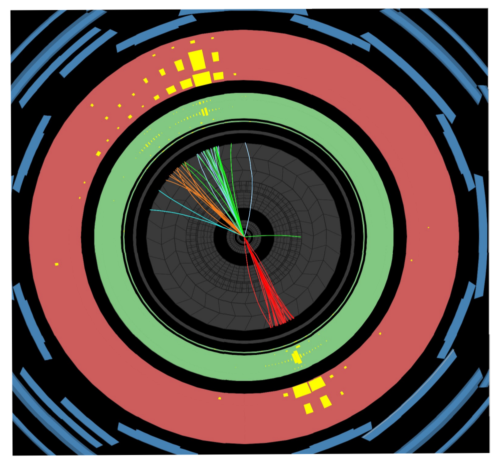
Measurement of jet production in proton-proton collisions at 7 TeV centre-of-mass energy with the Atlas detector

Tancredi Carli (CERN)
On behalf of the Atlas collaboration



All results are documented in:
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/
ATLAS-CONF-2010-050

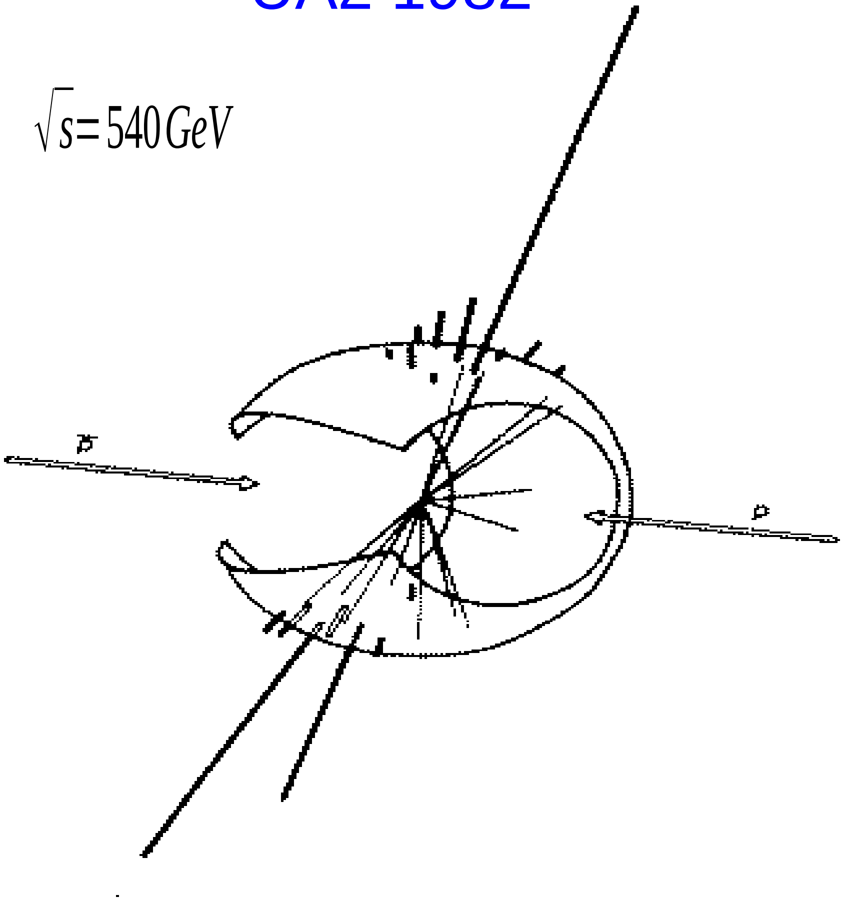
and performance studies in:
https://twiki.cern.ch/twiki/bin/view/Atlas/JetEtMissPublicCollisionResults
ATLAS-CONF-2010-052
ATLAS-CONF-2010-053
ATLAS-CONF-2010-054
ATLAS-CONF-2010-055
ATLAS-CONF-2010-056

Historical Remark

First convincing evidence for jet production has been presented at ICHEP in Paris 1982

UA2 1982

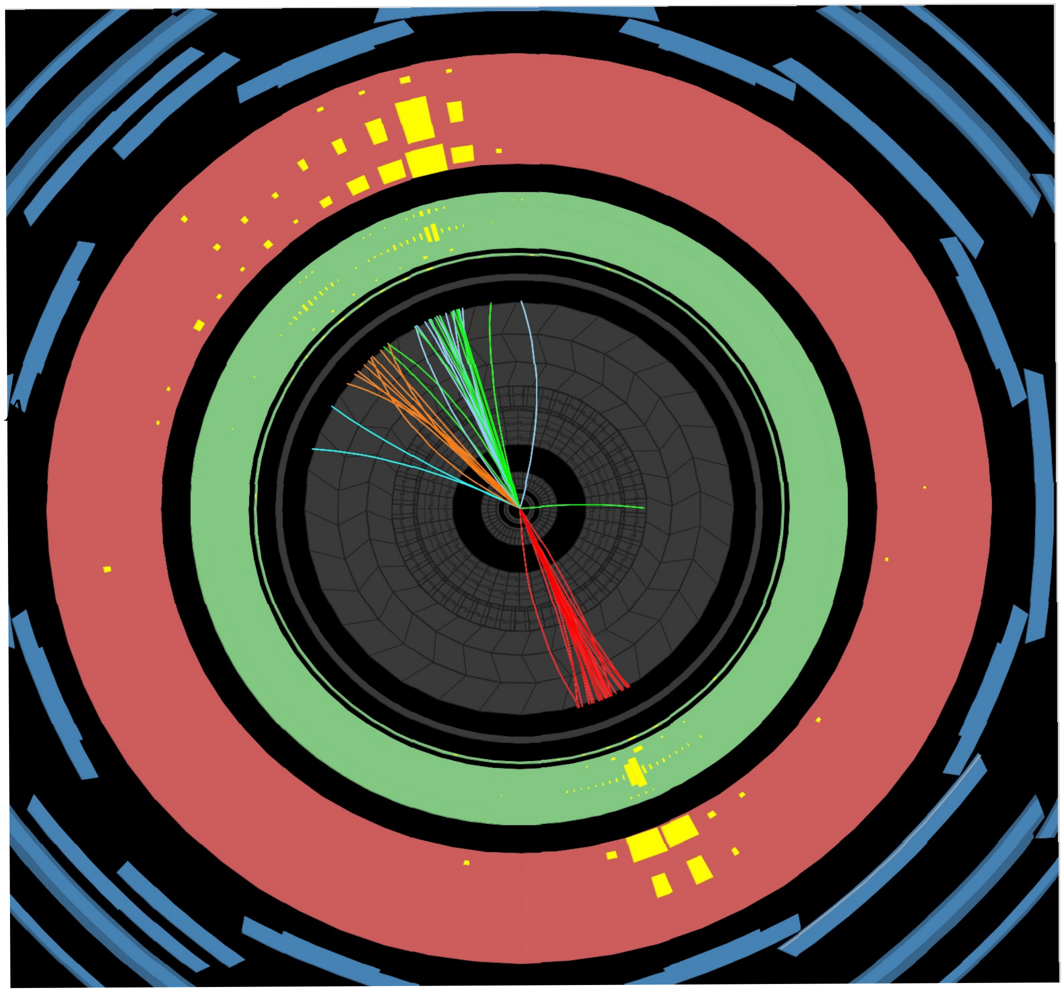
$\sqrt{s}=540\,GeV$



$P_{T,jet}$~60 GeV
$M_{1,2}$=140 GeV

Atlas 2010

$\sqrt{s}=7000\,GeV$



$P_{T,jet}$~800 GeV
$M_{1,2}$=2000 GeV

Definition of Observables

Data set:

March/April 2010 proton-proton collisions at 7 TeV with integrated luminosity about 17 nb^{-1}

Jet inputs:

Dynamically formed 3-d connected areas of energy depositions optimised for noise suppression and following the hadronic shower development (massless)

Anti-kt jet algorithm:

Infrared- and collinear jet algorithm clustering around hard objects producing geometrical well defined cone-like jets (experimentally friendly)

Resolution parameter is set to: R=0.4 or R=0.6

Jet selection:

Transverse momentum: $P_{T,jet} > 60$ GeV   Rapidity: $|y|<2.8$

Observables:

Inclusive jet cross-section: $d\sigma/d|y|dP_{T,jet}$

Di-jet cross-section: $d\sigma/ dM_{1,2}\, d|y_{max}|$

$M_{1,2}$ is invariant mass of first two leading jets with $P_{T,1} > 60$ GeV and $P_{T,2}>30$ GeV

$|y|_{max} = \max(|y|_1,|y|_2)$ with y_1 and y_2 rapidity of two leading jets

$d\sigma/d\chi\, dM_{1,2}$ with $\chi = \exp(|y1-y2|) \sim (1+\cos\theta^*)/(1-\cos\theta^*)$

Restricted to $y^* = 0.5\,|y_1-y_2|<0.5\log(30)$ and $y_{boost} = 0.5\,|y_1+y_2|<1.1$

Jet Calibration and Uncertainty

Jet calibration:

Simple $P_{T,jet}$ and y dependent correction applied to measured jets at the electro-magnetic scale.

Using particle level (truth) from Monte Carlo simulation as reference.

Jet energy scale uncertainty:

Evaluated using MC using various detector configurations, hadronic shower and physics models

Based on large test-beam experience.

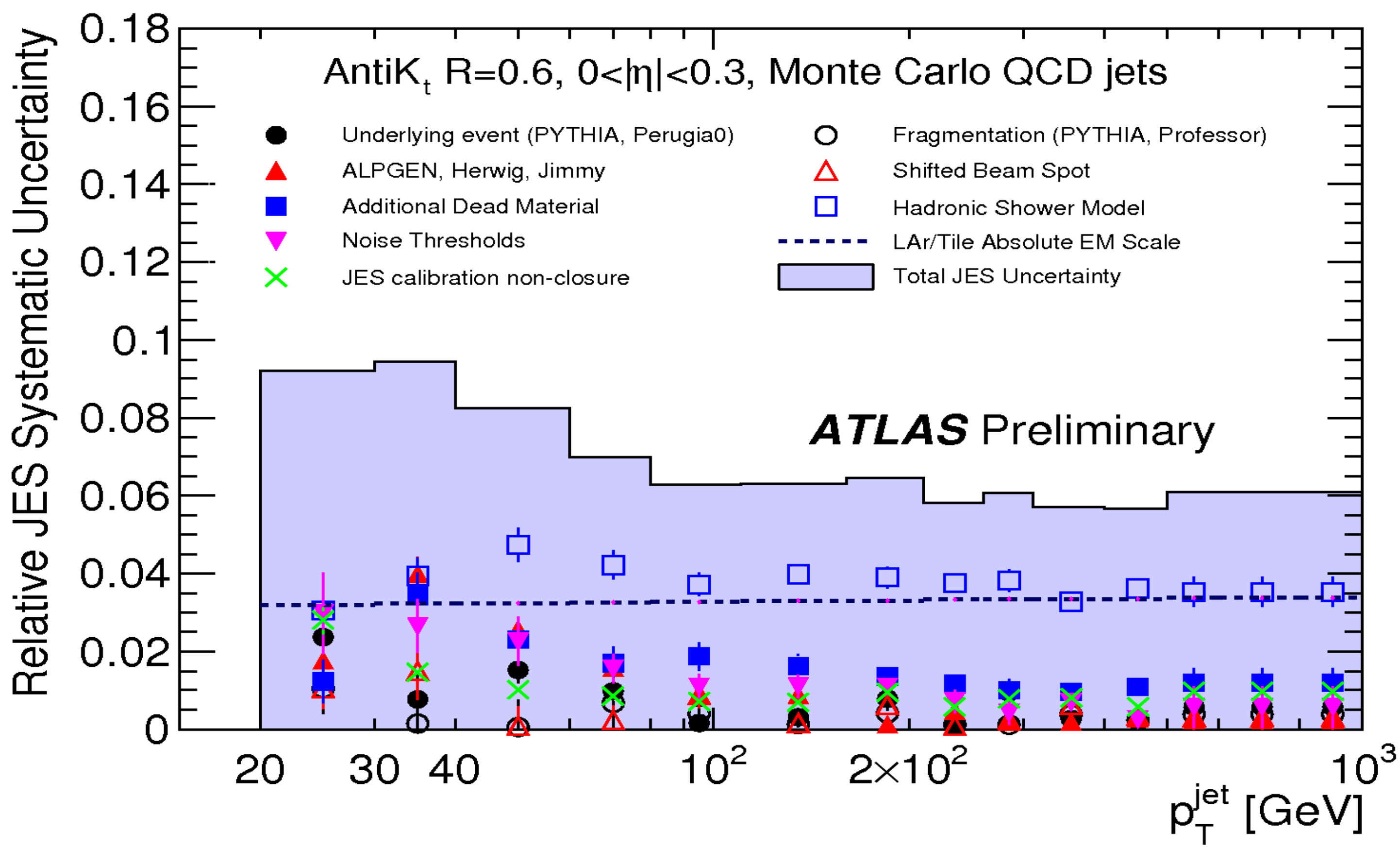
Example:

In-situ measurements:

1) Using Di-jet balance t
transport uncertainty
central -> forward

2) Additional uncertainty
for pile-up from averag
tower energy per verte

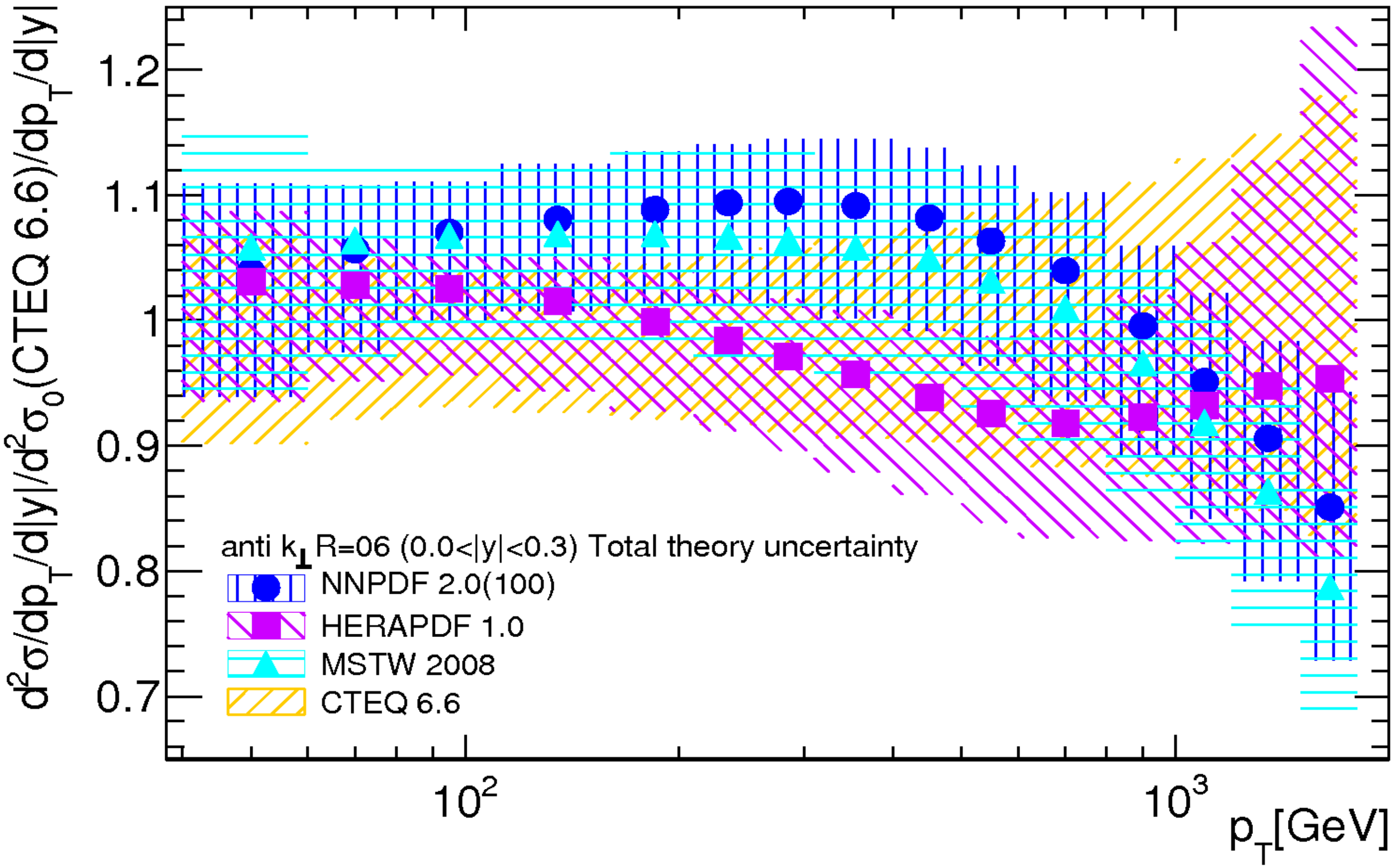
3) Cross-checked with
single isolated hadron
response measureme
(E_{calo}/p_{track})
Uncertainty via:
deconvolution of jets
in individual particles



