Searches for beyond-NLO DGLAP Dynamics with Multijets

Dr. Lee Sawyer

Louisiana Tech University

For the ATLAS Collaboration

Presented at the Jet Vetoes and Jet Multiplicity Observables at the LHC Workshop,
Institute for Particle Physics Phenomenology,
Durham, UK 18 July, 2013

Outline

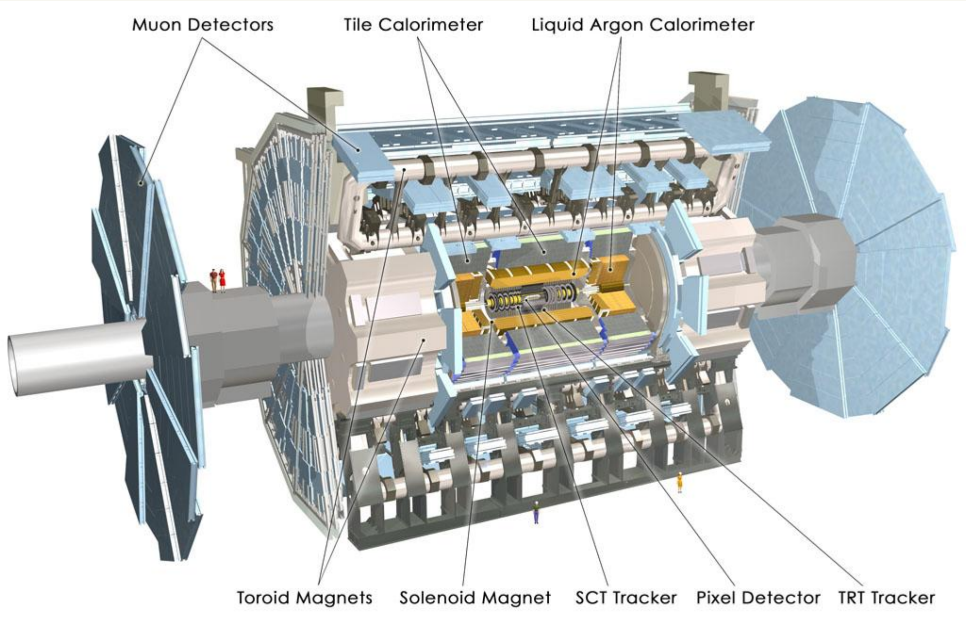
- Rapidity Gap Cross Sections
- Dijet Events with a Central Jet Veto

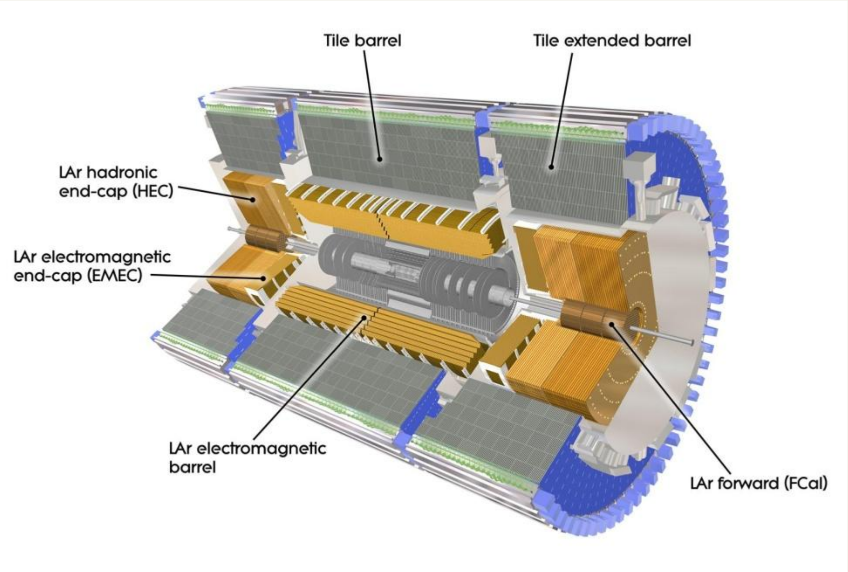
- Underlying Event in Jet Events
- Inclusive Jets at $\sqrt{s}$ = 2.76 and $\sqrt{s}$ = 7 TeV

NEW

The ATLAS Detector

- Inner Tracking Coverage $|\eta| < 2.5$
  - Silicon pixel, silicon strip, straw tube detectors
- Min Bias Trigger Scintillator in $2.1 < |\eta| < 3.2$



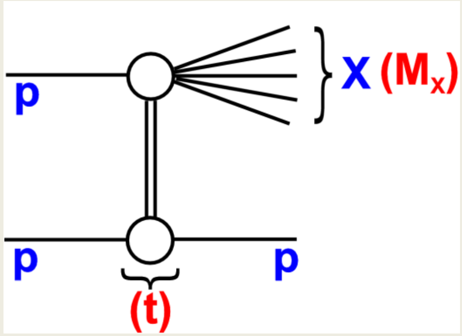


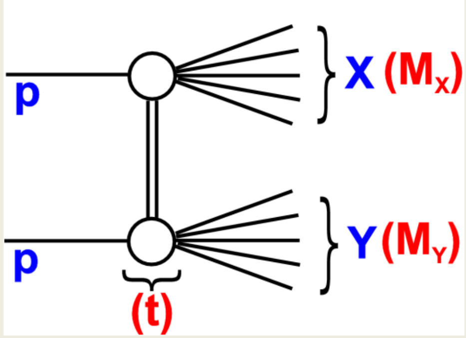
- Calorimeter coverage to $|\eta| < 4.9$
  - Central Pb/lAr EM $|\eta| < 4.9$
  - Scintillating Tile/Steel HAD
    - Central $|\eta| < 1.5$
    - Endcap $1.5 < |\eta| < 3.2$
  - FCAL $3.1 < |\eta| < 4.9$
    - EM and HAD components
    - Designed for high rates

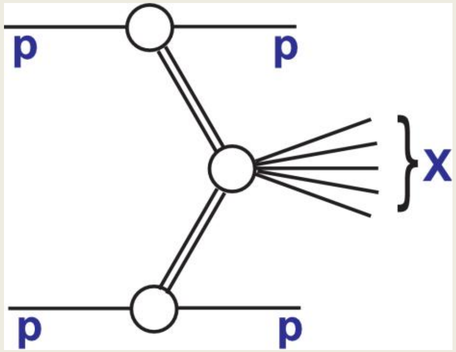
Eur. Phys. J. C72 (2012) 1926

Rapidity Gap Cross Sections

- Select diffractive sample with a large gap in rapidity
  - Expect $\Delta\eta \approx 0$ for non-diffractive events
  - Effected by hadronization fluctuations
  - Large gaps produced by color singlet exchanges
- Compare $d\sigma/d(\Delta\eta)$ to predictions/generators and study dependencies.





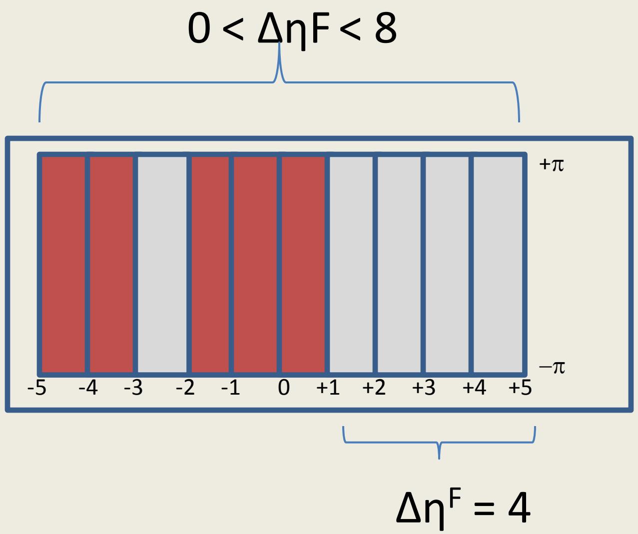


Size of the rapidity gap is correlated with the mass of the dissociated system

$$\Delta\eta \approx -\ln(\xi_X) = -\ln(M_X^2/s)$$

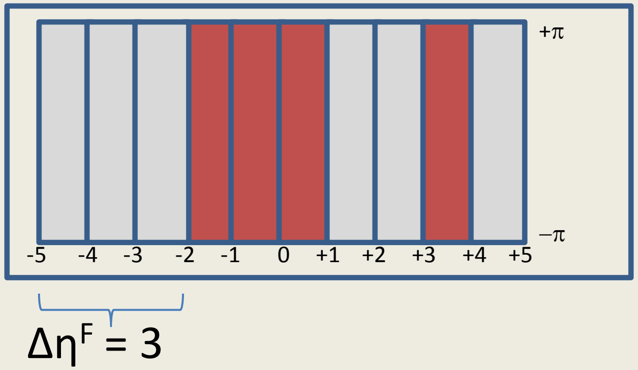
Forward Rapidity Gap $\Delta\eta^F$

- Measure the production of gaps in events triggered by MBTS
- 2010 two-bunch data: $L = 7.1\ \mu b^{-1}$
  - $\mu = 0.005$ ➔ No pileup



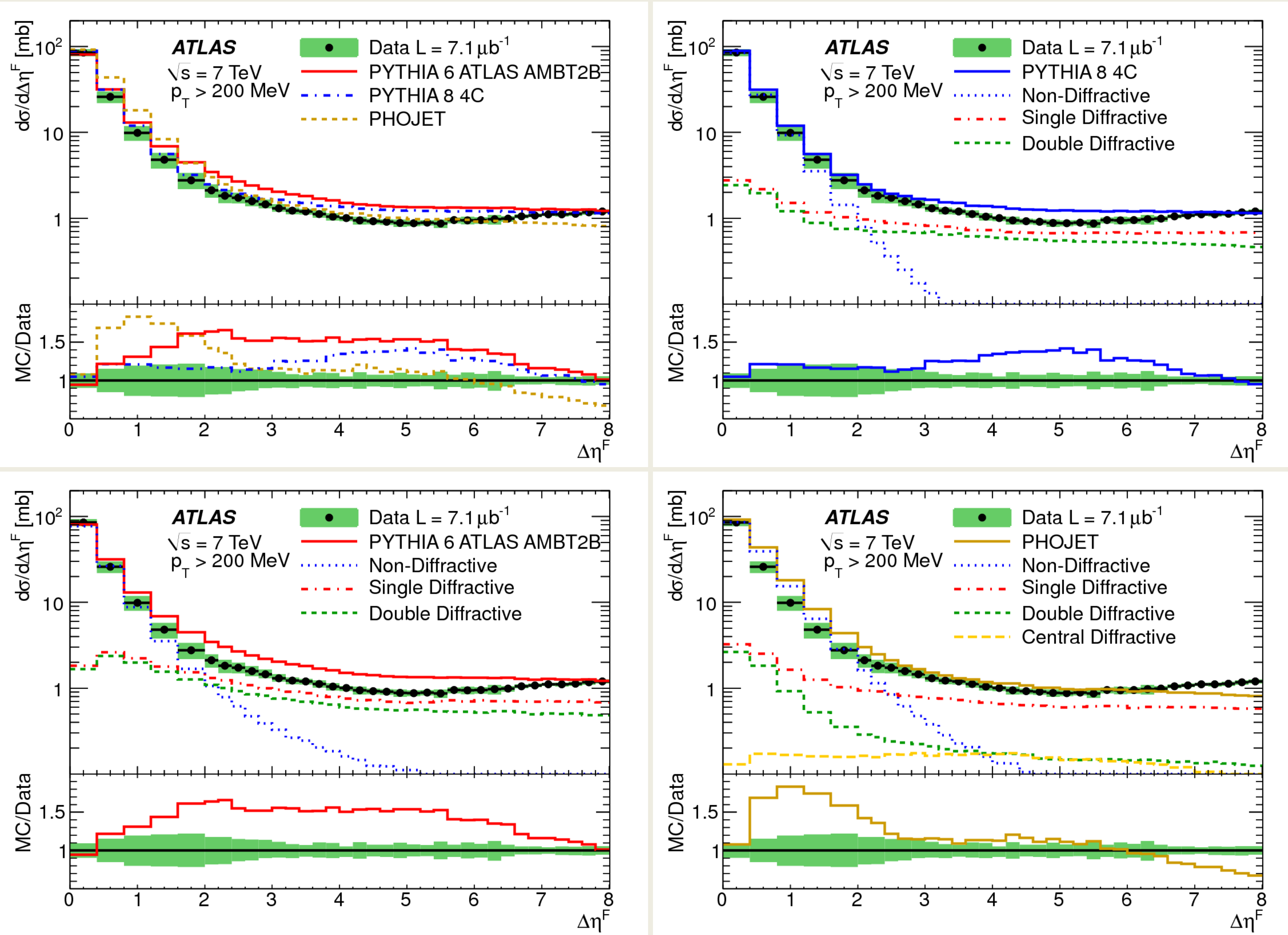
- Analysis variable: $\Delta\eta^F$
- The largest gap between calorimeter boundary ($\eta = \pm4.9$) and nearest activity
  - Either a track or calorimeter cluster with pT> 200 MeV
  - Or a Calorimeter cluster above noise threshold $|\eta| > 2.5$

For large gaps expect $d\sigma/d\,\Delta\eta^F \sim$ constant



- Comparisons made to several models & generators
  - PYTHIA6 - Tunes AMBT1 and AMBT2B
  - PYTHIA8 - Tune 4C
  - PHOJET
  - HERWIG++ - Tune UE7-2

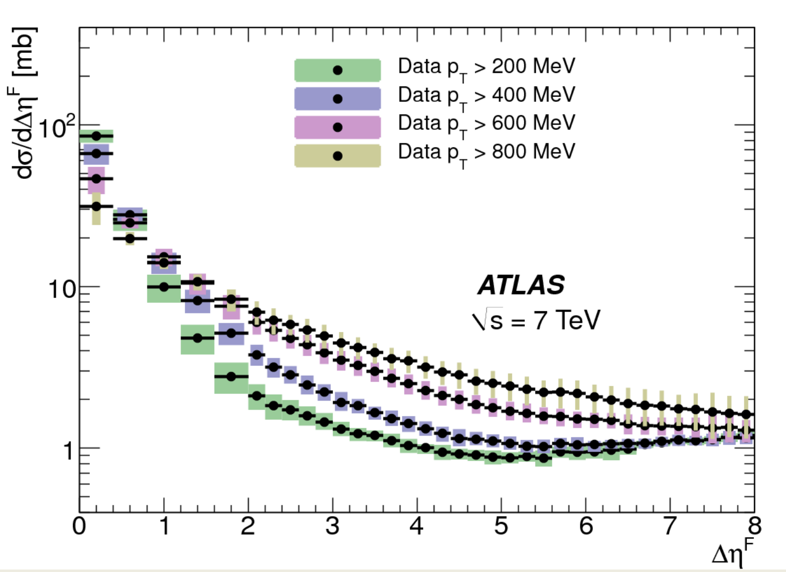
Cross Sections in $\Delta\eta^F$

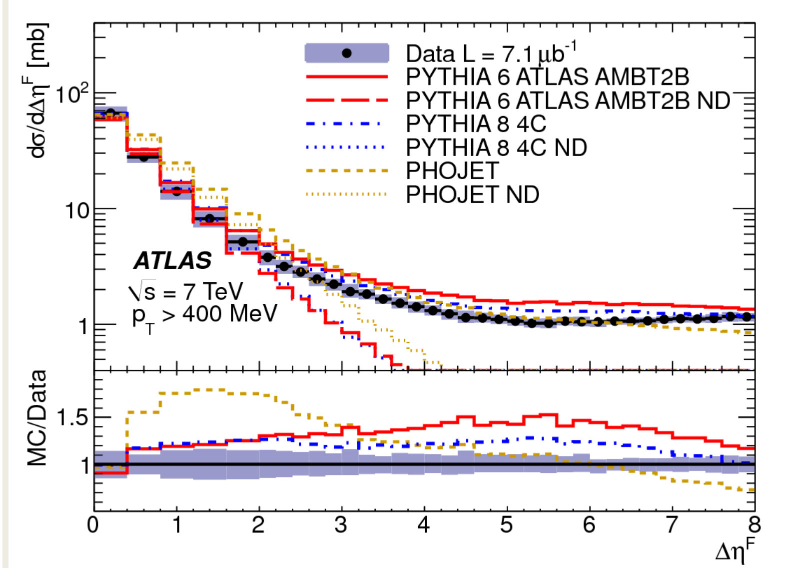


Inelastic differential cross section in $\Delta\eta^F$ compared to generators. (top left)

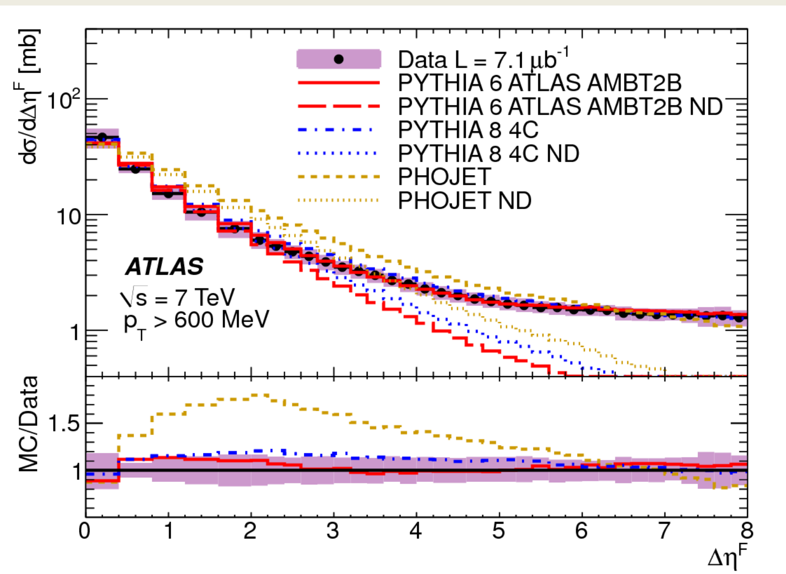
Contributions from ND, SD, and DD scattering from each model.

