Dijet and Multi-jet Cross Sections Measurements in ATLAS

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on behalf of the ATLAS Collaboration

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Overview

- ***Data:*** In 2010, the ATLAS detector acquired p-p collision data at centre-of-mass energy of 7 TeV.

- ***Measurements of :***

  i) *Multi-jet cross-section*
  (**ATLAS-CONF-2011-043**)

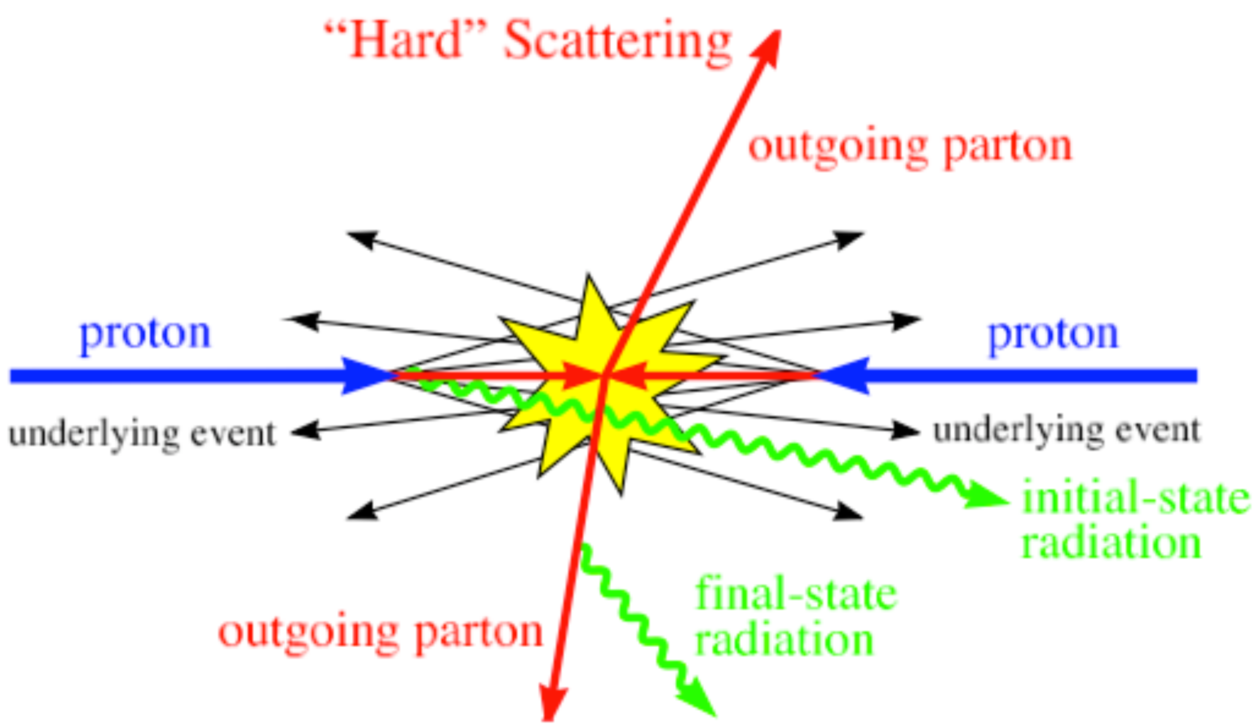
  ii) *Dijet azimuthal decorrelations*
  (**PH-EP-2011-013, arXiv:1102.2696**)

  iii) *Dijet production with a jet veto*
  (**ATLAS-CONF-2011-038**)

Background Introduction

Hard scattering
↓
Perturbative QCD (pQCD)

Soft scattering
↓
Non-perturbative QCD effects



$2 \to 2$ hard scattering

Predicting Approaches

Matrix Elements (ME)

All-order Treatment

Leading-order (LO) → CKKW → Parton-shower (PS)

Next-to-leading-order (NLO)

Resummation

Measurement of Multi-jet Cross-section

Integrated Lumi ~ 2.43 pb^{-1}

Motivation

Physics significance:

- Testify QCD effects at hadron colliders
- Understand the multi-jet events as background to new physics

Monte Carlo Tools:

Generator	pdf	tune	purpose
ALPGEN+HERWIG/JIMMY	CTEQ6L1 [10]	AUET1 [18]	central value*
ALPGEN+HERWIG/JIMMY	CTEQ6L1 [10]	MC09 [17]	UE studies*
ALPGEN+PYTHIA	CTEQ6L1 [10]	MC09′ [17]	PS studies
ALPGEN+PYTHIA	CTEQ6L1 [10]	D6	UE/PS studies
ALPGEN+PYTHIA	CTEQ6L1 [10]	Perugia 6 [20]	UE/PS studies
PYTHIA	MRST2007 LOmod [21,22]	AMBT1 [19]	UE/PS studies*
PYTHIA	CTEQ5L [23]	Perugia2010 [20]	UE/PS studies

LO-ME PS

NLO-ME: NLOJet++
Lack of interface to PS

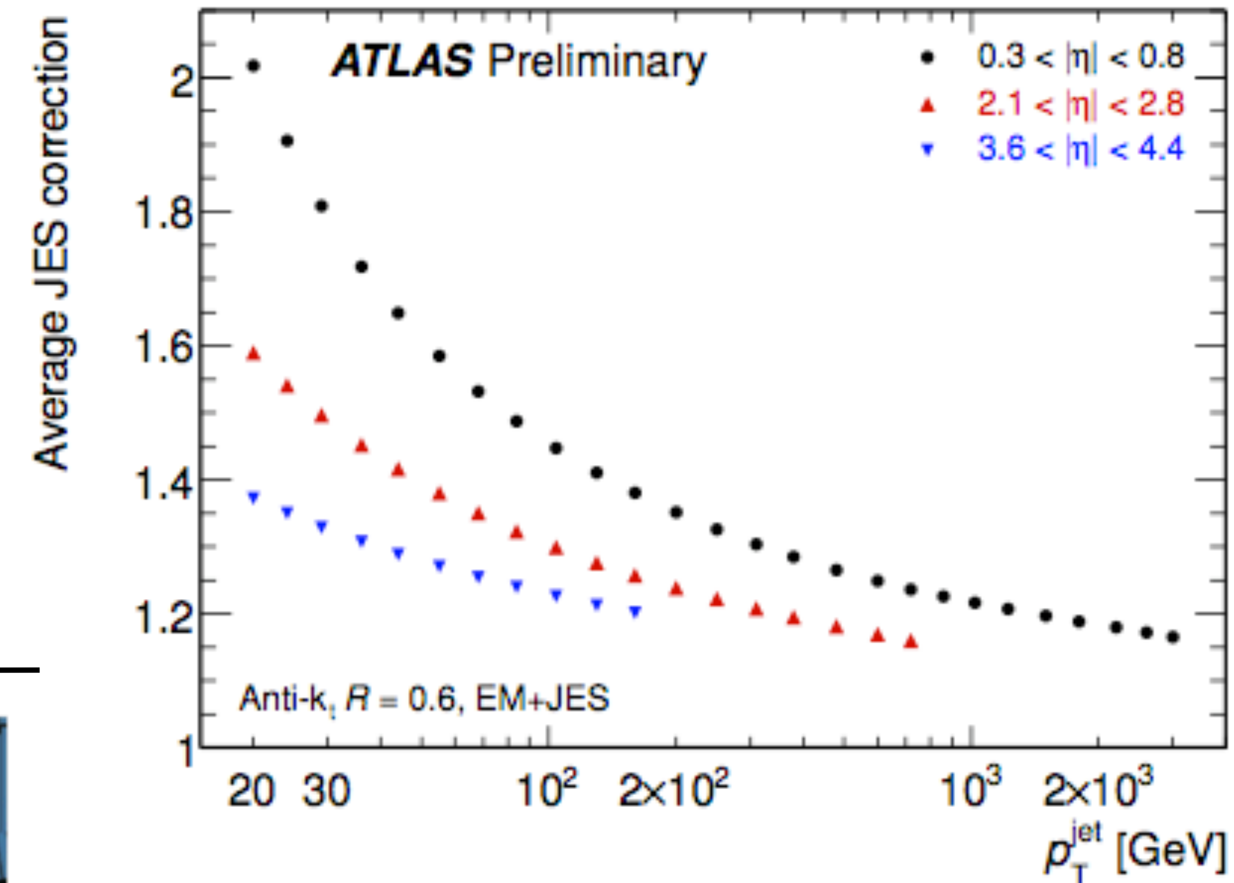
Event Selection

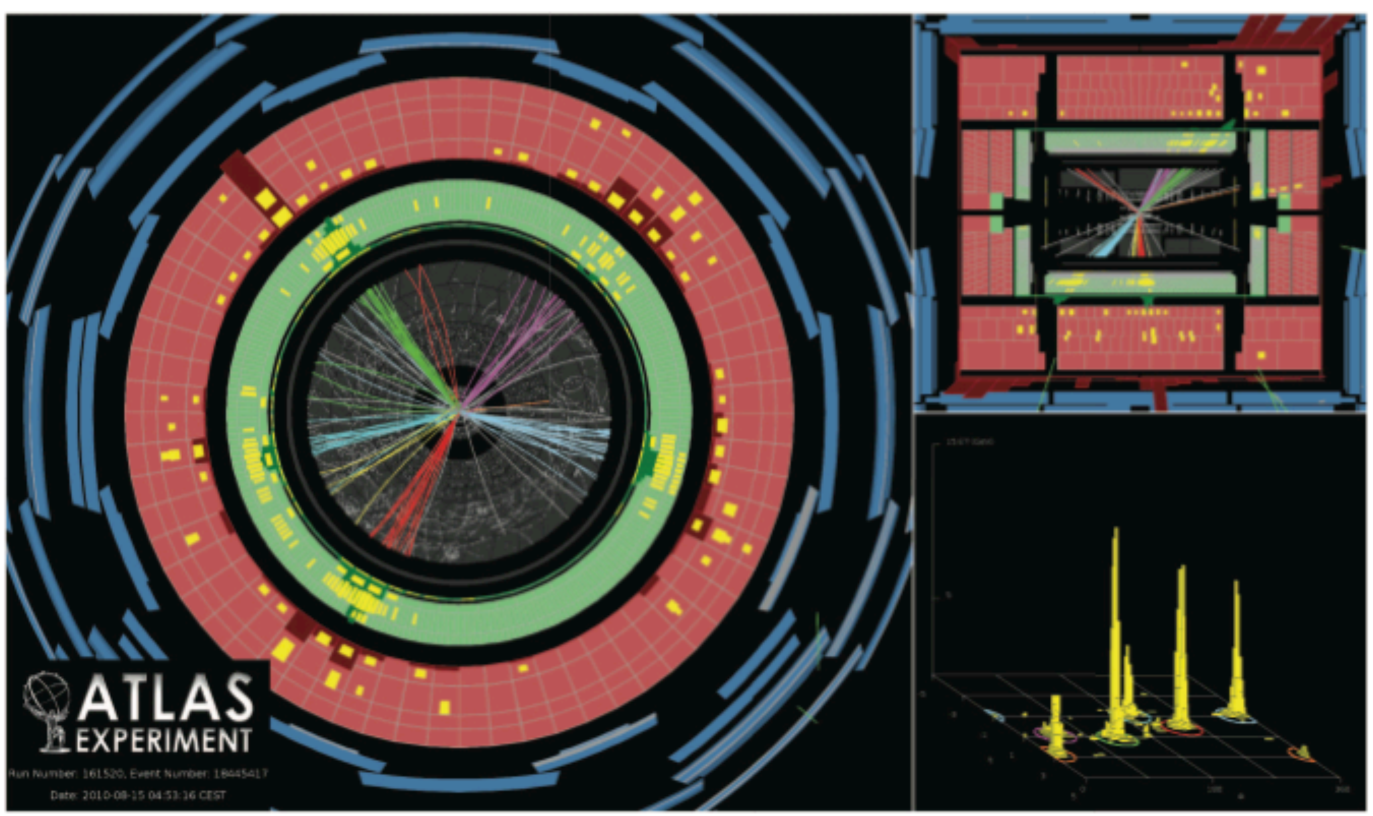
Jet: EM topocluster input + anti-kt algorithm + Jet Energy Scale (JES) Calibration

Why anti-kt jet?

- infrared safe to all orders
- geometrically well-defined cone-like
- same calculation as the pQCD

The anti-kt jet algorithm is the primary algorithm for ATLAS (and CMS).





An example six-jet event in ATLAS

Good jets:

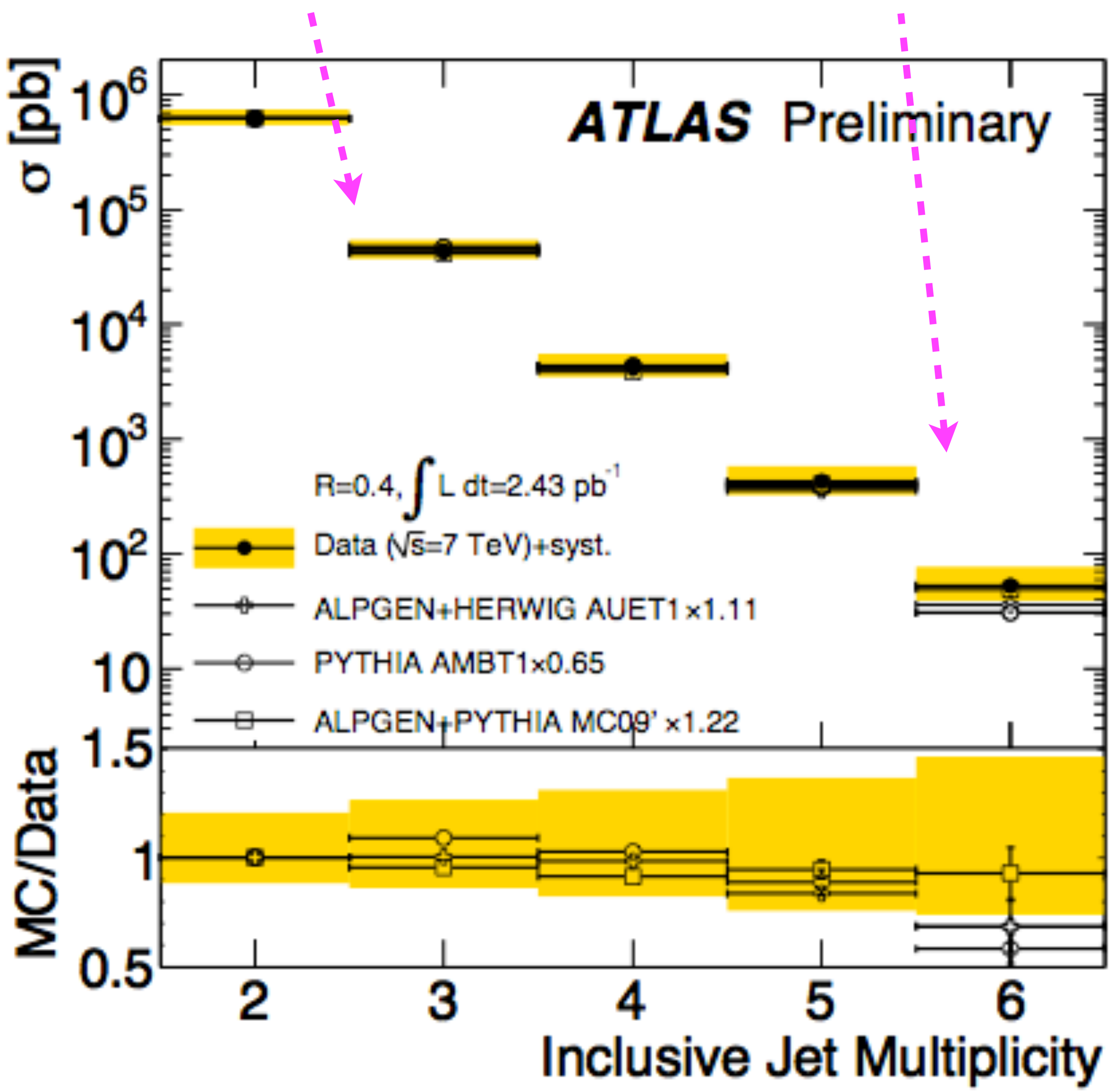
$|y| \leq 2.8$ & $p_T \geq 60$ GeV (y is rapidity)

Event Selection:

At least two good jets & At least one of them $p_T \geq 80$ GeV

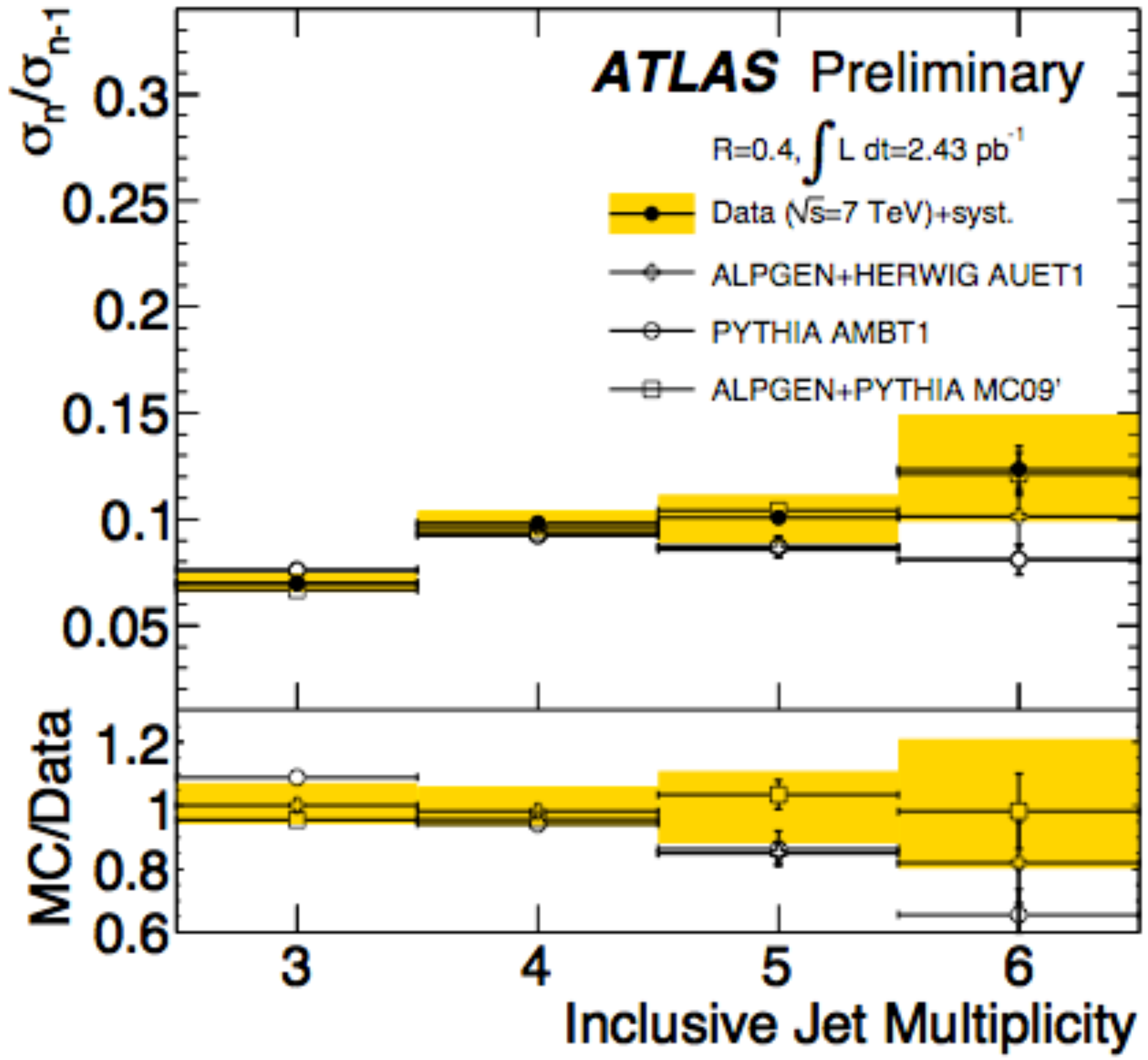
Total Cross-section

systematic about 10-20%   systematic about 30-40%



Total inclusive jet cross section as function of multiplicity

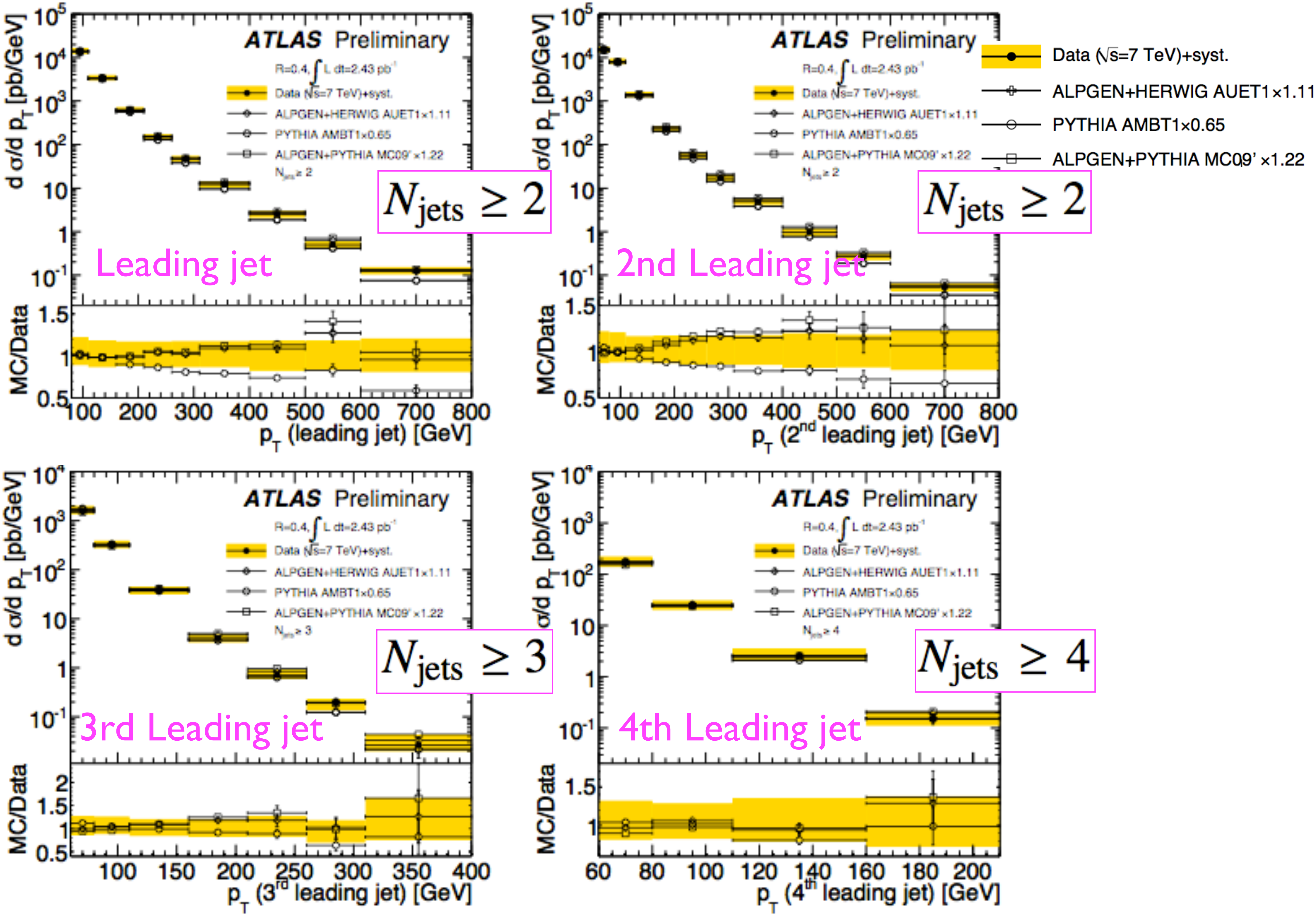
- JES uncertainty dominates



Ratio of the n-jet total cross section to the (n-1)-jet total cross section as function of multiplicity

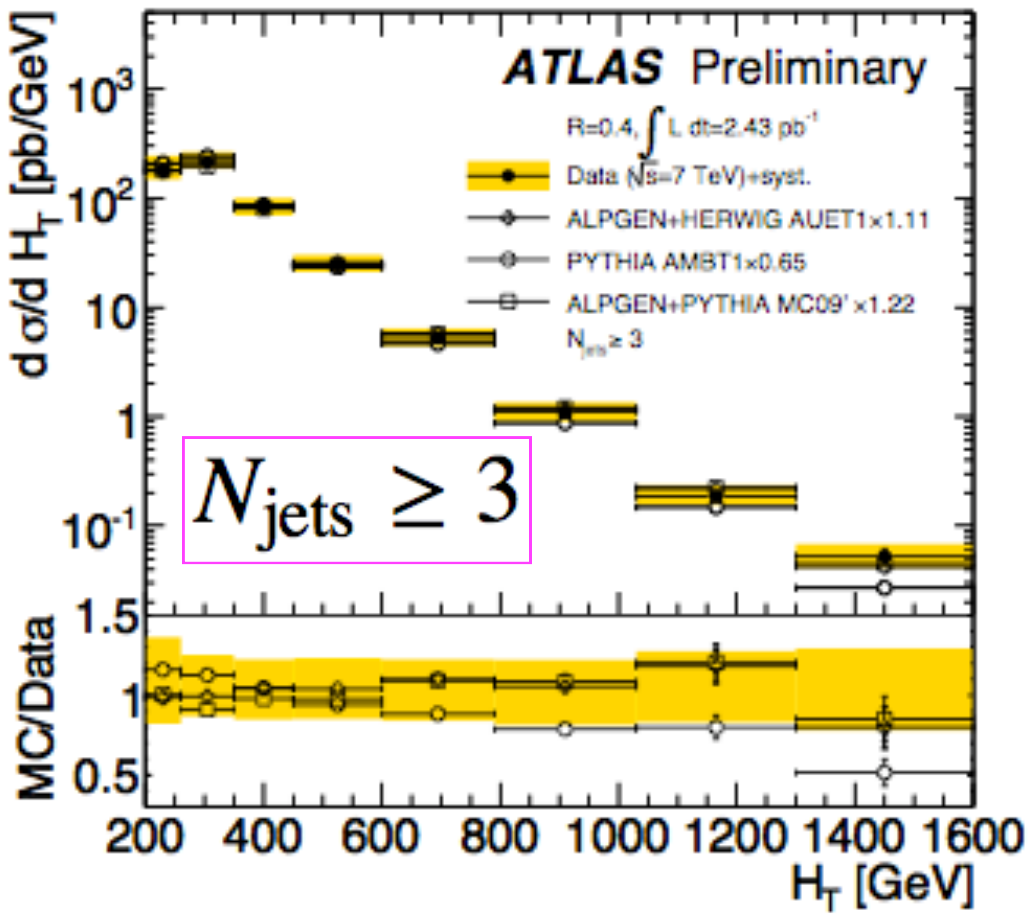
- JES uncertainty reduces
- Differences exists for different MC simulations.