Jet energy scale uncertainty smaller than 7% for $p_{t,jet}$>100 GeV

NLO QCD Theory Calculation

Perturbative Predictions:
NLO pQCD calculated with NLOJET++,
efficient uncertainty calculation using: APPLGRID
default PDF: CTEQ6.6 variations: HERAPDF, MSTW2008, NeuralNet-PDF
Leading jet Pt as renormalisation and factorisation scale, independently varied by factor of 2

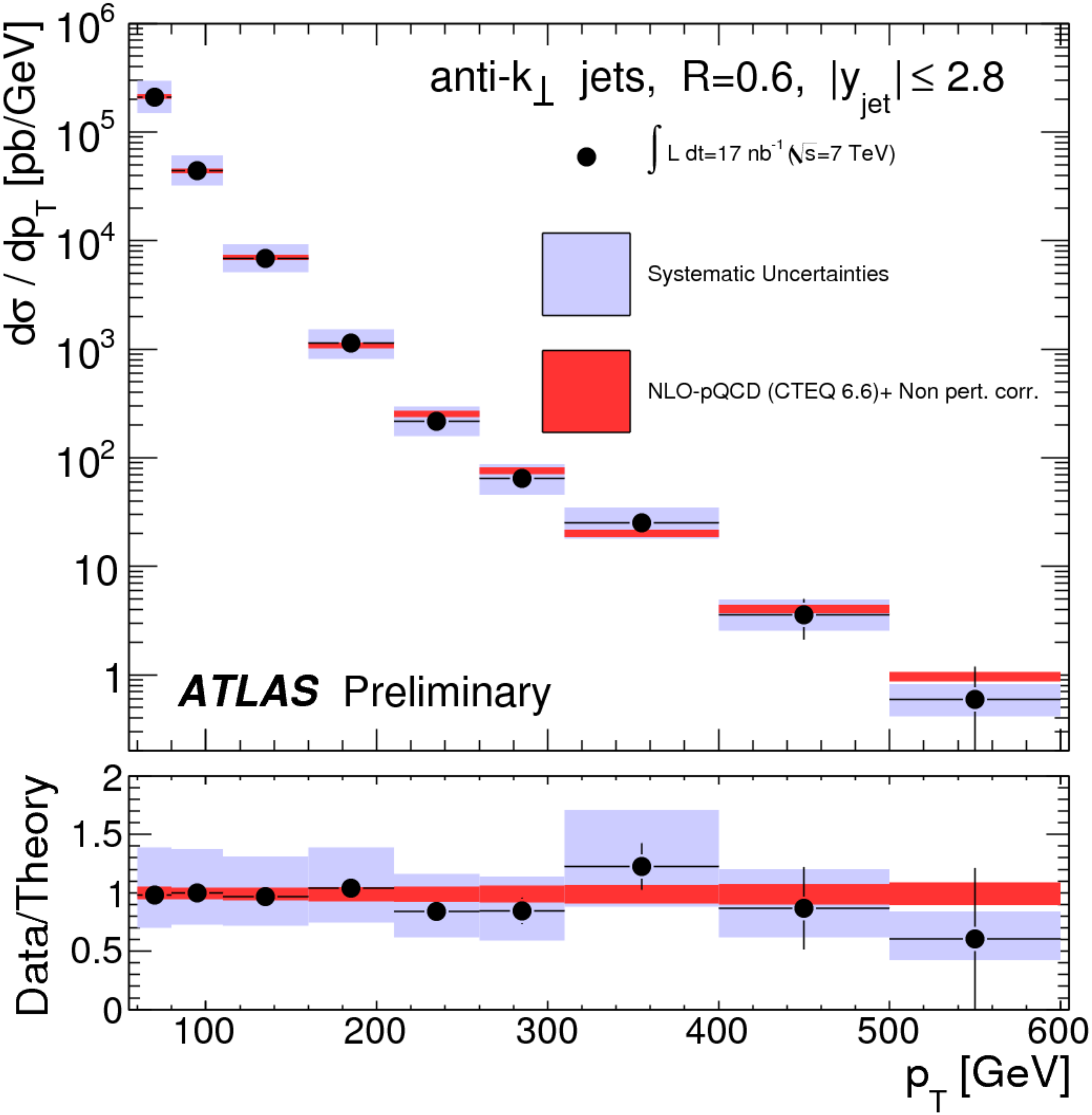


Theory uncertainty about 10% over measurable $P_{T,jet}$ range

Non-perturbative corrections: (hadronisation and underlying event):
Pythia using Atlas-MC09 tuning + various tunes and Herwig+Jimmy
Correction is: R=0.6: +10% R=0.4: -10% at $P_{T,jet}$ = 60 GeV
(using Rivet) small for $P_{T,jet}$>300 GeV

$$C = \frac{\sigma_{had.on,U.E.on}}{\sigma_{had.off,U.E.off}}$$

Measured Single Inclusive Jet Cross-section for R=0.6



$P_{T,jet}$ reach up to 600 GeV

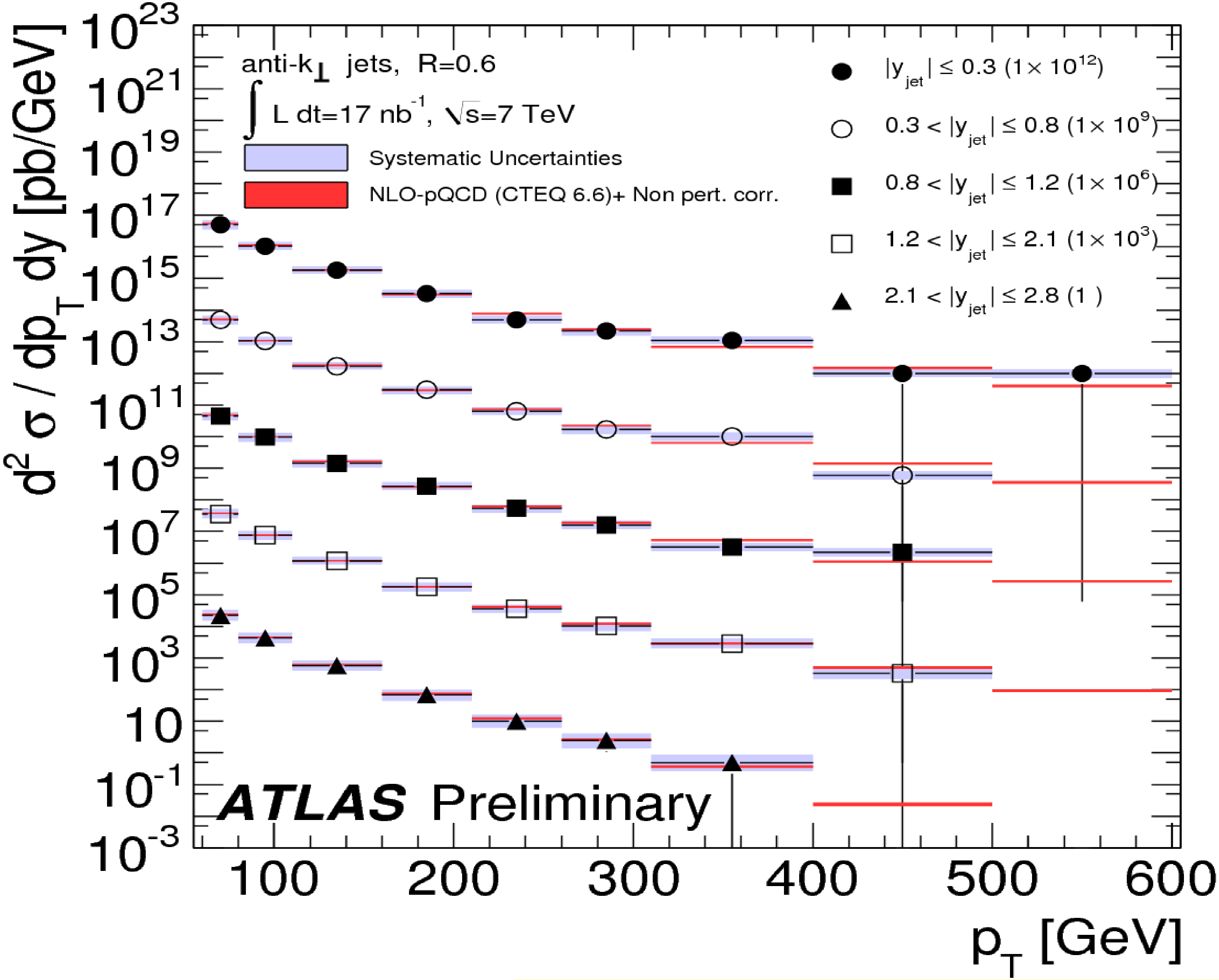
Similar $P_{T,jet}$ reach as latest Tevatron measurements

Data and theory are consistent

Uncertainty in data larger than in theory

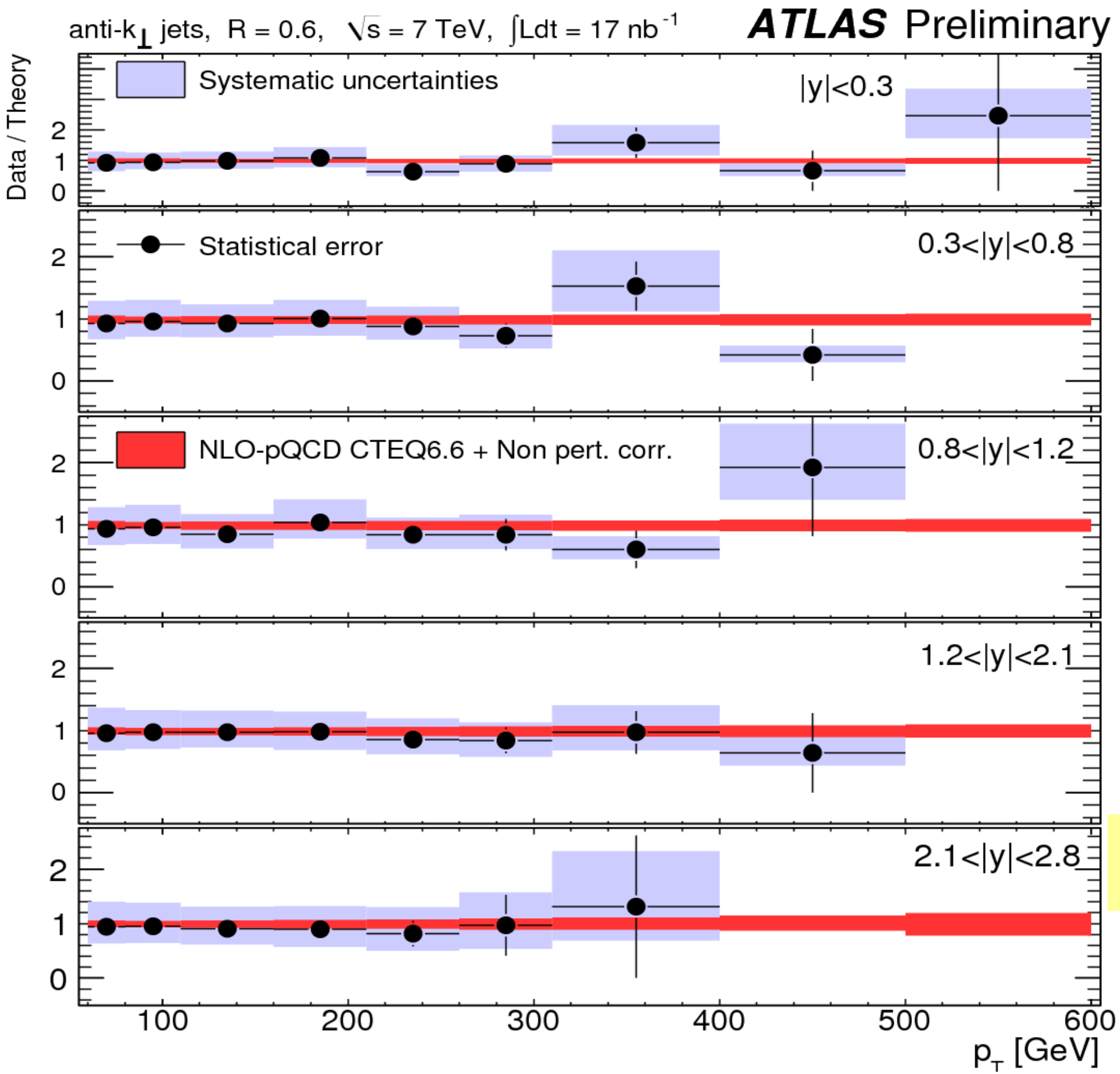
Dominated by jet energy scale

Measured Single Inclusive Jet Cross-section for R=0.6 in Rapidity Regions



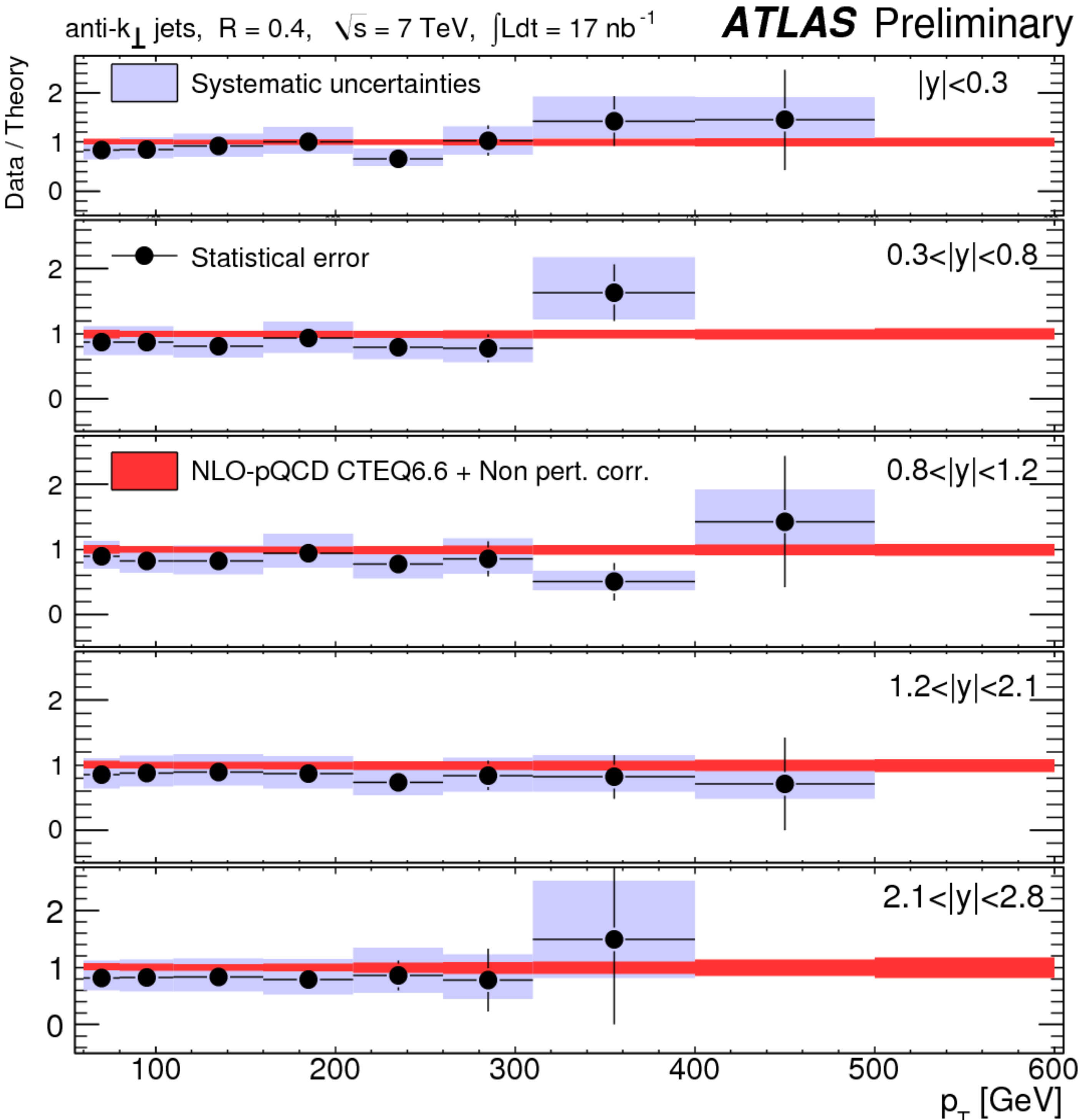
Data and theory are consistent in all rapidity regions