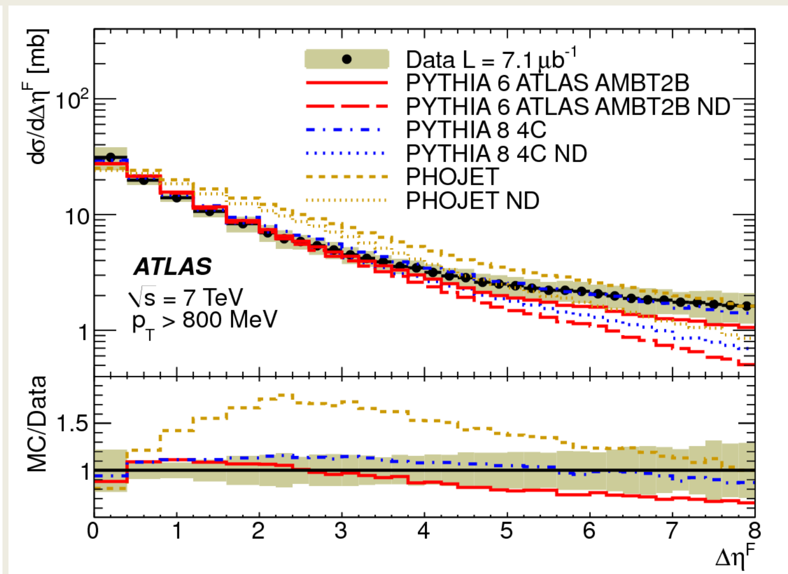
Cross Sections in $\Delta\eta^F$: Vary p_T^{cut}





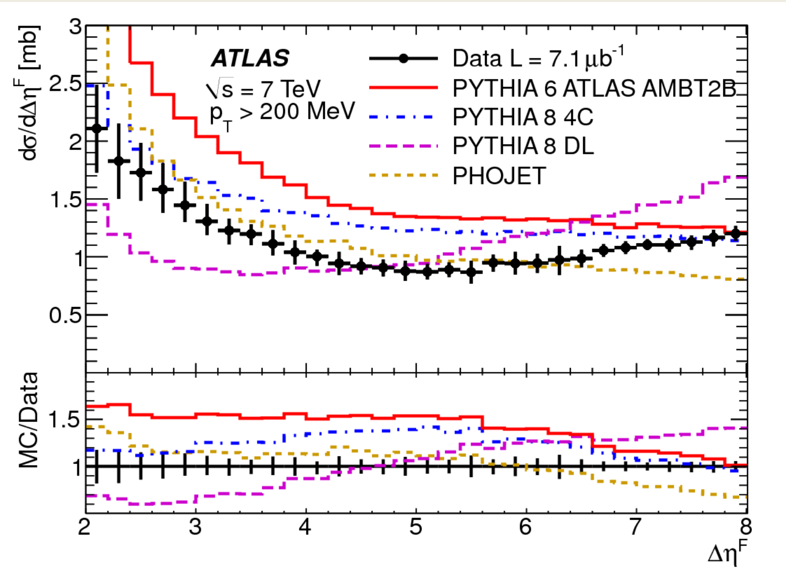
Inelastic cross section differential in $\Delta\eta^F$ for p_T^{cut} varied from 200 MeV to 800 MeV (top left)

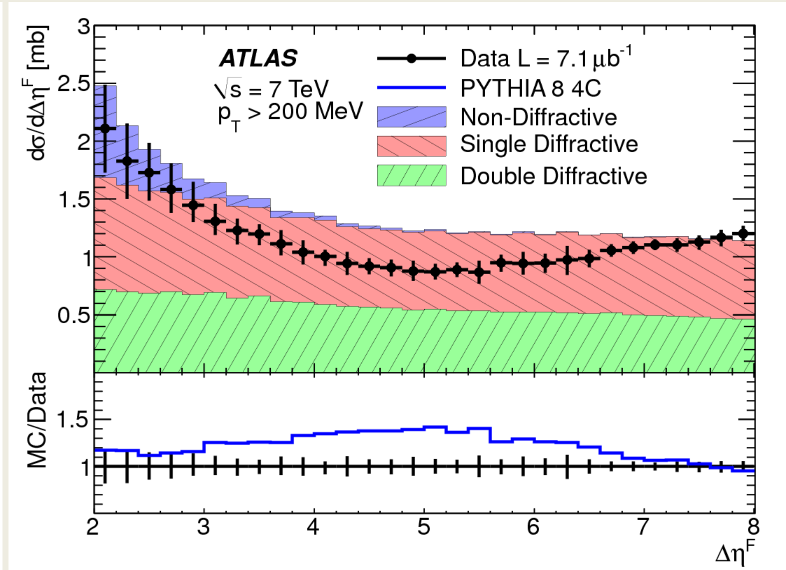


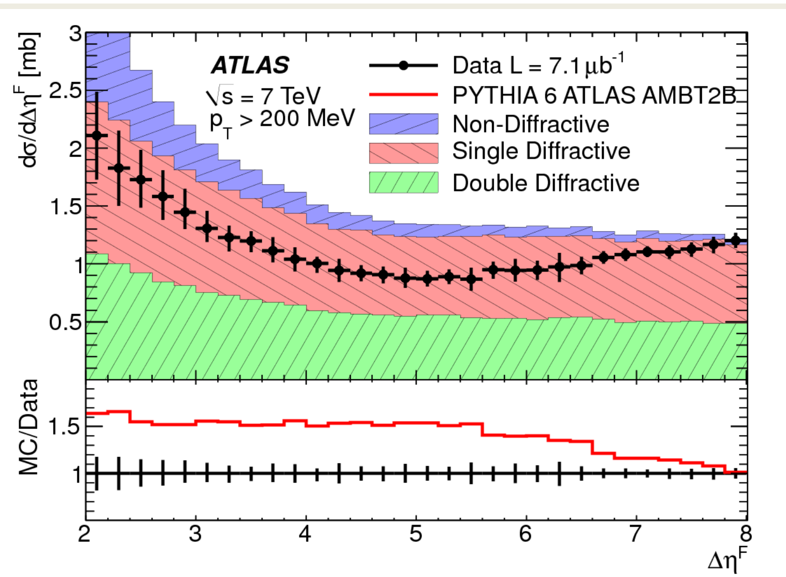


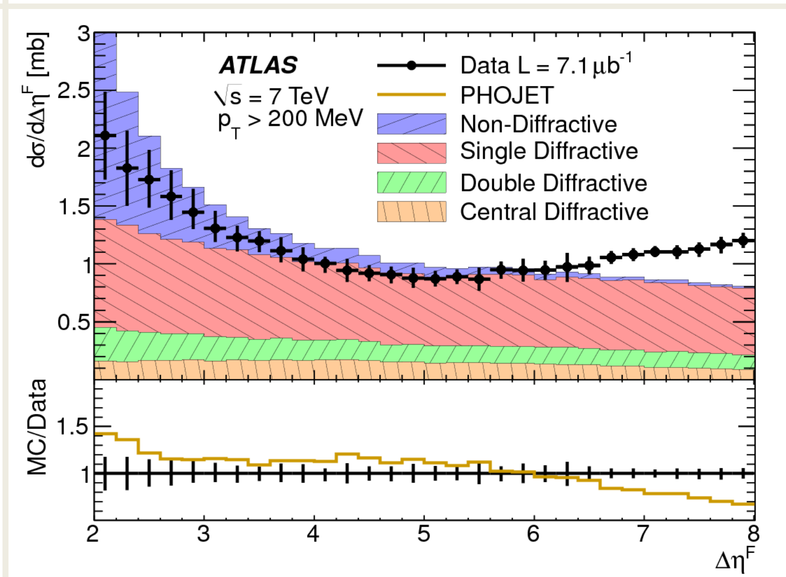
Comparison to MC model predictions for p_T^{cut} = 400, 600, and 800 MeV

Cross Sections in $\Delta\eta^F$: $\Delta\eta^F > 2$









Detail of $d\sigma/d\,\Delta\eta^F$ for $\Delta\eta^F > 2$

Features:

-Little ND contribution

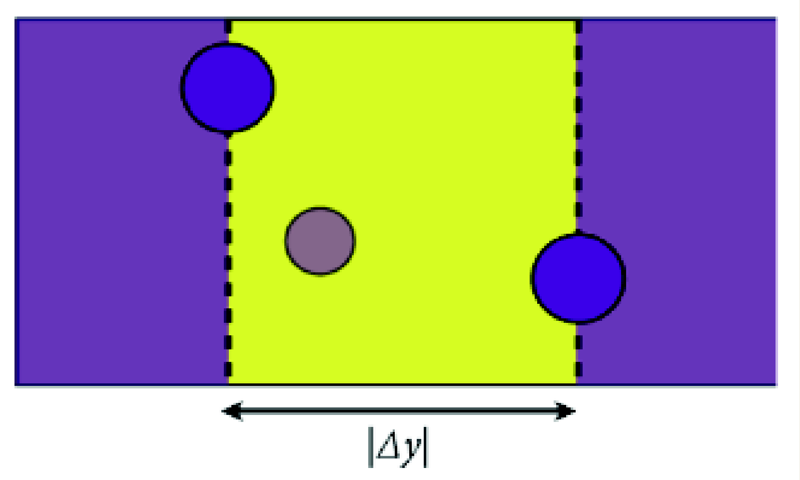
-Cross section roughly constant for $\Delta\eta^F > 3$

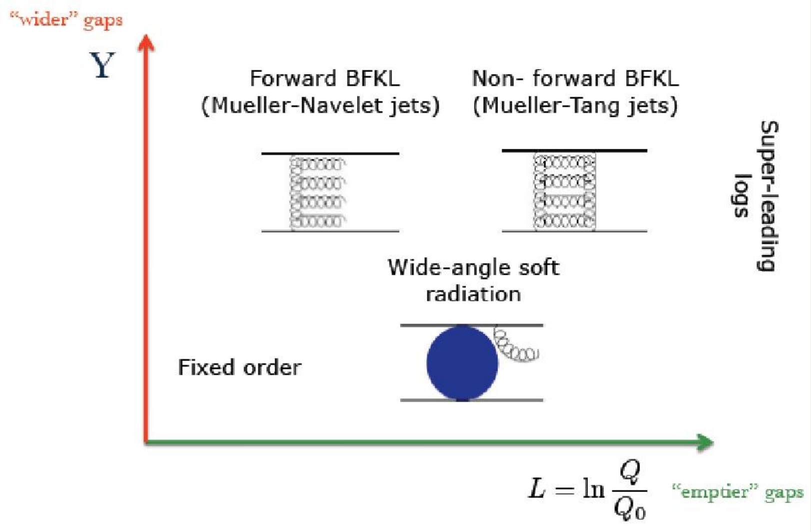
-Slight rise for very large gaps ($\Delta\eta^F > 5$)

JHEP 1109 (2011) 053

Dijet Events With a Gap

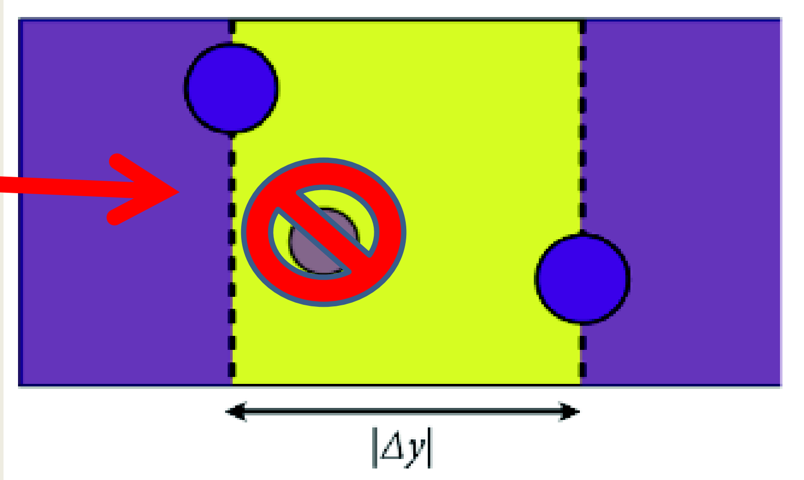
- Measurement of additional hadronic activity in high p_T dijet events in the rapidity interval Δy between the two leading jets
- Measure additional hadronic activity in events with two high pT jets
  - Study rapidity interval Δy between the jets.
- Study the effects of QCD radiation and compare to predictions
  - Expect BKFL-like dynamics to be more important at large Δy
  - Wide-angle gluon radiation important for large average dijet p_T
- Two variables to quantify the amount of additional radiation in rapidity interval Δy:
  - ➔ Gap fraction - fraction of events that do not have an additional jet with $p_T > Q_0$
  - ➔ Mean number of jets with $p_T > Q_0$





