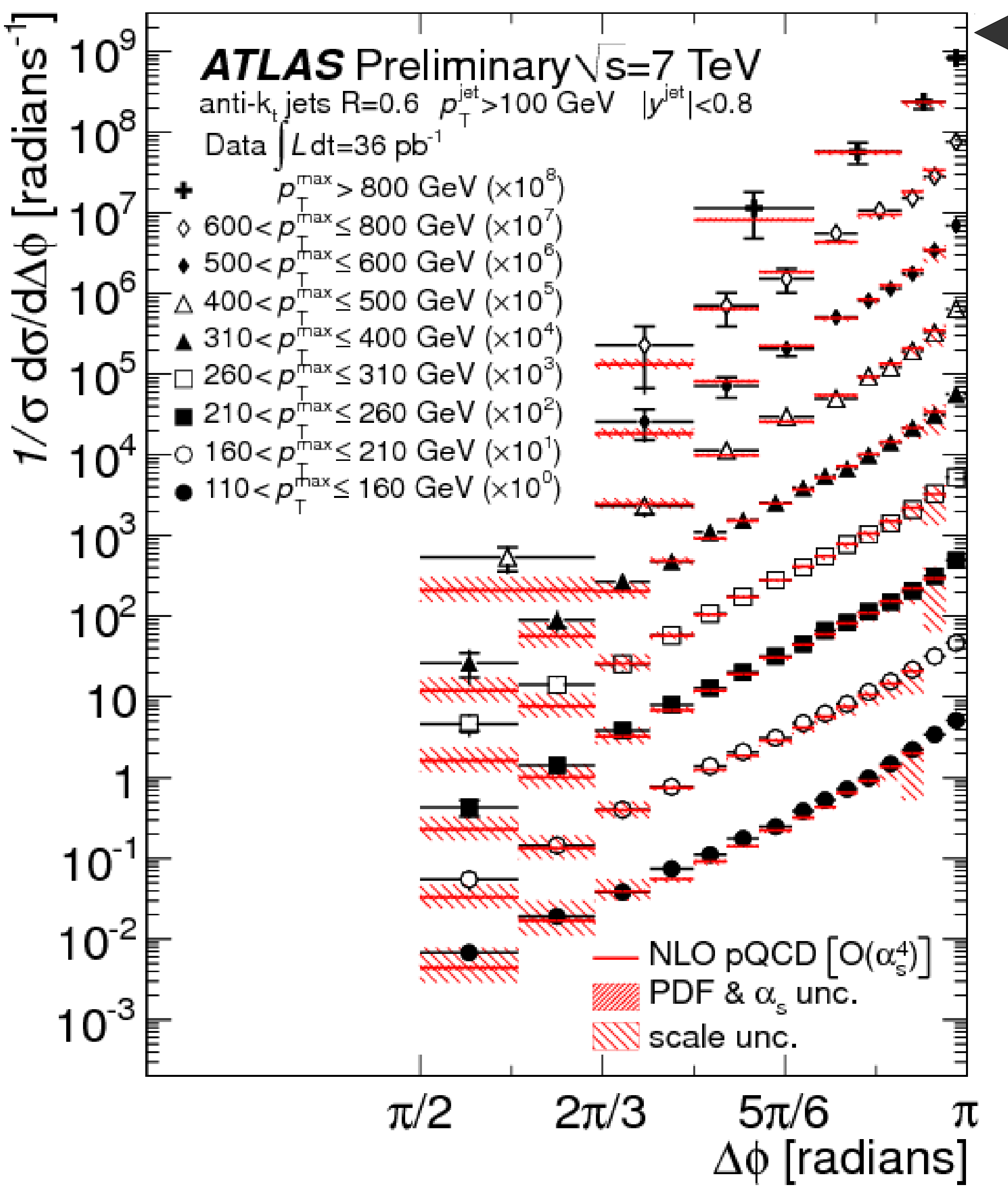


Normalized differential cross-sections

Ratio vs SHERPA

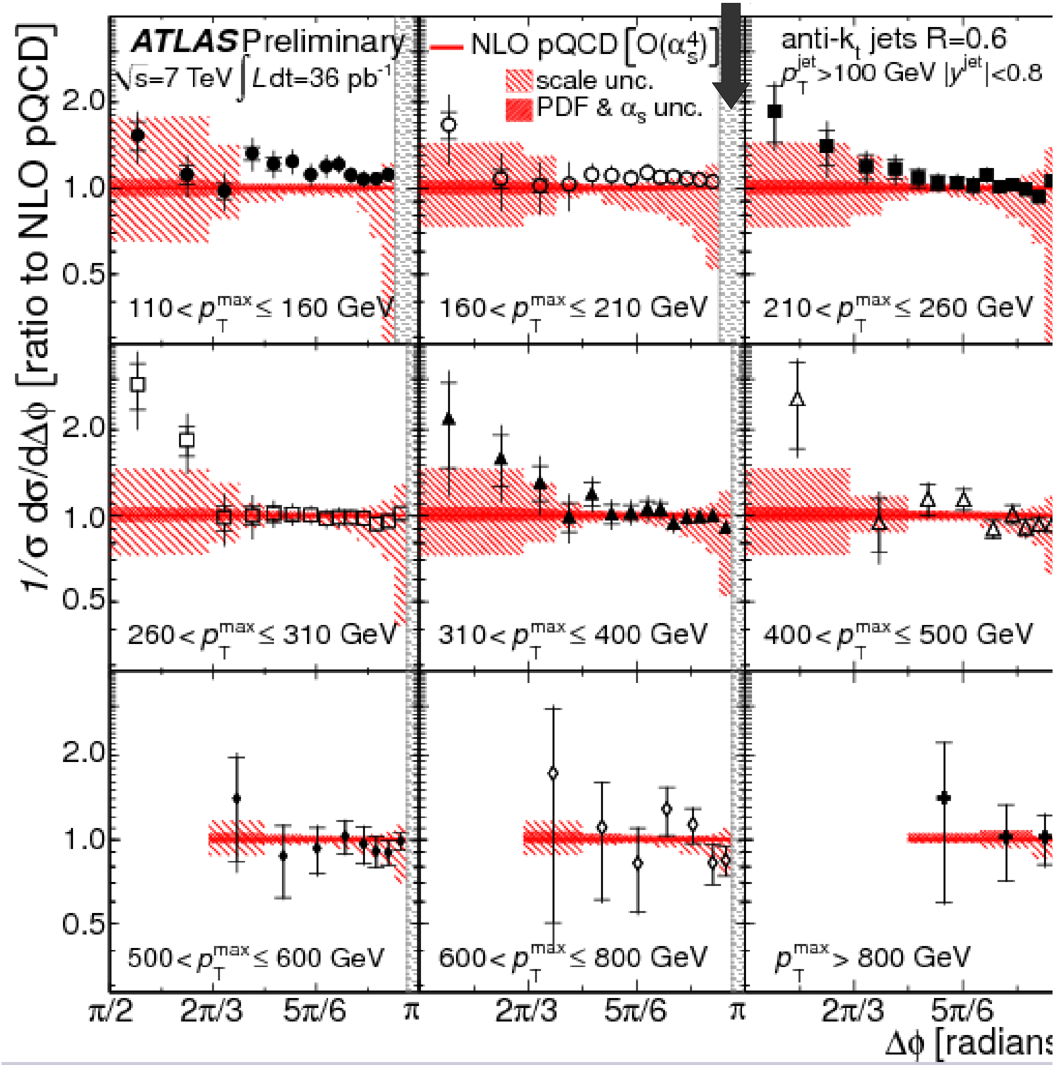


Azimuthal decorrelation



Normalized differential cross-sections

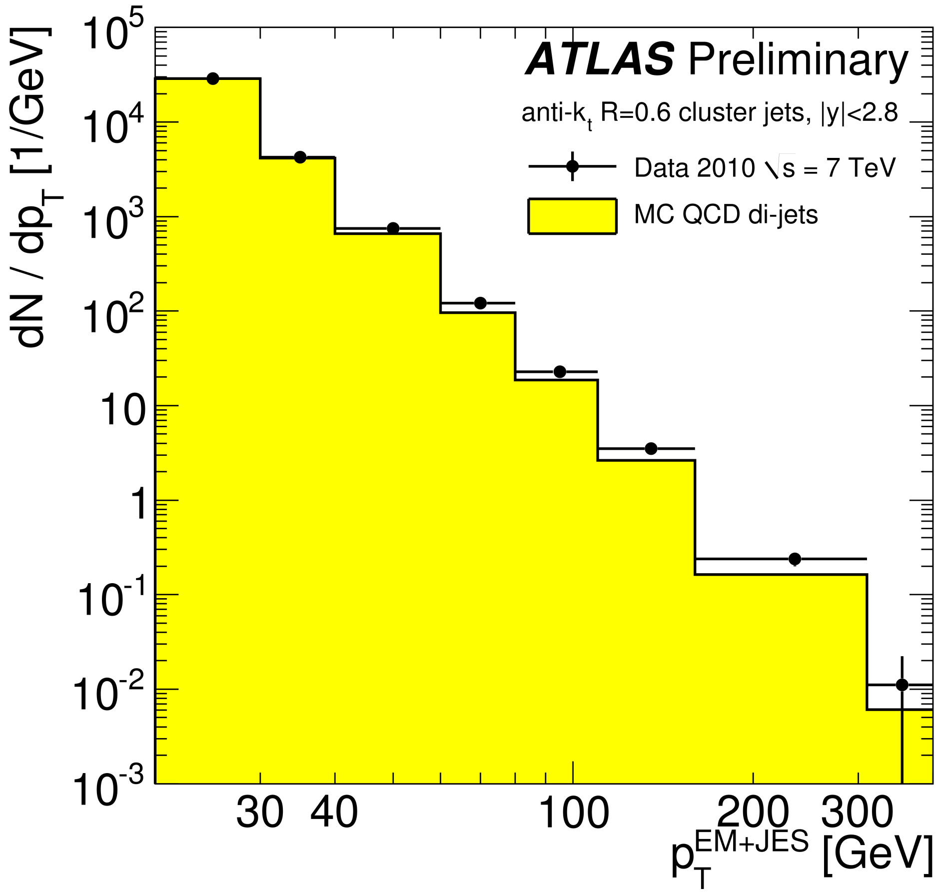
Ratio Data/theory