Data/Theory Inclusive Jet Cross-section for R=0.6 in Rapidity Regions



Data and theory consistent in all rapidity regions

Data/Theory Single Inclusive Jet Cross-section for R=0.4 Rapidity Regions



Measurement repeated for anti-kt jet algorithm with R=0.4

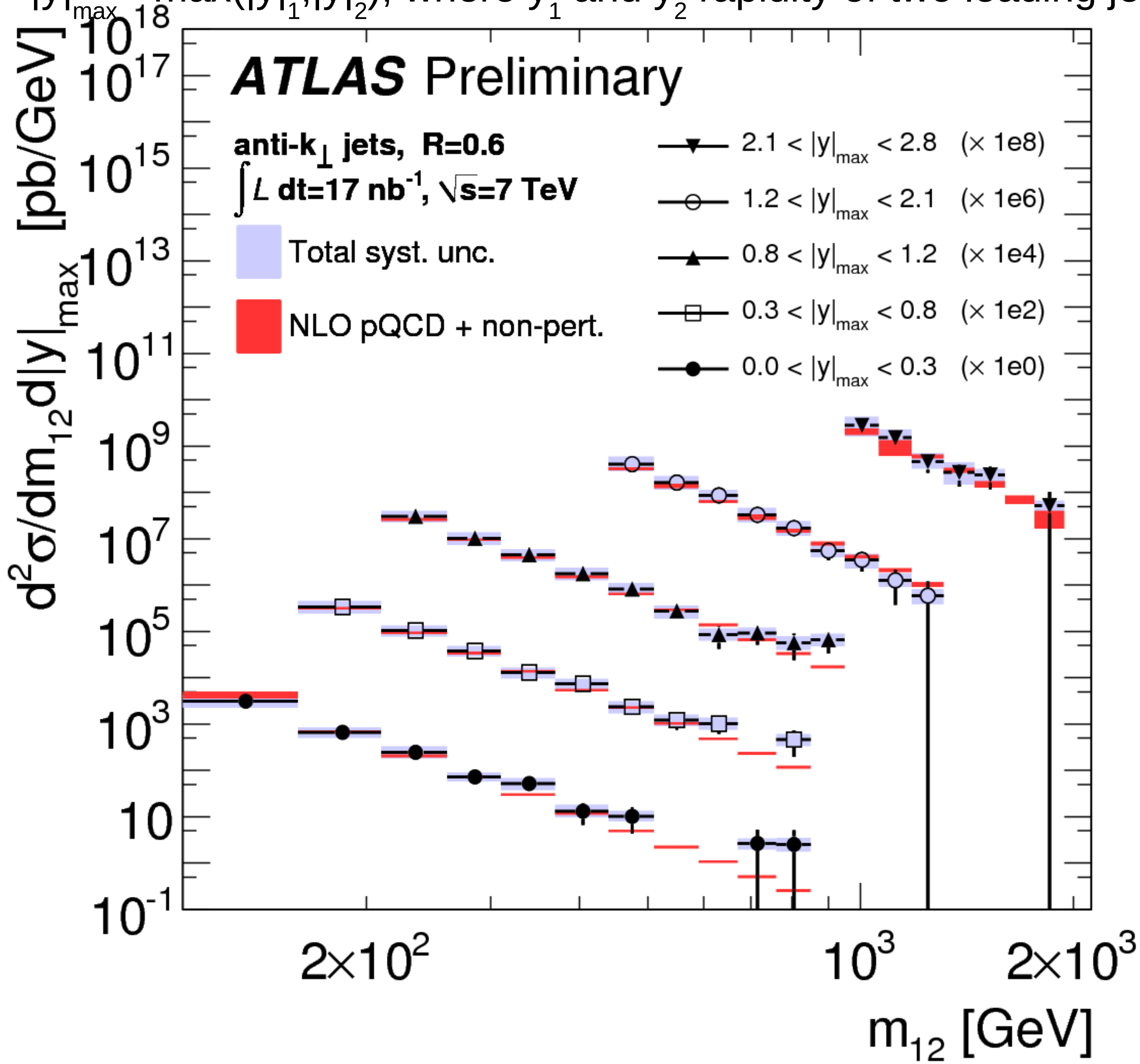
Data and theory consistent

R- dependence (~cone size) will be important handle on non-perturbative corrections

Di-jet Cross-section for R=0.6 as Function of Di-Jet Mass in Rapidity Bins

$M_{1,2}$ is invariant mass of first two leading jets with $P_{T,1}$> 60 GeV and $P_{T,2}$>30 GeV

$|y|_{max}$= max($|y|_1$,$|y|_2$), where y_1 and y_2 rapidity of two leading jets



Di-jet masses up to ~ 2 TeV !

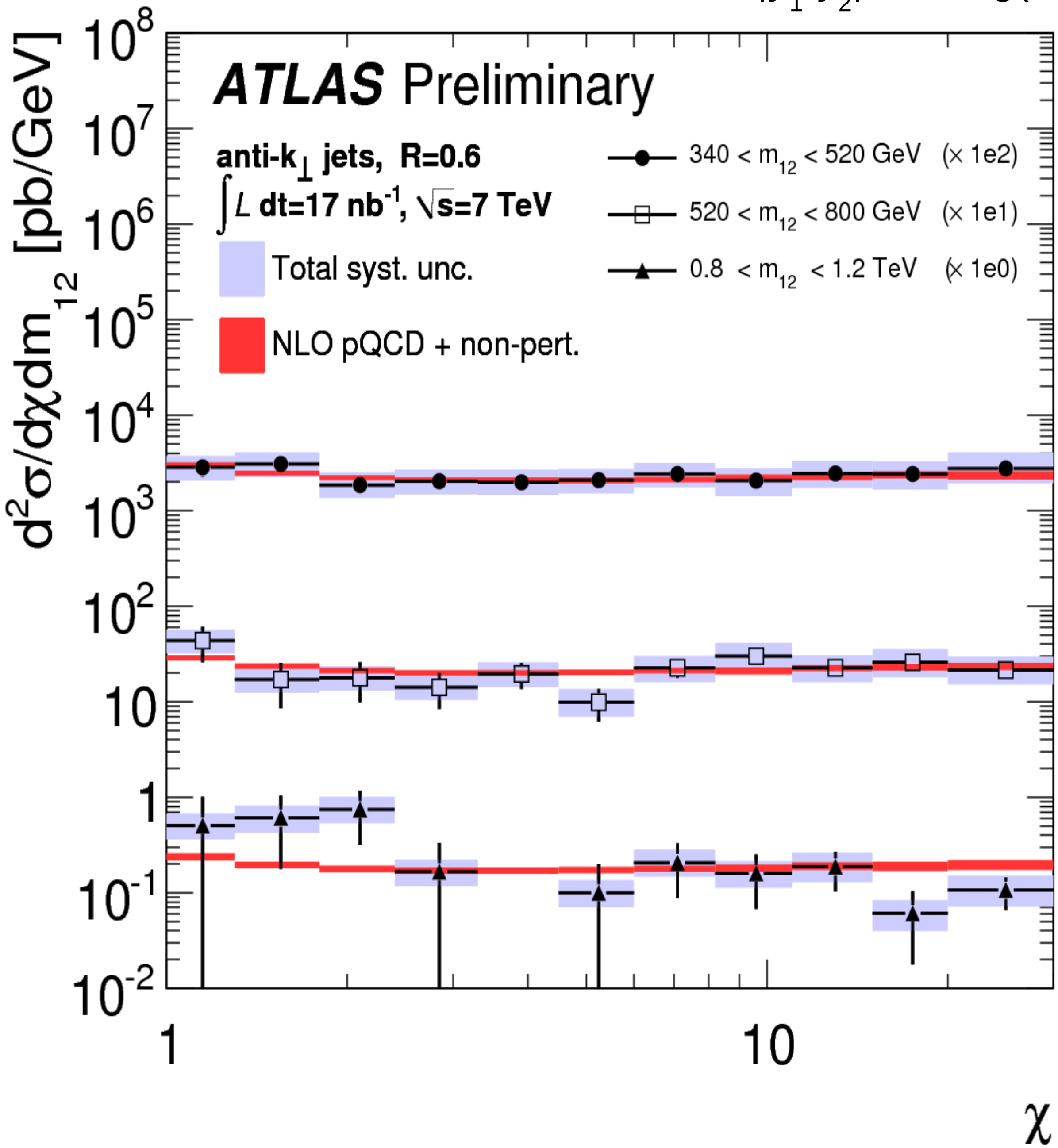
Overtaking Tevatron analysis in mass reach.

Data and theory consistent in all rapidity regions

Di-jet Cross-section for R=0.6 vs Jet Opening Angles in Mass Bins

$d\sigma/d\chi\, dM_{1,2}$ with $\chi = \exp(|y1-y2|) \sim (1+\cos\theta^*)/(1-\cos\theta^*)$, where θ^* angle in cm system

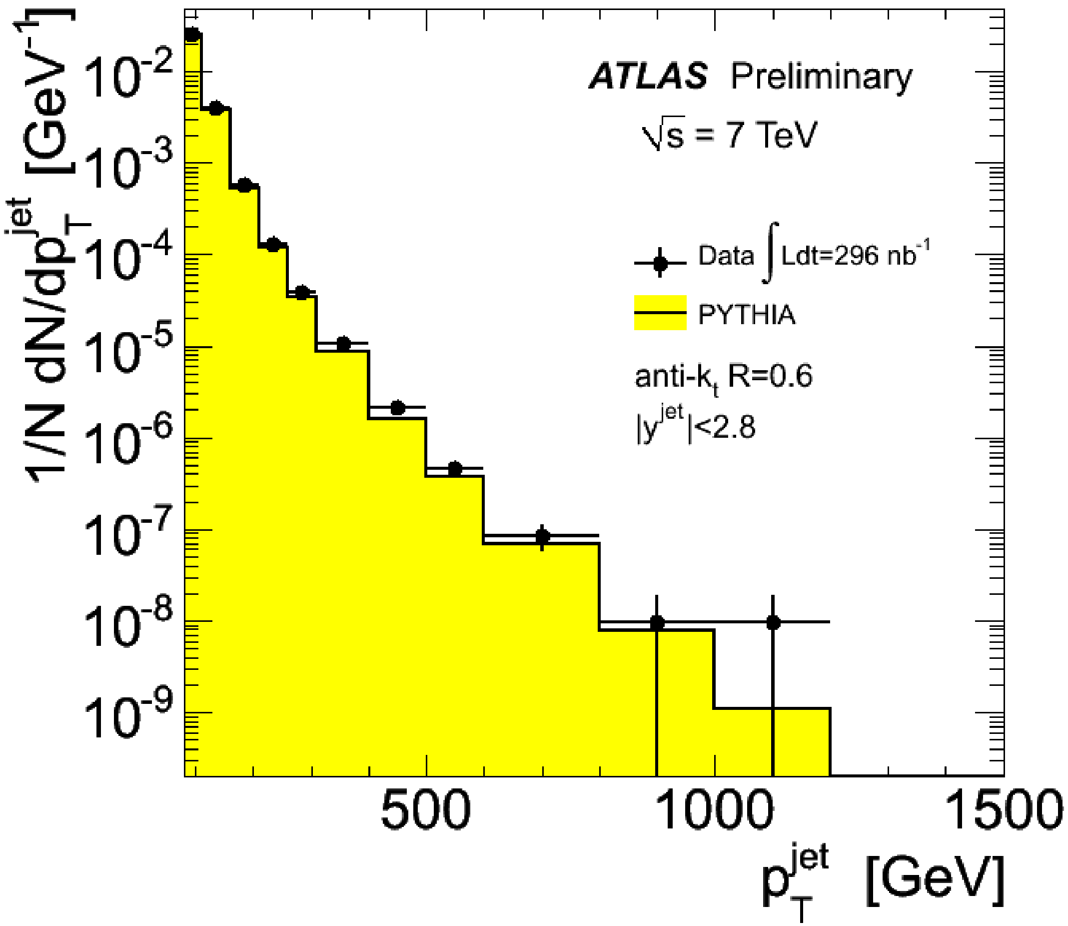
Restricted to $0.5\,|y_1-y_2|<0.5\log(30)$ $y_{boost} = 0.5\,|y_1+y_2|<1.1$

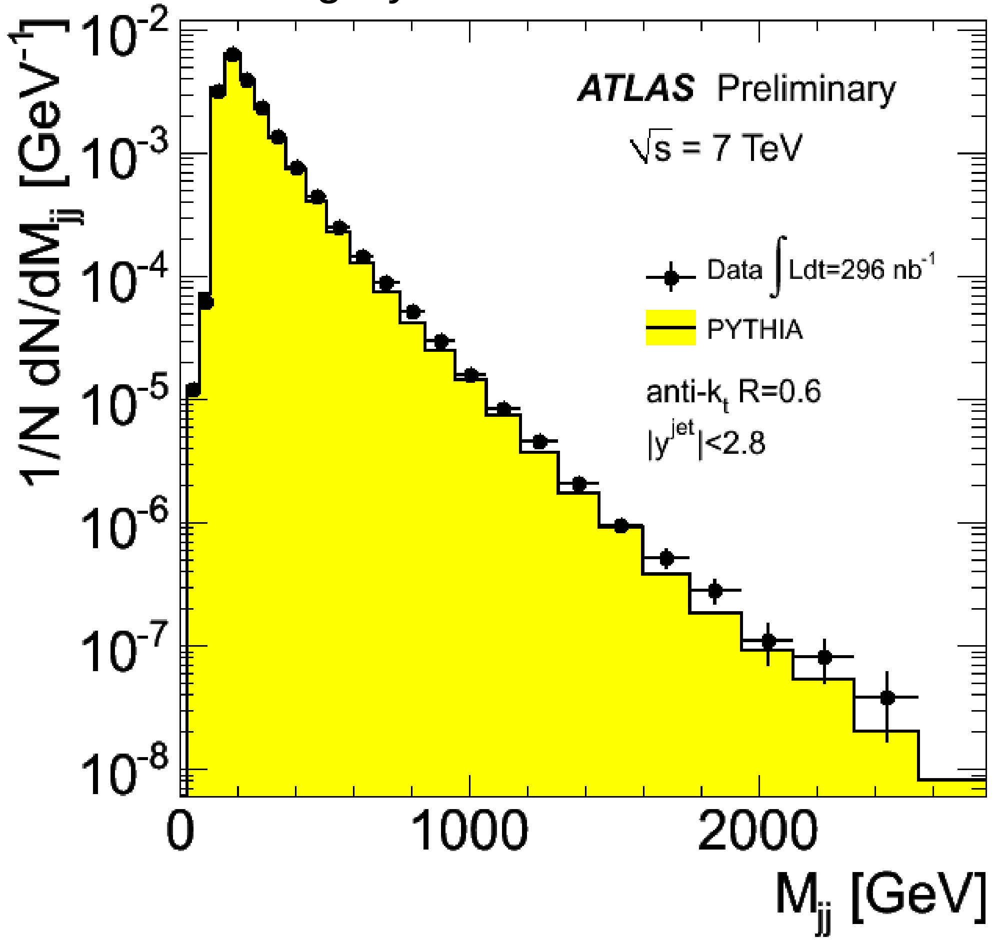


Data and theory consistent in all mass regions

Most recent Data-Set

About 20 times more data are already on tape:
Comparison on detector level with standard ATLAS MC using Pythia

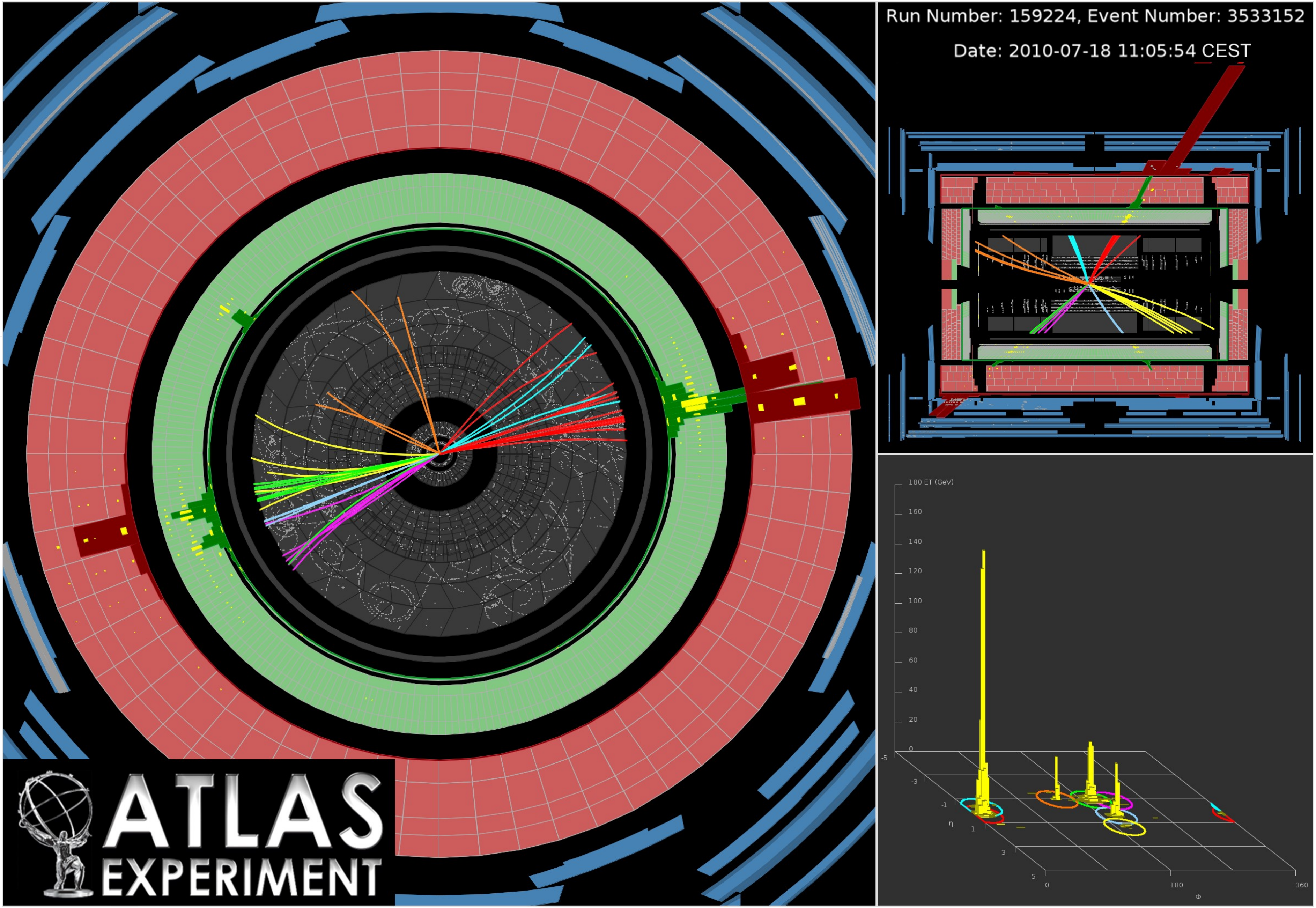




Jets with transverse momenta beyond 1 TeV and dijet masses to about 2.5 TeV are observed.
Higher $p_{t,jet}$ than observed at Tevatron.
Di-jet mass larger than Tevatron cms energy !