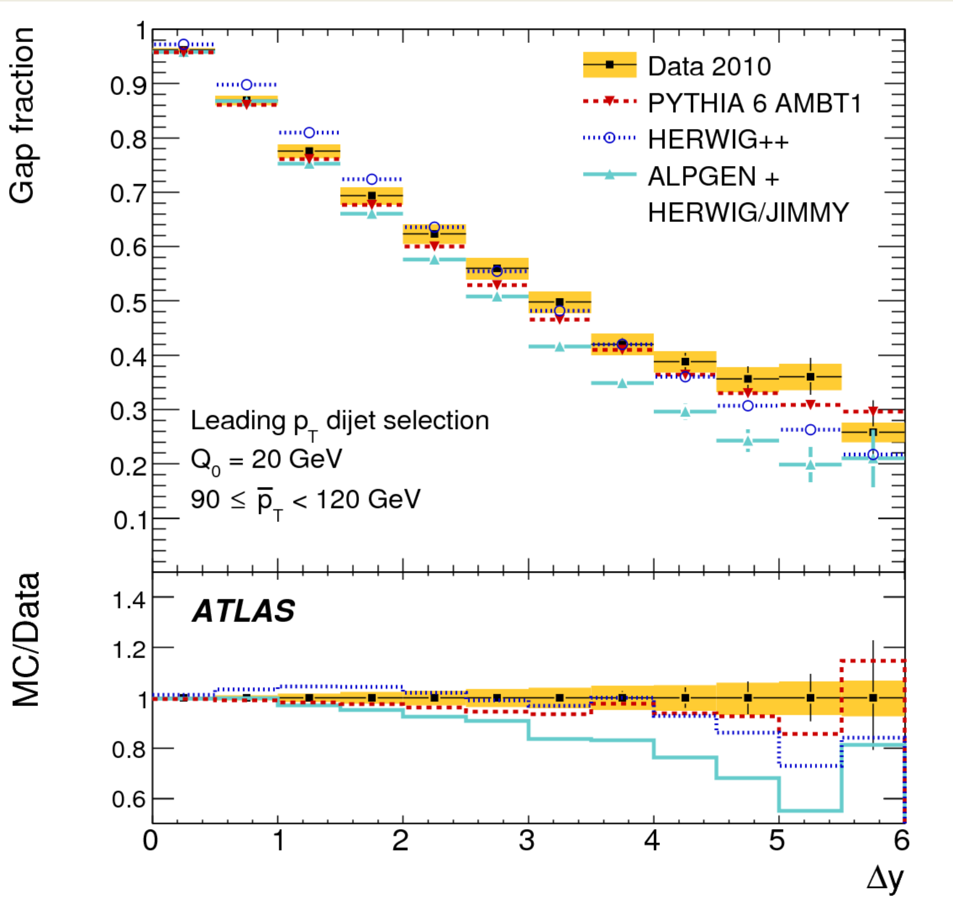
Event Selection

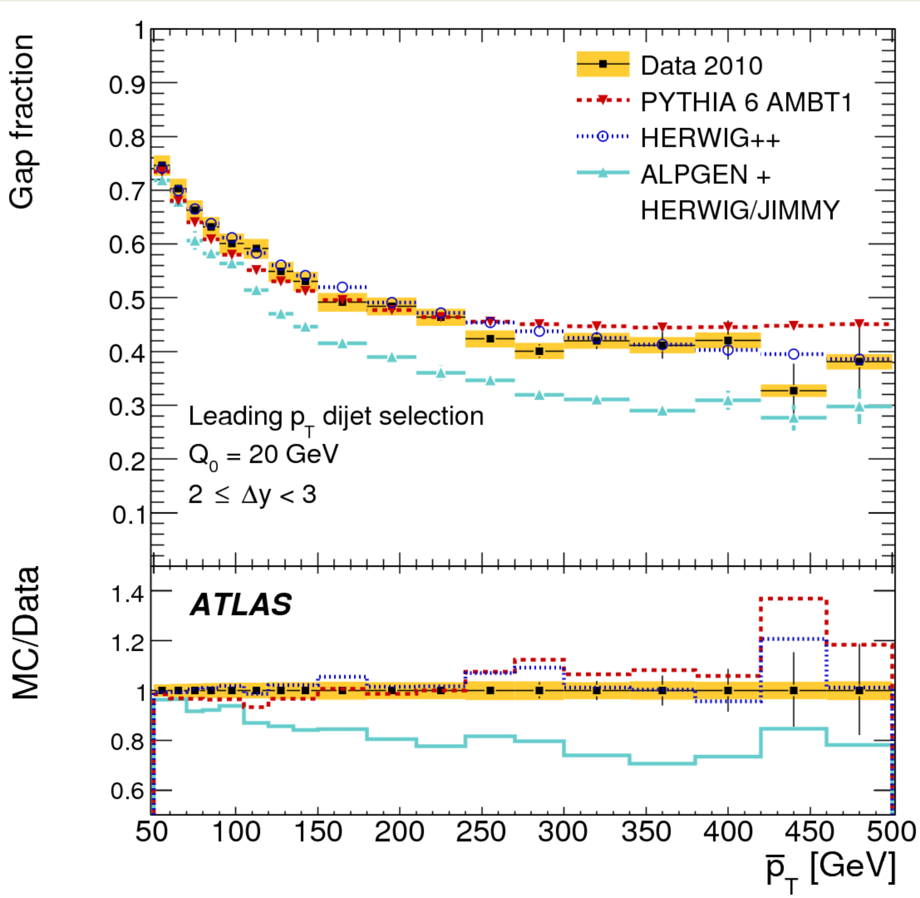
- 2010 data. Low pileup. Require single vertex events
- Single jet triggers. L = 37 pb^{-1}
- Jets reconstructed with anti-kT algorithm with R=0.6
  - Require two jets with p_T> 20 GeV in |y|<4.4
  - Mean dijet p_T > 50 GeV
  - Require no jet in Δy with pT > Q_0
    - Default Q_0 = 20 Gev
    - Study Q_0 dependence



- Boundary jets defined two ways:
  - Two highest p_T jets
  - Most forward/backward jets
- Compare to Several Theoretical Models:
  - HEJ: Parton-level generator for wide-angle emissions
  - POWHEG-BOX: NLO dijet calculation interfaced with PYTHIA or HERWIG
    - MSTW2008 PDF + PYTHIA tune AMBT1 or HERWIG Tune AUET1
  - PYTHIA, HERWIG++, ALPGEN

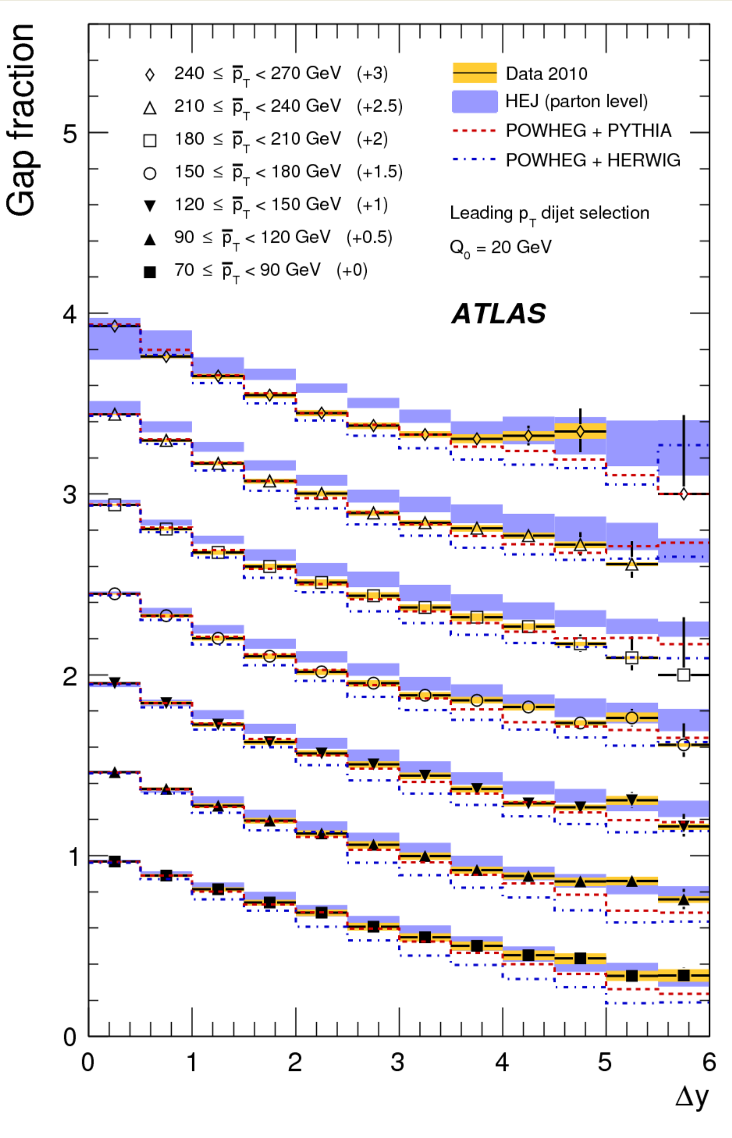
Gap Fractions

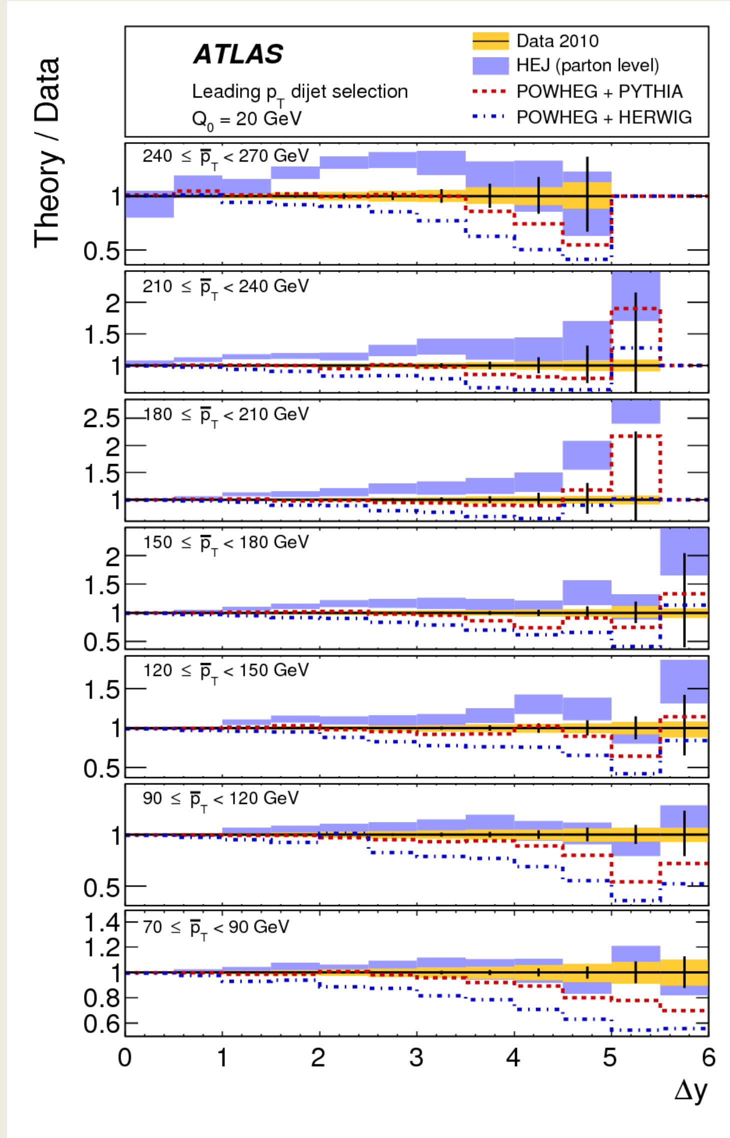




- For all results, data corrected for experimental effects (particle-level comparison)
- Gap boundary defined by the two leading p_T jets
- Good agreement with PYTHIA and HERWIG for most Δy
- ALPGEN predicts fewer gap events

Gap Fractions





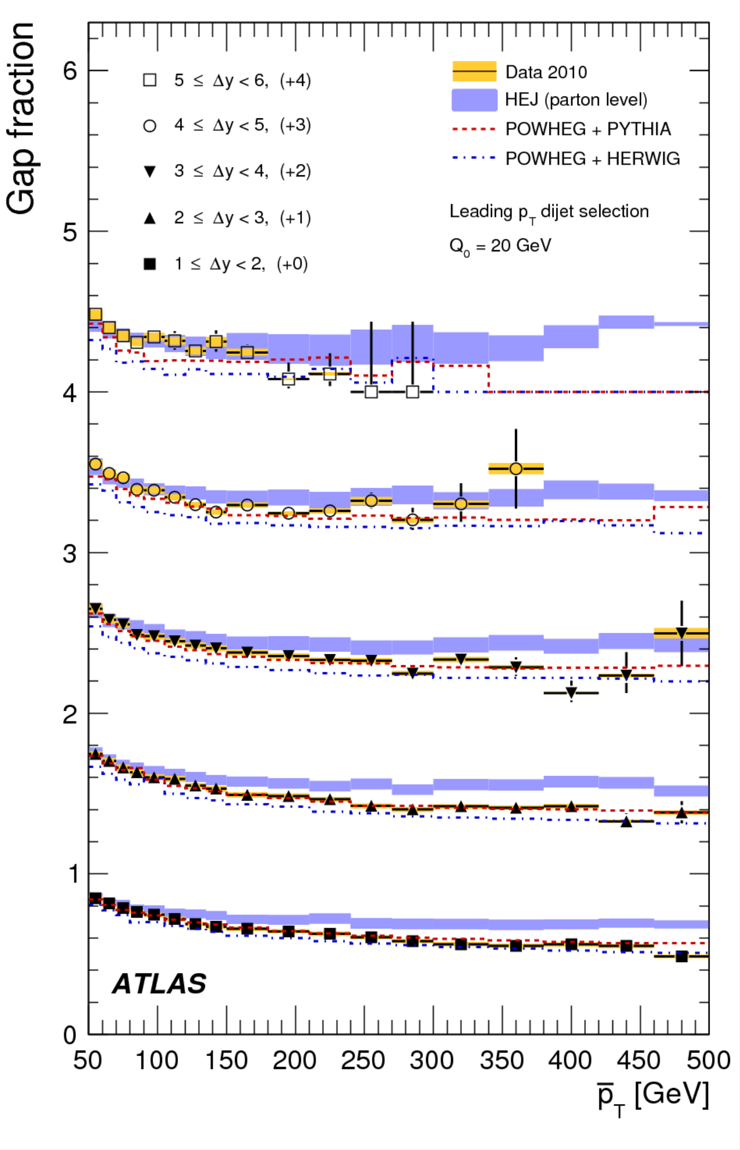
–Δy dependence for various average p_T regions.

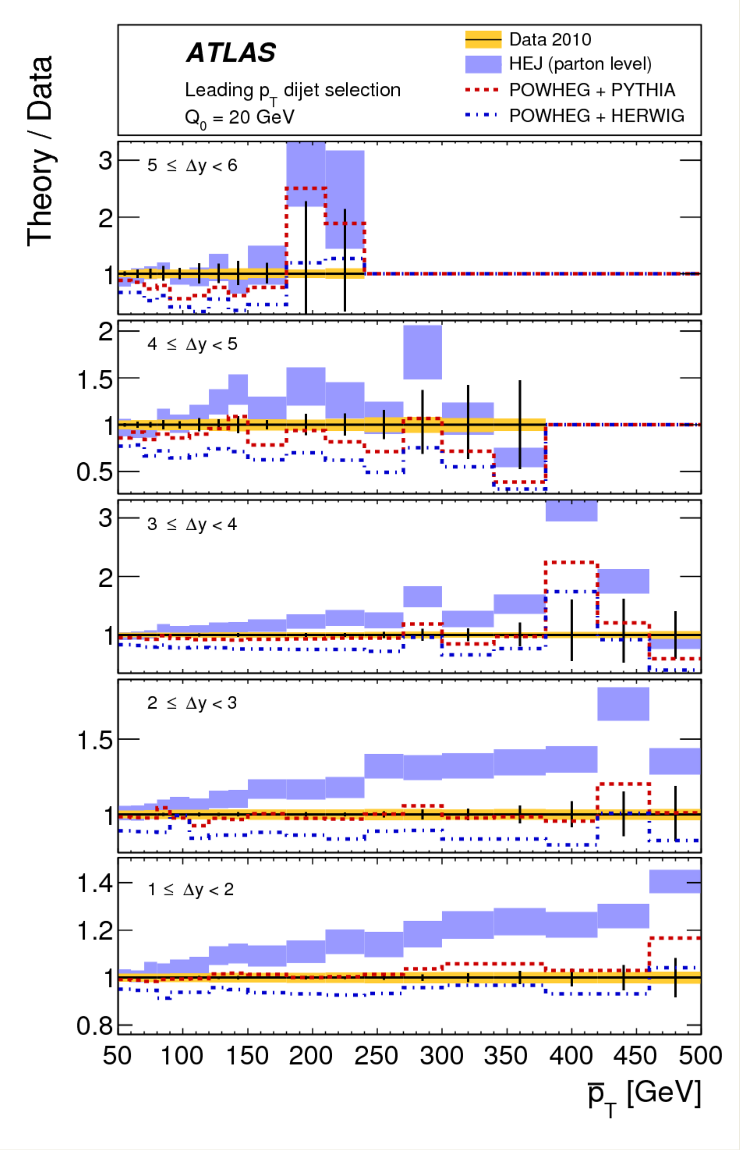
-Gap boundary defined by two leading p_T jets

- HEJ shows good agreement for lower Ave. p_T slices.