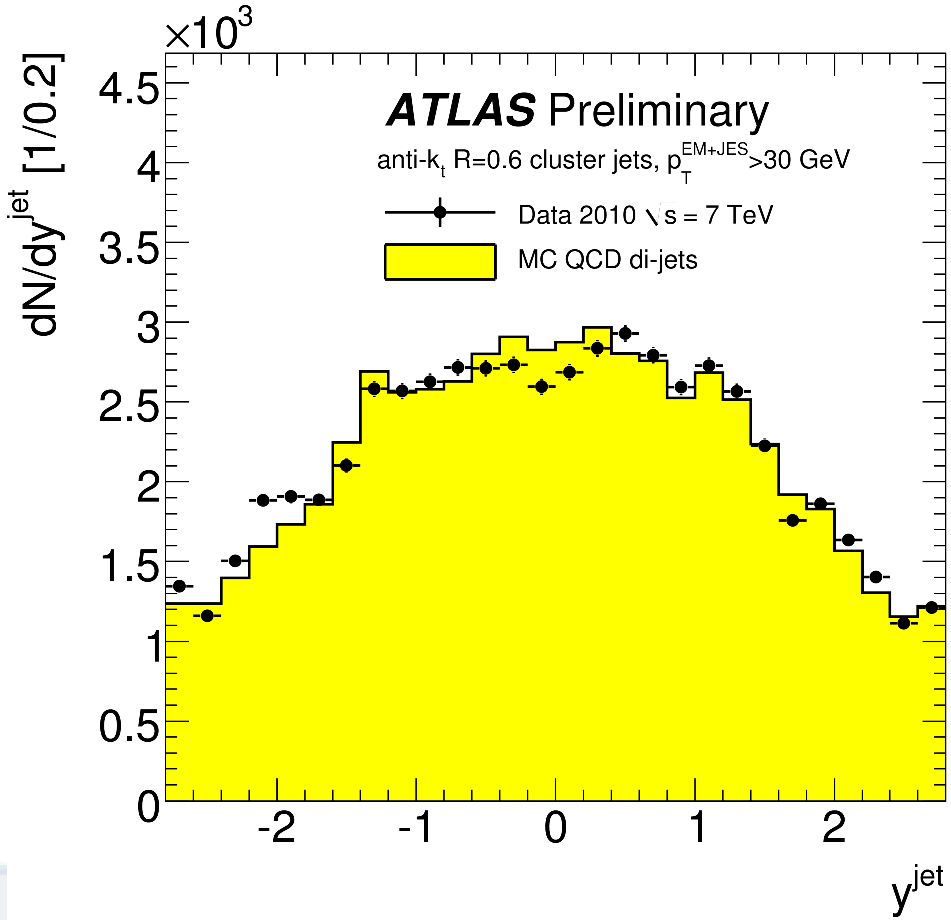
Conclusions

- First high pT jets analysis with early data
  - Limited statistics
    - Already exceeding some Tevatron results (di-jet xsection up to m=1.8TeV)
  - Overall good agreement between Data and theory
  - Helps estimations of SM backgrounds to new physics
- Understanding of detector is improving quickly
- Expect significant updates of analysis soon
  - Full 2010 data (~35pb^{-1}, scale stats by 100-1000)
  - Better control of systematics (JES)
  - Refined analysis