It starts to get interesting !

Highest transverse Momentum Event



Highest pT jet has a pT = 1.12 TeV.

Conclusions

The first LHC data already open a window to short distance physics at the TeV scale
Atlas has observed first events beyond $P_{T,jet}$ ~ 1 TeV and beyond $M_{1,2}$ ~ 2.5 TeV

Based on systematic Monte Calo simulations, test-beam experience and in-situ response measurements of single isolated hadrons, Atlas has established a jet calibration and determined a conservative uncertainty:
smaller than 7% for $p_{t,jet} > 100$ GeV and $|y|<2.8$
Excellent calorimeter understanding after first few months of data taking.

Based on the first data Atlas has measured the single inclusive jet cross-section for $60<P_{T,jet}<600$ GeV and $|y| < 2.8$ using the anti-kt jet clustering algorithm with R=0.4 and R=0.6

Di-jet cross-sections have been measured as a function of the di-jet mass and the scattering angle

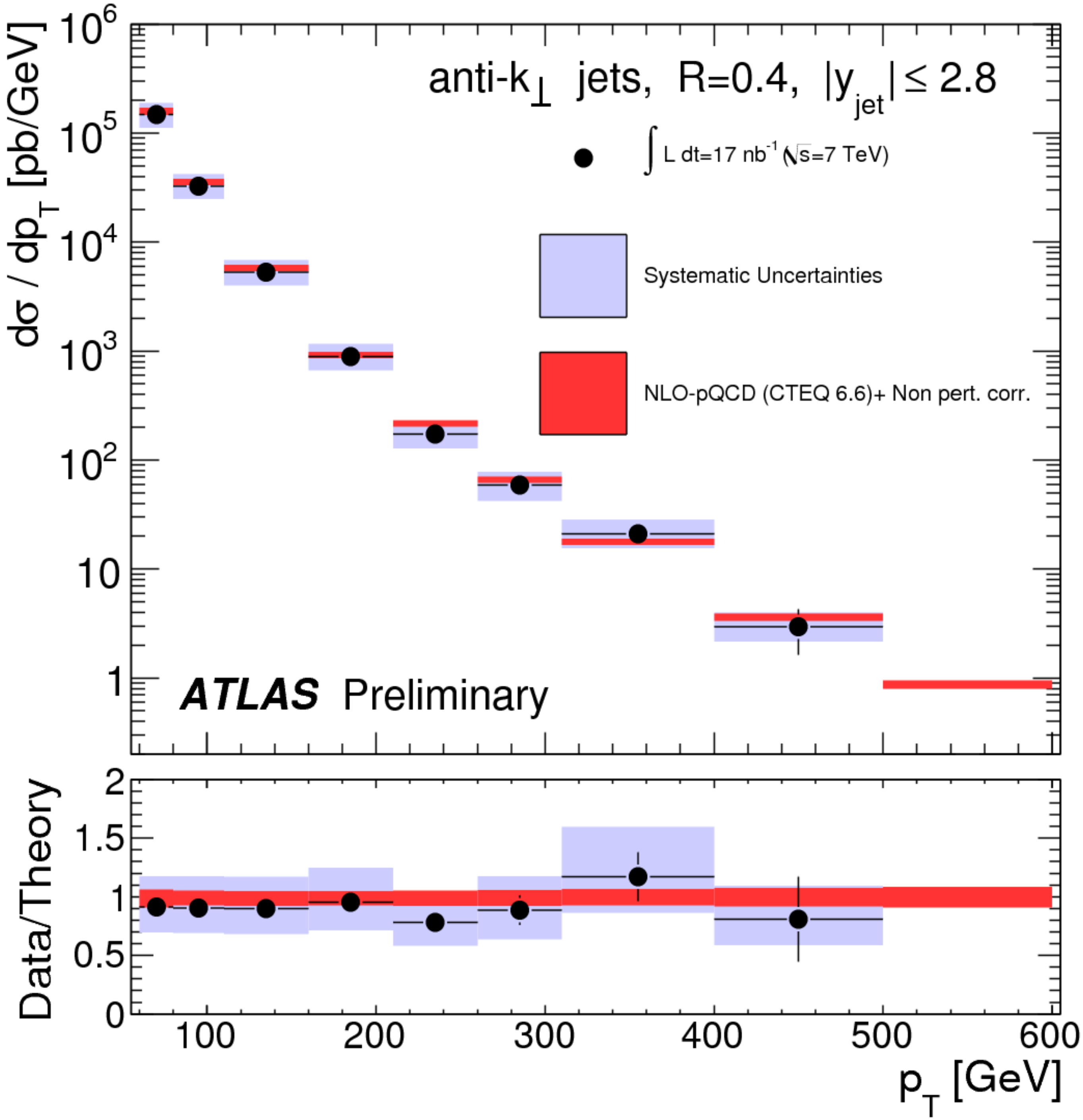
The data are consistent with a NLO QCD theory calculation
Theory uncertainty about 10% (PDF and scale)
Data uncertainty about 30-40% (driven by jet energy scale)

Future plans: use of larger data set already on tape (~300 nb^{-1}) to make precise measurement in previously unexplored $P_{T,jet}$ and $M_{1,2}$ range
Good calorimeter understanding and large data set will allow to reduce jet energy scale uncertainty

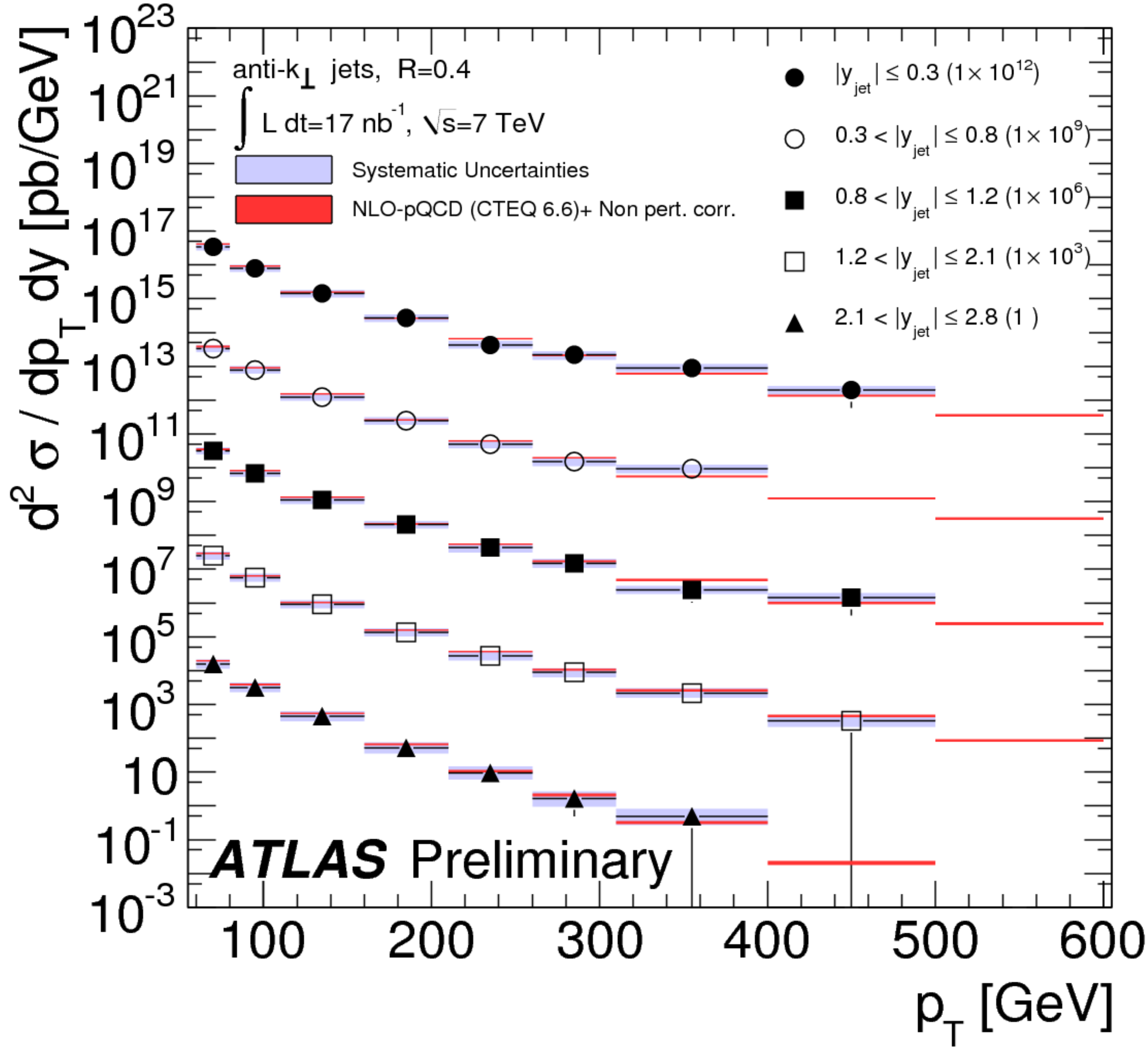
Back-up

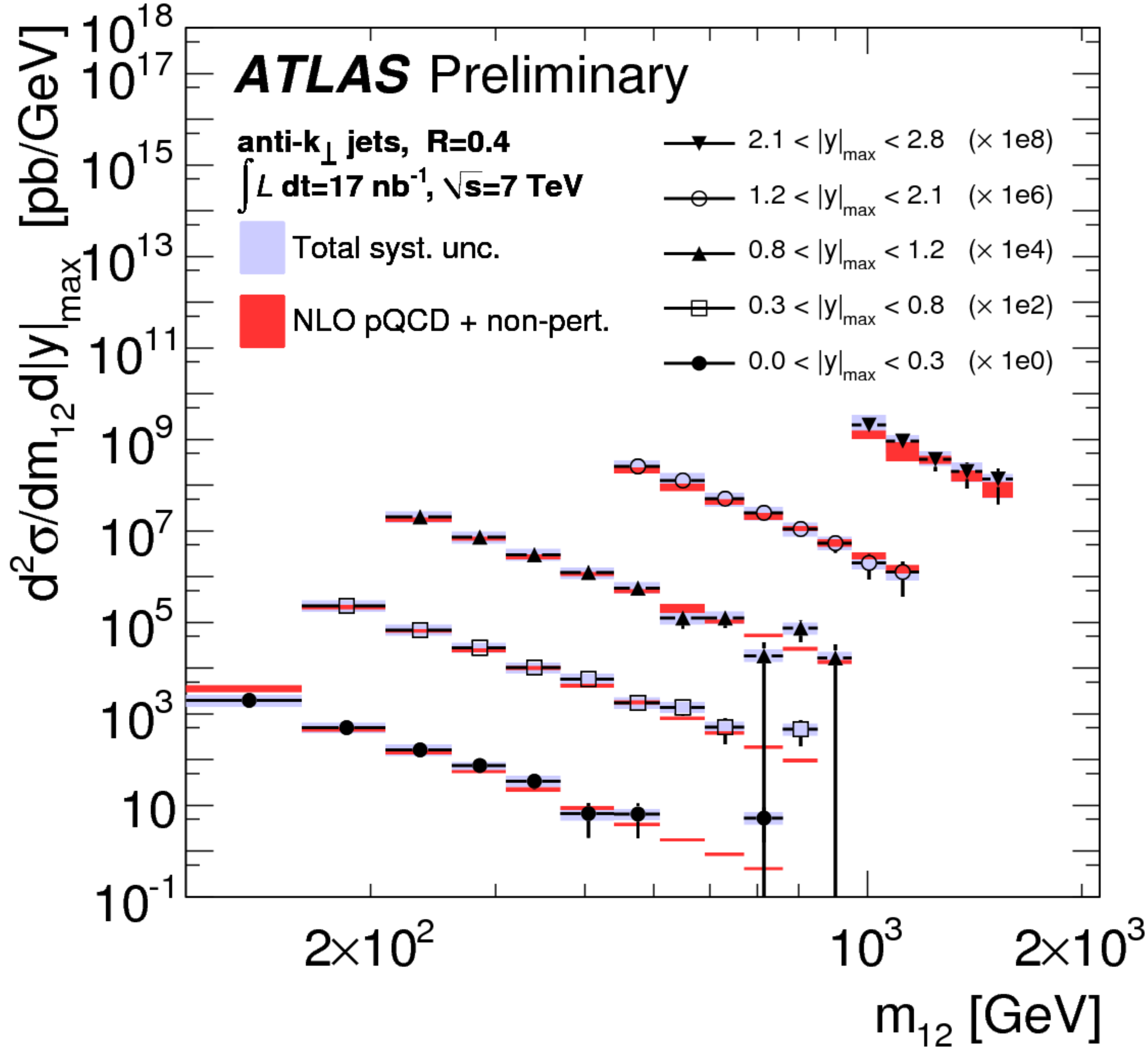
References

Anti-kt jet algorithm: Cacciari, Salam, Soyez, JHEP 0804 (2008) 063
NLOJET++: Nagy, PR D68 (2003) 094002
APPLGRID: Carli, Salam, Staravoitov, Sutton et al., Eur. Phys. J C66 (2010) 503
CTEQ6: Nadolsky, Phys.Rev.D78:013004,2008
Rivet A. Buckley et al., arXiv:1003.0694