-Generally POWHEG+PYTHIA give best description

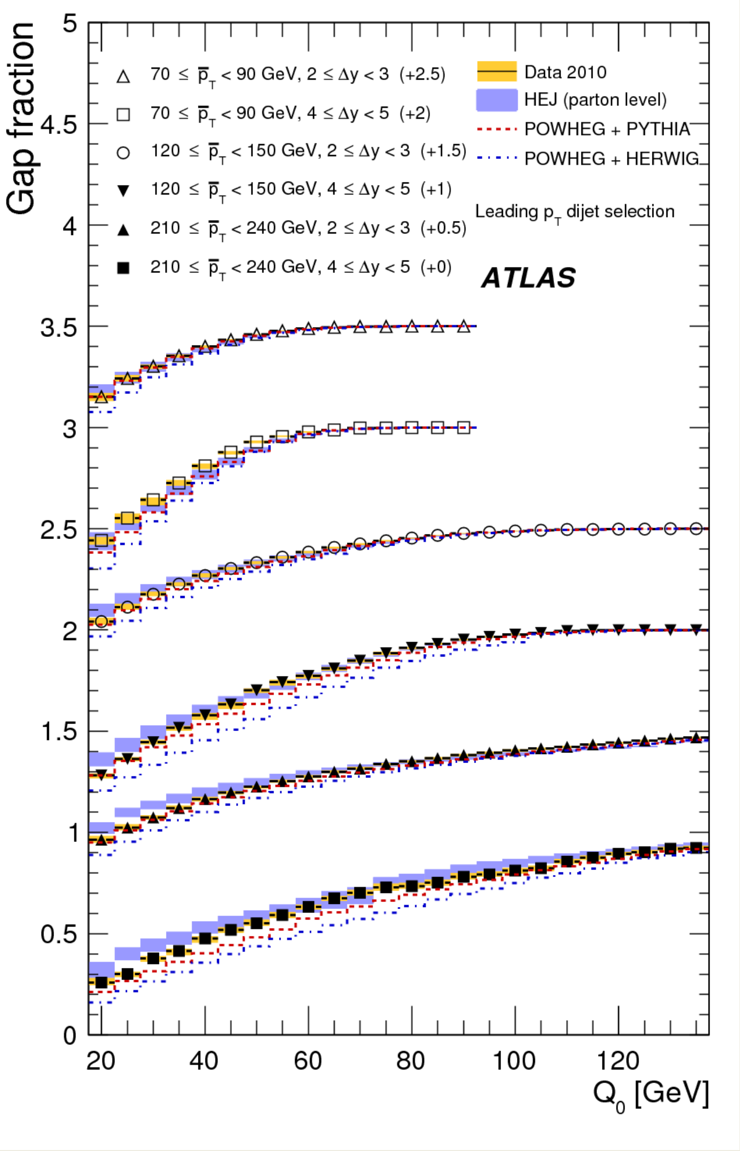
Gap Fractions: Vary pT

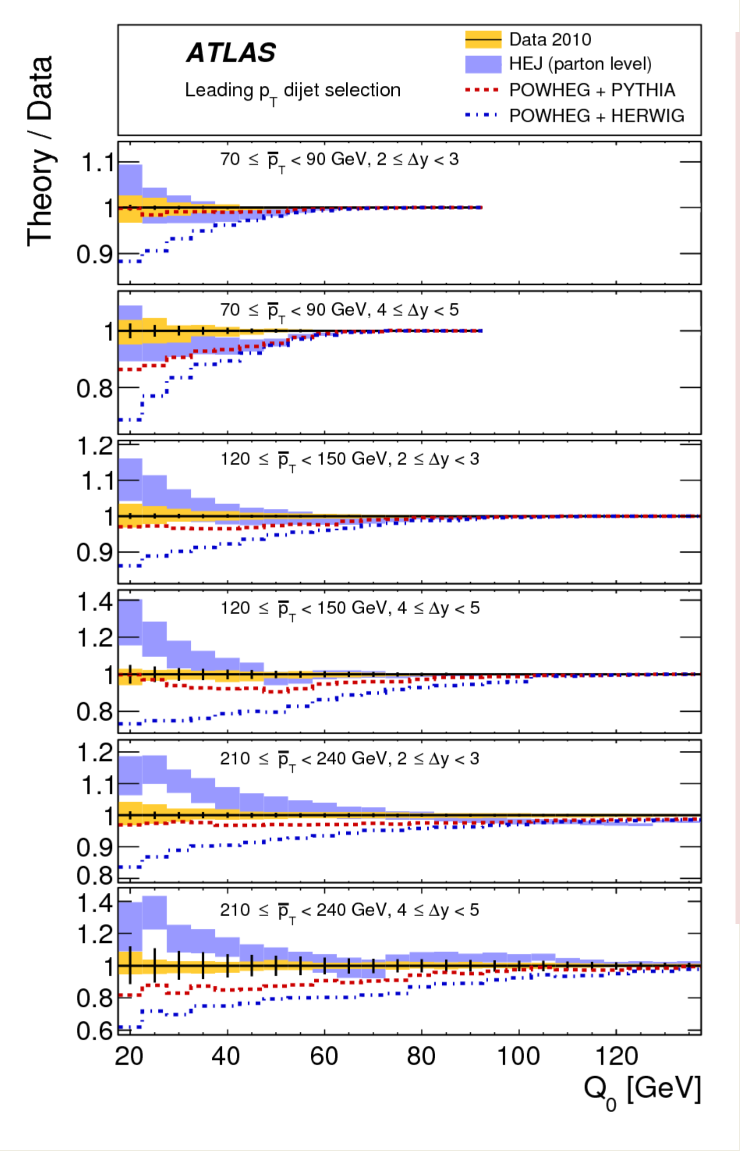




- -Average p_T dependence for Δy various regions.
- -Gap boundary defined by two leading p_T jets
- - HEJ predicts too many gap events at higher Ave. p_T .
- -Generally POWHEG+PYTHIA give best description

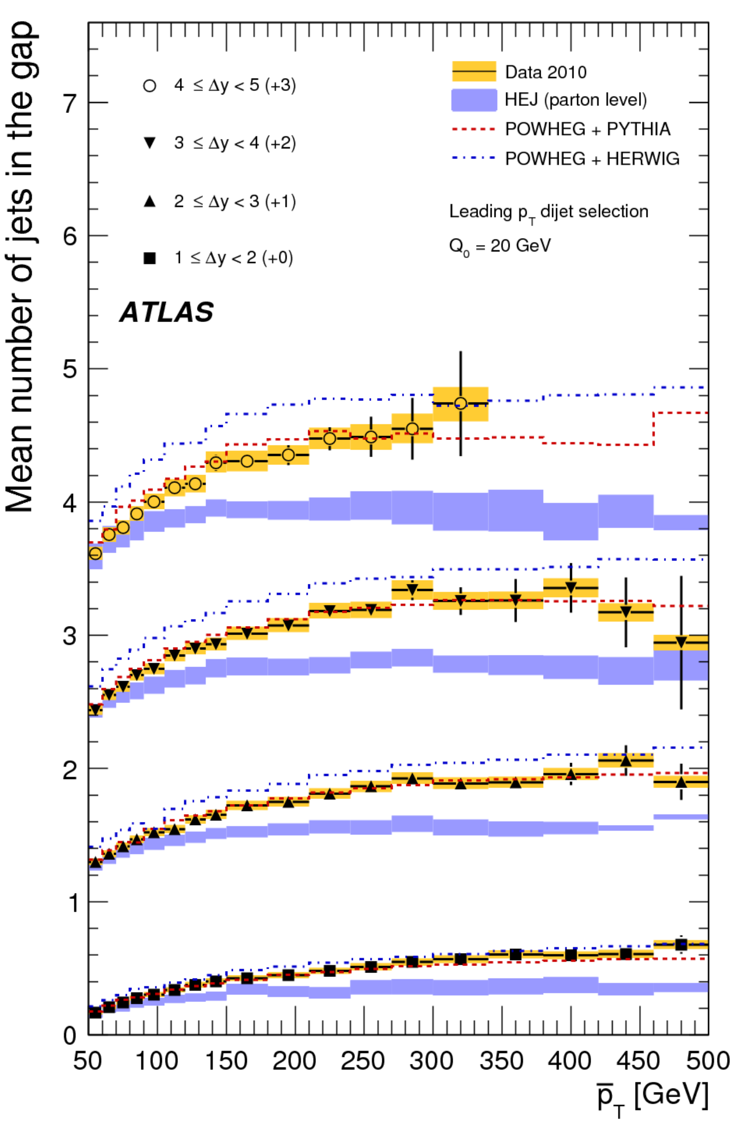
Gap Fractions: Vary Q_0

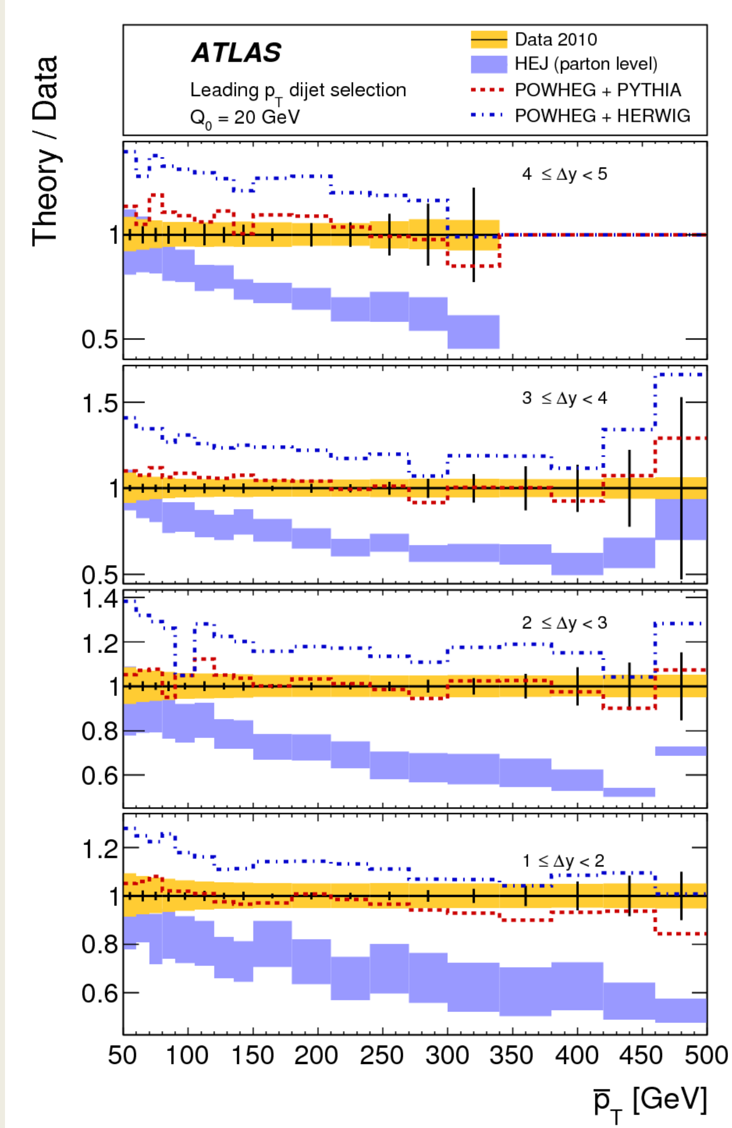




- Dependence on the veto scale Q_0
- Gap boundary defined by two leading pT jets.
- POWHEG+PYTHIA and POWHEG+HERWIG show differences from data
- Good agreement with HEJ as Ave p_T approaches Q_0 (typ.)

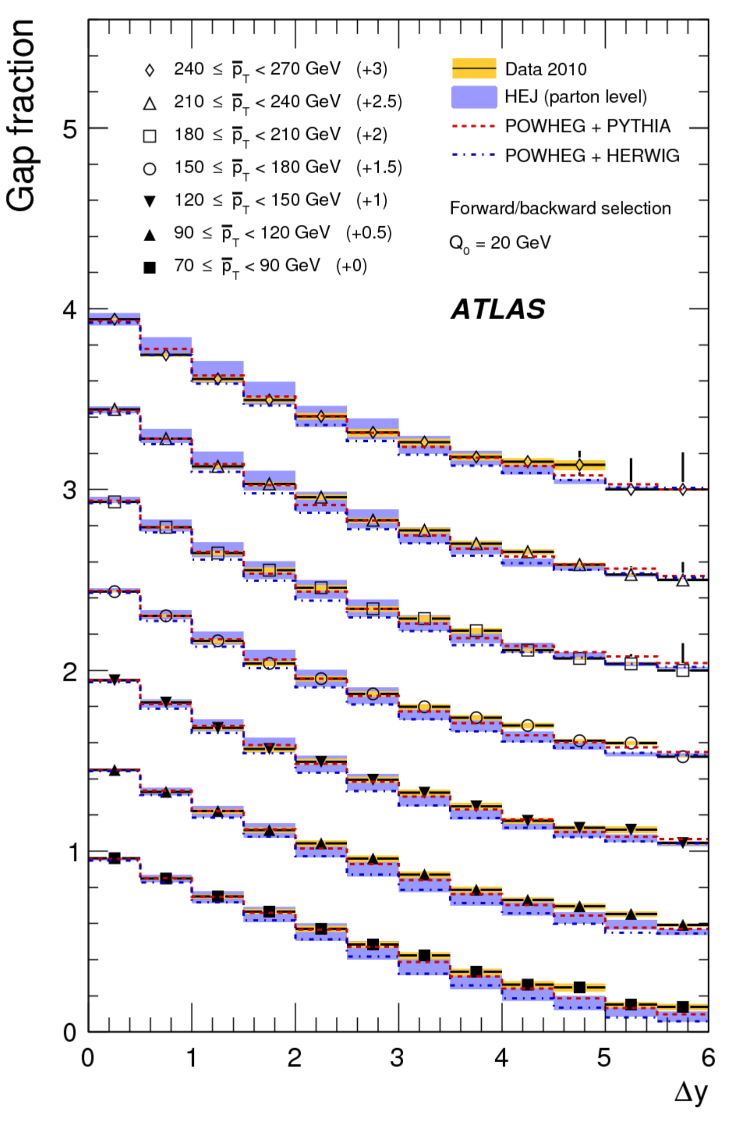
Mean Number of Jets in the Gap

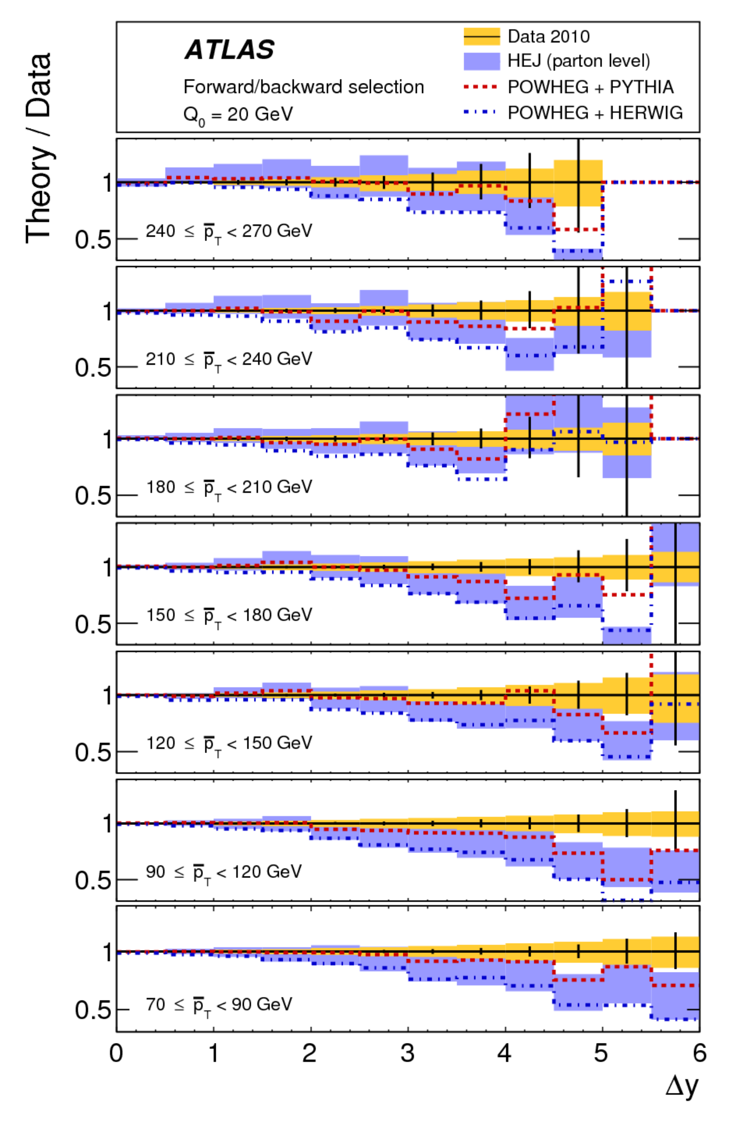




- Alternative way to measure hadronic activity in Δy
- Boundary jets defined by two leading p_T jets.
- Best agreement with POWHEG+PYTHIA
- POWHEG+HERWIG deviates from data at low Ave. p_T (not seen in gap fractions)