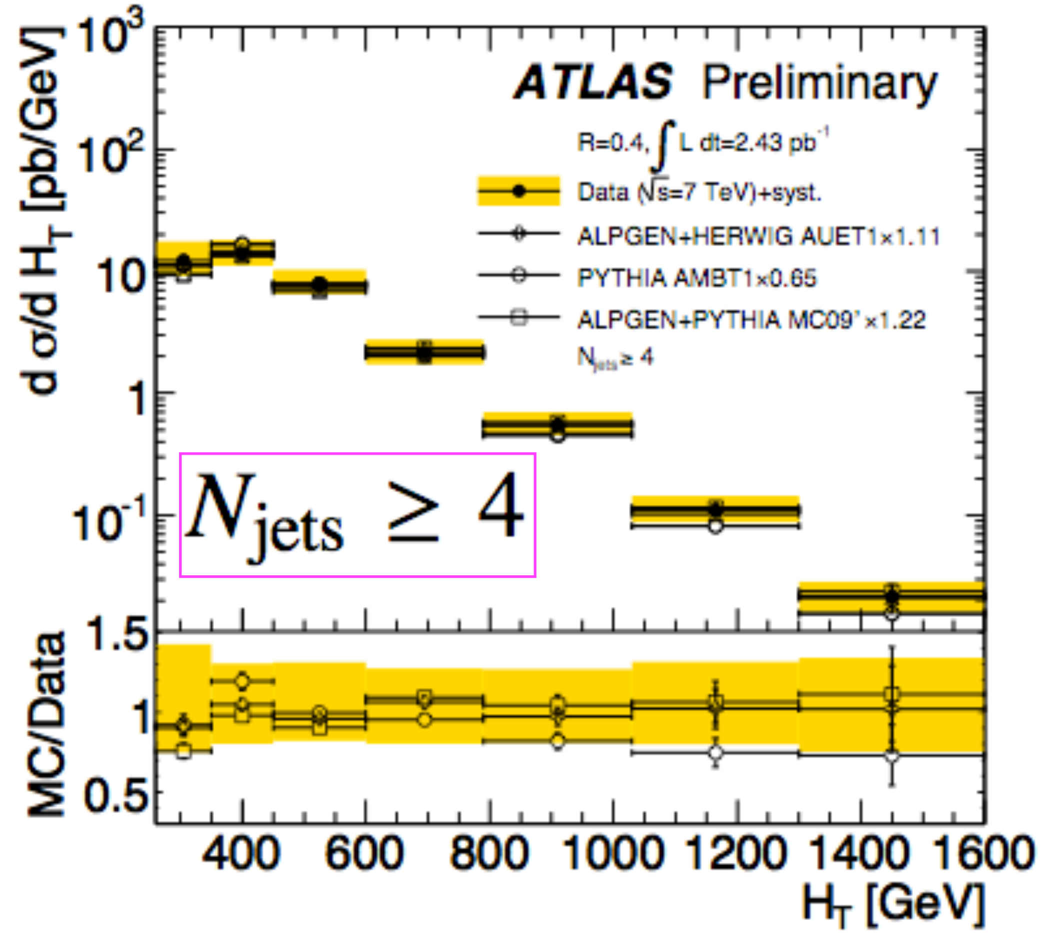
Differential Cross-section

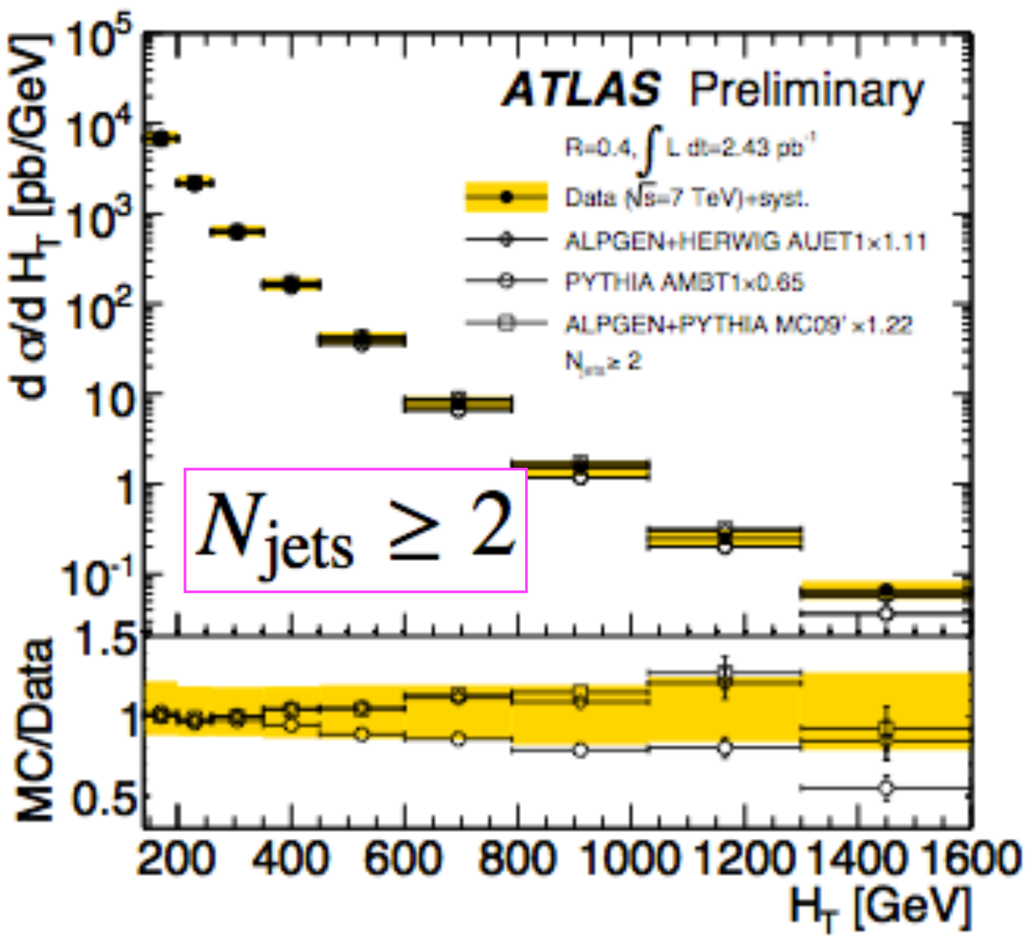


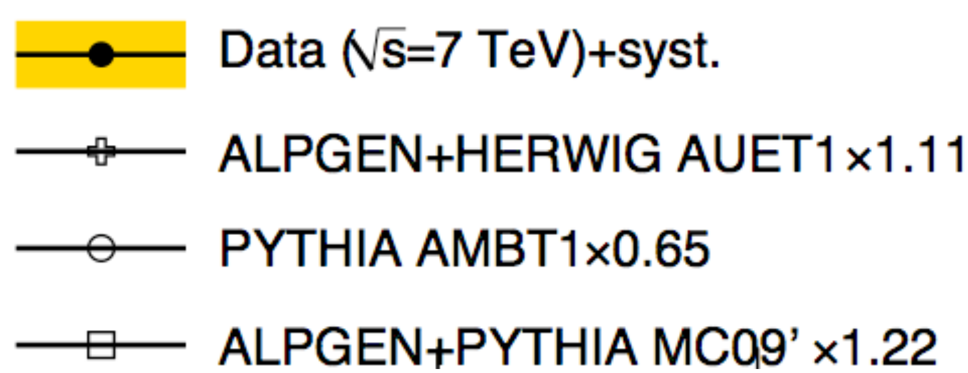
Diff. Cross-section w.r.t. H_T

H_T is the scalar sum of the pT of selected jets in the event



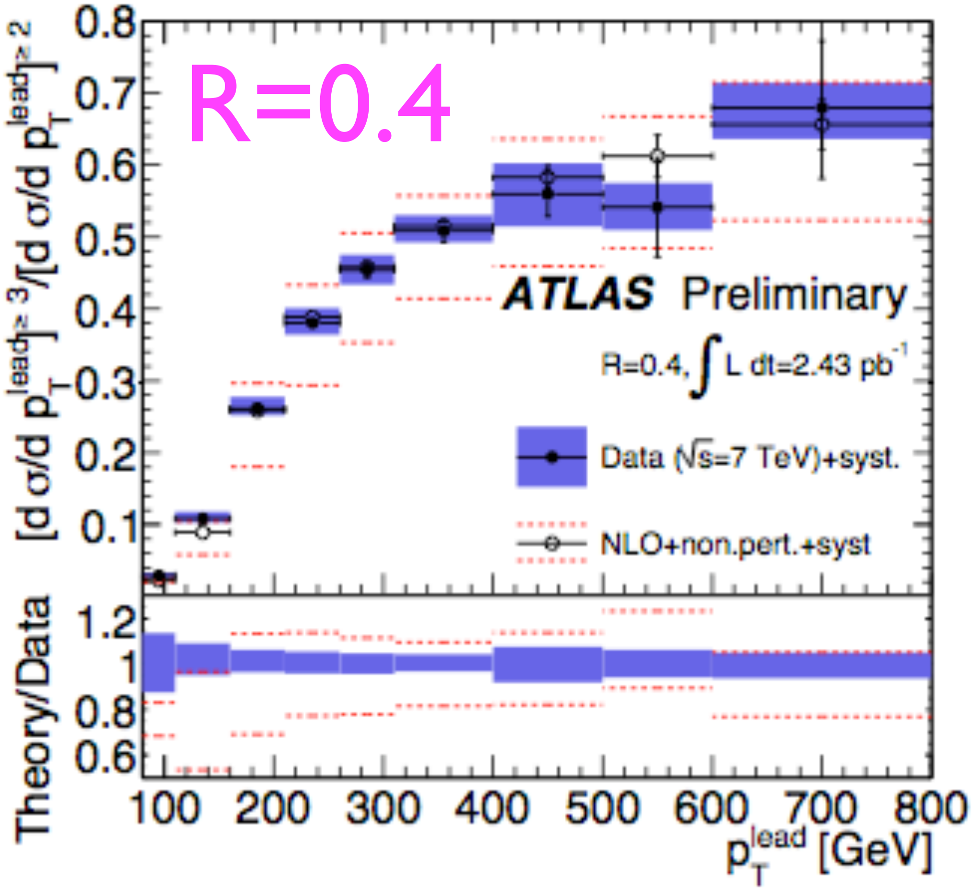


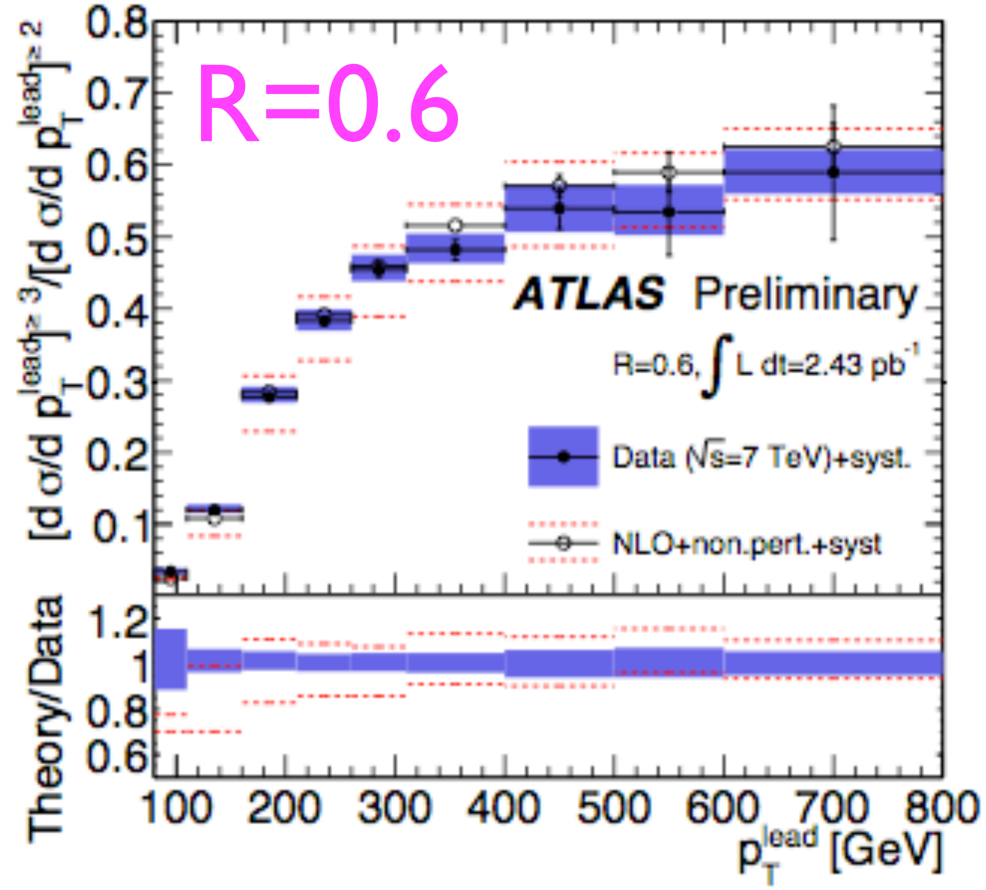




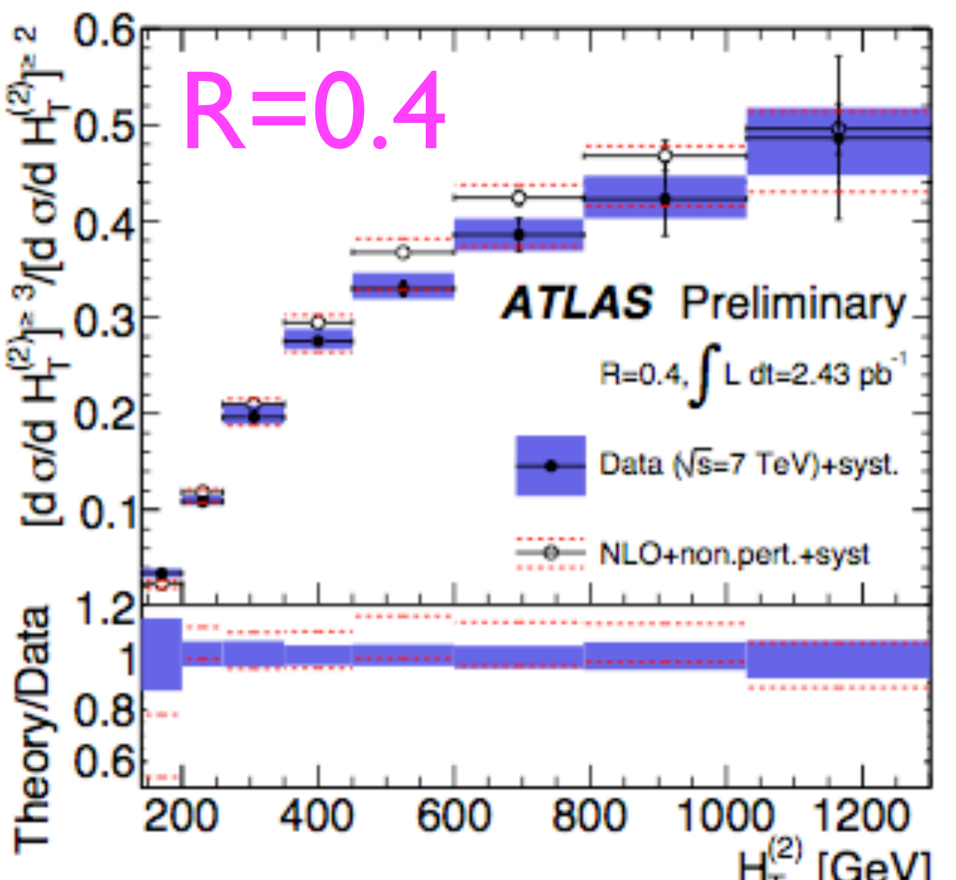
Ratio of 3-to-2 jet Diff. x-section (NLO)

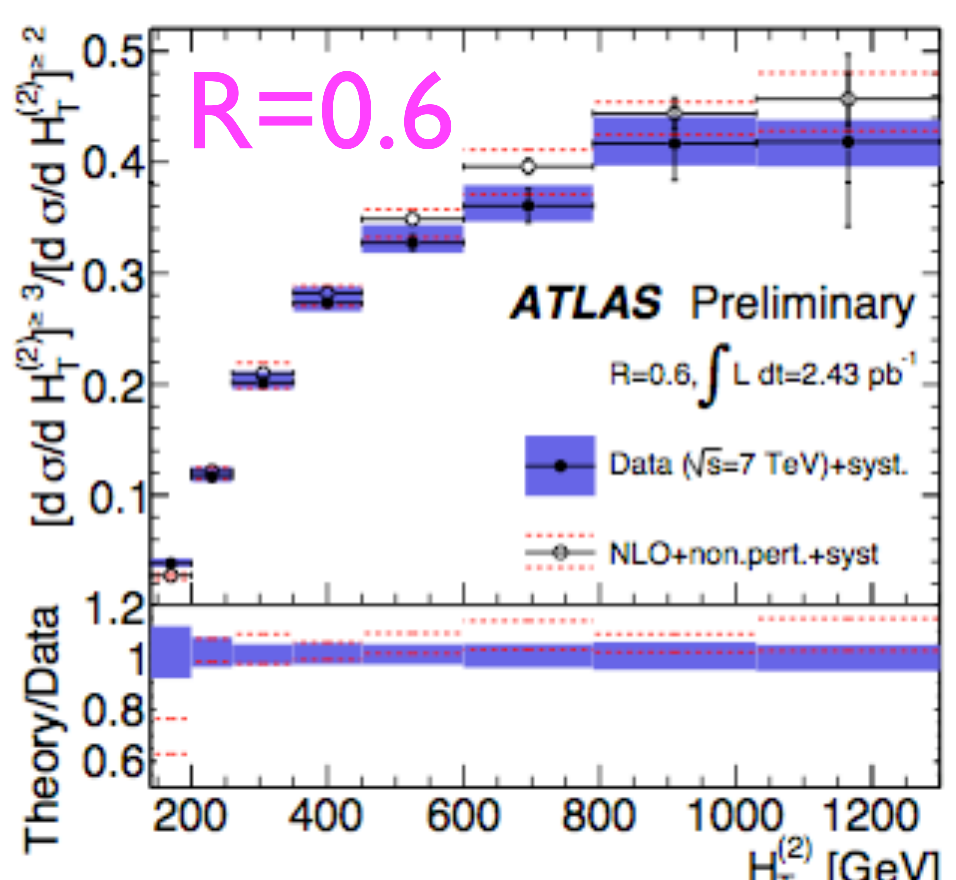
$[d\sigma/d\, p_T^{lead}]^{\geq 3}/[d\sigma/d\, p_T^{lead}]^{\geq 2}$





$[d\sigma/d\, H_T^{(2)}]^{\geq 3}/[d\sigma/d\, H_T^{(2)}]^{\geq 2}$

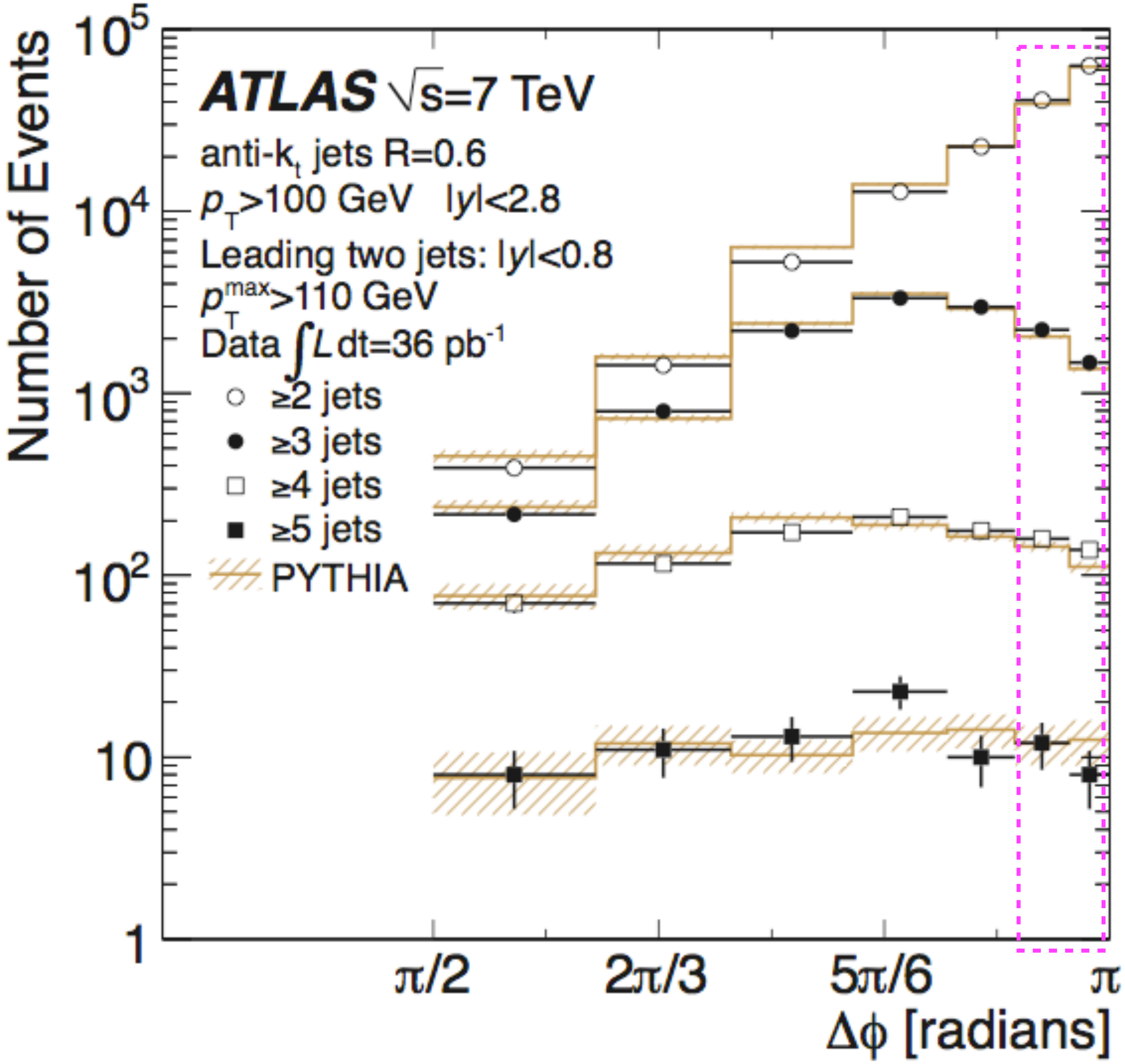




Measurement of Dijet Azimuthal Decorrelations

Integrated Lumi ~ 36 pb^{-1}

Dijet Azimuthal Decorrelation



$$\Delta\phi \equiv \left|\phi_{\text{jet}}^{1^{st}\text{-leading}} - \phi_{\text{jet}}^{2^{nd}\text{-leading}}\right|$$

Configurations:

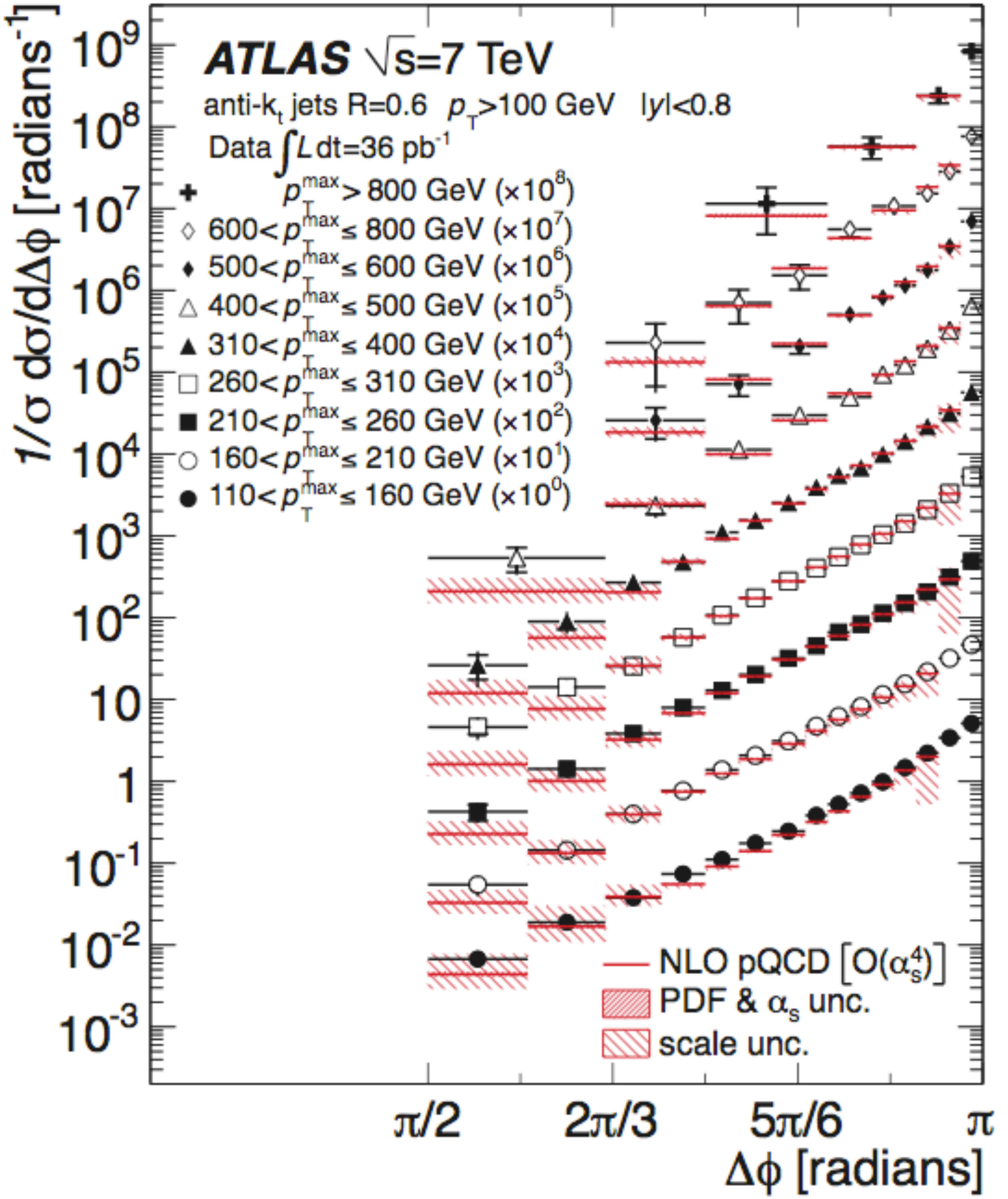
- Data are calibrated but uncorrected.
- All uncertainties are statistical only.
- Trigger efficiency is about 100%.

Comments:

- QCD predicted decorrelation is revealed at higher jet pT values (up to 1.3 TeV)
- Good agreement between data and MC
- The decorrelation increases when a third high-pT jet is also required.
- Events with additonal high-pT jets widen the overall distribution.

$\Delta\phi \to \pi$ means two back-to-back leading jets

Differential Cross-section



Configurations:

- Data are corrected in a single step with bin-by-bin unfolding method
- The correction factors (PYTHIA) lie within $\pm 9\%$ of unity.
- The leading sources of systematic uncertainty are:
  (1) JES calibration
  (2) bin-by-bin unfolding method
  (3) jet energy and position resolution
- $\Delta\phi \to \pi$ is excluded (divergence)

Notice the slope change!