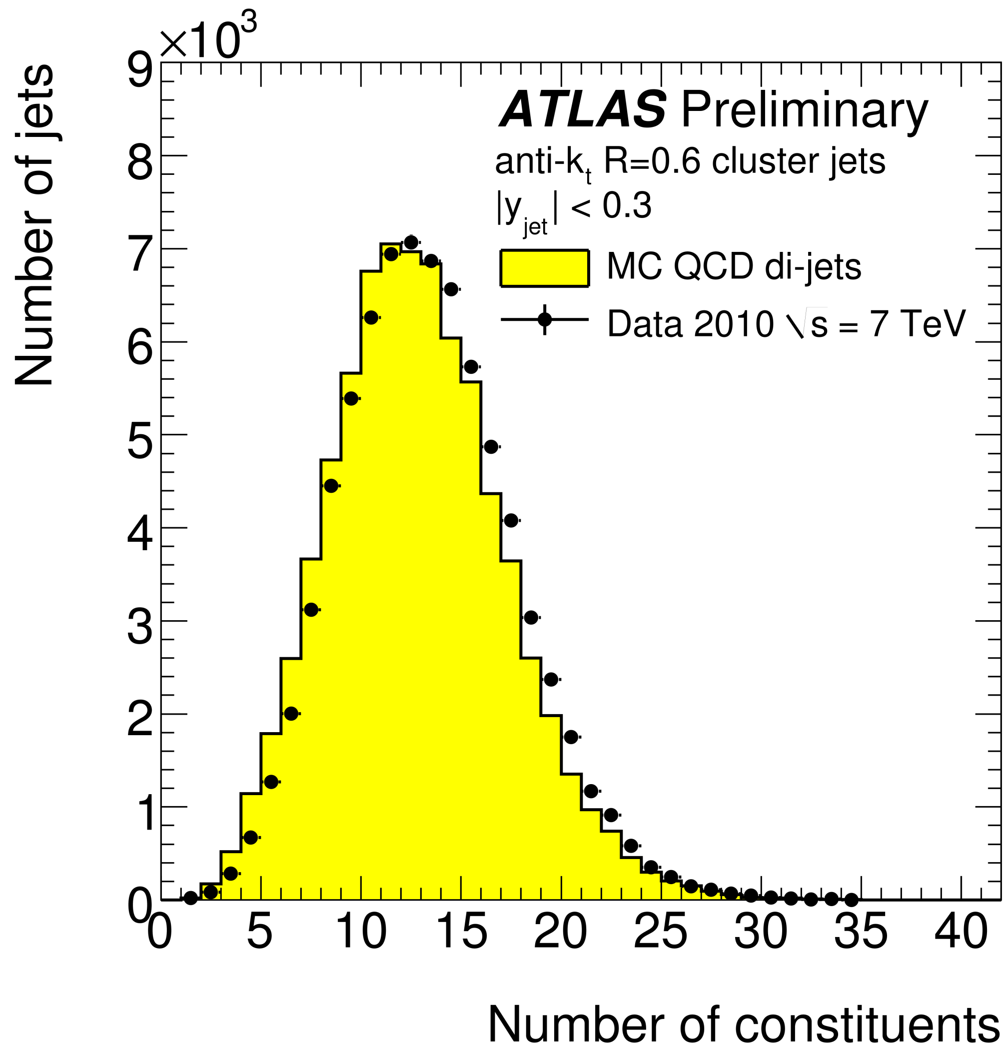
Backup slides



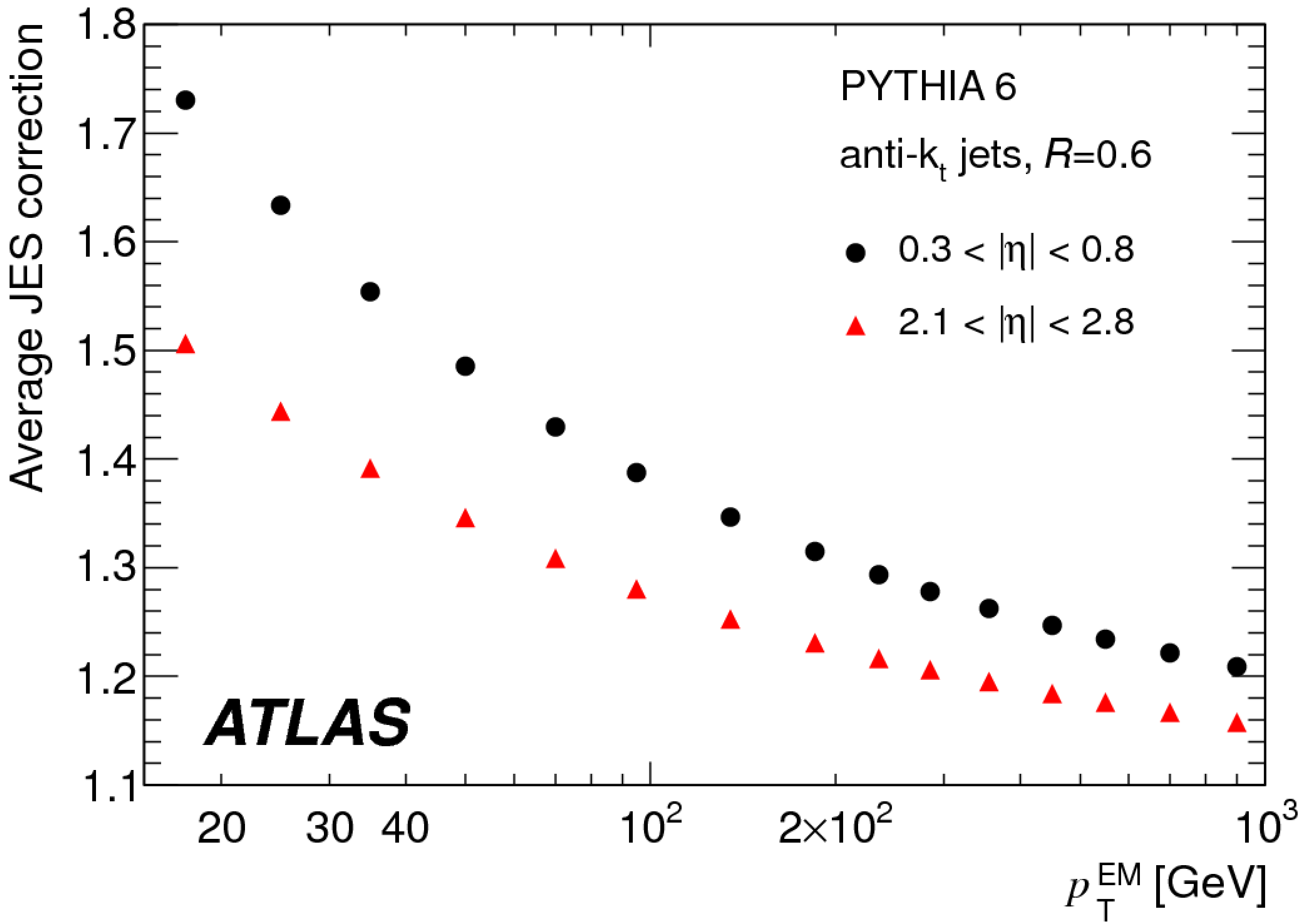
ATLAS Preliminary
anti-k$_t$ R=0.6 cluster jets, |y|<2.8
Data 2010 √s = 7 TeV
MC QCD di-jets
dN / dp$_T$ [1/GeV]
p$_T^{EM+JES}$ [GeV]