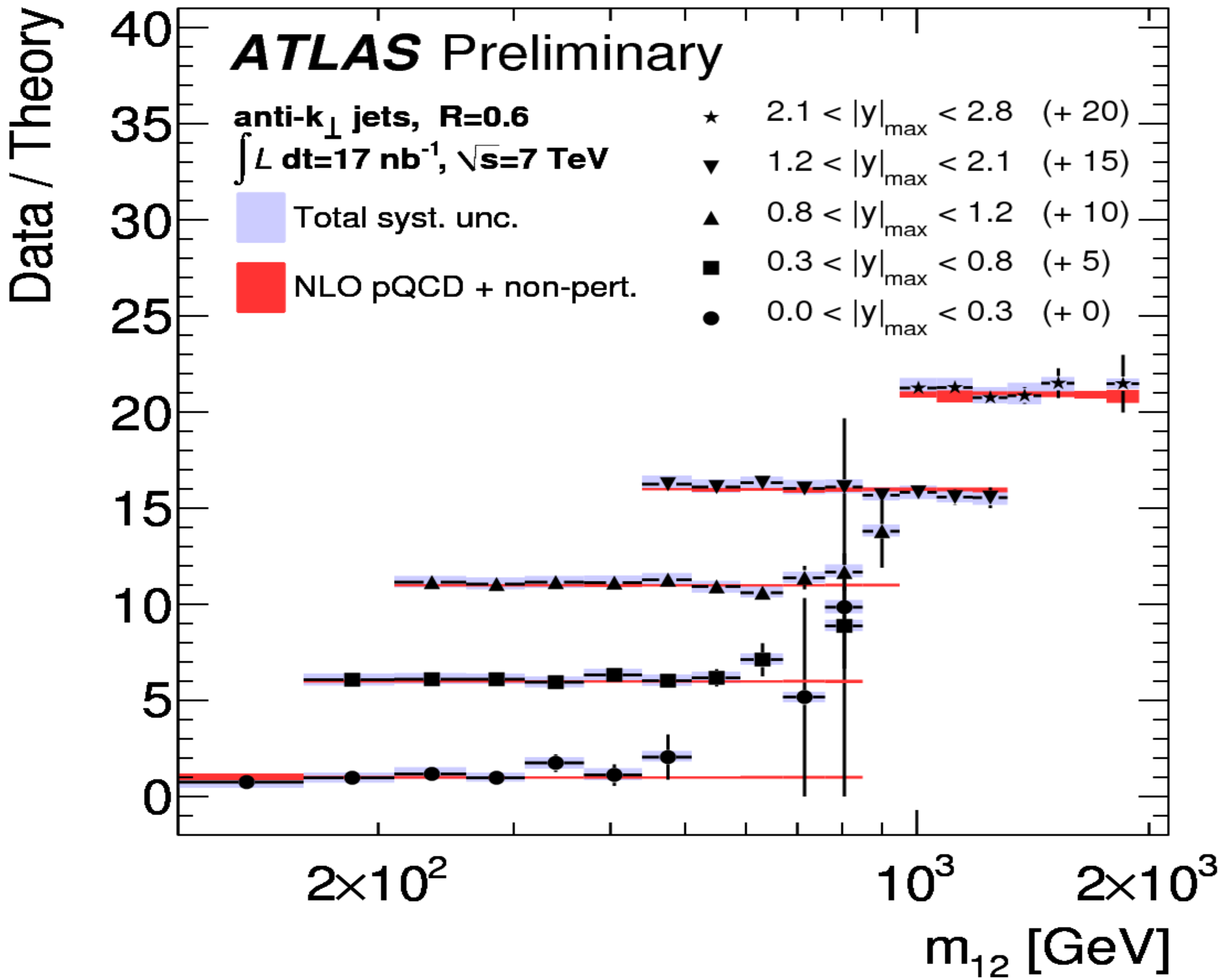


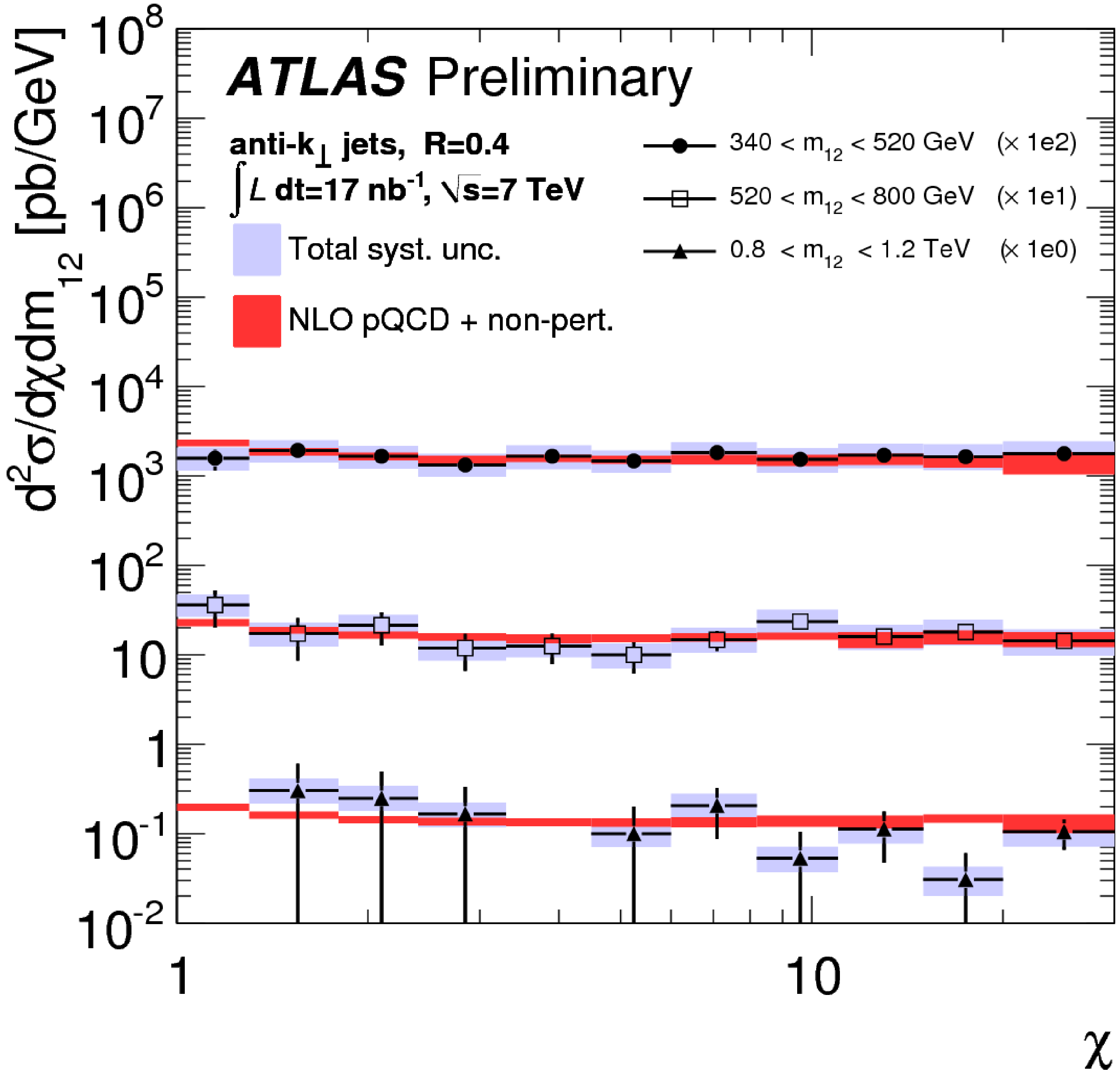
anti-k⊥ jets, R=0.4, $|y_{jet}| \leq 2.8$
$\int$ L dt=17 nb^{-1} ($\sqrt{s}$=7 TeV)
Systematic Uncertainties
NLO-pQCD (CTEQ 6.6)+ Non pert. corr.
ATLAS Preliminary
dσ / dp$_T$ [pb/GeV]
Data/Theory
p$_T$ [GeV]

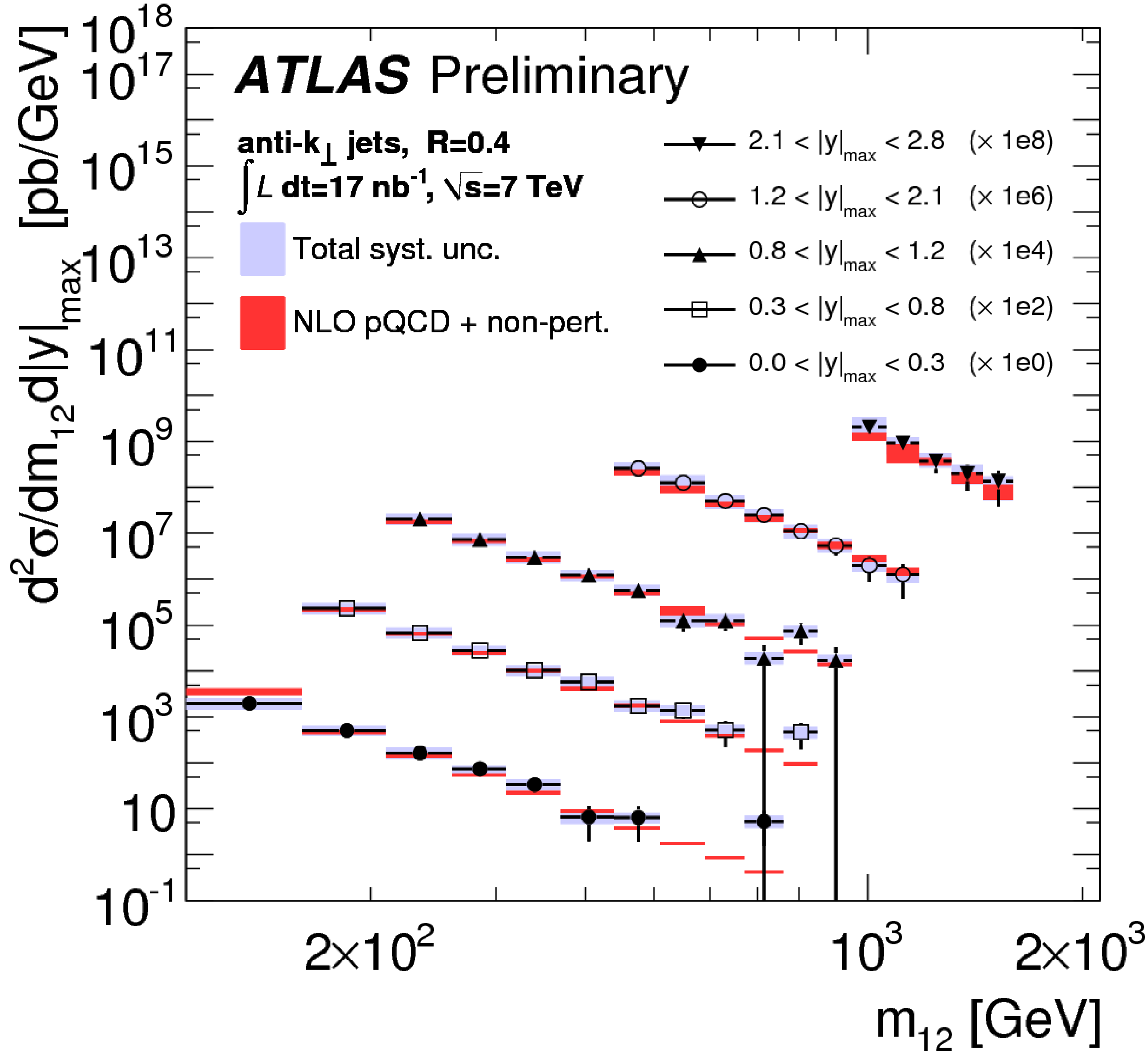

anti-k⊥ jets, R=0.4
∫ L dt=17 nb-1, √s=7 TeV
Systematic Uncertainties
NLO-pQCD (CTEQ 6.6)+ Non pert. corr.
|y jet| ≤ 0.3 (1× 10^12)
0.3 < |y jet| ≤ 0.8 (1× 10^9)
0.8 < |y jet| ≤ 1.2 (1× 10^6)
1.2 < |y jet| ≤ 2.1 (1× 10^3)
2.1 < |y jet| ≤ 2.8 (1)
ATLAS Preliminary
d^2 σ / dp_T dy [pb/GeV]
p_T [GeV]



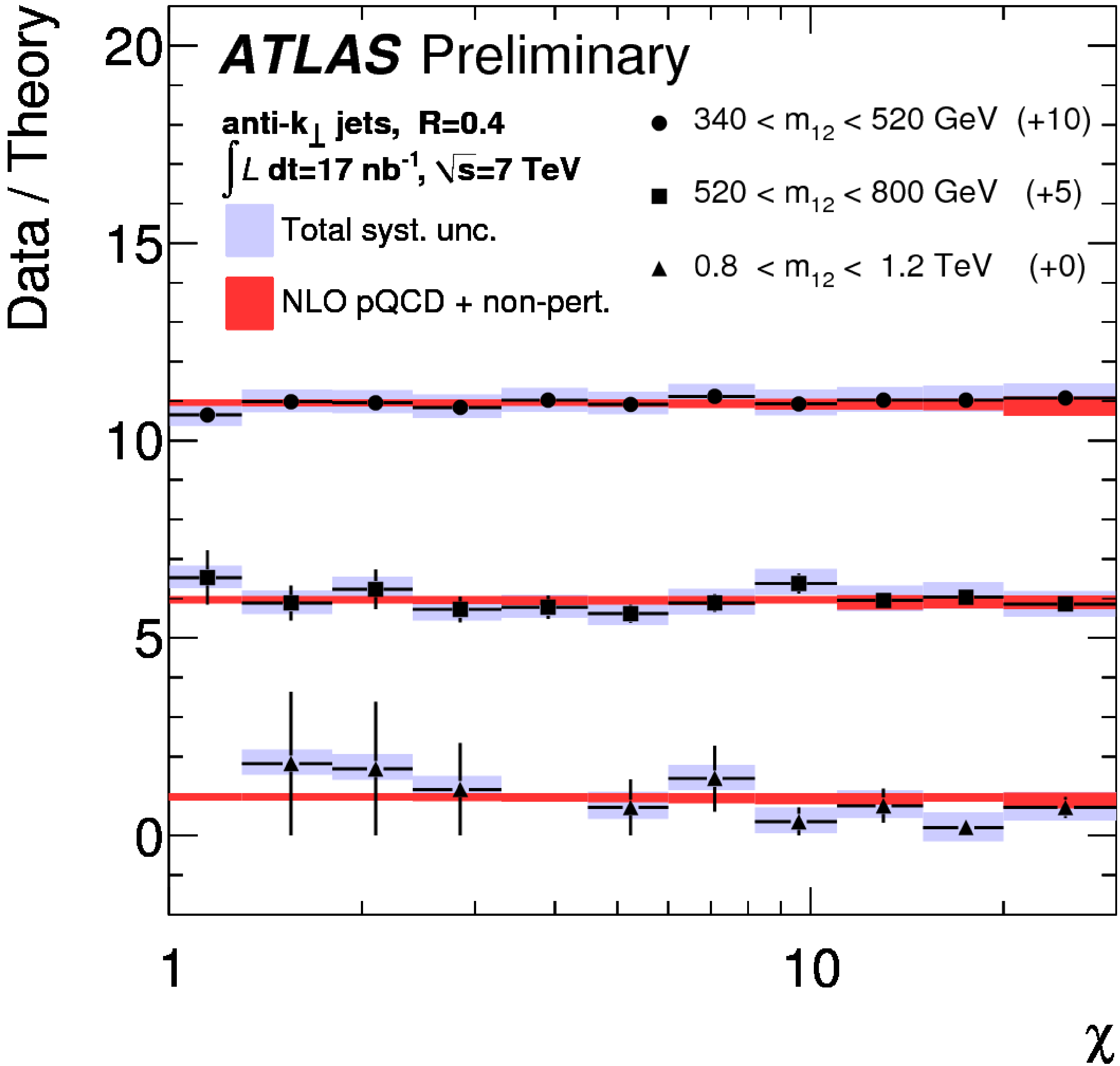
ATLAS Preliminary
anti-k⊥ jets, R=0.4
∫L dt=17 nb⁻¹, √s=7 TeV
Total syst. unc.
NLO pQCD + non-pert.
2.1 < |y|max < 2.8 (× 1e8)
1.2 < |y|max < 2.1 (× 1e6)
0.8 < |y|max < 1.2 (× 1e4)
0.3 < |y|max < 0.8 (× 1e2)
0.0 < |y|max < 0.3 (× 1e0)
d²σ/dm12d|y|max [pb/GeV]
m12 [GeV]


ATLAS Preliminary
anti-k⊥ jets, R=0.6
∫L dt=17 nb-1, √s=7 TeV
Total syst. unc.
NLO pQCD + non-pert.
2.1 < |y|max < 2.8 (+ 20)
1.2 < |y|max < 2.1 (+ 15)
0.8 < |y|max < 1.2 (+ 10)
0.3 < |y|max < 0.8 (+ 5)
0.0 < |y|max < 0.3 (+ 0)
Data / Theory
m12 [GeV]
0
5
10
15
20
25
30
35
40
2×10^2
10^3
2×10^3


ATLAS Preliminary
anti-k⊥ jets, R=0.4
∫L dt=17 nb-1, √s=7 TeV
Total syst. unc.
NLO pQCD + non-pert.
340 < m12 < 520 GeV (× 1e2)
520 < m12 < 800 GeV (× 1e1)
0.8 < m12 < 1.2 TeV (× 1e0)
d2σ/dχdm12 [pb/GeV]
χ