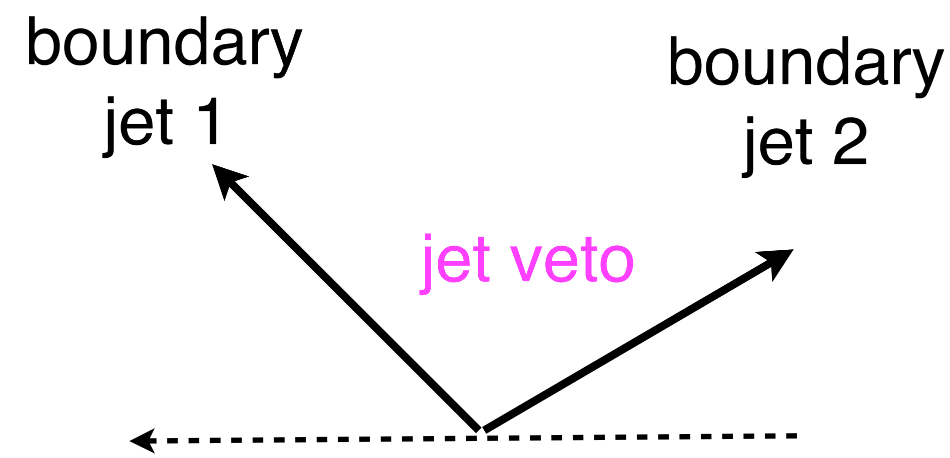
Measurement of Dijet Production with a jet veto

Integrated Lumi ~ 38 pb^{-1}

Motivation

Motivation :

- BFKL-like dynamics for large jet rapidity separation.
- Effect of wide-angle soft-gluon radiation in the limit that the average dijet transverse momentum is much larger than the scale used to veto on additional jet.
- Background for Higgs production via vector boson fusion.



Dijet production with a veto on additional radiation (with a scale) in the rapidity interval

Boundary jets: ***physics:***

Selection A	Use the two leading jets	→	wide-angle gluon radiation
Selection B	Use the two jets with largest absolute rapidity	→	BFKL-like dynamics

Configuration

Two measurements:

- gap-fraction: The fraction of dijet events that satisfy a jet veto in the rapidity interval.
- mean number: The mean number of jets in the rapidity interval

Event selection:

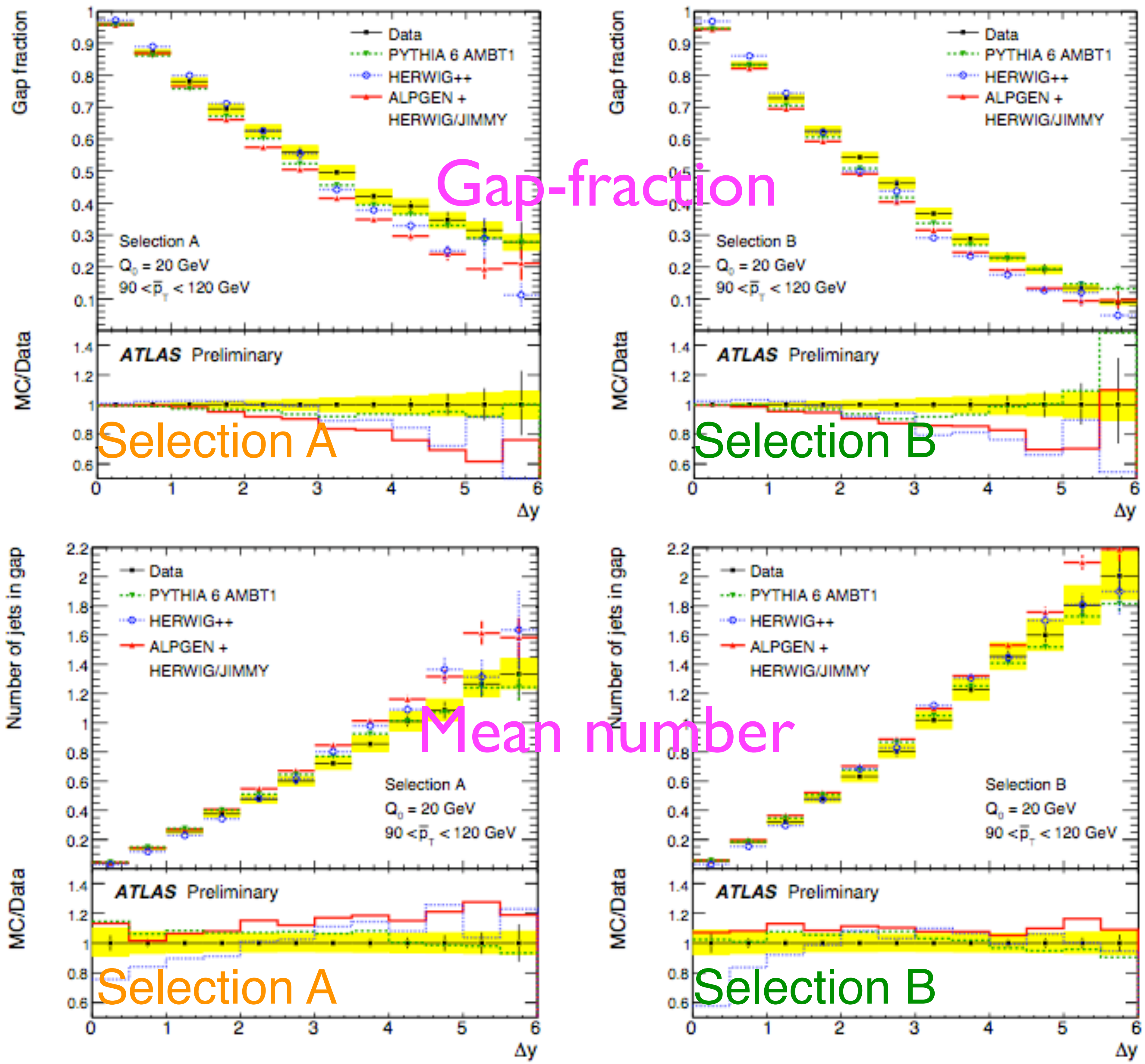
- Each boundary jet must satisfy pT>20 GeV and |y|<4.5
- The average transverse momentum of the boundary jets should be greater than 50 GeV

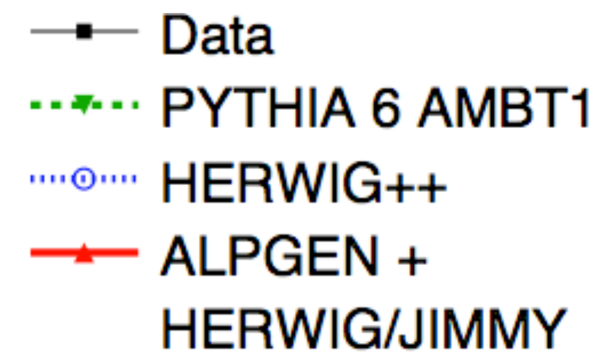
Veto Scale: $Q_0 = 20\ \mathrm{GeV}$

MC Tools: HEJ (LO + resummation)

POWHEG Box (NLO)

Comparison of Event Generators

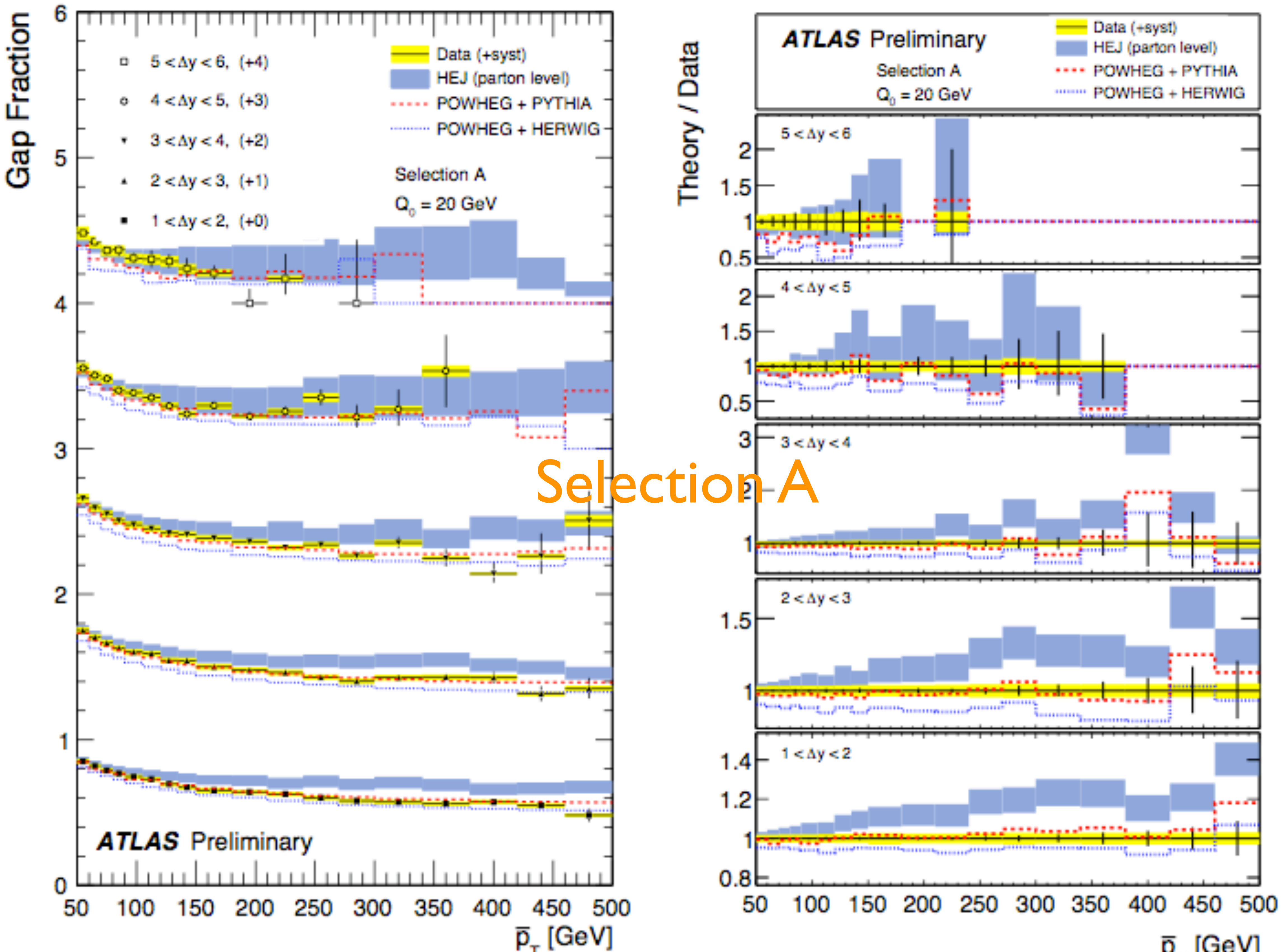




PYTHIA is best, slightly overestimate jet activity at low delta y

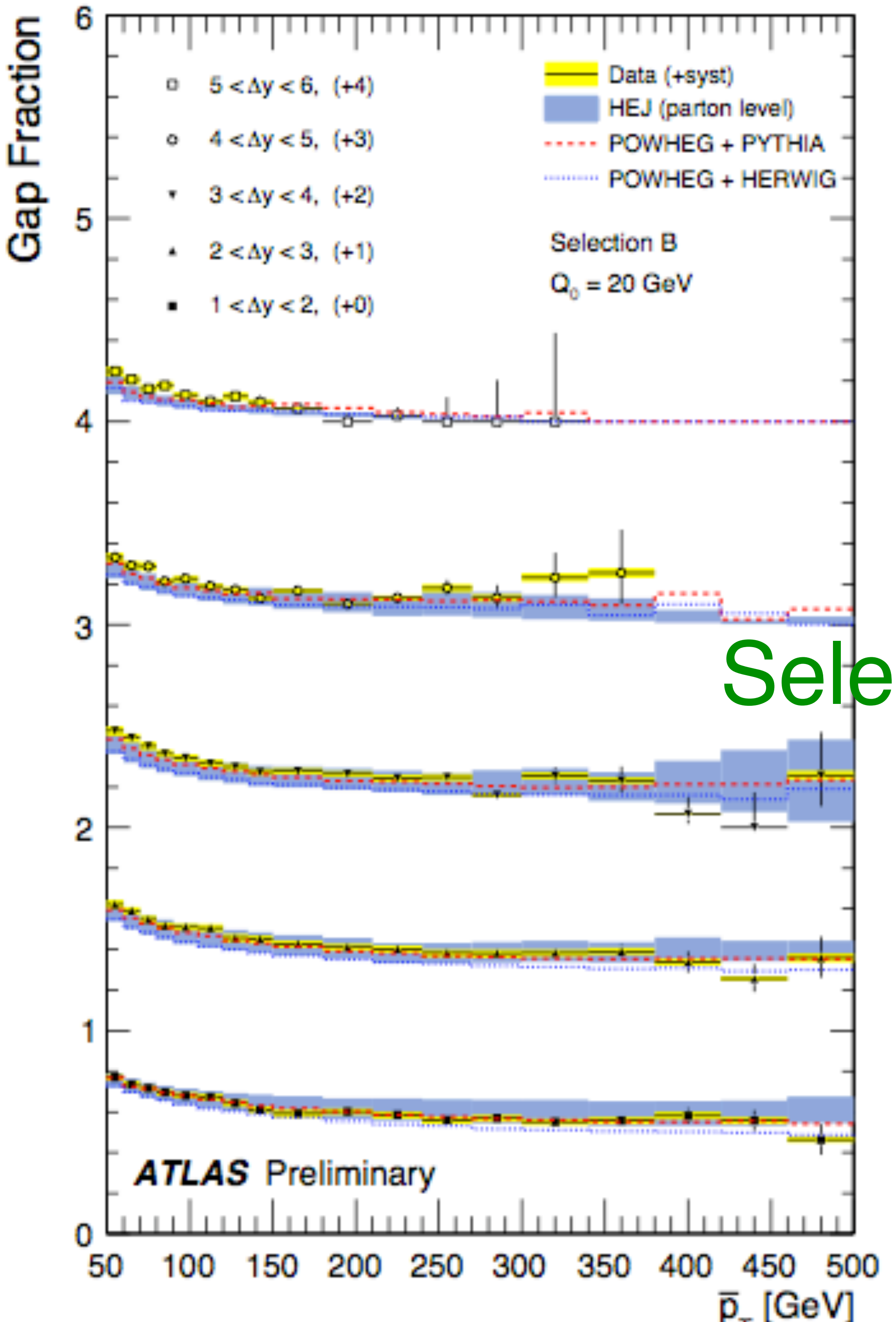
ALPGEN shows the largest deviation: predict too much jets activity at large value of delta y