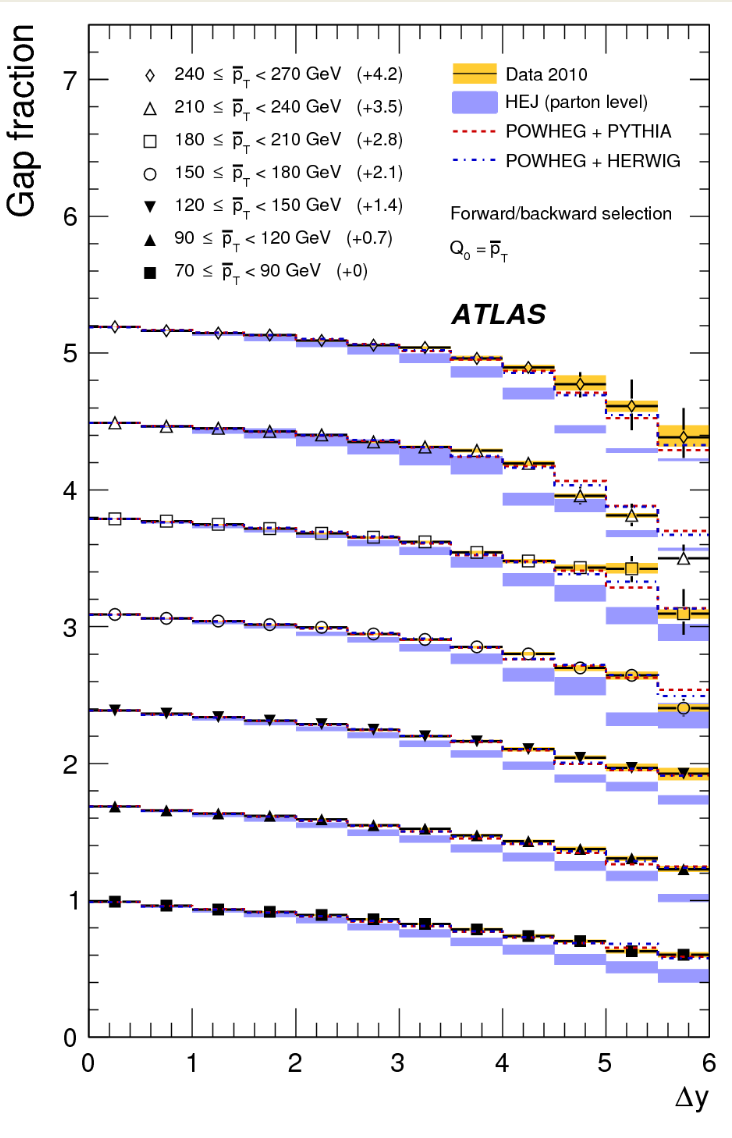
Gap Fractions vs Δy

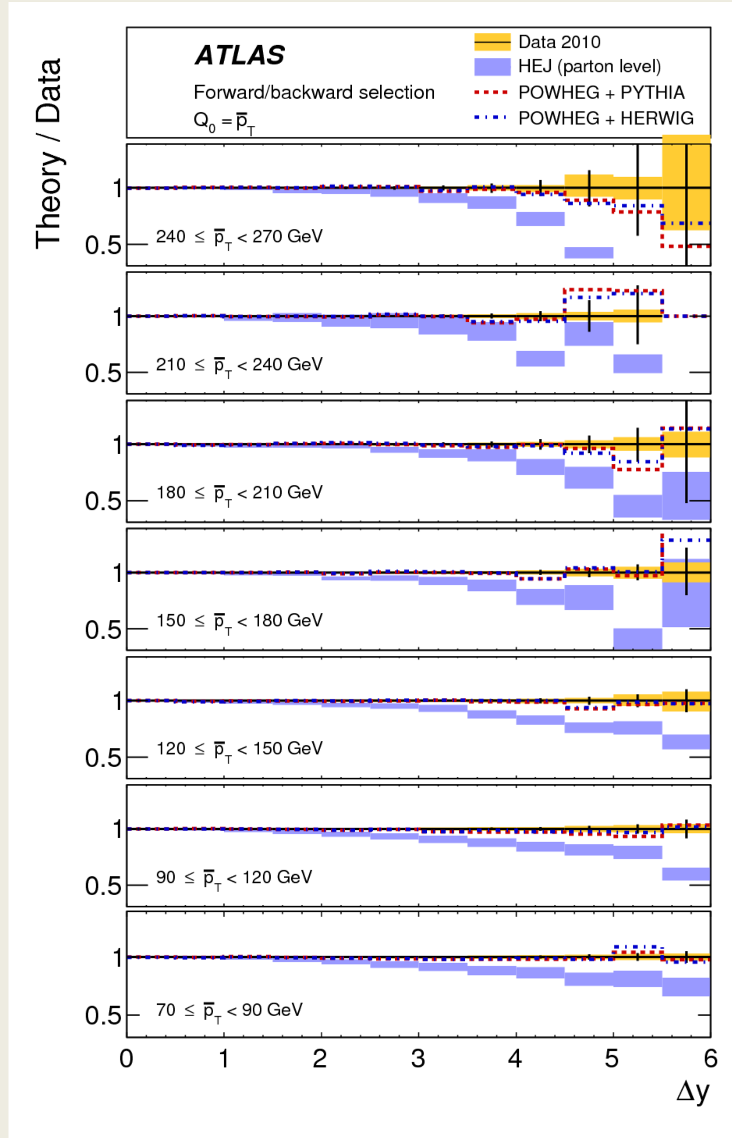




- Gap fractions in events with gap boundary defined by most forward/most backward jets in the event
- Jet p_T imbalance typically much higher
- HEJ and POWHEG predict gap fractions that are two small.

Gap Fractions vs Δy

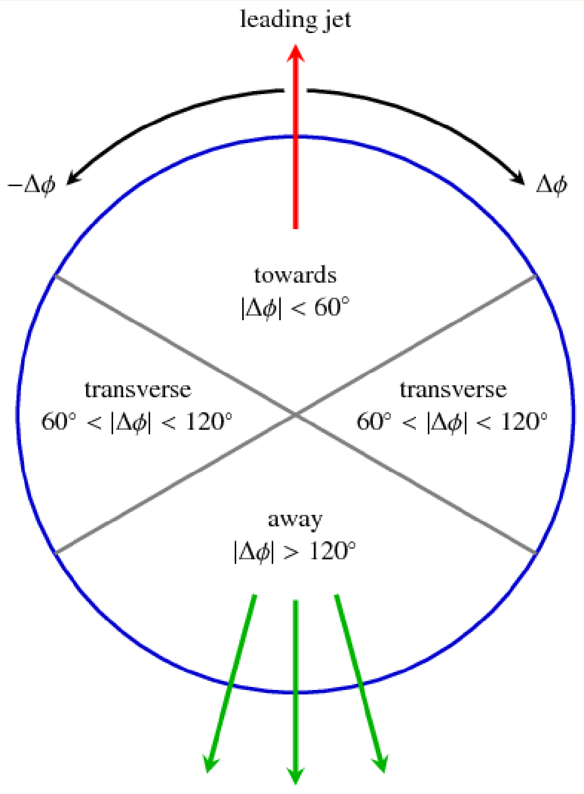




- Gap boundary defined by most forward and backward jets
- Here, set veto scale Q_0 = Ave. dijet p_T
- Better agreement with POWHEG
- HEJ description does not improve with veto scale.

Underlying Event in Jet Events

- Study soft QCD effects in the underlying event in both inclusive jet and exclusive dijet events.
  - Study dependencies and compare to model tunes.
- Underlying Event Observables:
  - p^T_{lead} = Lead jet transverse momentum
  - $d^2N_{ch}/d\eta d\phi = \langle N_{ch} \rangle$ per unit $\eta-\phi$
  - $d^2\Sigma p_T/d\eta d\phi = \langle \text{Scalar } p_T \rangle$ of stable charged particles per unit $\eta-\phi$
  - $\langle p_T \rangle$ = Ave. p_T of stable charged particles
  - $d^2\Sigma E_T/d\eta d\phi = \langle \text{Scalar } E_T \rangle$ of stable charged and neutral particles per unit $\eta-\phi$
- Define two sub-regions per event
  - Trans-Max = More active transverse region
  - Trans-Min = Less active transverse region
  - |Trans-Max – Trans-Min| = “Trans-Diff”

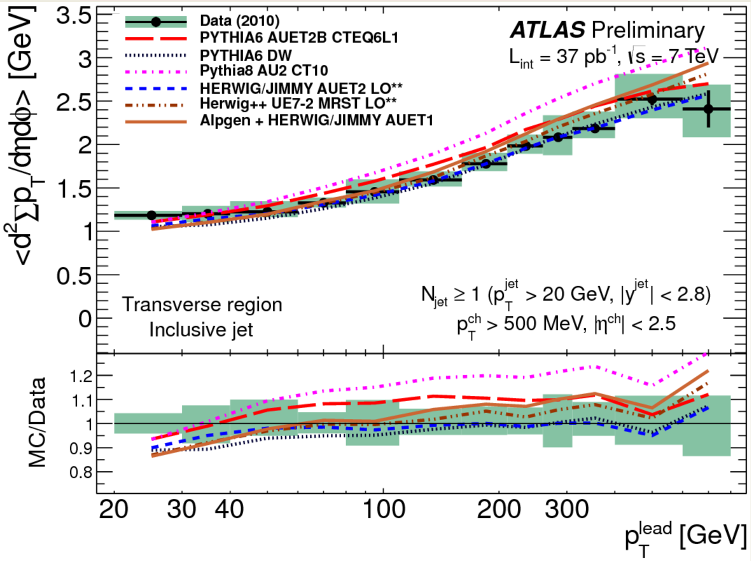


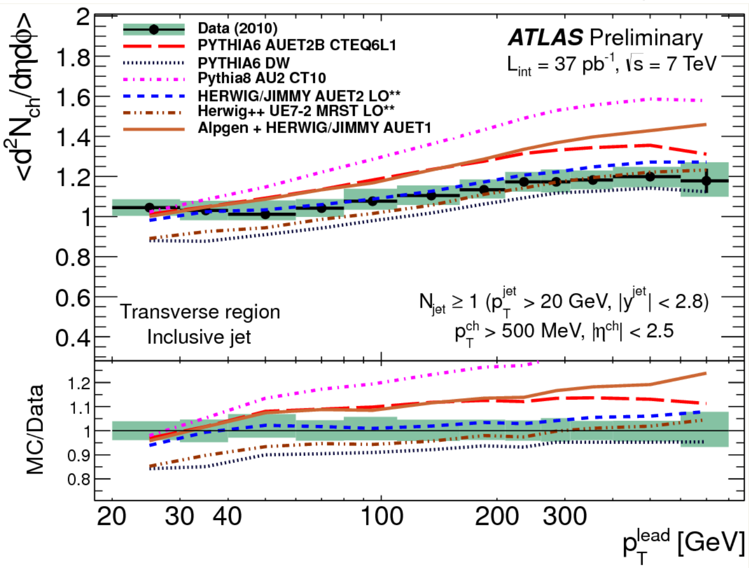
Underlying Event Analysis

- Analysis based on 37 pb^{-1} of data at $\sqrt{s}$ = 7 TeV
- Event Selection:
  - Require 1 PV with 2 or more tracks
  - Require anti-kT R=0.4 jets with p_T> 20 GeV and |y|<2.8
  - Inclusive Jet Topology: No additional requirement beyond 1 jet
  - Exclusive dijet topology:
    - Only one subleading jet with $p_T^{sub}/p_T^{lead} > 0.5$ and $|\Delta\phi| > 2.5$
- Events were corrected for experimental effects and unfolded to the particle level
- Data was compared to
  - PYTHIA6 with AUET2B CTEQ6L1 and DW tunes
  - HERWIG+JIMMY with AUET2 tune
  - PYTHIA 8 with AU2 CT10 tune
  - ALPGEN+HERWIG/JIMMY with AUET1 tune
  - HERWIG++ with UE7-2 tune

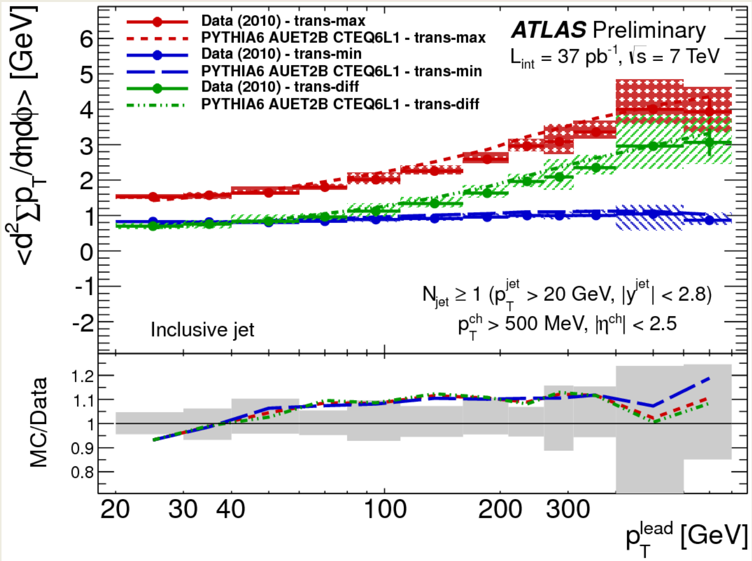
Underlying Event: Charged Σp_T vs p_T^{lead}