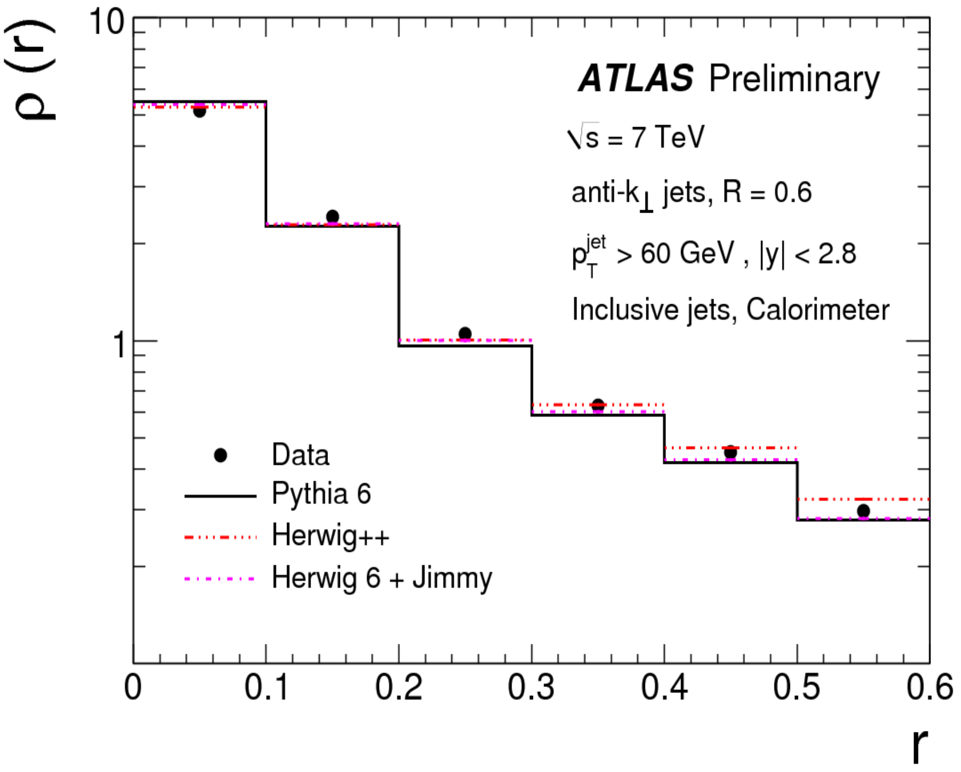


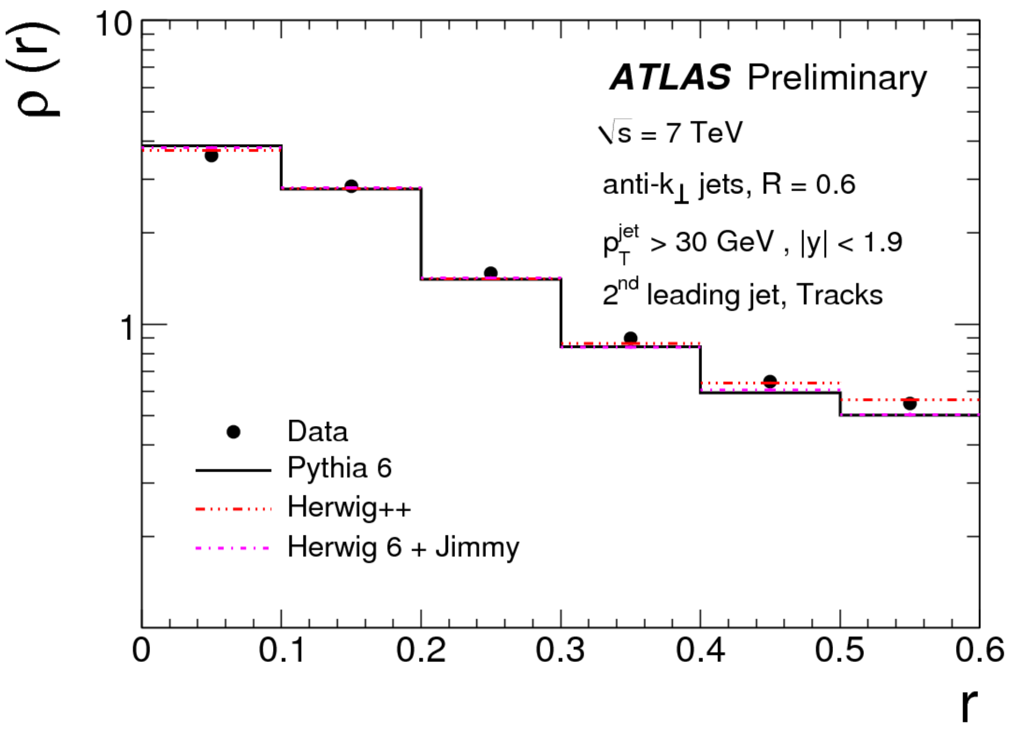
ATLAS Preliminary
anti-k⊥ jets, R=0.4
∫L dt=17 nb-1, √s=7 TeV
Total syst. unc.
NLO pQCD + non-pert.
2.1 < |y|max < 2.8 (× 1e8)
1.2 < |y|max < 2.1 (× 1e6)
0.8 < |y|max < 1.2 (× 1e4)
0.3 < |y|max < 0.8 (× 1e2)
0.0 < |y|max < 0.3 (× 1e0)
d2σ/dm12d|y|max [pb/GeV]
m12 [GeV]



ATLAS Preliminary
anti-k⊥ jets, R=0.4
∫L dt=17 nb-1, √s=7 TeV
Total syst. unc.
NLO pQCD + non-pert.
340 < m12 < 520 GeV (+10)
520 < m12 < 800 GeV (+5)
0.8 < m12 < 1.2 TeV (+0)
Data / Theory
20
15
10
5
0
1
10
χ

Internal Jet Structure



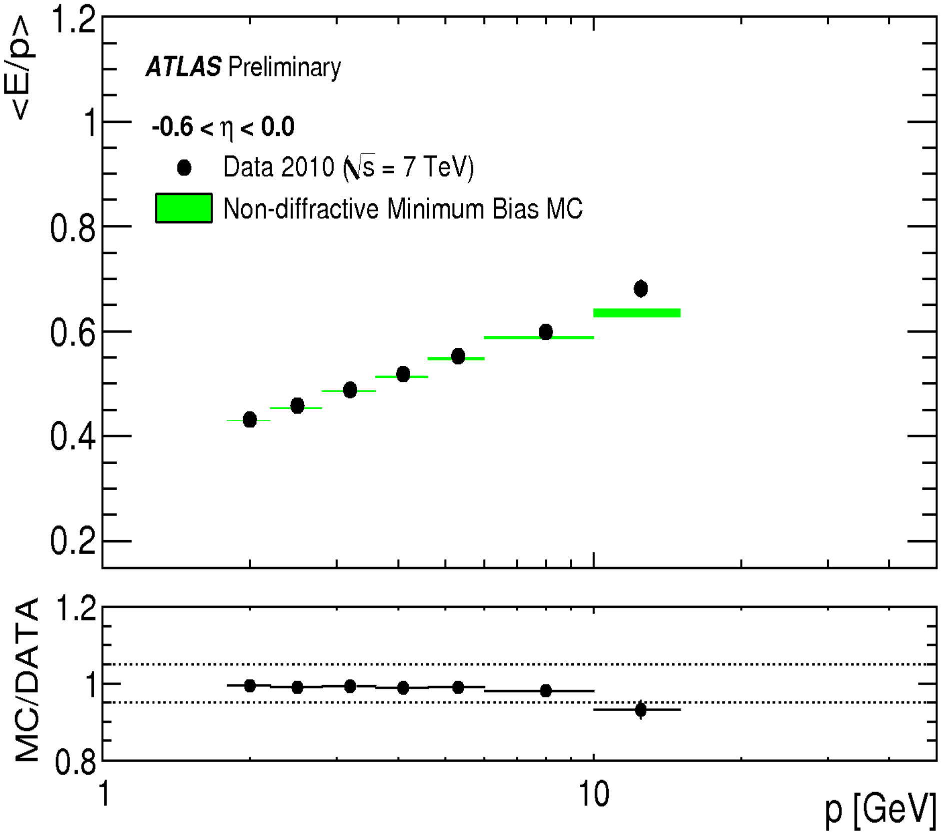


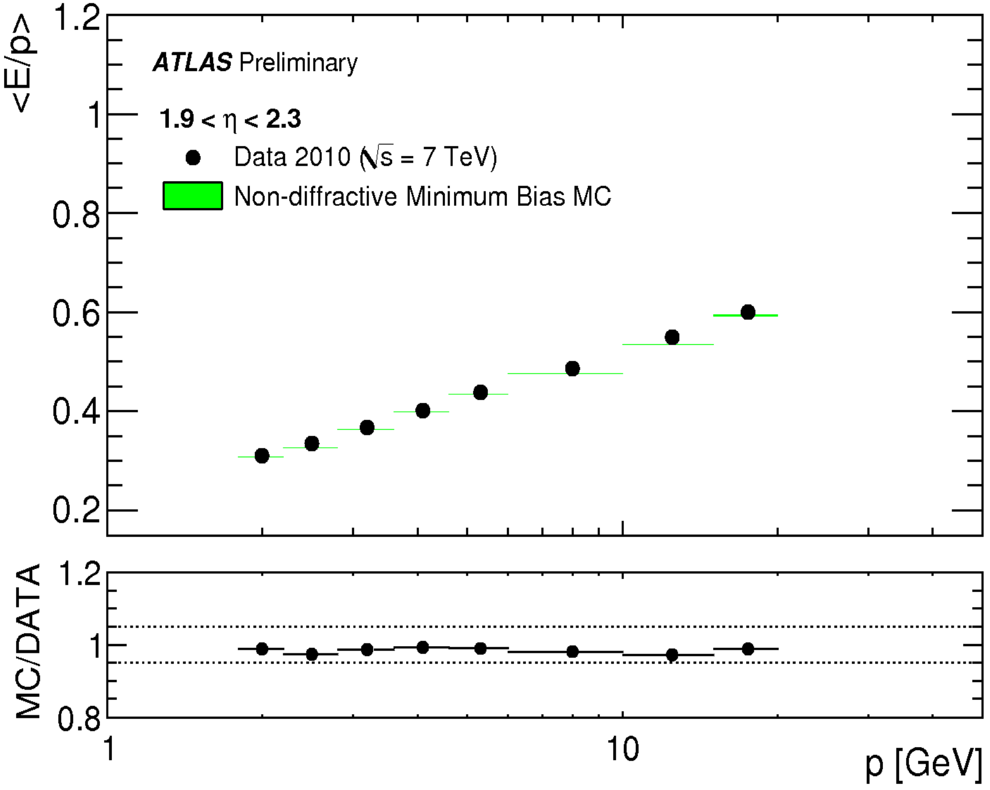
Single isolated hadron calorimeter response

Measure calorimeter response around isolated tracks vs pt and eta

Repeat analysis of 900 GeV data (ATLAS-CONF-2010-017) on 7 TeV data

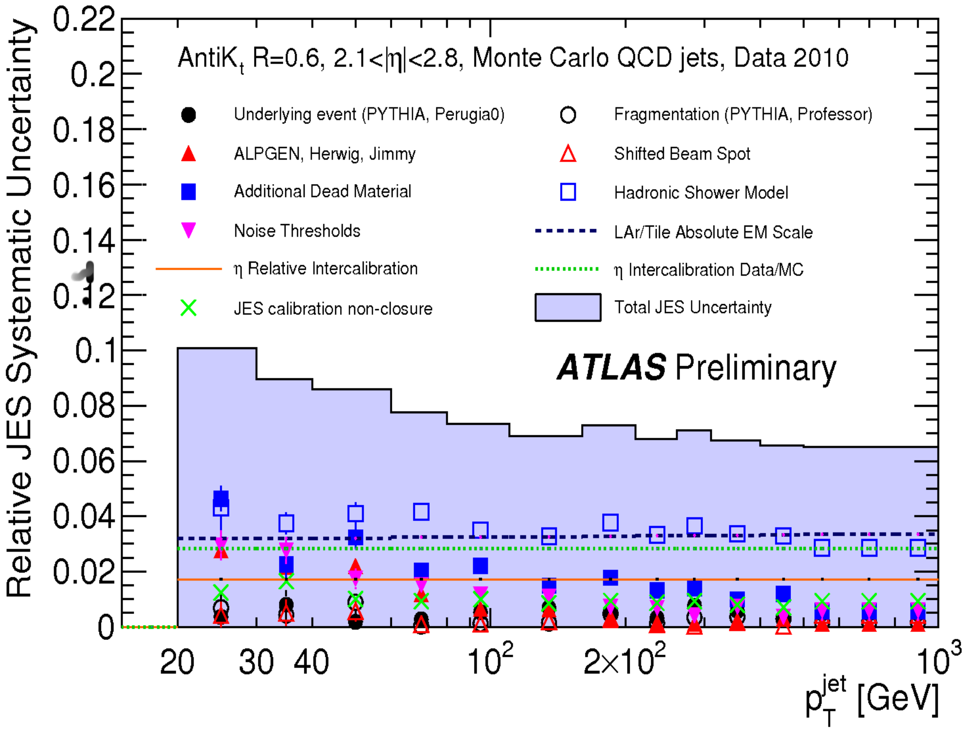
Example:

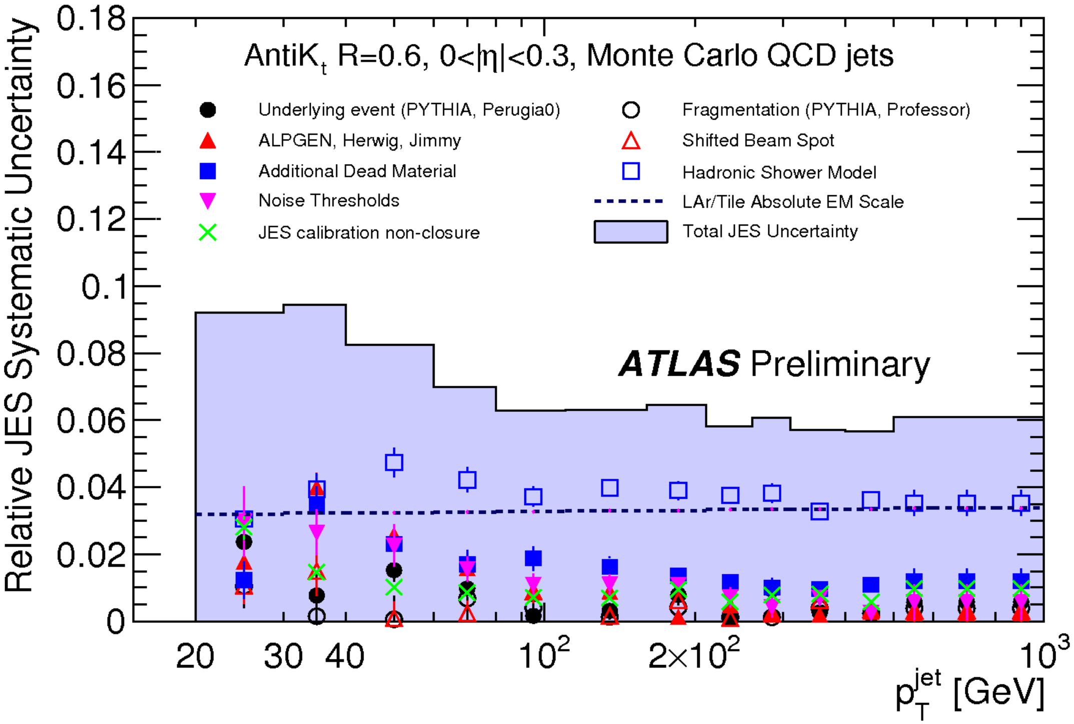




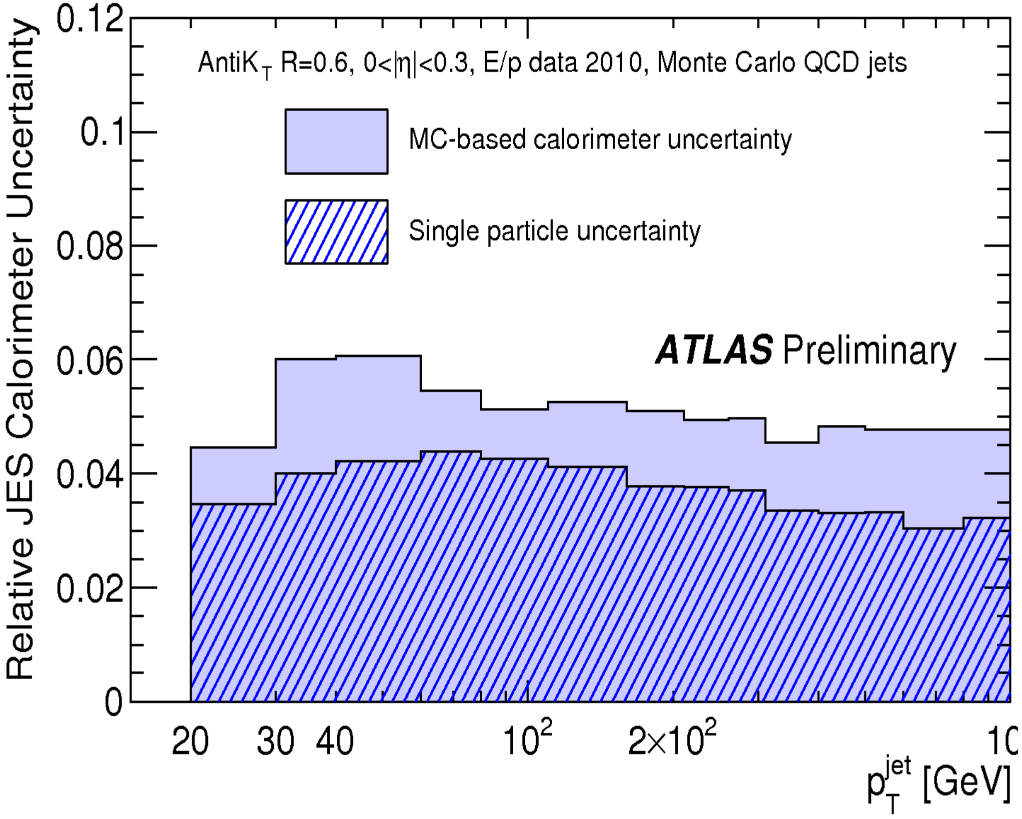
Increased neutral back-ground with increased CM energy
Data compatible after background subtraction
Response of single isolated hadrons within 3% of simulated response