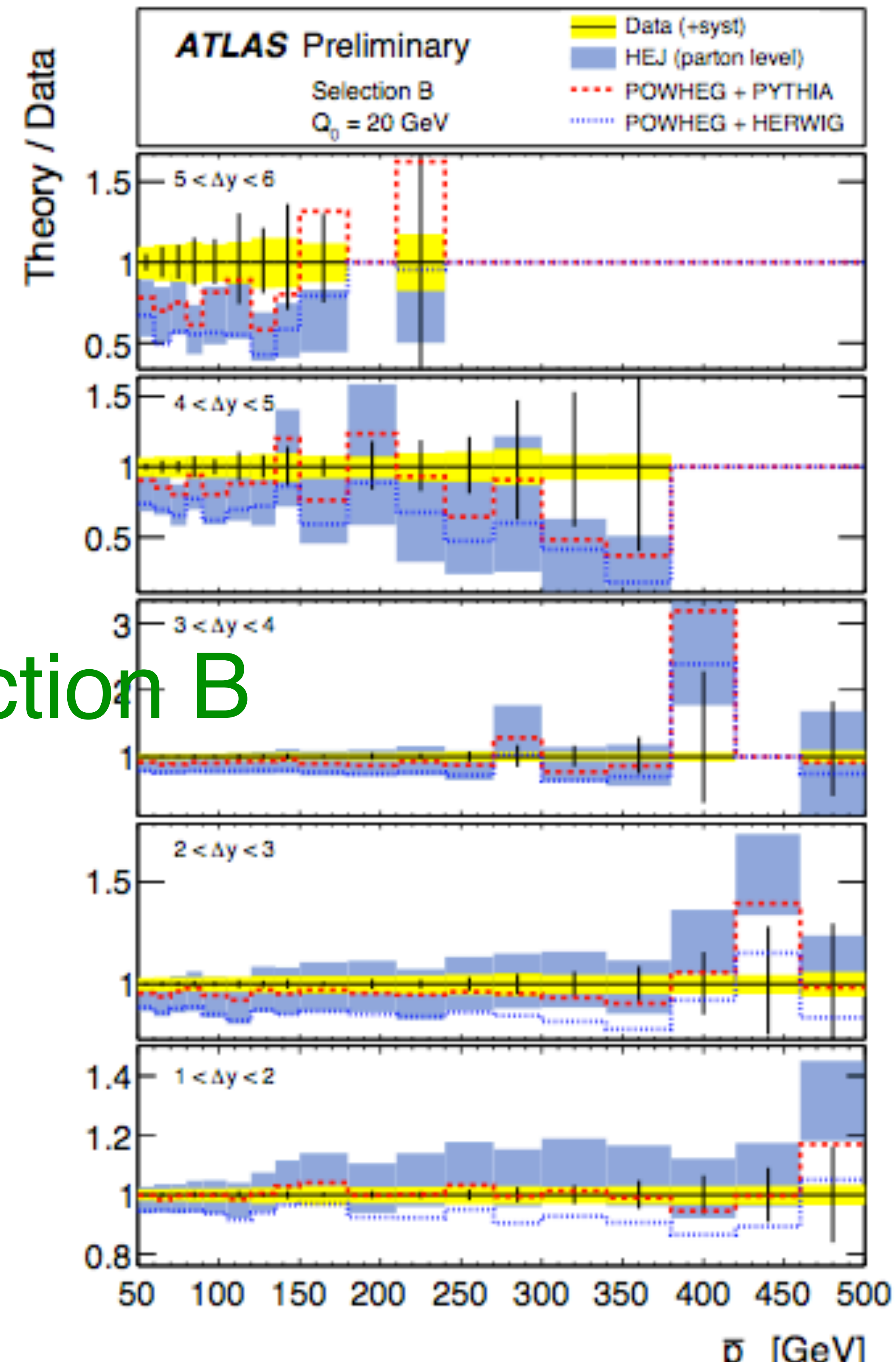
Comparison of HEJ and POWHEG



Selection A

Comparison of HEJ and POWHEG





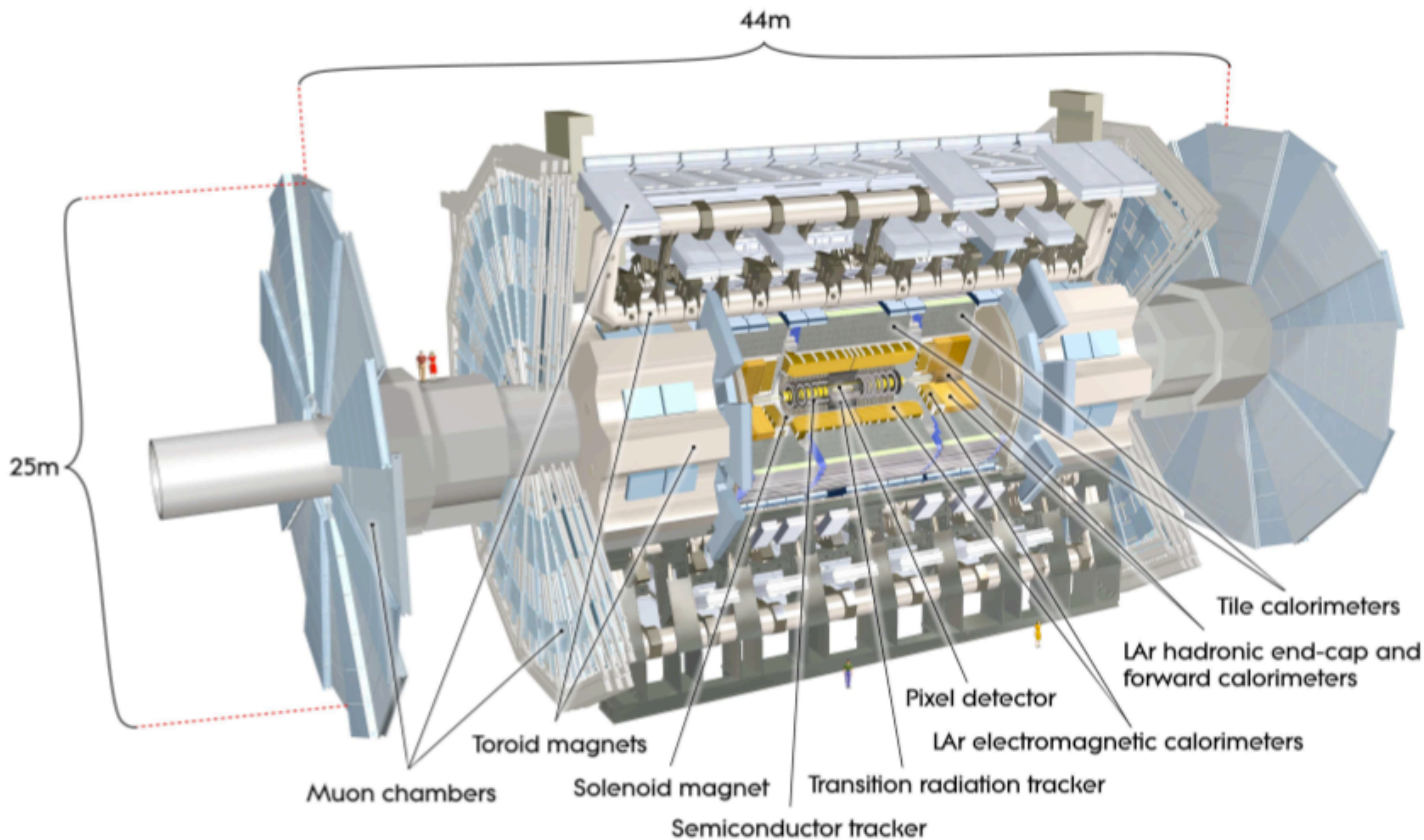
Selection B

Summary and Conclusion

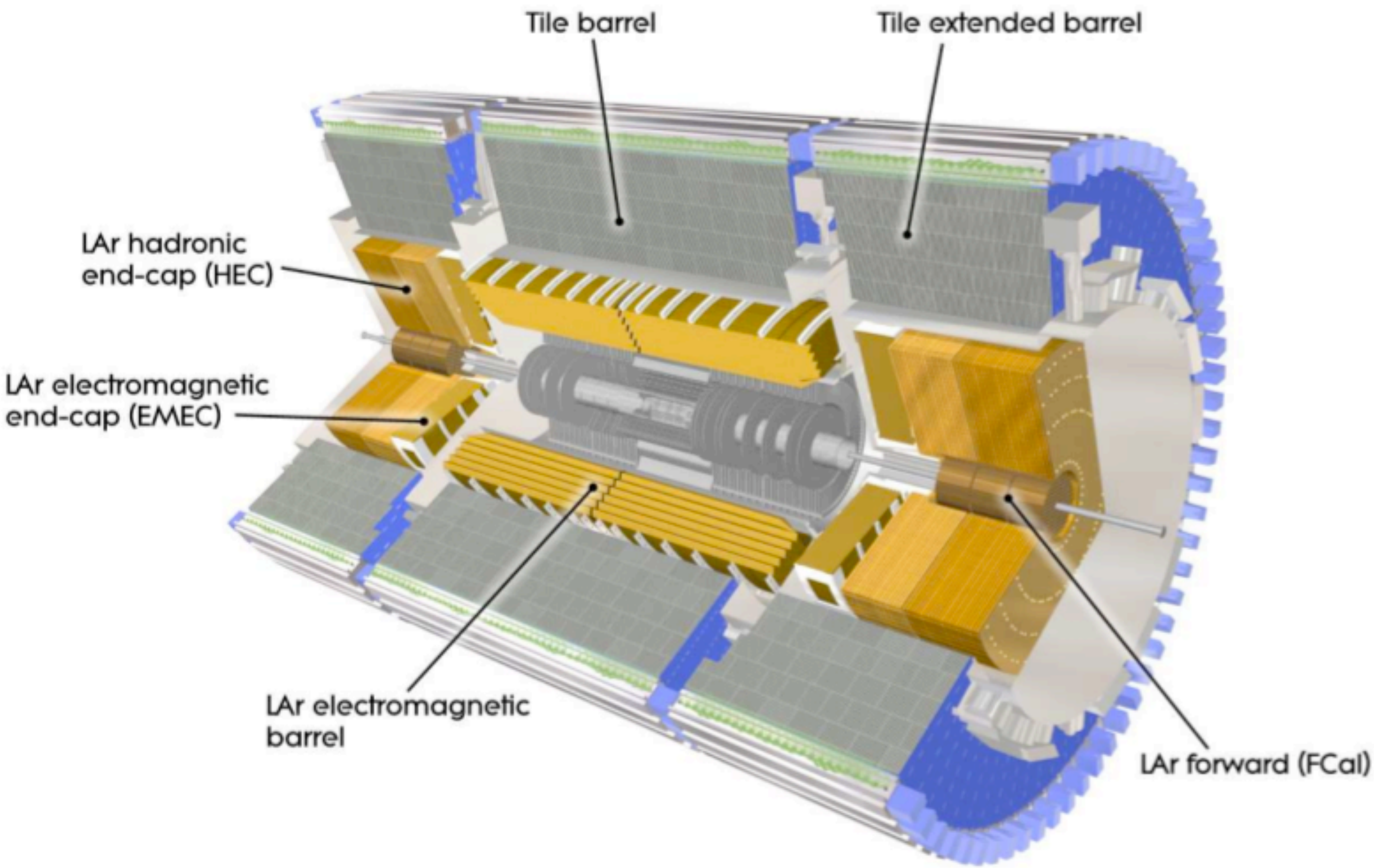
- Multi-jet cross-section, dijet azimuthal decorrelation and dijet production with a veto jet have been studied using early ATLAS 7 TeV data.
- In general, there is good agreements between theoretical predictions and data.
- Comparisons to Monte Carlo simulations illustrate the advantages and disadvantages of different QCD predictions (LO+PS, LO +resummation and NLO).

Backup

The ATLAS Detector

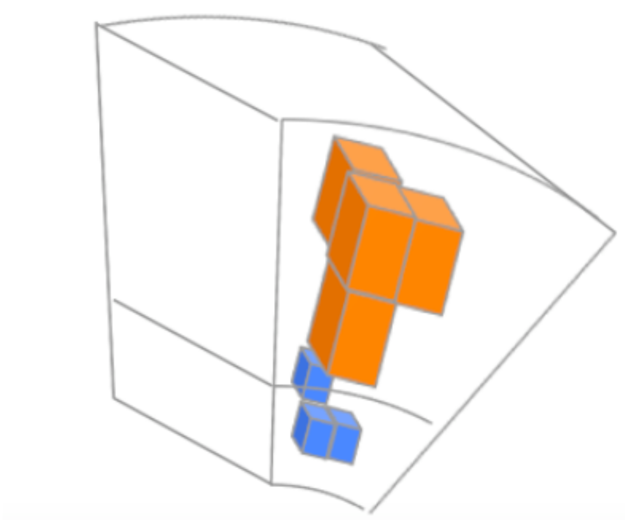


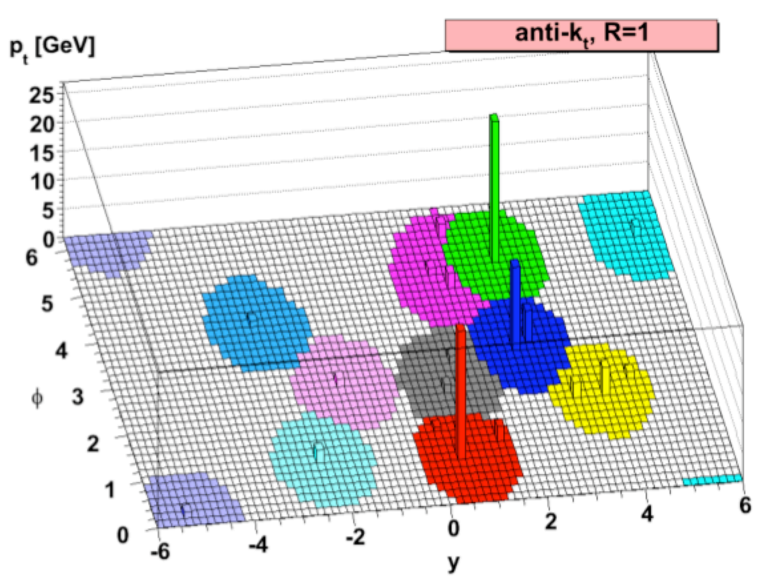
The ATLAS Calorimeter



The ATLAS Jets

Topological clusters





anti-kt algorithm:

- Using AntiKt algorithm of the fastjet [1] library
- Use clusters or towers as proto-jets and define a distance measure:

$$d_{ij} = min\left(\frac{1}{p_{T_i}^2}, \frac{1}{p_{T_j}^2}\right)\frac{\Delta_{ij}^2}{R^2} \quad (1)$$

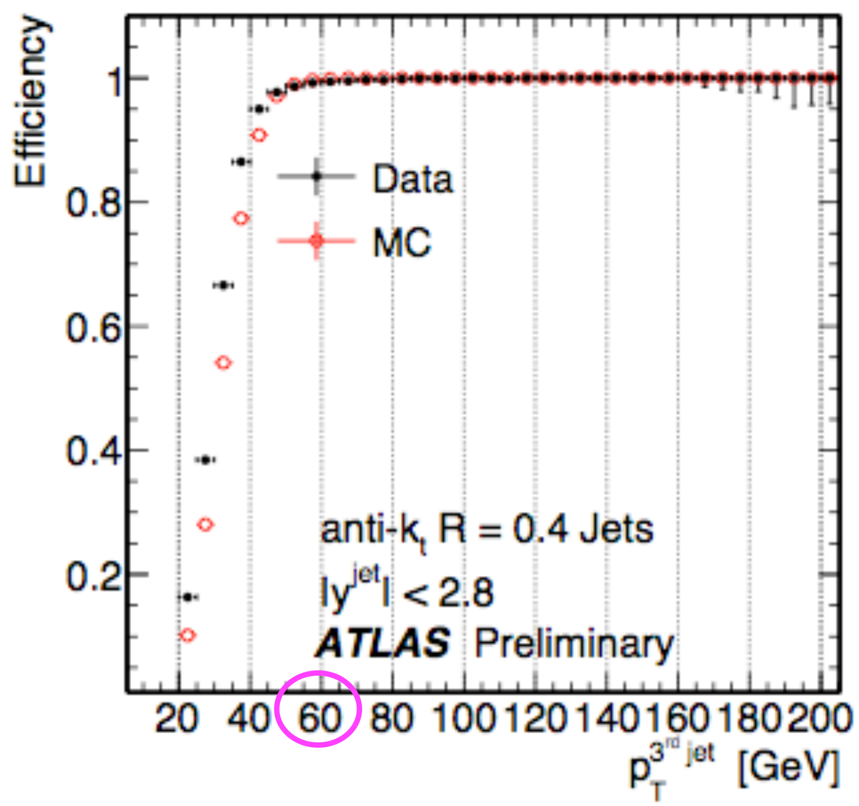
$$d_{ii} = \frac{1}{p_{T_i}^2} \quad (2)$$

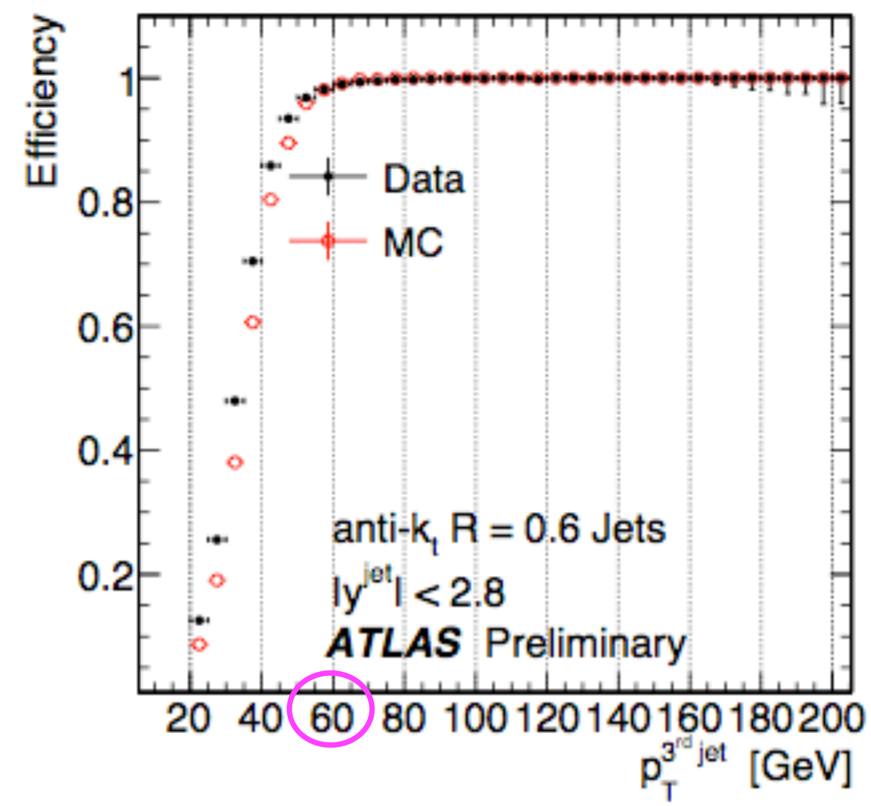
where:

  - $\Delta_{ij} = (\phi_i - \phi_j)^2 + (y_i - y_j)^2$
  - p_{T_i}, y_i, and ϕ_i are the transverse momentum, rapidity and azimuth of proto-jet i
  - $R = 0.6$ (0.4) in ATLAS reconstruction
- Until no proto-jet are left compute all d_{ij} and take smallest d_{ij}:

$i \neq j$ Remove proto-jet i and j and add 4-vector sum as new proto-jet
$i = j$ Remove proto-jet i and call it a final jet