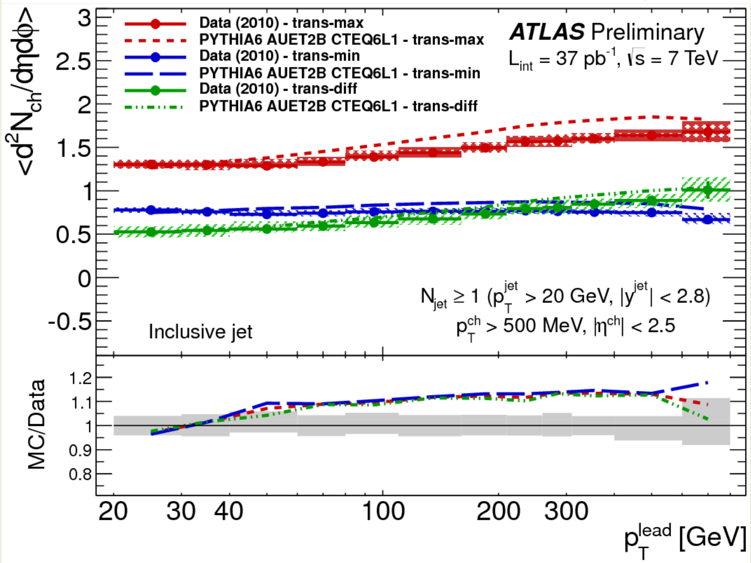
Total Transverse Region





Trans-Max/Min/Diff



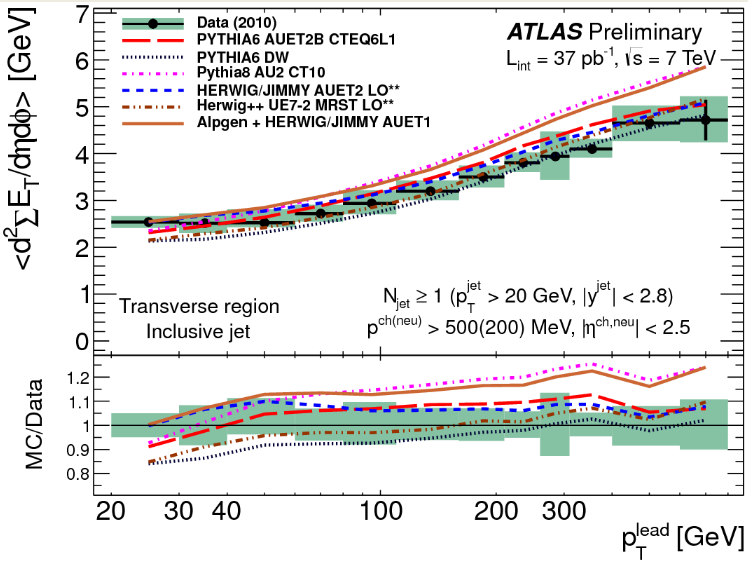


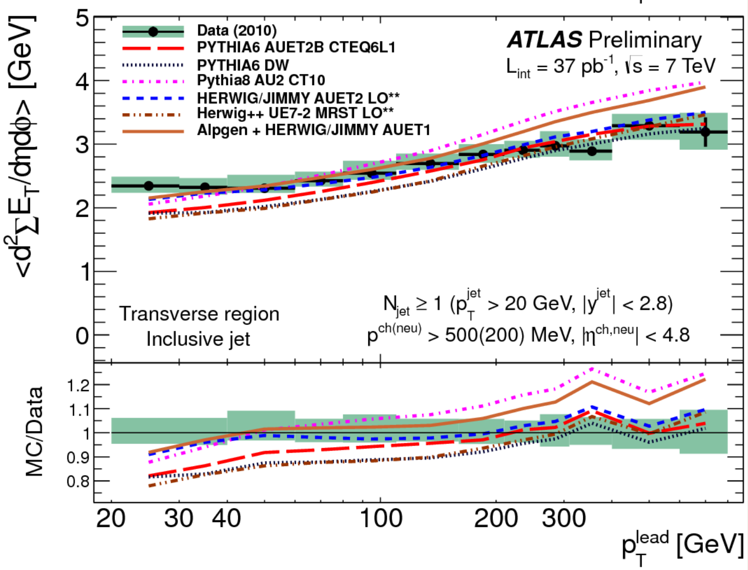
- -Inclusive jet topology
- --Trans-Max component grows with p_T^{lead}
- -Trans-Min is nearly constant

- -PYTHIA6 models slightly farther from data than HERWIG++ and HERWIG+JIMMY

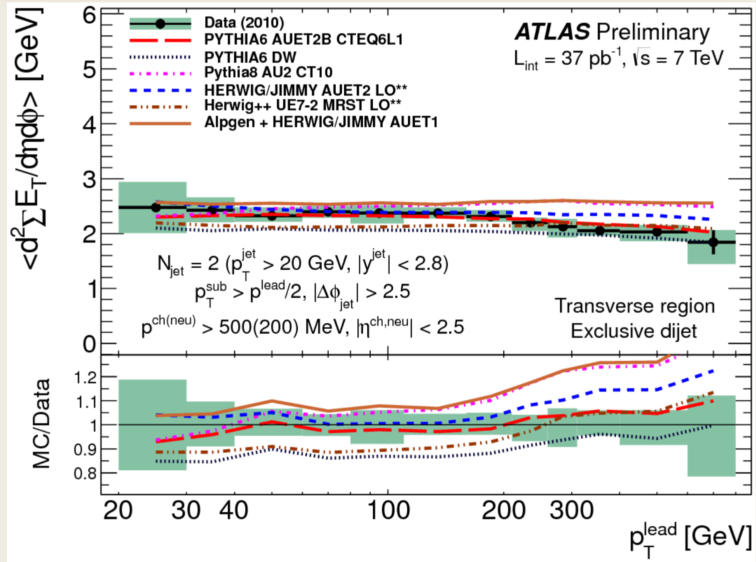
Underlying Event: Charged & Neutral ΣE_T vs p_T^{lead}

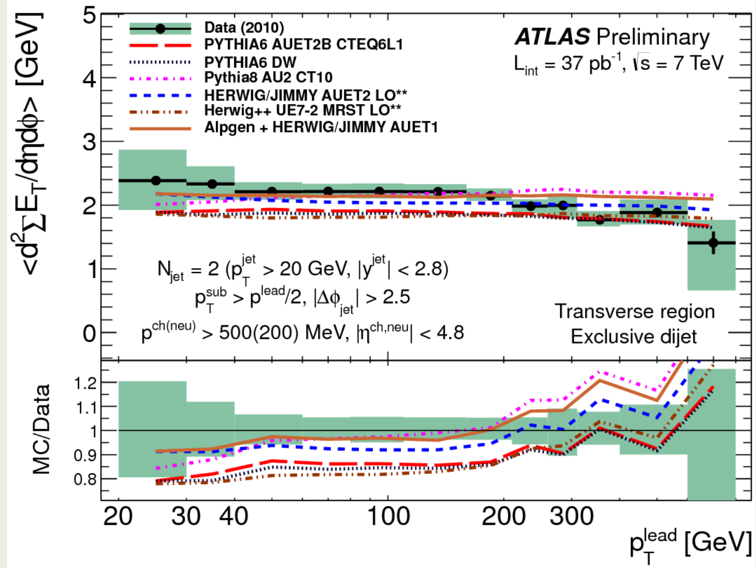
Total Transverse Region/Incl. Jets





Total Transverse Region/Excl. Dijets



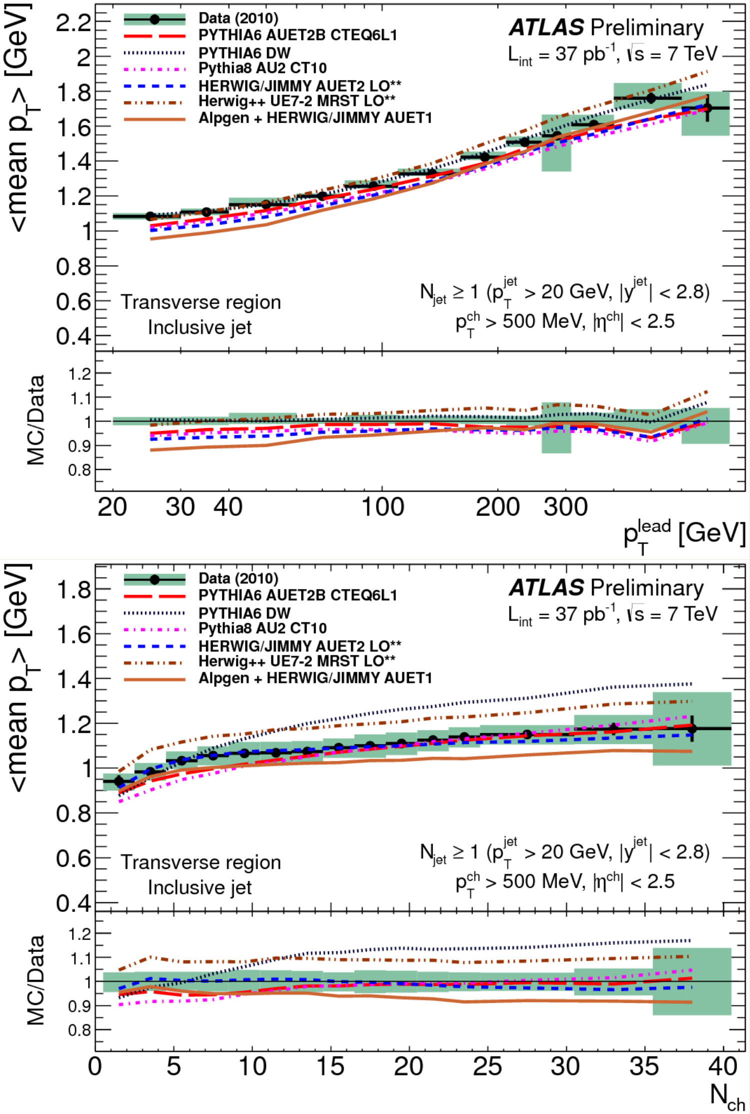


- -Inclusive Jet (l) and Exclusive Dijet (r) topologies
- -Similar trends to track-based quantities

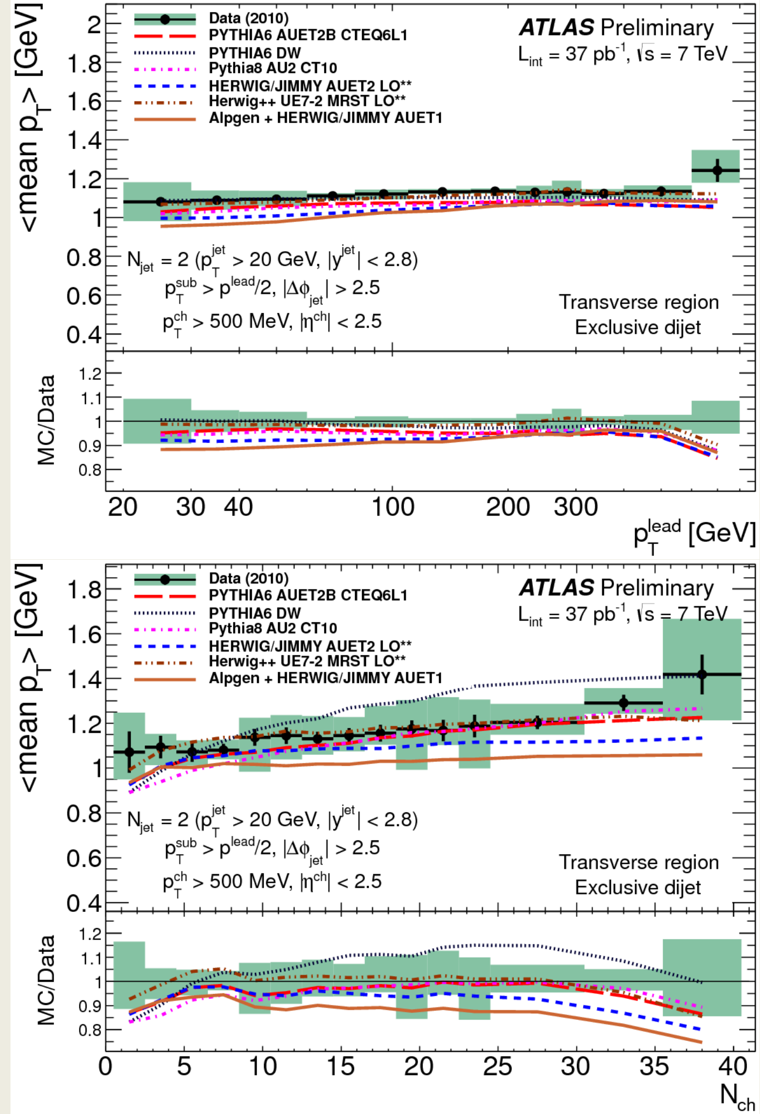
- -Full η-acceptance (bottom row) shows increased disagreement between MC models and data.

Underlying Event: Charged $<p_T>$ vs p_T^{lead} and N_{ch}

Total Transverse Region/Incl. Jets



Total Transverse Region/Excl. Dijets



- $<p_T>$ shows very different behavior between inclusive jet & exclusive dijet topologies.
- Rise in $<p_T>$ related to slow rise in N_{ch} seen earlier.
- High p_T tails in UE production removed by exclusive dijet req.
- Good description by MC models

Submitted to Eur. Phys. J. C

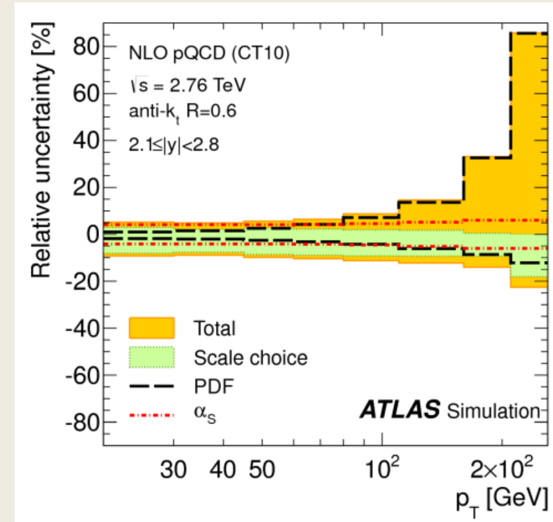
Inclusive Jet Cross Sections

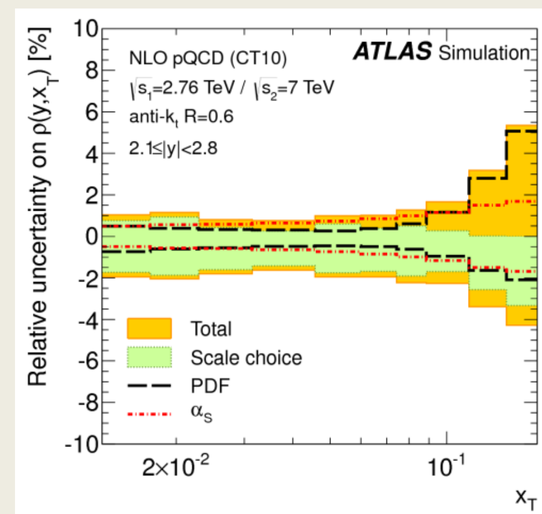
- Inclusive jet production is an important test of pQCD predictions
- Inclusive jet production measured at √s = 2.76 (L=0.20 pb^{-1})
  - Compared to previously published measurement at √s = 7 TeV (L=37 pb^{-1}) as functions of p_T and $x_T = 2p_T/\sqrt{s}$

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

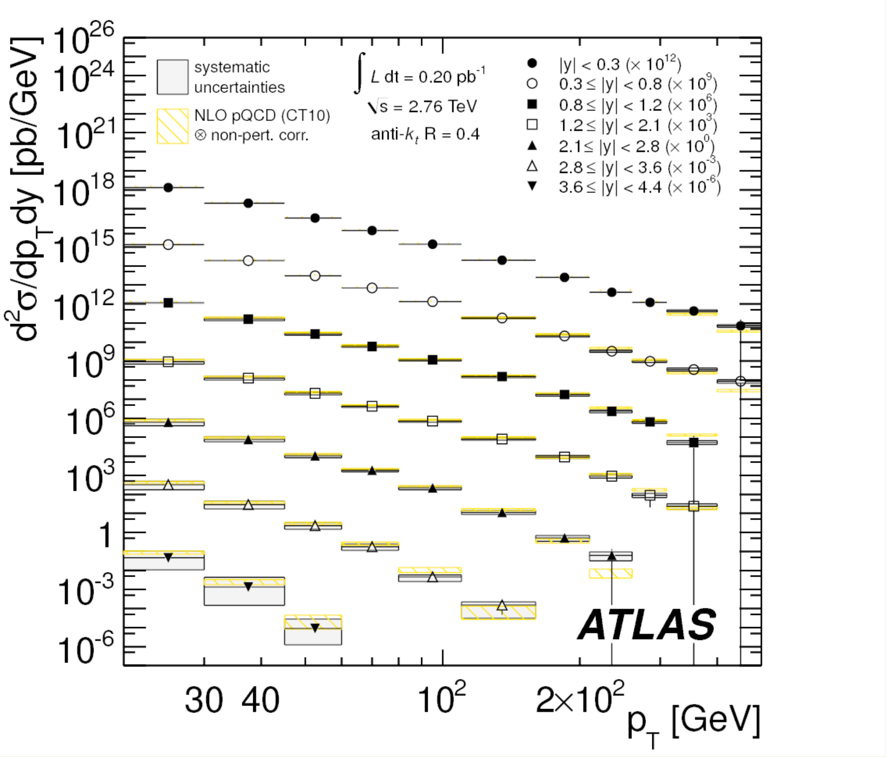
$$\rho(y, p_T) = \frac{\sigma(y, p_T, 2.76\ \text{TeV})}{\sigma(y, p_T, 7\ \text{TeV})}.$$