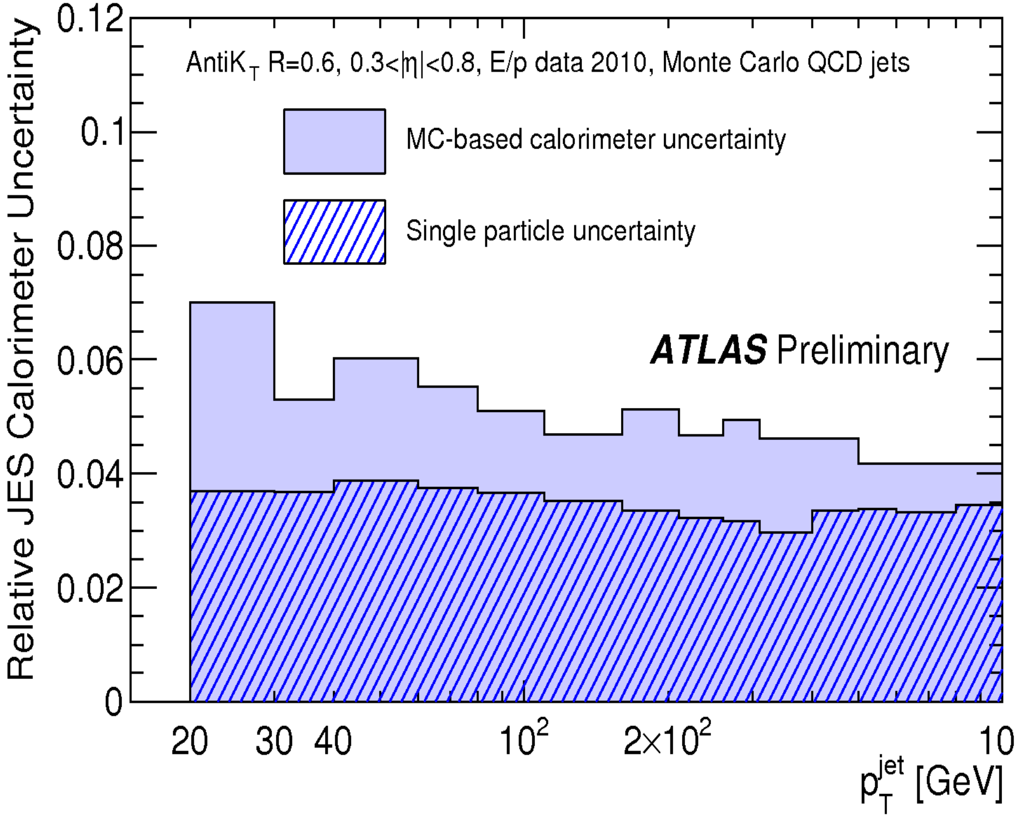
Jet Calibration and Uncertainty in Central and Forward Region





Comparison of JES uncertainty from single isolated hadron analysis and MC study



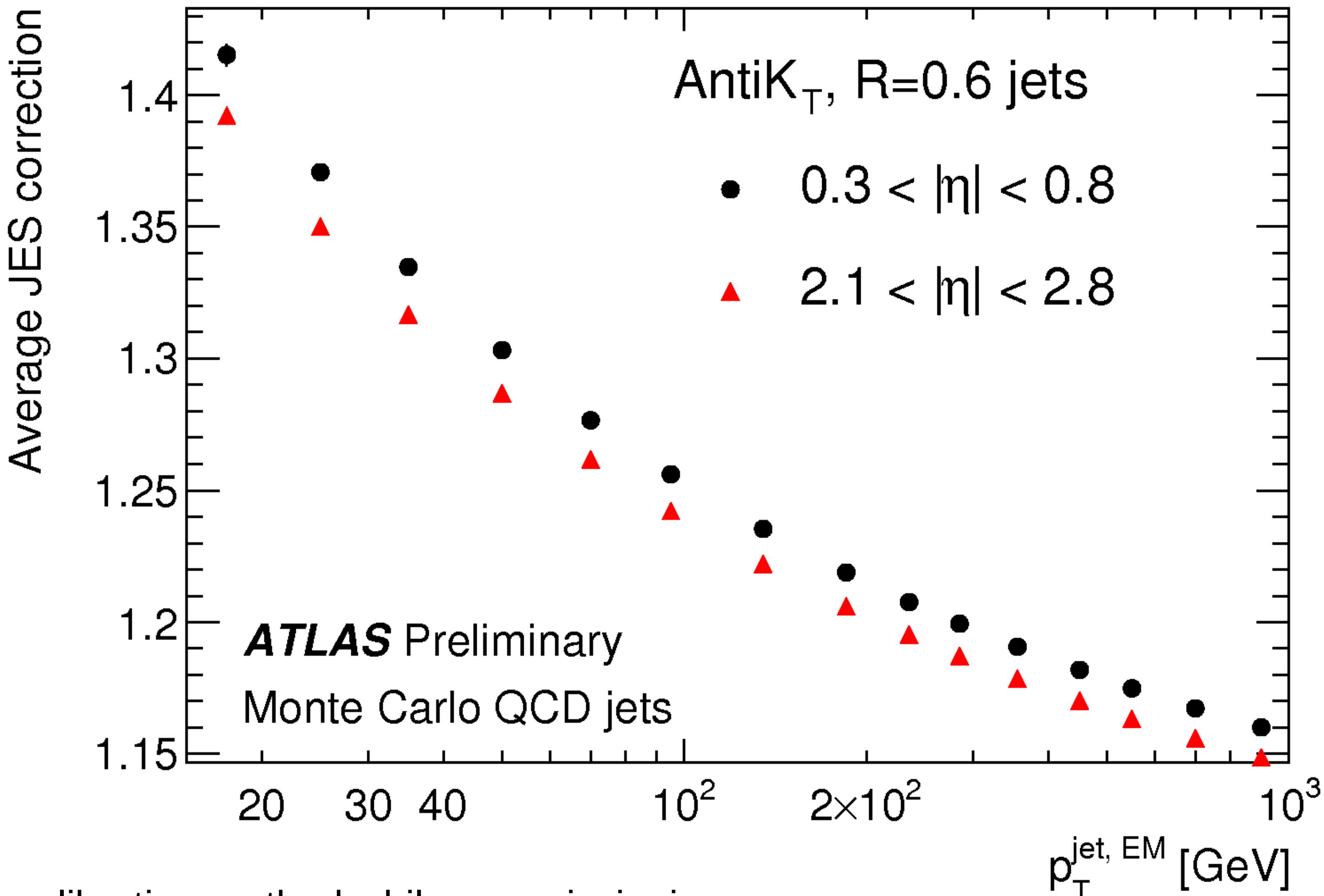


In-situ measurement of isolated hadron calorimeter response will allow to reduce the uncertainty of the jet calorimeter response uncertainty

Jet calibration:

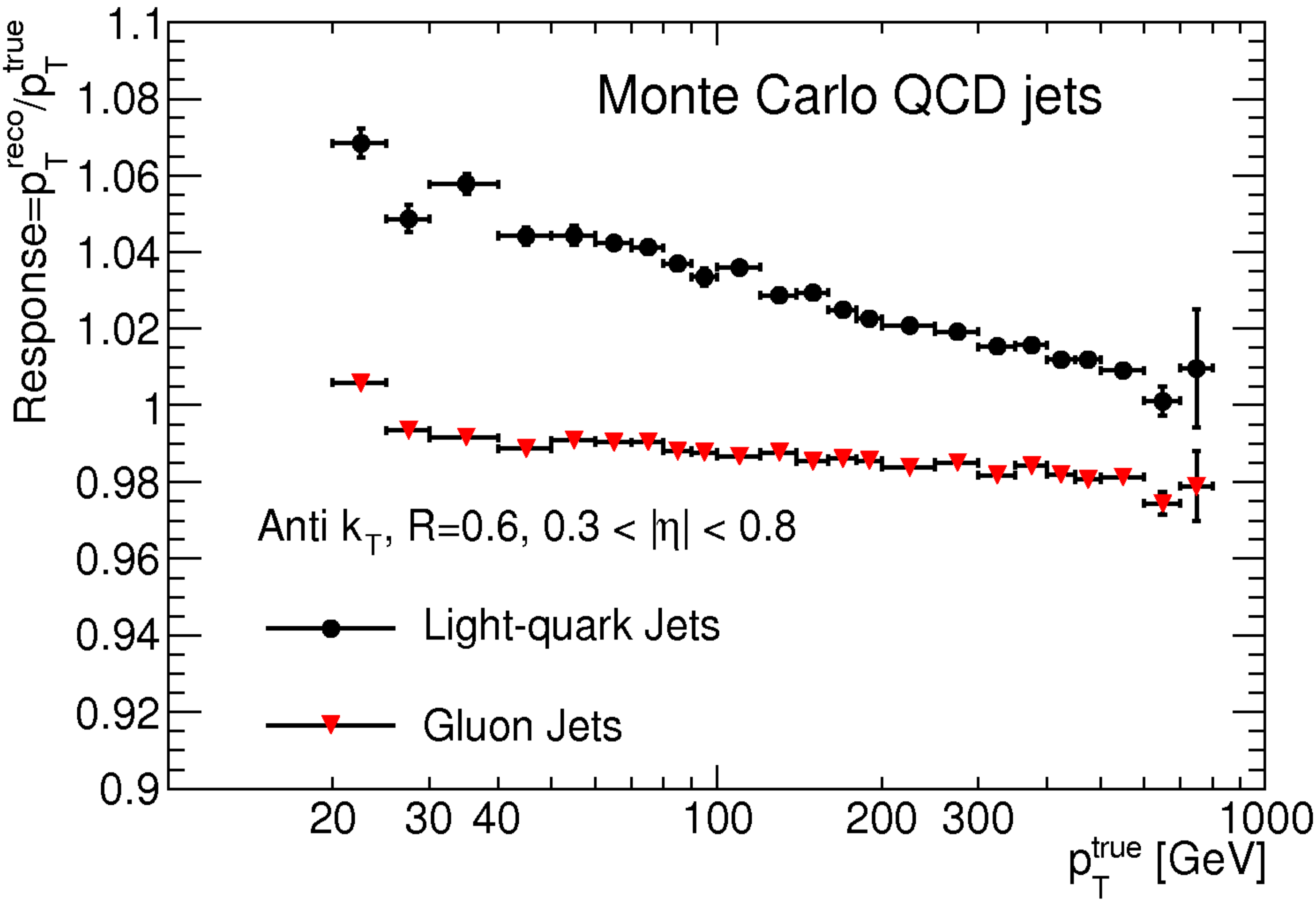
Simple $P_{T,jet}$ and y dependent correction applied to measured jets at the electro-magnetic scale.
Using particle level (truth) from Monte Carlo simulation as reference.

Factor:



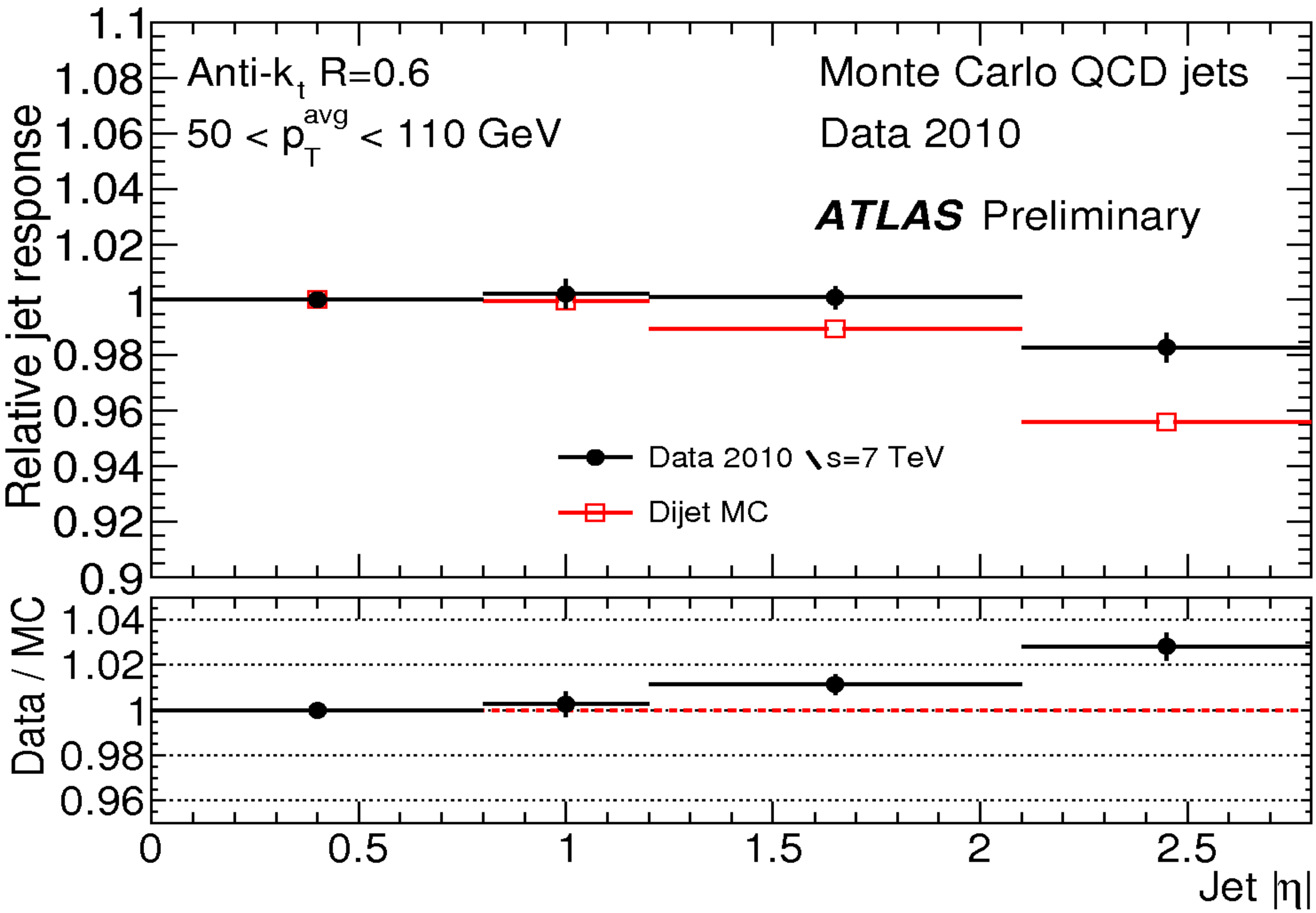
Robust calibration method while commissioning
of more sophisticated calibration schemes on-going

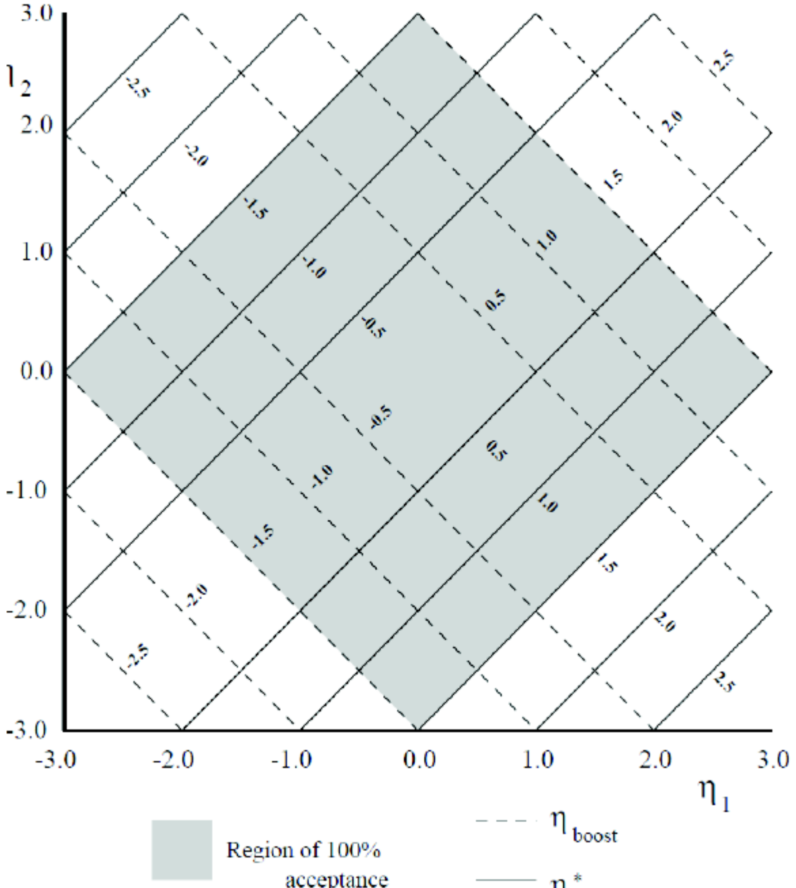
Flavour dependence for EM+JES calibration