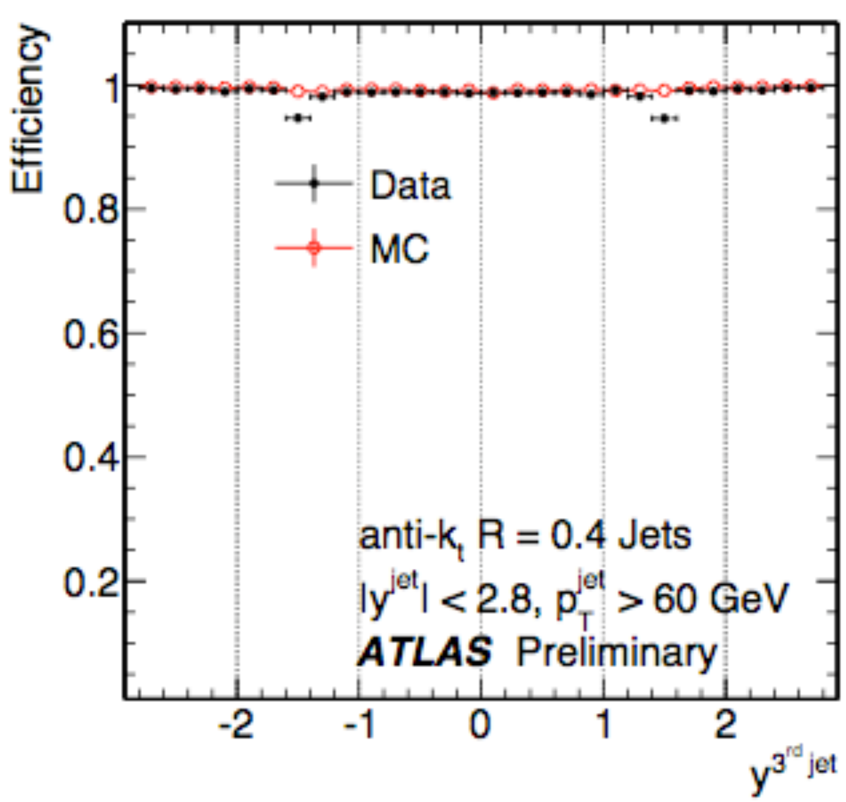
Jets Trigger Efficiency

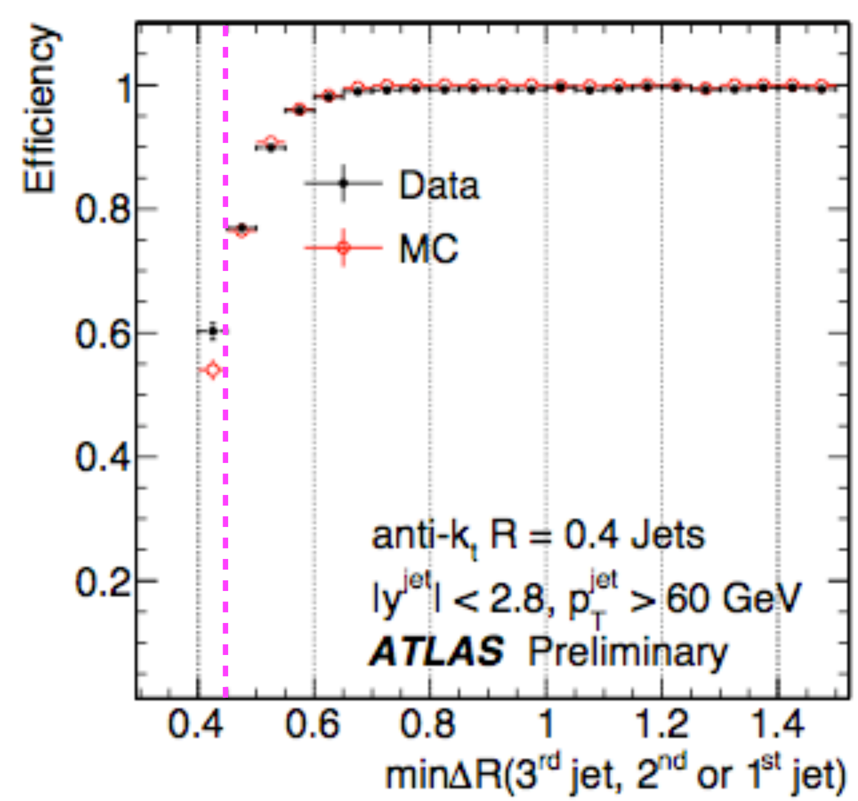




Efficiency plateau pT>60 GeV

small inefficiency in the data is not presented in the MC



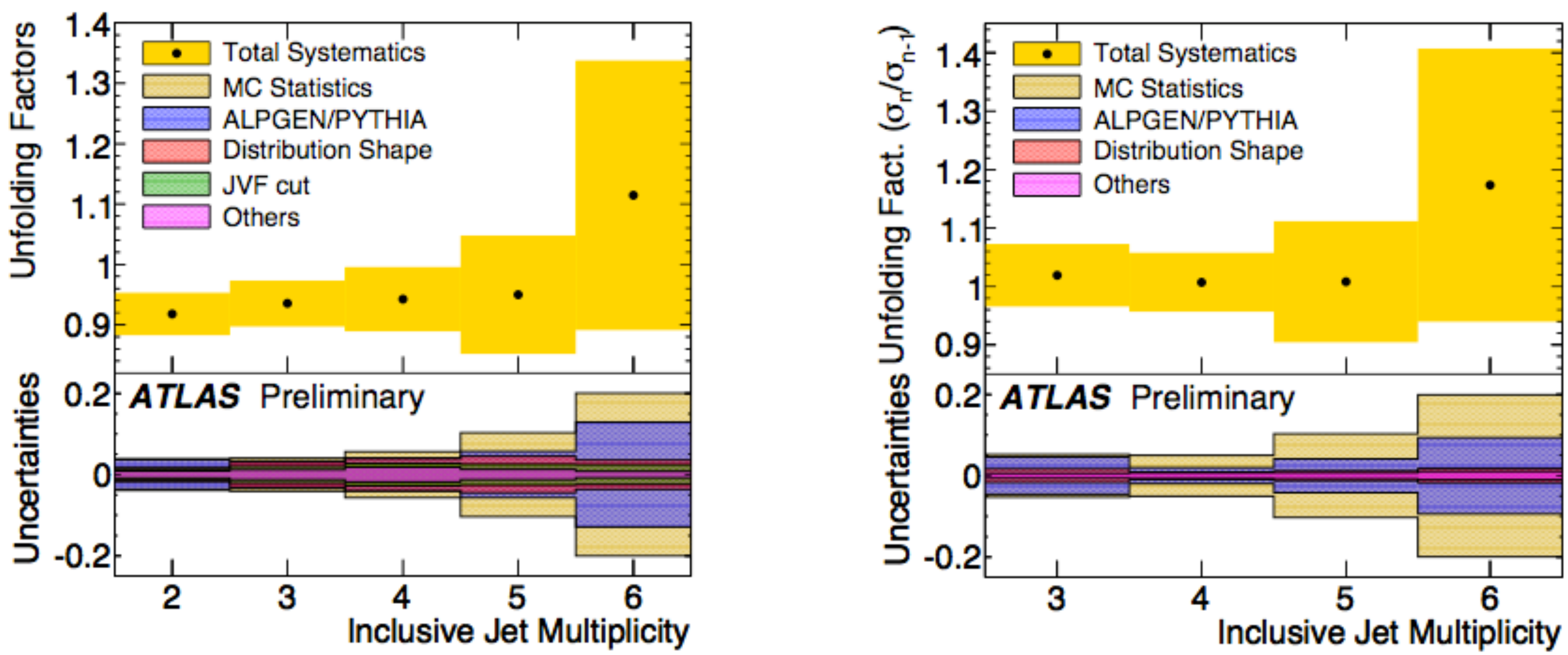


good agreement between data and MC

Systematic Uncertainty

Absolute JES ⊕ Relative JES ⊕ Unfolding factors

- The JES uncertainty is the dominant systematic uncertainty
- Besides the absolute (standard) JES uncertainty, multi-jet analysis introduce additional systematic uncertainties - relative JES uncertainty, due to factors such as near-by activity in the calorimeter, light-quark/gluon response.
- Unfolding factors are for detector effects like trigger inefficiencies etc.

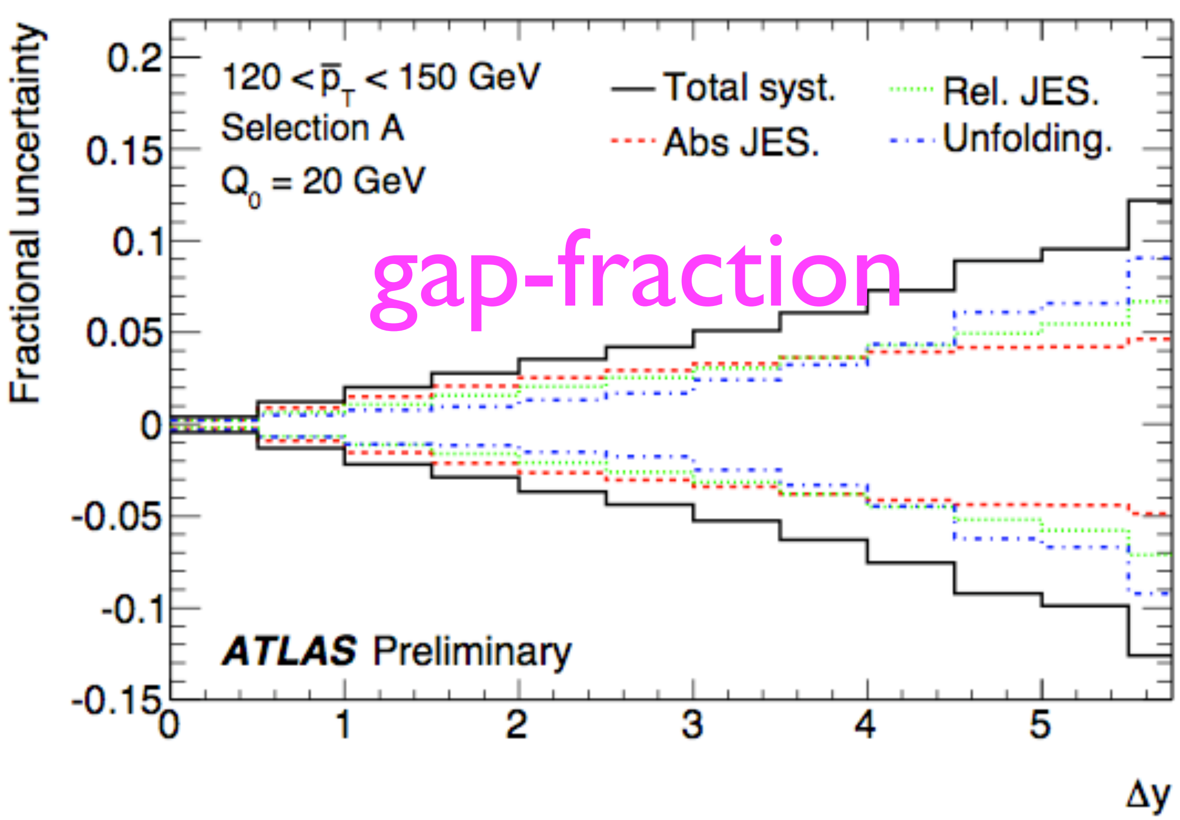


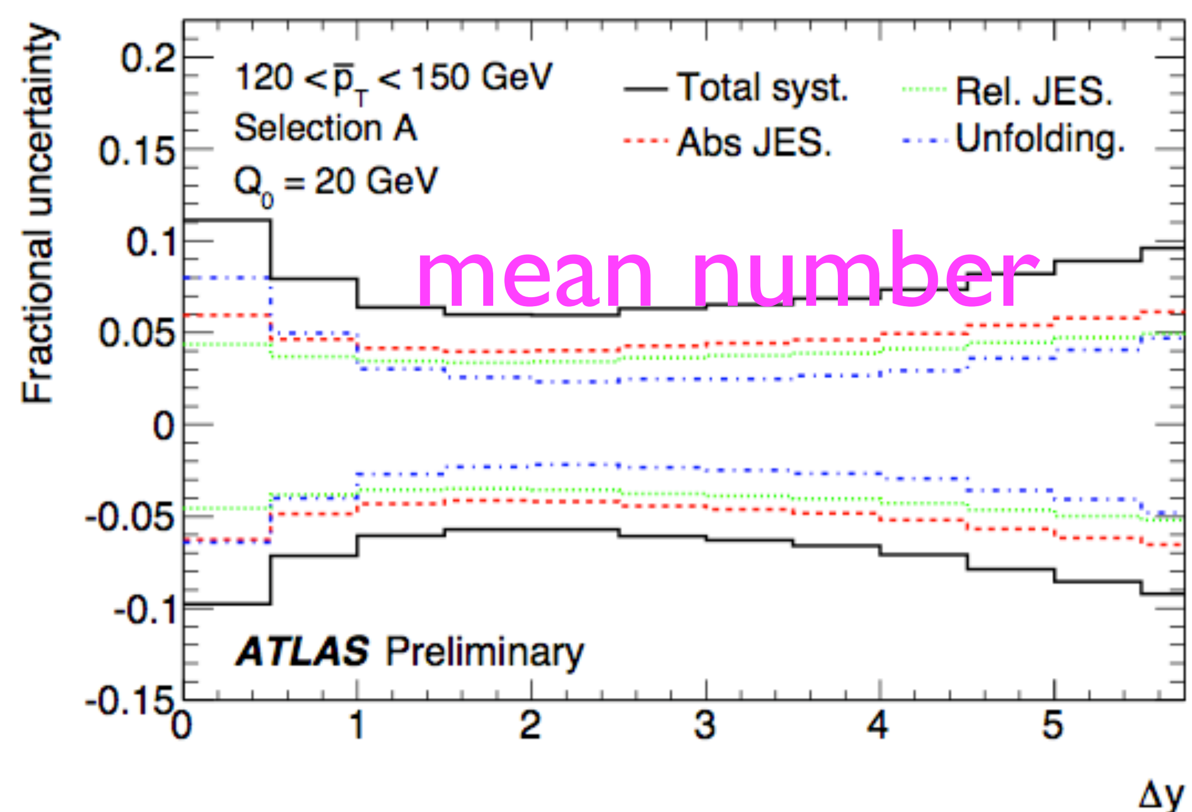
Unfolding factors as a function of the inclusive jet multiplicity for the cross sections (left) and for the n to n-1 cross section ratios (right).

Summary of Systematic Uncertainties

Sources of systematic uncertainties were investigated: pileup, cosmic and beam related backgrounds, impact of jet cleaning cuts, trigger strategy.

So, the relevant systematic uncertainties are those associated to JES and detector unfolding.

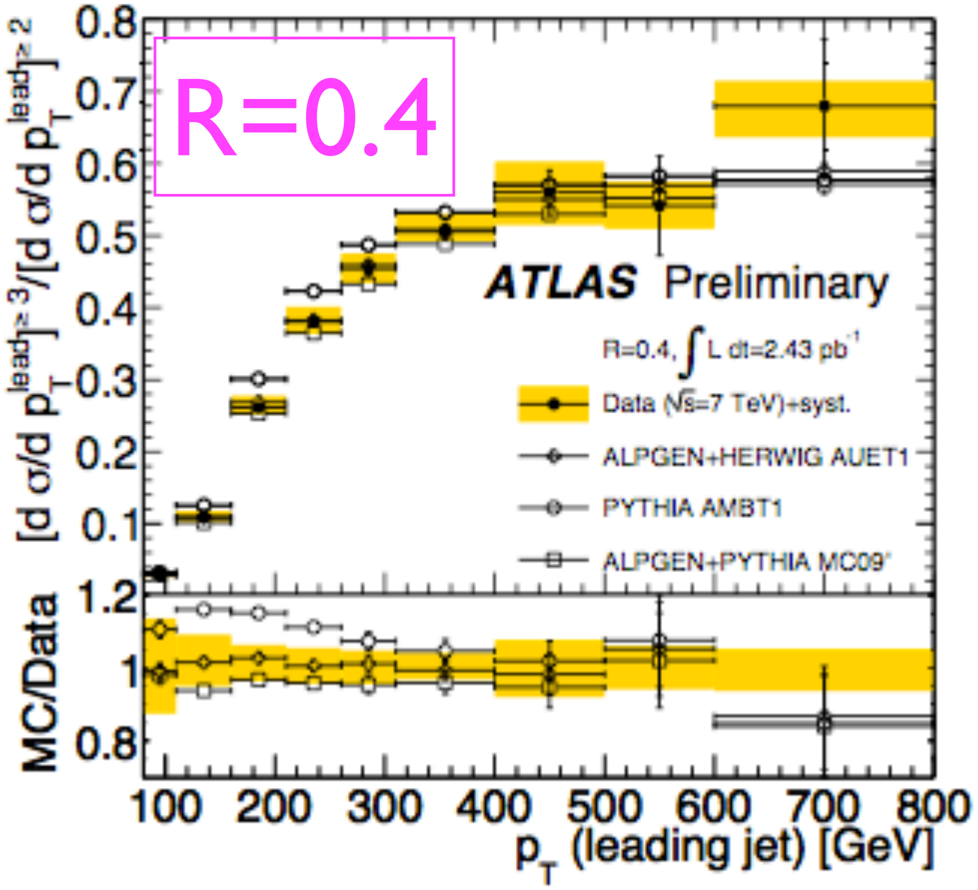


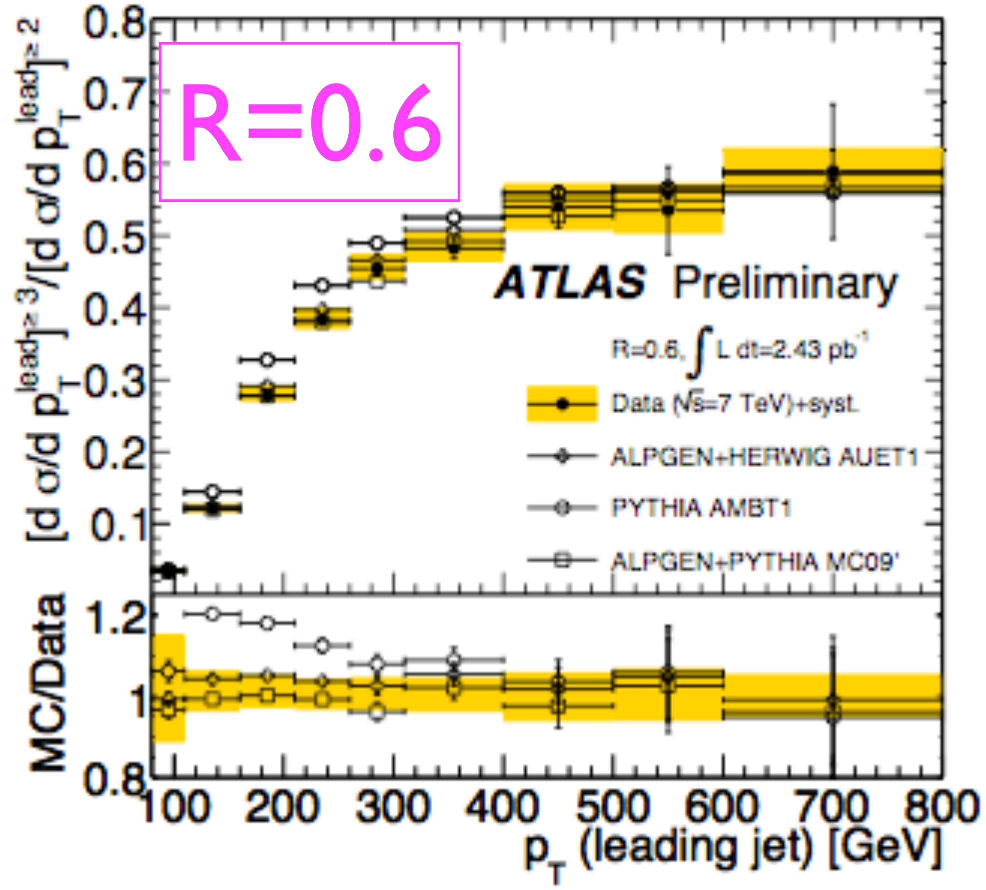


Example of the contribution to the systematic uncertainty

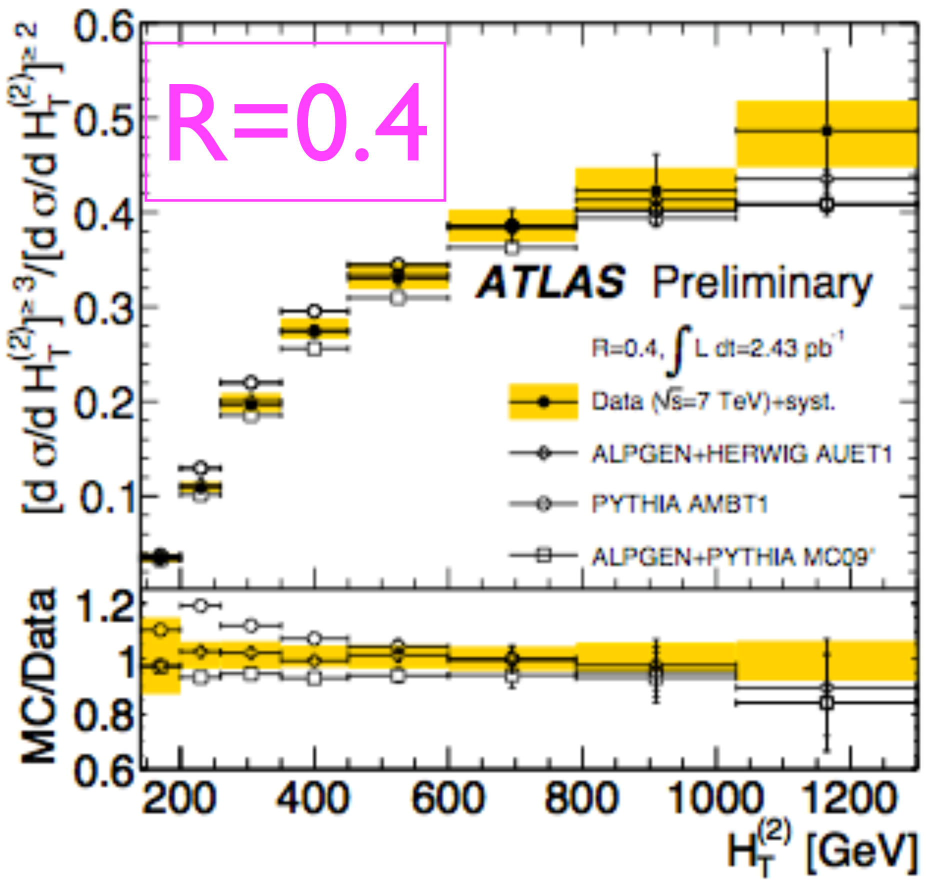
Ratio of 3-to-2 jet Diff. x-section (LO)