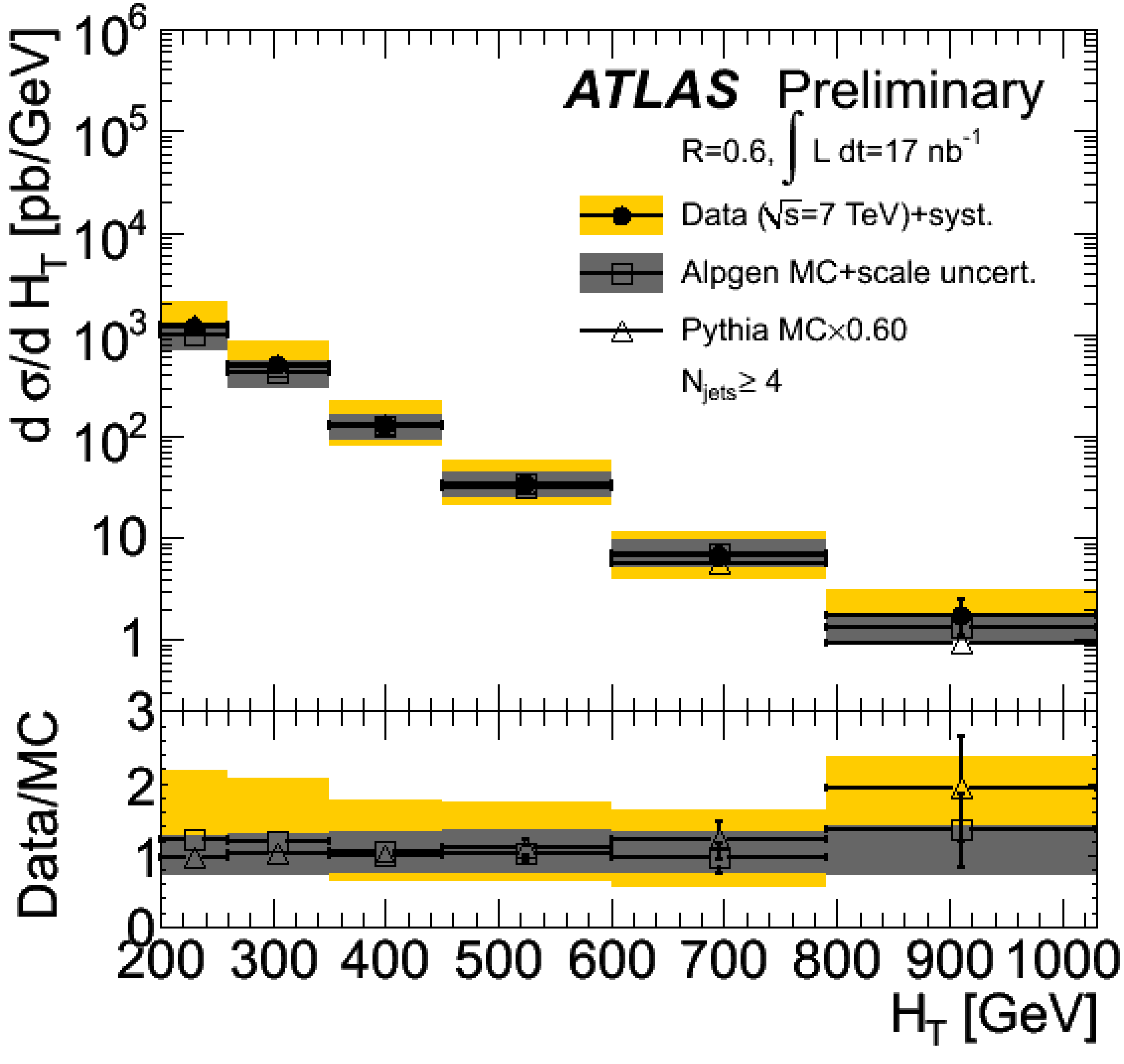
ATLAS Preliminary
anti-k$_t$ R=0.6 cluster jets, p$_T^{EM+JES}$>30 GeV
Data 2010 √s = 7 TeV
MC QCD di-jets
dN/dy^{jet} [1/0.2]
y^{jet}