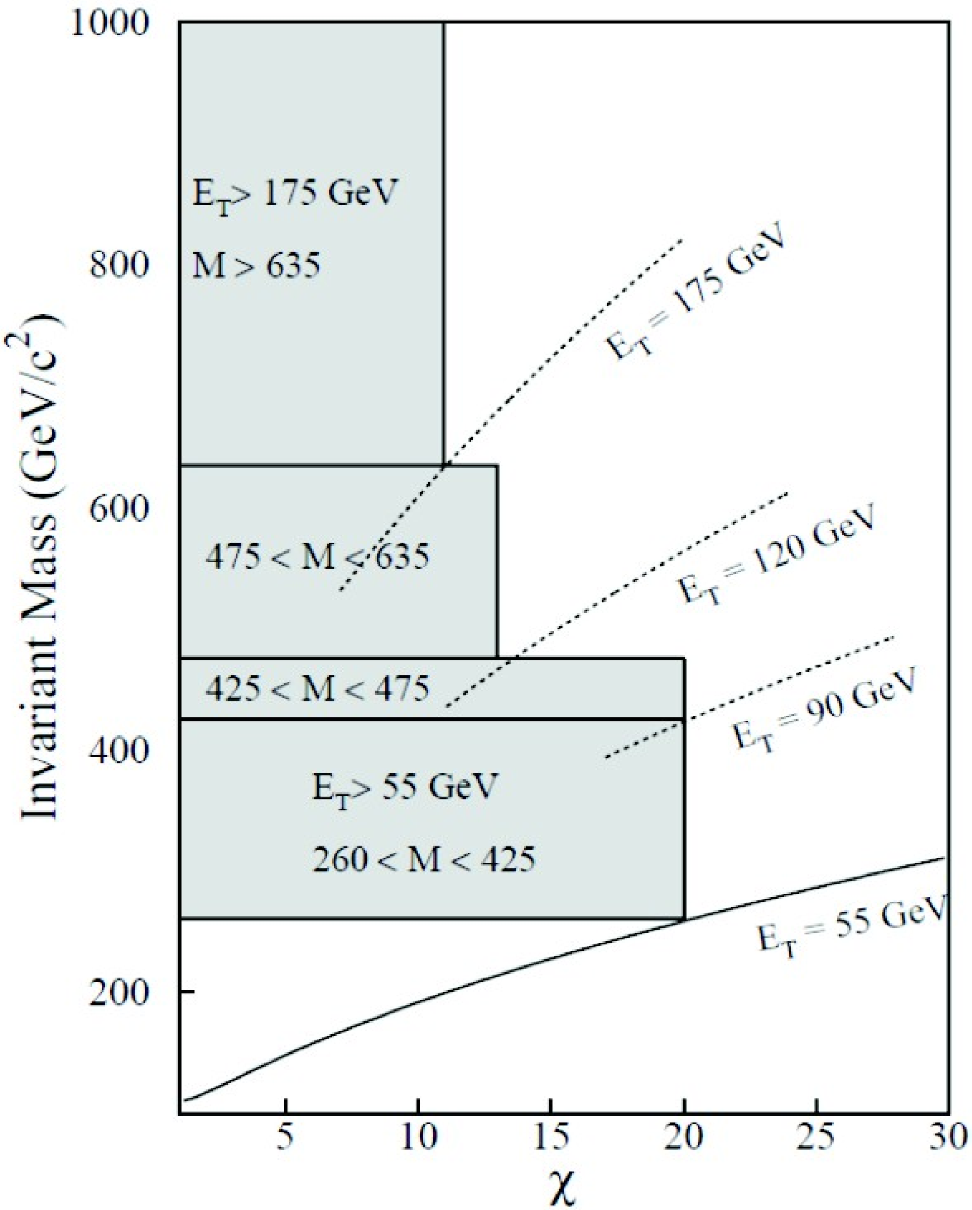


Flavour dependence can be reduced using more sophisticated calibration schemes

Rapidity Inter-calibration using Di-jet Balance



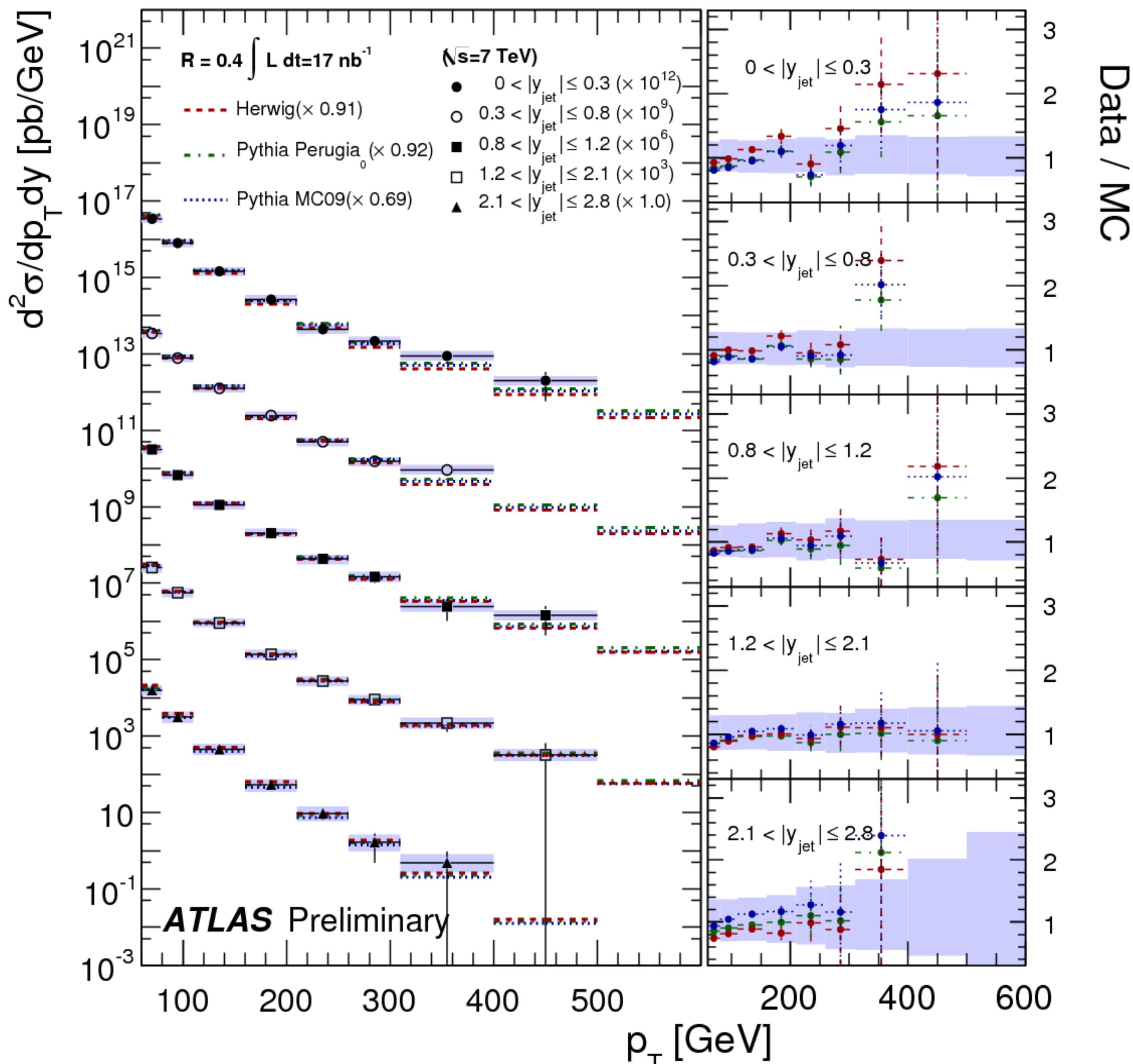




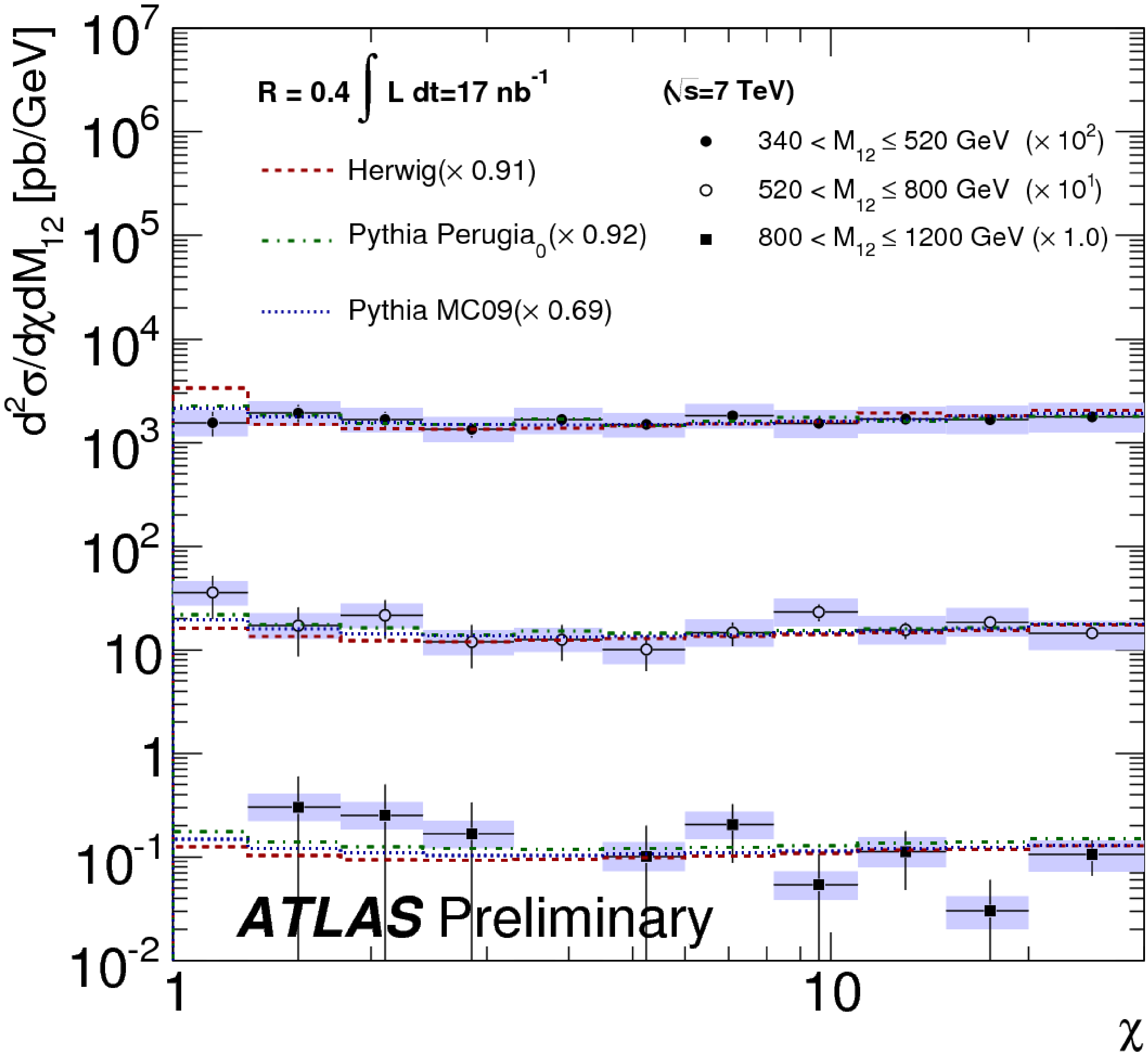
$d\sigma/d\chi\, dM_{1,2}$ with $\chi = \exp(|y1-y2|) \sim (1+\cos\theta^*)/(1-\cos\theta^*)$

Restricted to $y^* = 0.5\,|y_1-y_2| < 0.5\log(30)$ $y_{boost} = 0.5\,|y_1+y_2| < 1.1$

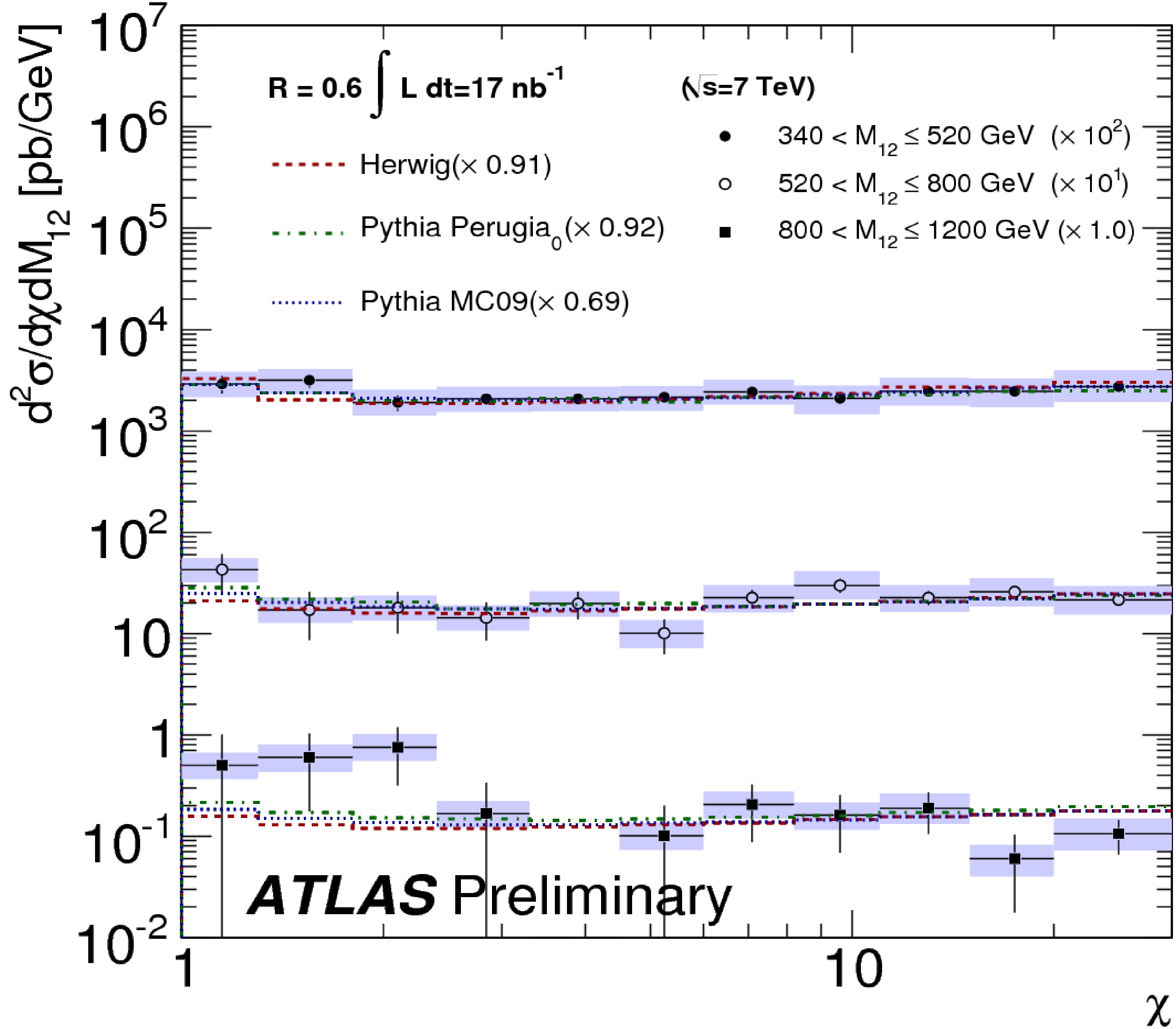
Inclusive Jet Cross-section R=0.4: Monte Carlo Generators



Di-jet Cross-section R=0.4: Monte Carlo Generators



Di-jet Cross-section R=0.6: Monte Carlo Generators



Inclusive Jet Cross-section R=0.6: Monte Carlo Generators