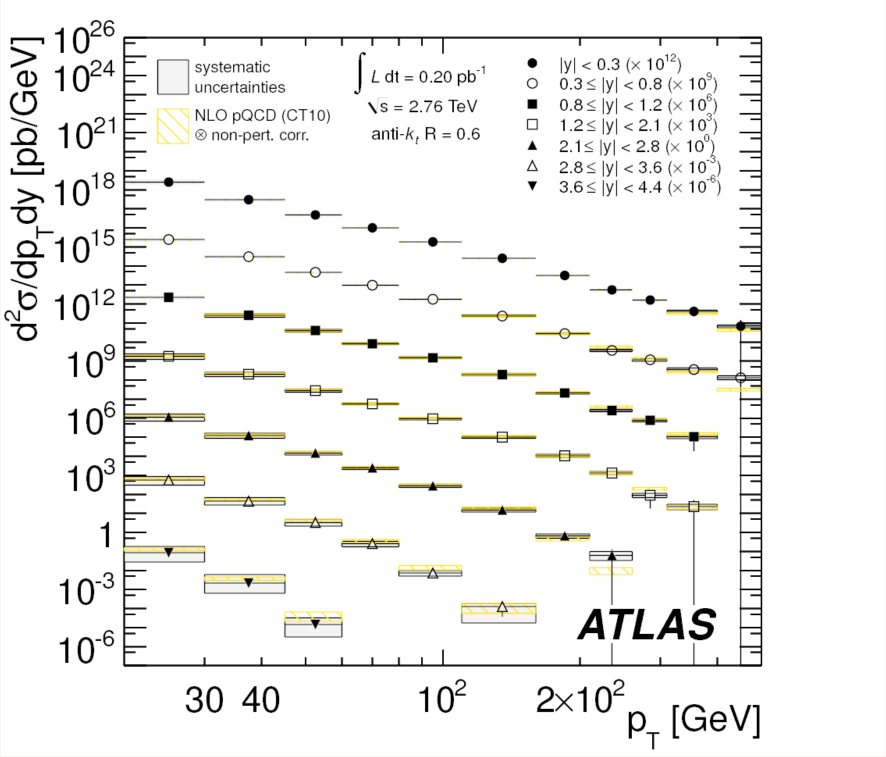
  - Many experimental systematics cancel in the ratio
    - Exceptions: Luminosity (uncorrelated), pile-up in 7 TeV data
- Anti-kT jets. Measured for both R=0.4 and R = 0.6
- Measure jets with p_T > 20 GeV in |y|<4.4
- Cross sections corrected to particle level
- Compared to NLO pQCD (NLOJET++ w/ CT10)
  - Corrections applied for non-perturbative effects





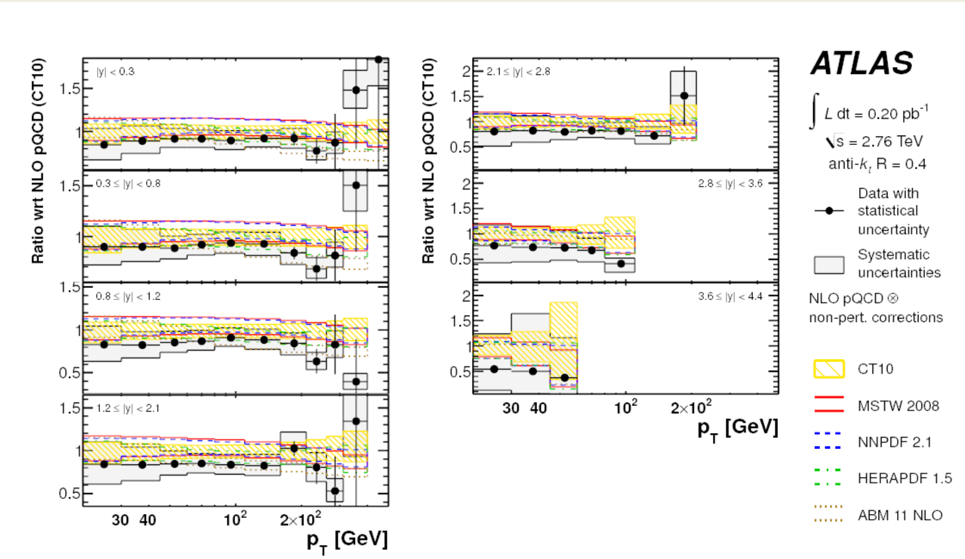
Inclusive Jet Cross Section √s = 2.76 TeV

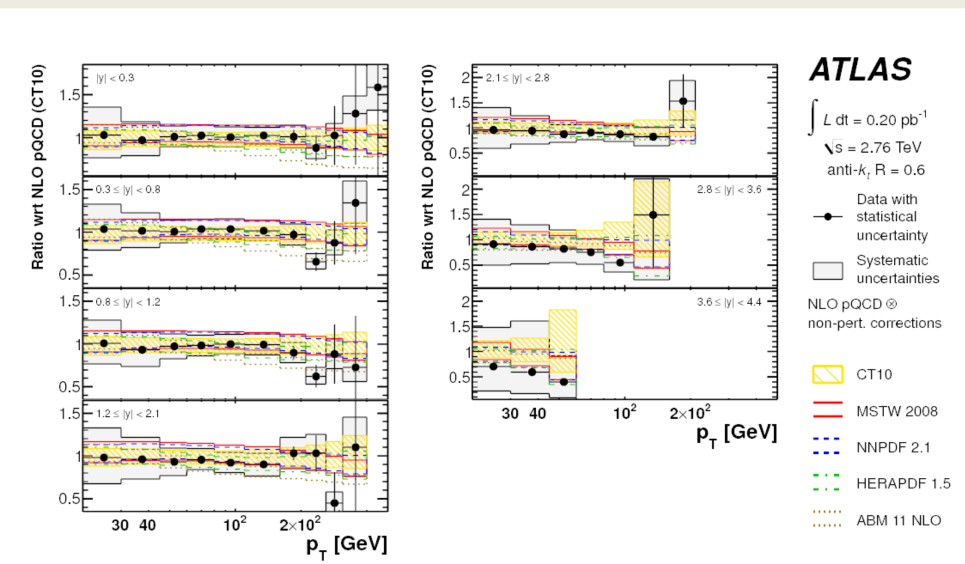




-Inclusive jet cross section in slices of rapidity
-R=04 (left) and R=0.6 (right) anti-kT jets.
-Good agreement with NLO predictions

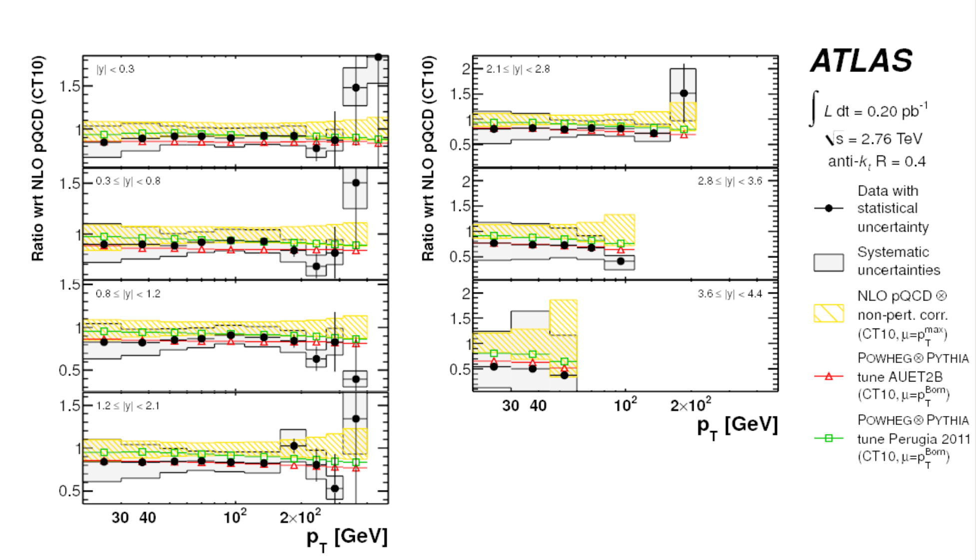
Inclusive Jet Cross Section $\sqrt{s}$ = 2.76 TeV

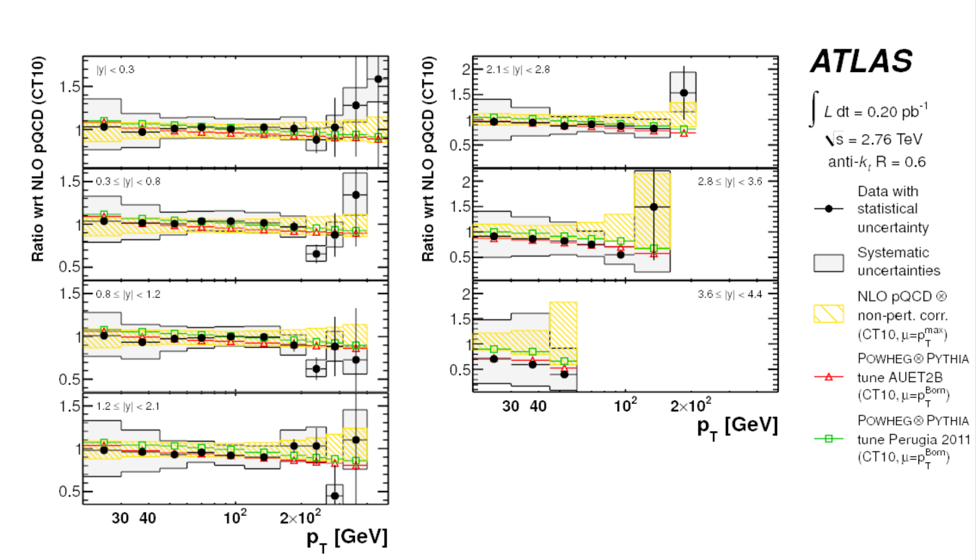




-Data/Theory vs p_T in bins of rapidity
-R=0.4 (top) and R=0.6 (bottom) jets
-Good agreement for most rapidity regions
-Central results shown for CT10 PDFs
-Also shown:
- -MSTW2008
- -NNPDF 2.1
- -HEREPDF 1.5,
- -ABM 11.

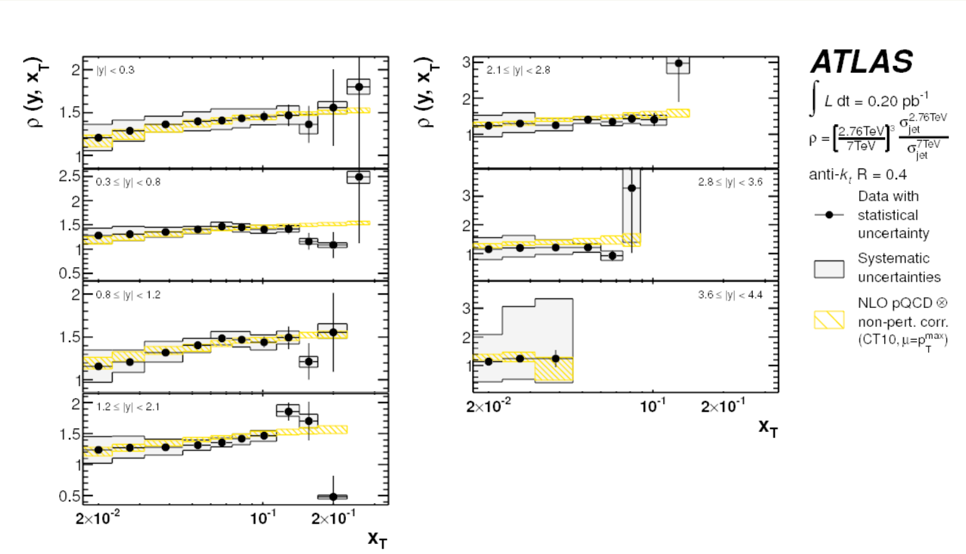
Inclusive Jet Cross Section √s = 2.76 TeV

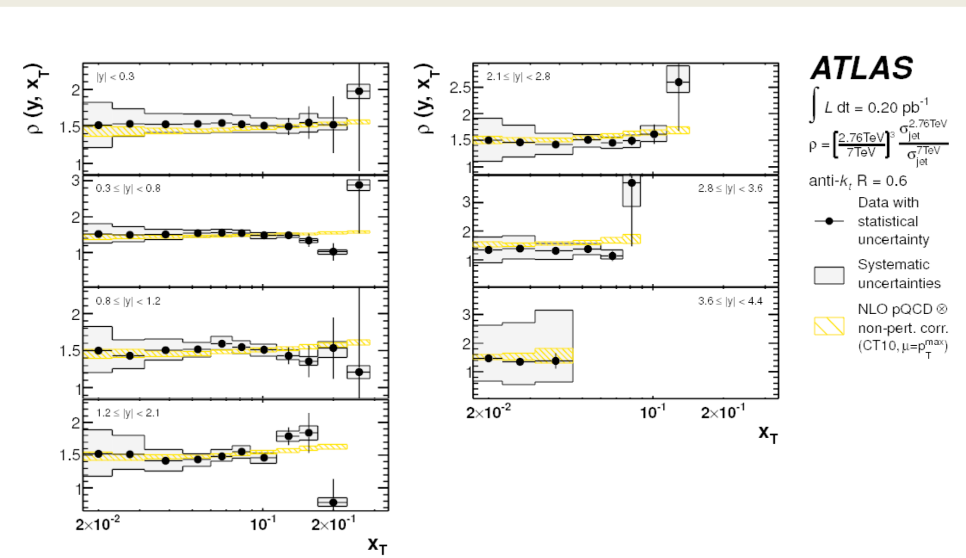




- -Data/Theory vs p_T in bins of rapidity
- -R=0.4 (top) and R=0.6 (bottom) jets
- -CT 10 PDF
- -Comparison made to MC models:
  - -POWHEG+PYTHIA, Tune AUET2B
  - -POWHEG+PYTHIA, Tune Perugia 2011