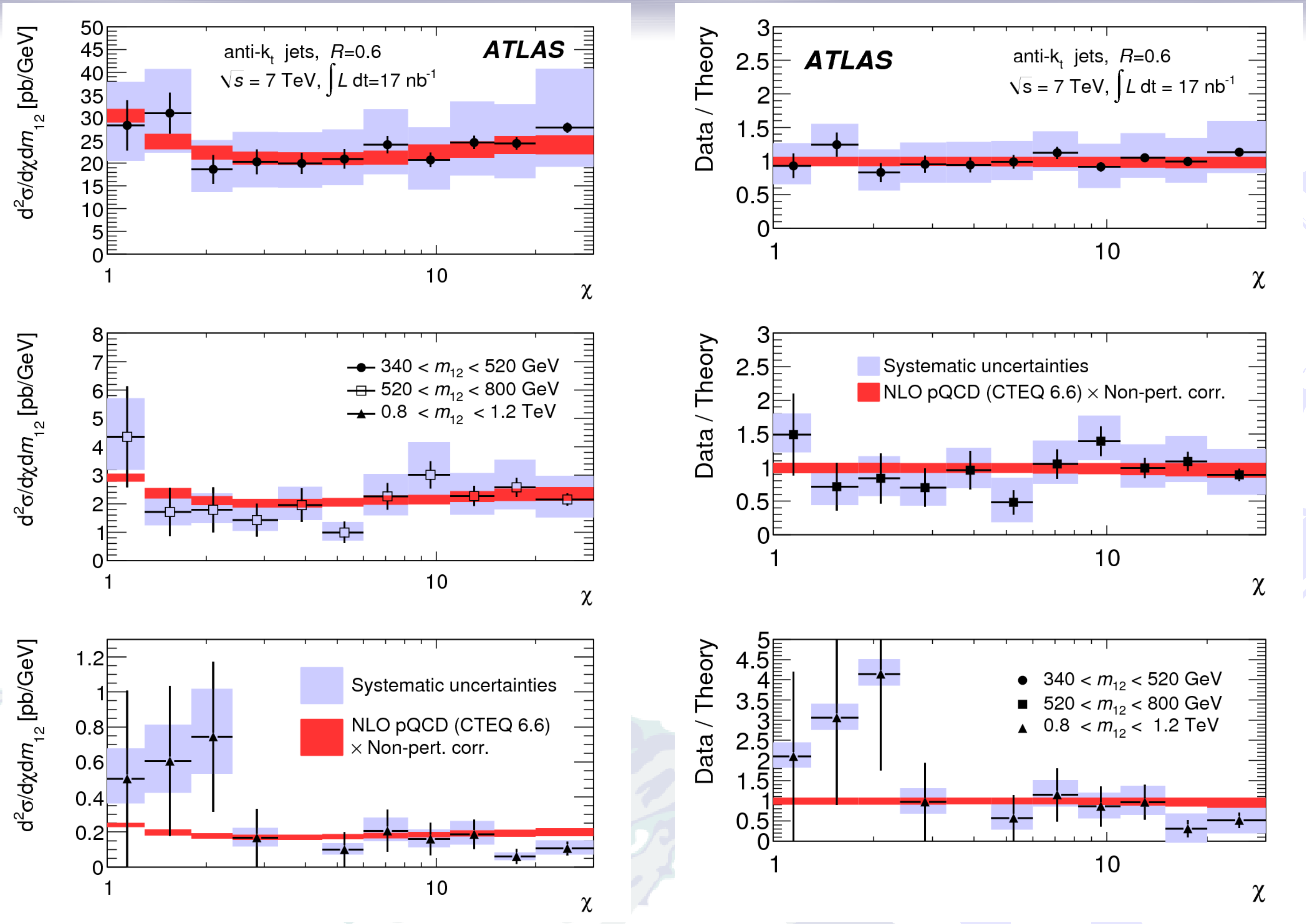
ATLAS Preliminary
anti-k$_t$ R=0.6 cluster jets
$|y_{jet}| < 0.3$
MC QCD di-jets
Data 2010 $\sqrt{s}$ = 7 TeV
Number of jets
$\times 10^3$
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
35
40
Number of constituents



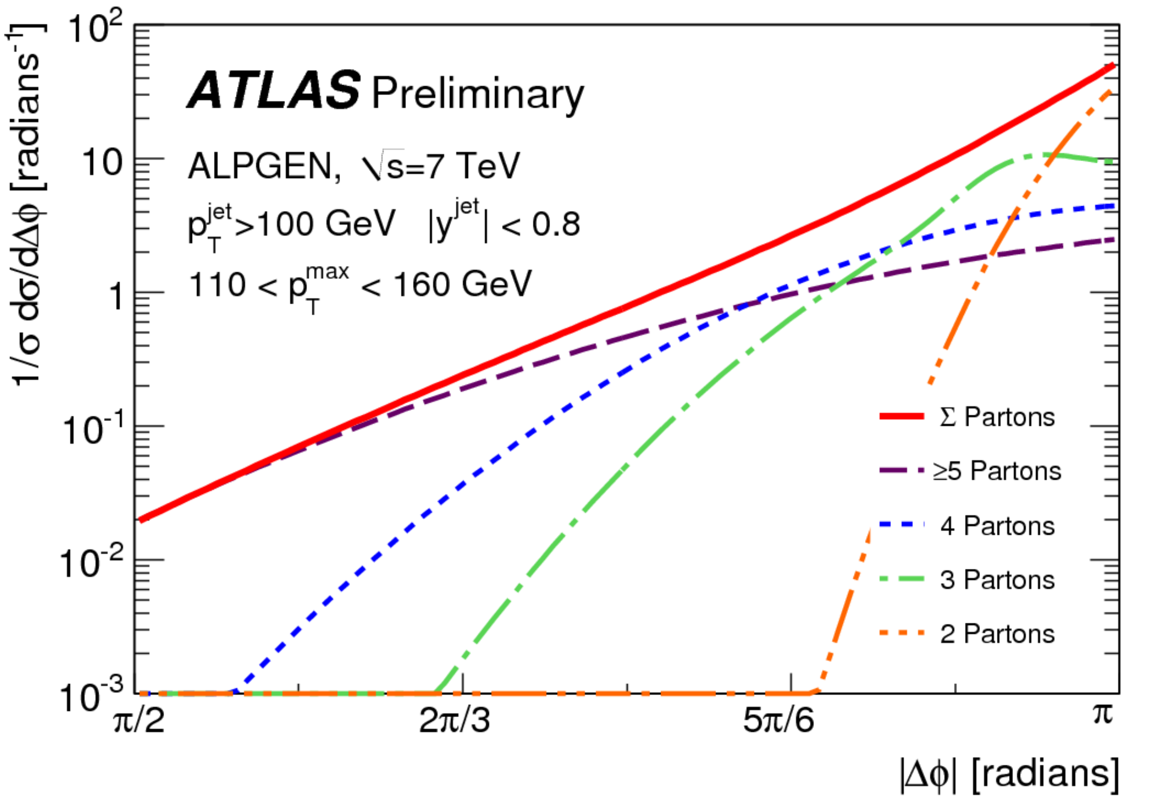
Average JES correction
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
PYTHIA 6
anti-k$_t$ jets, R=0.6
0.3 < |η| < 0.8
2.1 < |η| < 2.8
ATLAS
20
30
40
10^2
2×10^2
10^3
p_T^{EM} [GeV]