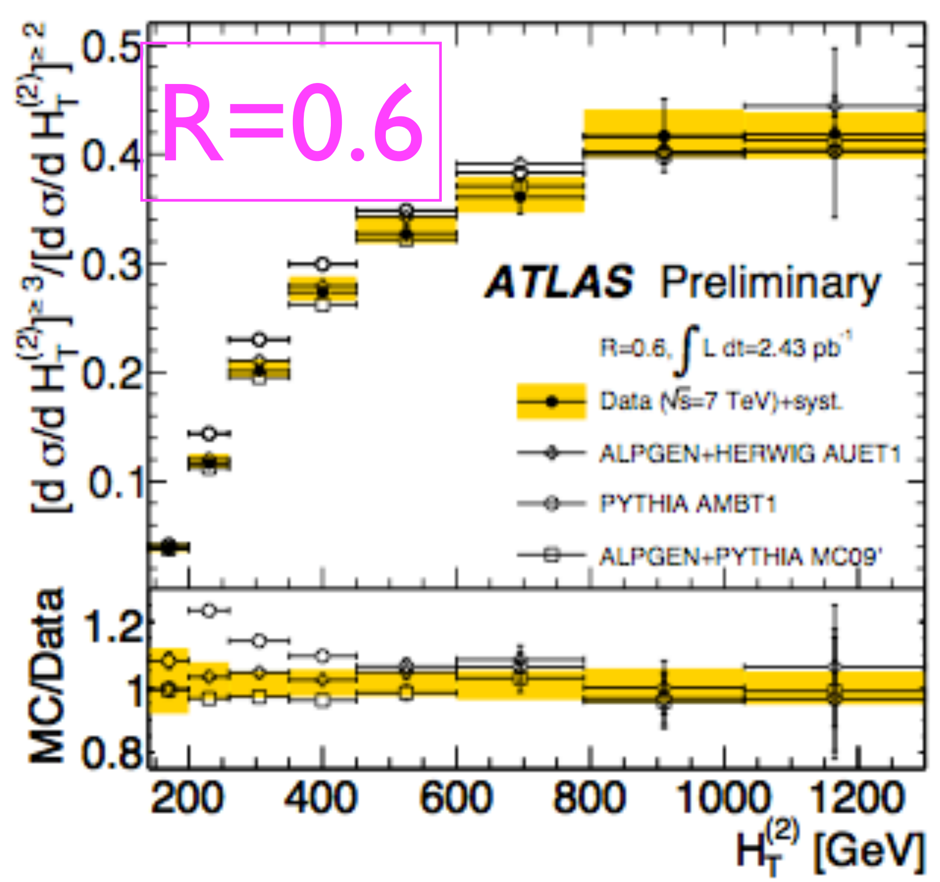
$[d\sigma/d p_T^{lead}]^{\geq 3}/[d\sigma/d p_T^{lead}]^{\geq 2}$





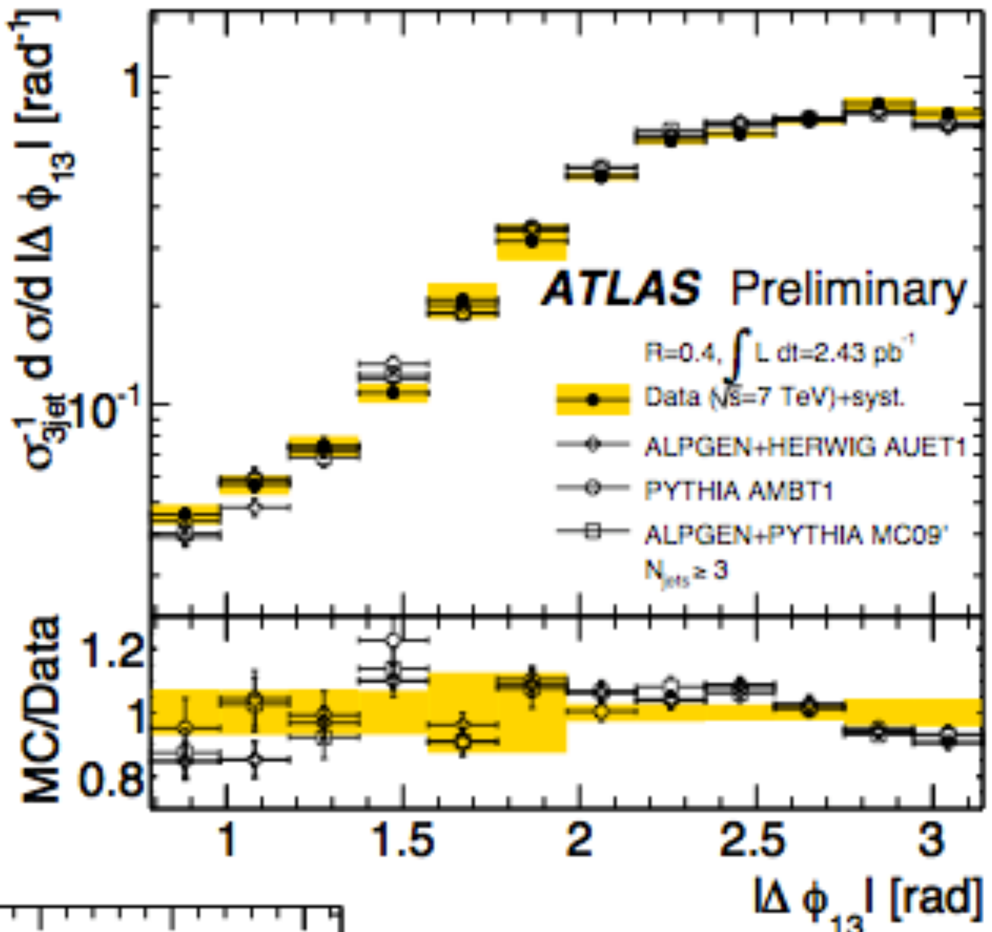
$[d\sigma/d H_T^{(2)}]^{\geq 3}/[d\sigma/d H_T^{(2)}]^{\geq 2}$