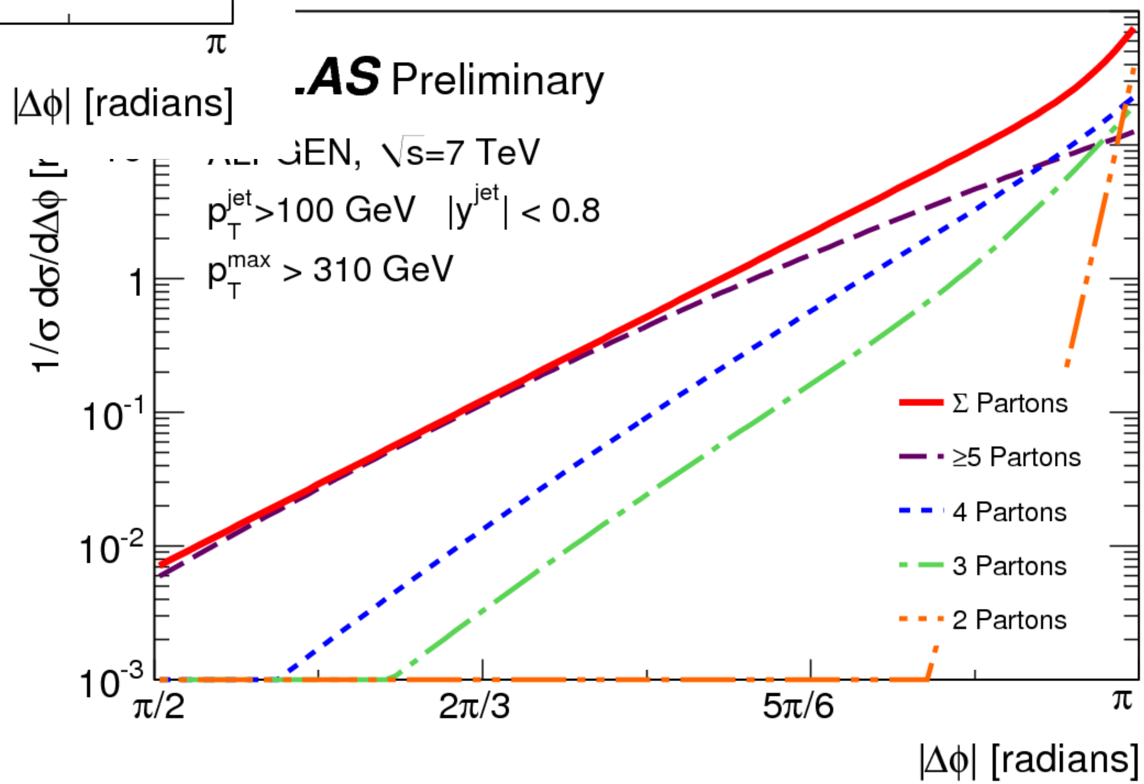


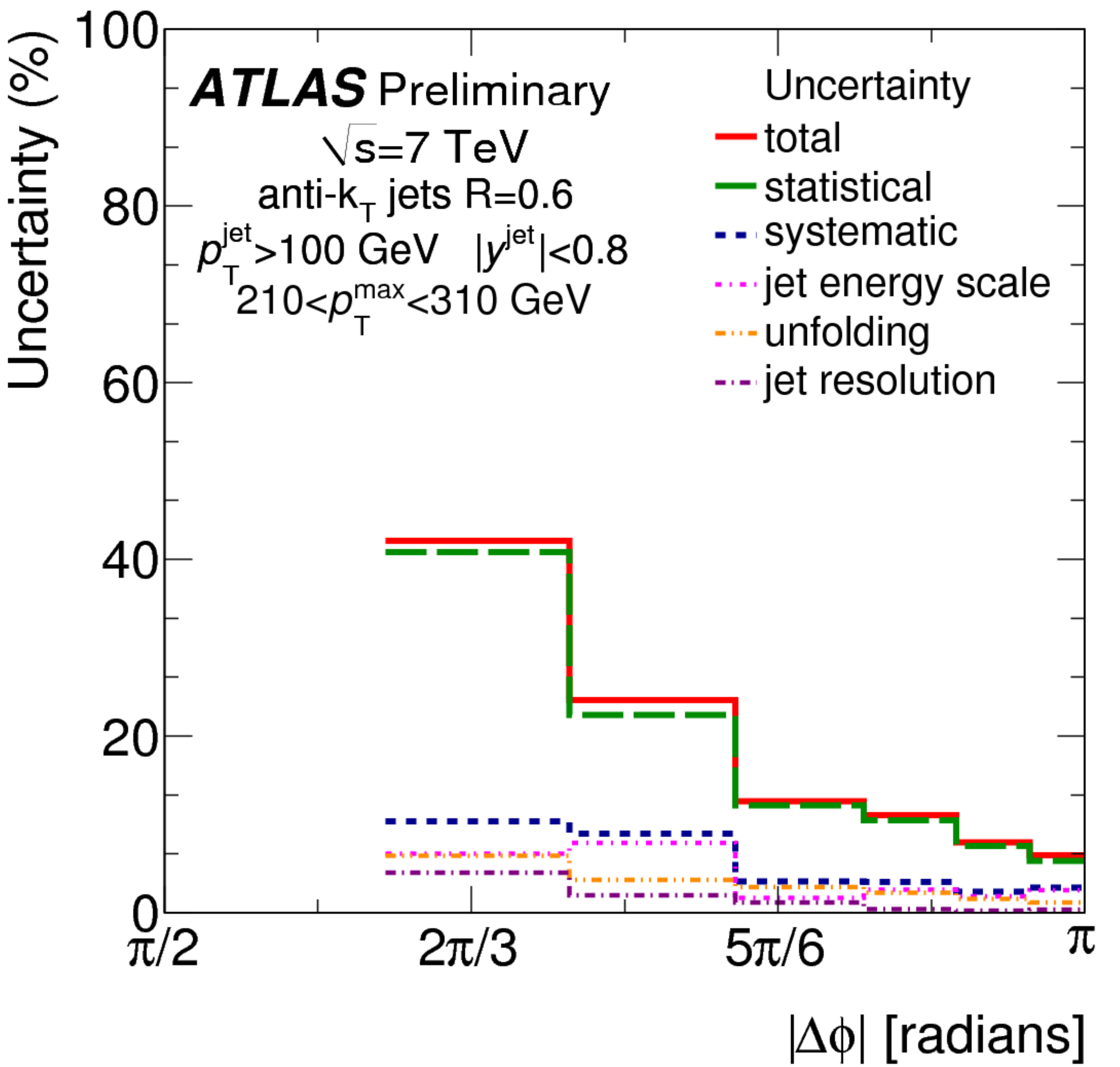
ATLAS Preliminary
R=0.6, $\int L\,dt$=17 nb^{-1}
Data ($\sqrt{s}$=7 TeV)+syst.
Alpgen MC+scale uncert.
Pythia MC×0.60
$N_{jets} \geq 4$
d σ/d H_T [pb/GeV]
Data/MC
H_T [GeV]
200 300 400 500 600 700 800 900 1000



ATLAS
anti-k$_t$ jets, R=0.6
$\sqrt{s}$ = 7 TeV, $\int L$ dt=17 nb^{-1}
$d^2\sigma/d\chi dm_{12}$ [pb/GeV]
Data / Theory
χ
340 < m_{12} < 520 GeV
520 < m_{12} < 800 GeV
0.8 < m_{12} < 1.2 TeV
Systematic uncertainties
NLO pQCD (CTEQ 6.6) × Non-pert. corr.


ATLAS Preliminary
ALPGEN, √s=7 TeV
p_T^{jet}>100 GeV |y^{jet}| < 0.8
110 < p_T^{max} < 160 GeV
Σ Partons
≥5 Partons
4 Partons
3 Partons
2 Partons
1/σ dσ/dΔϕ [radians^{-1}]
|Δϕ| [radians]
π/2
2π/3
5π/6
π


.AS Preliminary
GEN, √s=7 TeV
p_T^{jet}>100 GeV |y^{jet}| < 0.8
p_T^{max} > 310 GeV
Σ Partons
≥5 Partons
4 Partons
3 Partons
2 Partons
1/σ dσ/dΔϕ
|Δϕ| [radians]
π/2
2π/3
5π/6
π



ATLAS Preliminary
$\sqrt{s}$=7 TeV
anti-k_T jets R=0.6
p_T^{jet}>100 GeV $|y^{jet}|$<0.8
210<p_T^{max}<310 GeV
Uncertainty
total
statistical
systematic
jet energy scale
unfolding
jet resolution
Uncertainty (%)
100
80
60
40
20
0
π/2
2π/3
5π/6
π
|Δφ| [radians]

A. Author1,
B. Author2