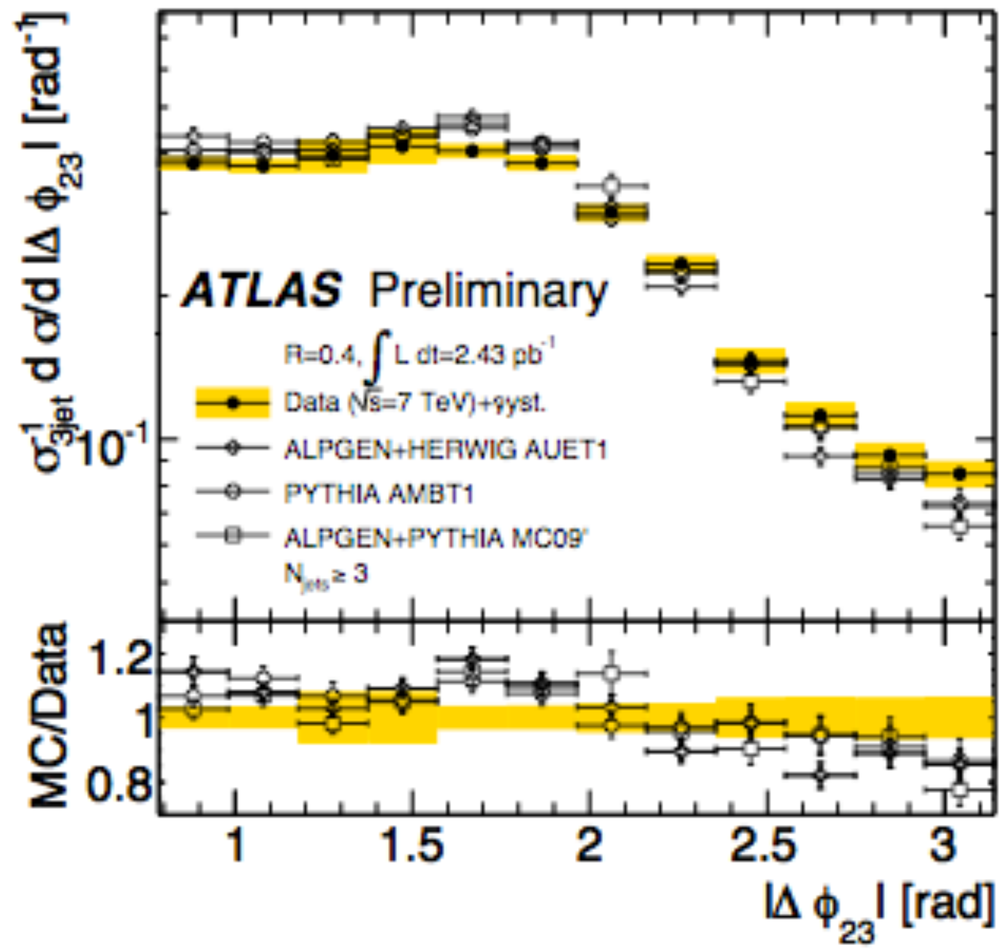


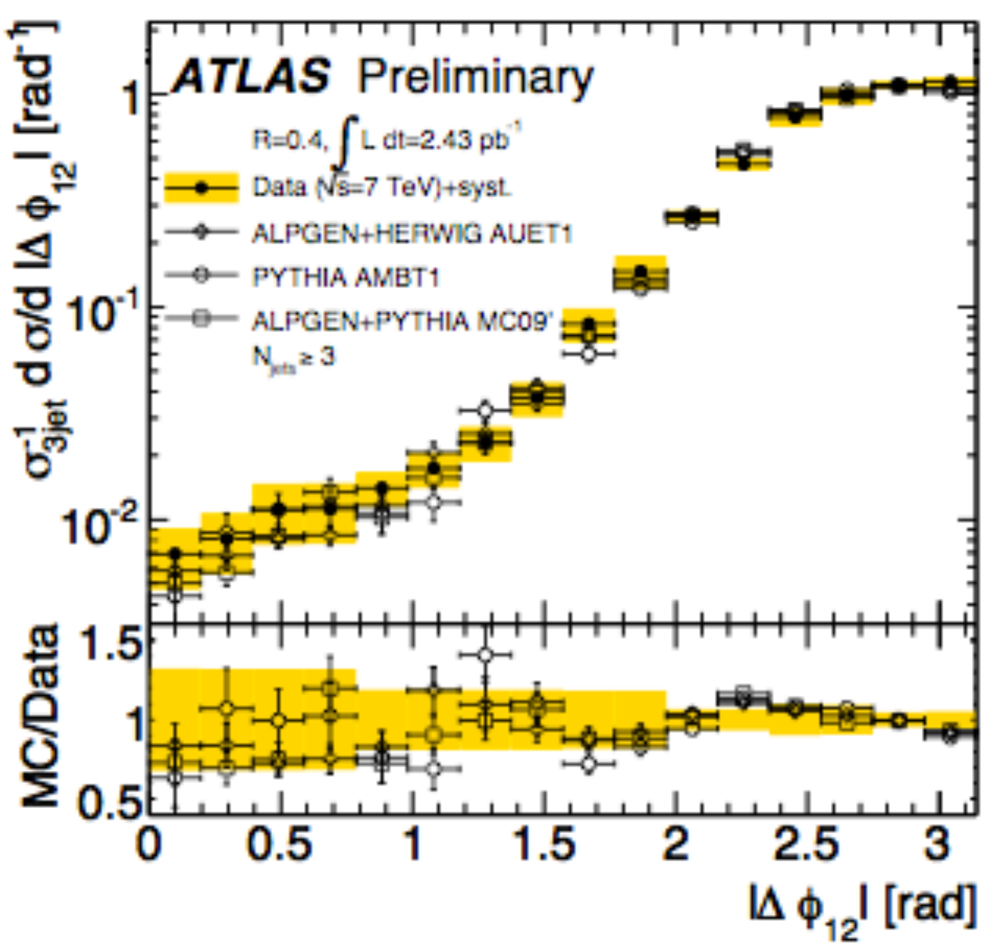


Angular Distributions

$N_{\mathrm{jets}} \geq 3$

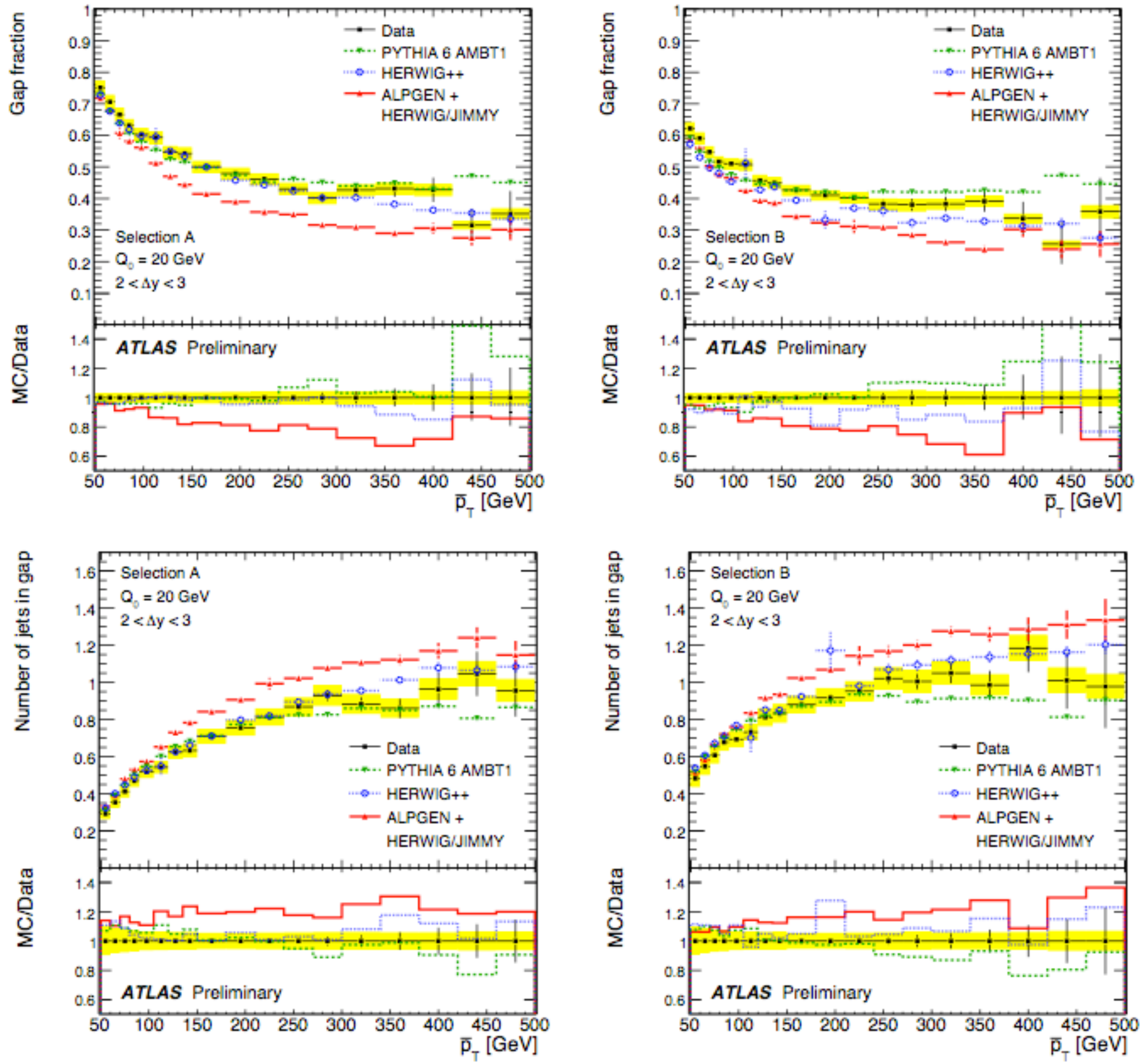




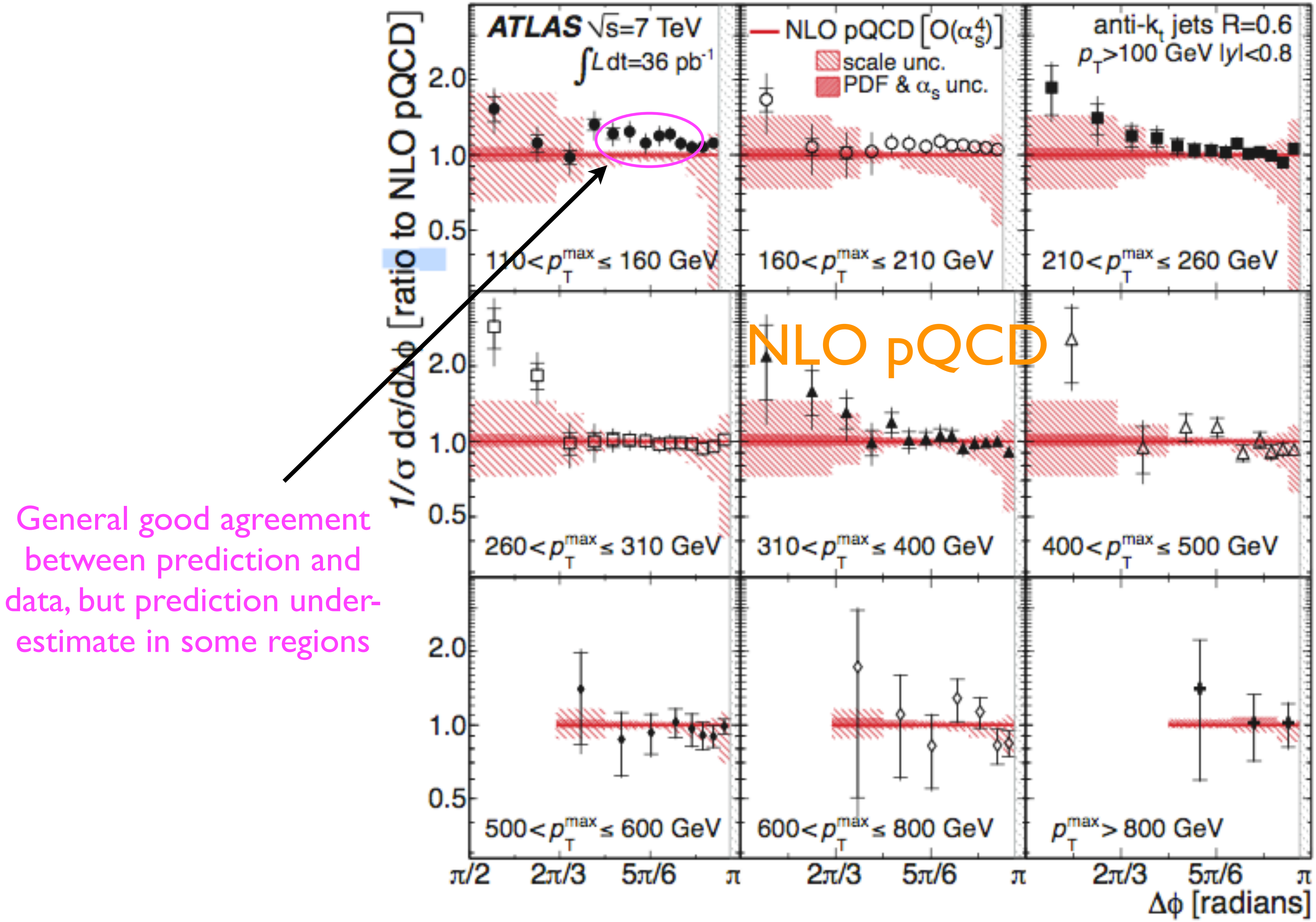


$|\Delta \phi_{12}|$ is the absolute phi difference between the leading jet and the 2nd leading jet

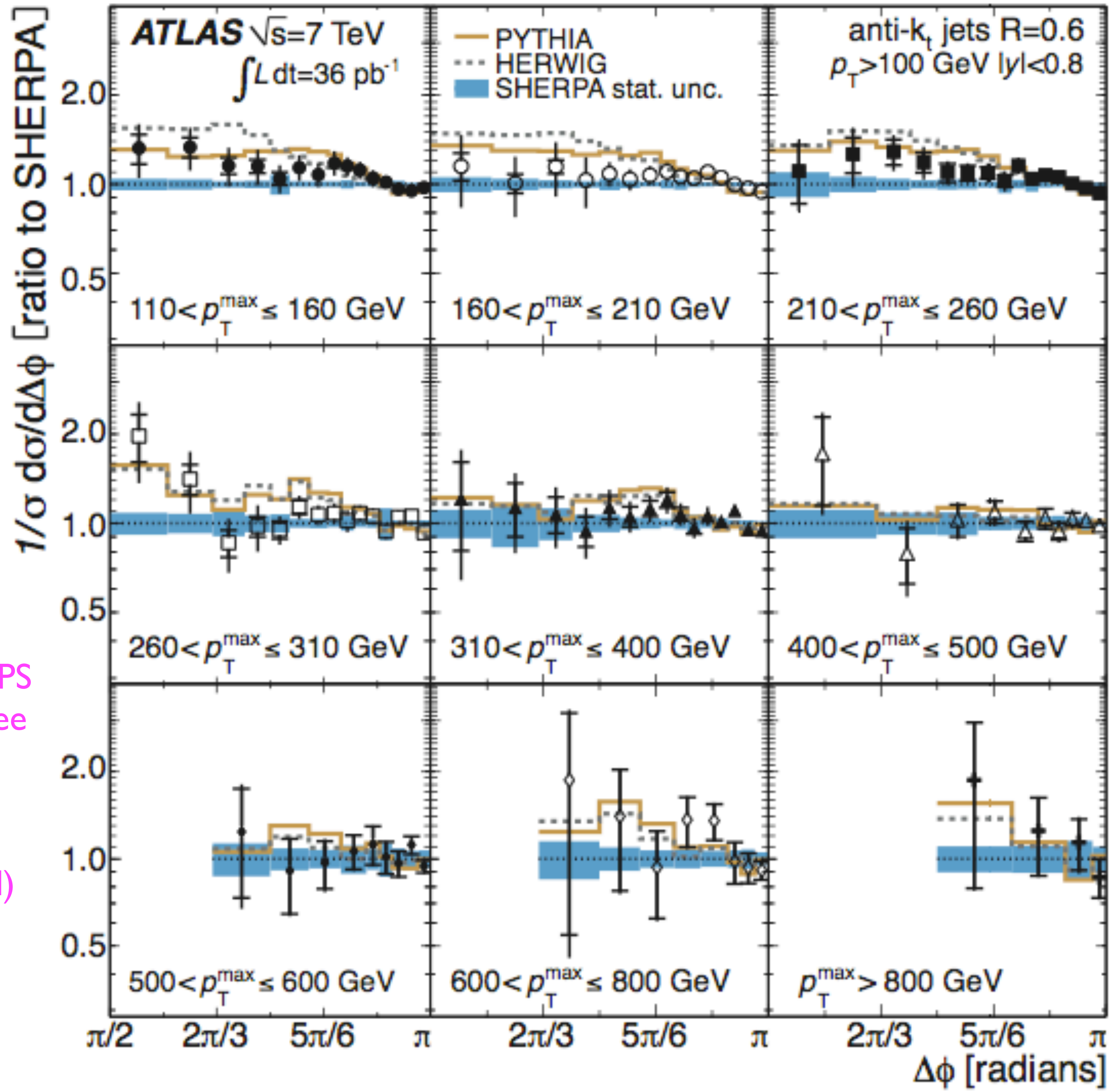
Comparison of Event Generators (pT)



Ratio of Diff. Cross-section

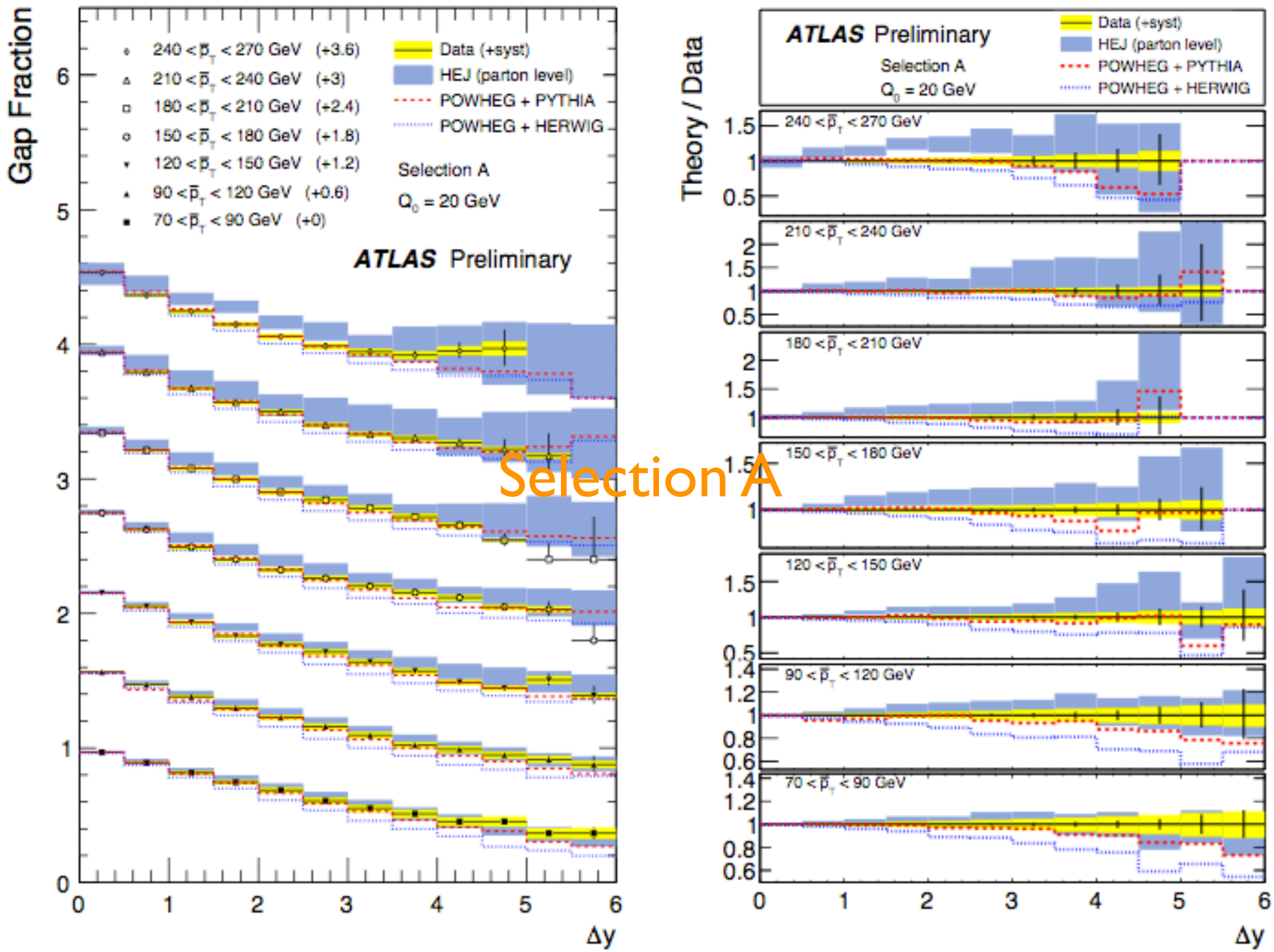


Ratio of Diff. Cross-section (continued)

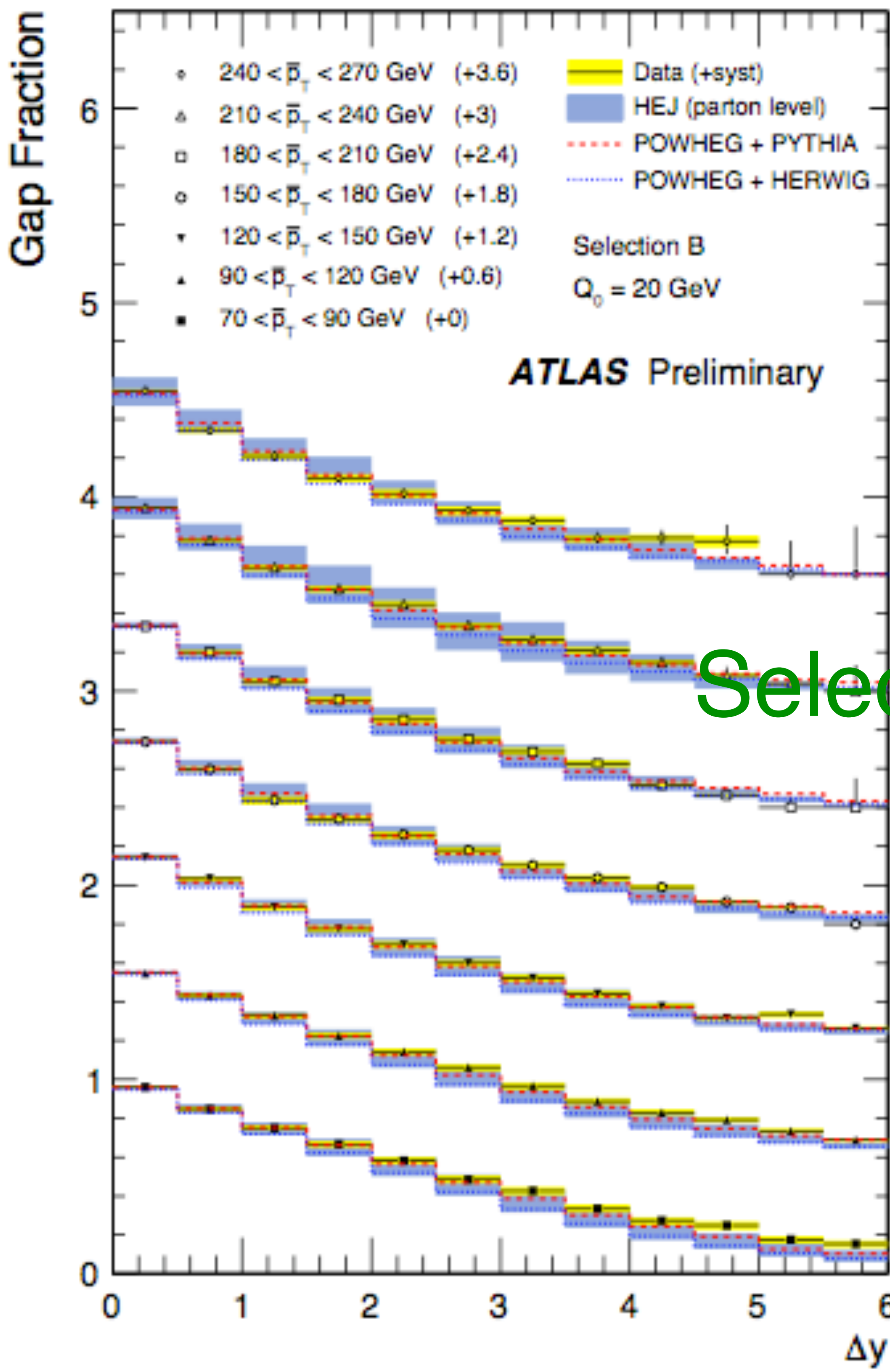


- Divergence is regulated by PS
- In region close to Pi, all three describes data well
- In region close to Pi/2, SHERPA is best (high-order tree-level is explicitly included)

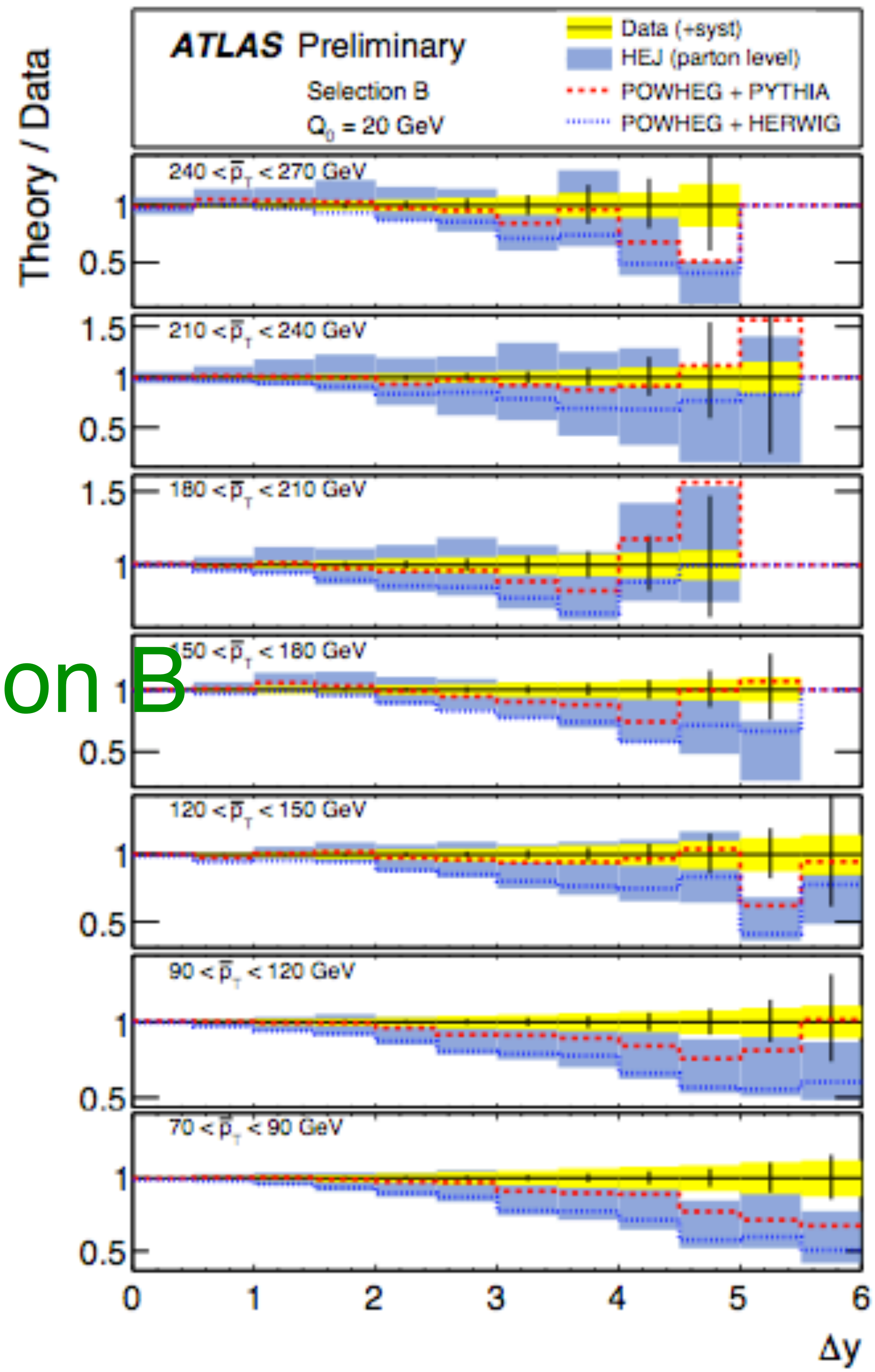
Comparison of HEJ and POWHEG



Comparison of HEJ and POWHEG



Selection B



Increase the Veto Scale $Q_0 = \bar{p}_T$