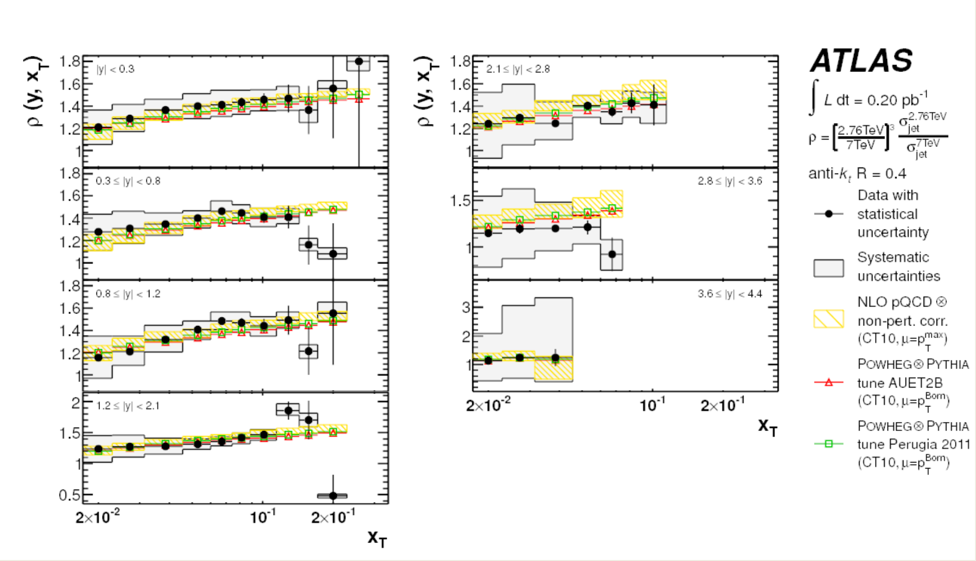
Inclusive Cross Section Ratios vs x_T

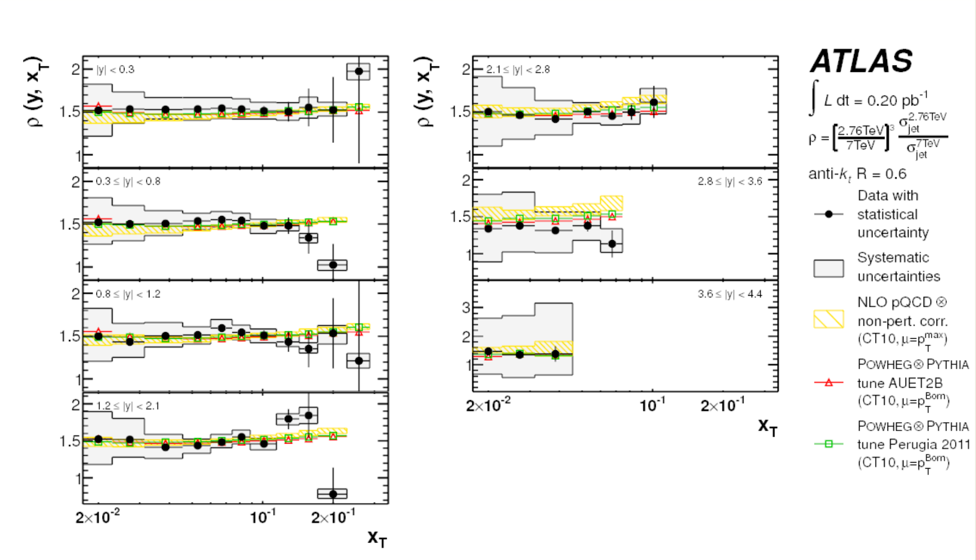




- Extracted Cross Section Ratio ρ(y,xT) vs xT
- Comparison made to NLO pQCD
- R=0.4 (top) and R=0.6 (bottom)
- Generally 1.1< ρ(y,xT)<1.5 for both R parameter values
  - Asymptotic freedom
  - Evolution of gluon distribution with QCD scale.
- Good agreement with NLO predictions

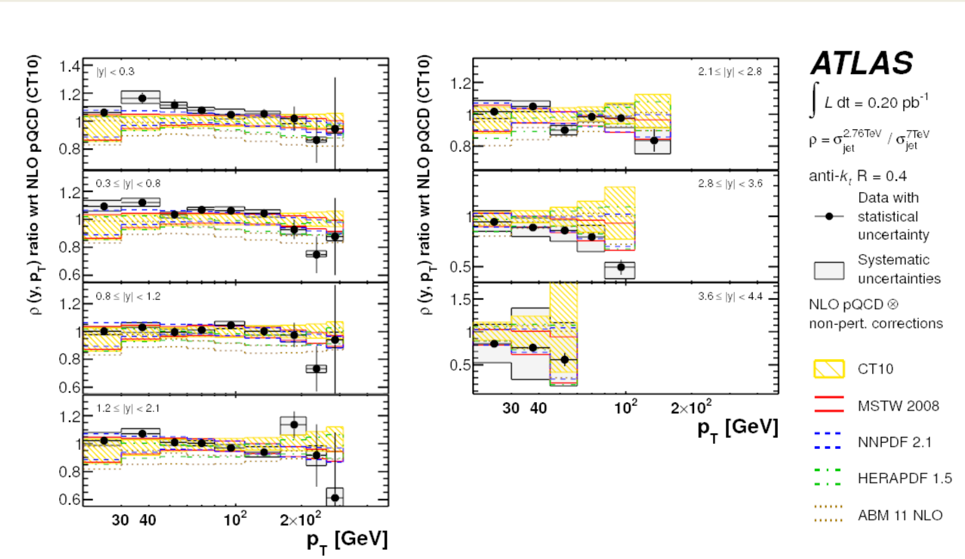
Inclusive Cross Section Ratios vs x_T

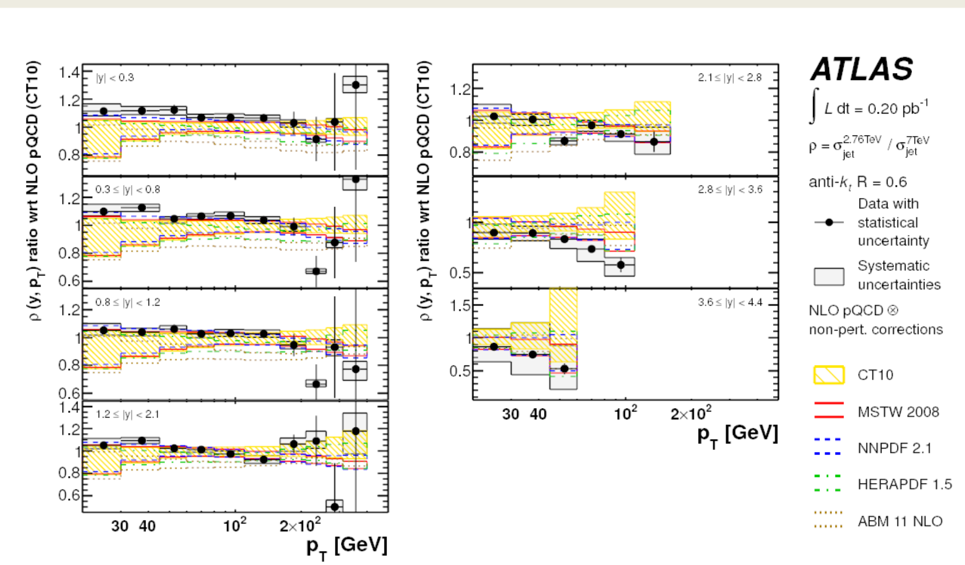




- Extracted Cross Section Ratio ρ(y,xT) vs x_T
- Comparison made to NLO pQCD
- R=0.4 (top) and R=0.6 (bottom)
- Comparison made to MC Models:
  - -POWHEG+PYTHIA, Tune AUET2B
  - -POWHEG+PYTHIA, Tune Perugia 2011
- Very similar predictions from both

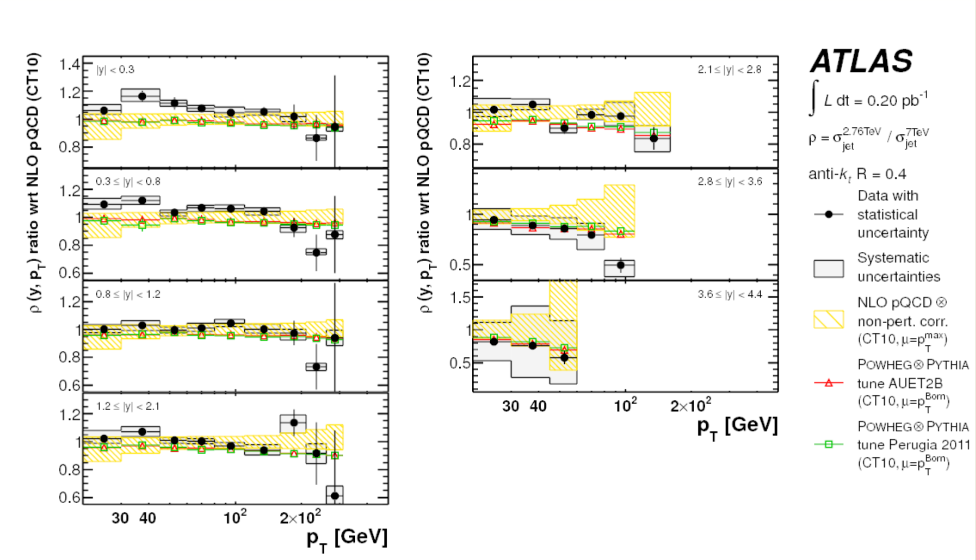
Inclusive Cross Section Ratios vs p_T

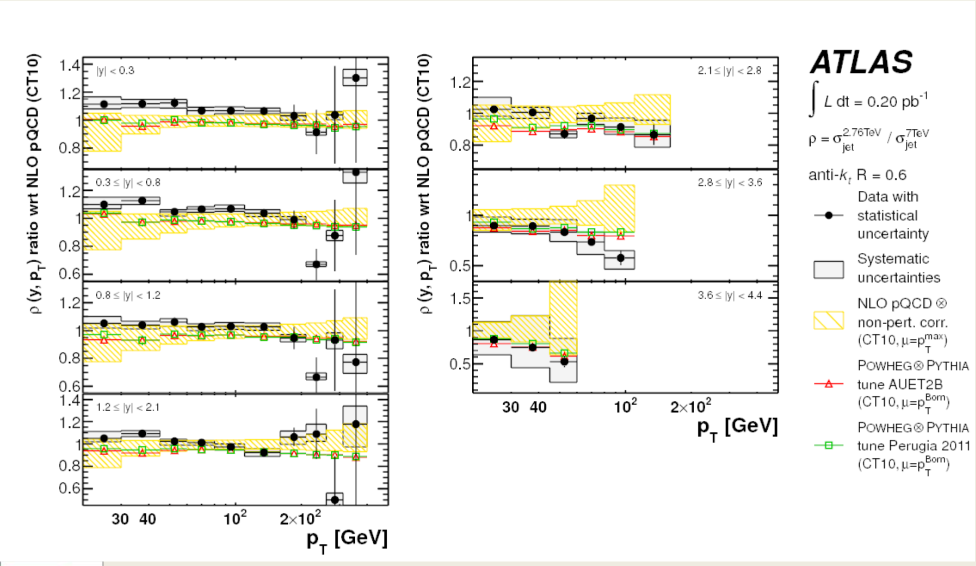




- Extracted Cross Section Ratio $\rho(y,p_T)$ vs p_T
- Comparison made to NLO pQCD
- R=0.4 (top) and R=0.6 (bottom)
- Reduced systematic uncertainties generally smaller than theoretical uncertainties.
- Data points generally higher than NLO prediction in central rapidity regions.

Inclusive Cross Section Ratios vs p_T





- Extracted Cross Section Ratio $\rho(y,p_T)$ vs p_T
- Comparison made to NLO pQCD
- R=0.4 (top) and R=0.6 (bottom)
- Comparison made to MC Models:
  - -POWHEG+PYTHIA, Tune AUET2B
  - -POWHEG+PYTHIA, Tune Perugia 2011
- Differences between tunes is small.
- Deviations seen mostly in the most forward region.
  - - Roughly ~10% deviations in central rapidity at lower p_T

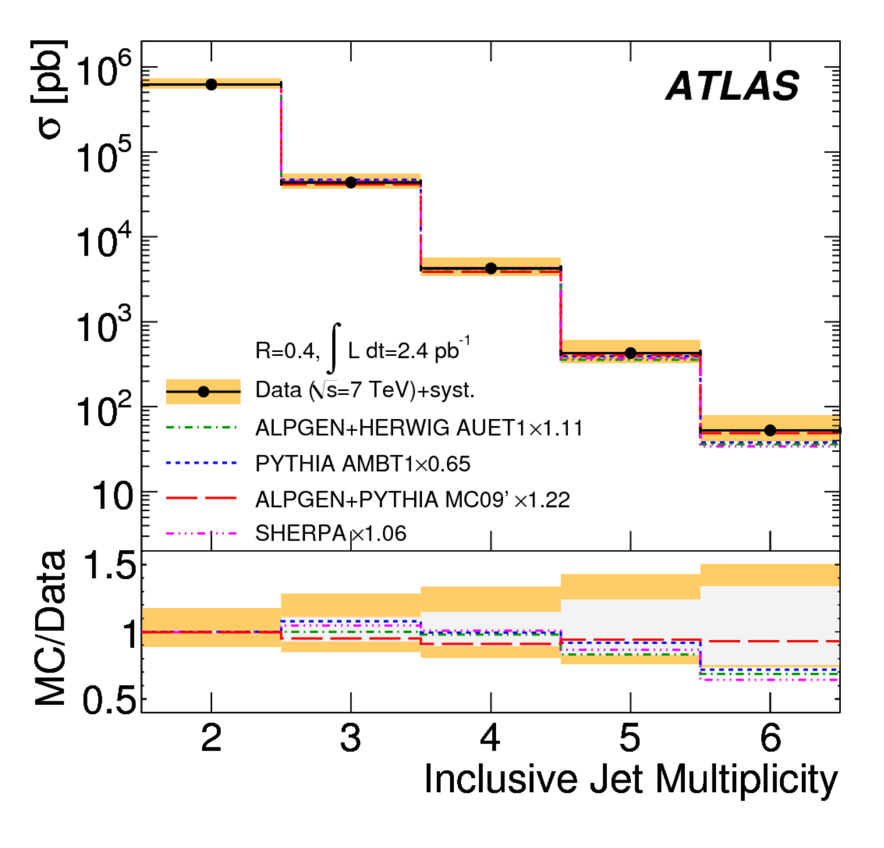
Summary

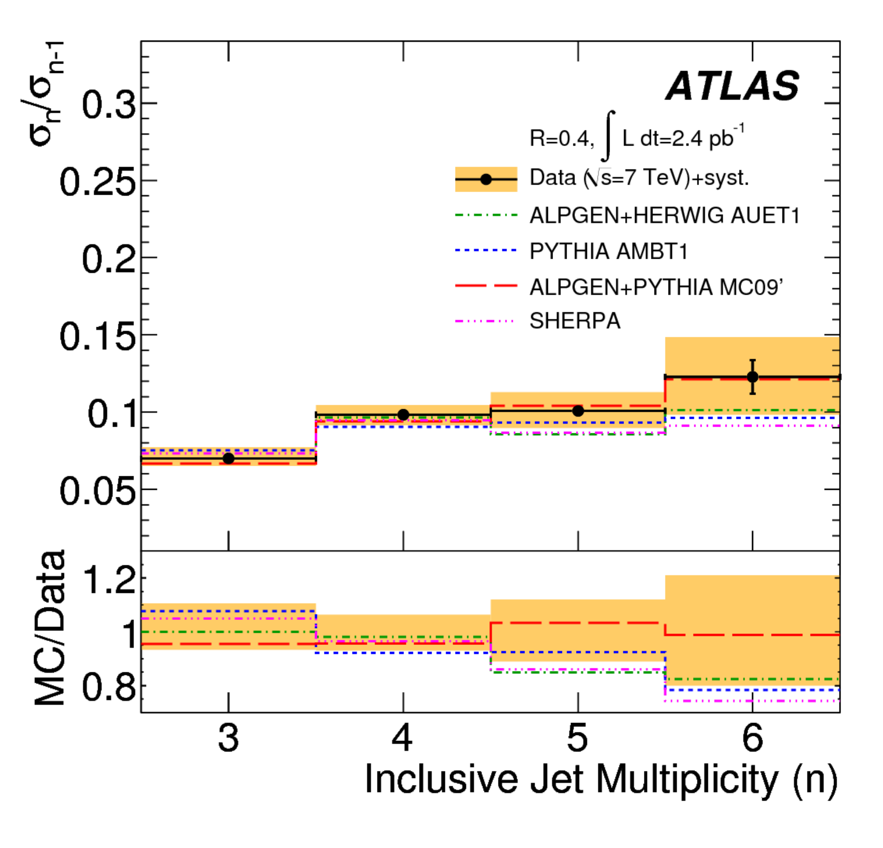
- ATLAS has measured the cross section for rapidity gap production and rapidity gap fraction in events with a central jet veto.
  - Cross sections of gaps of $0 < \Delta\eta_F < 8$ measured
  - Exponential falling non-diffractive contribution observed at small gap sizes
  - PYTHIA, PHOJET, and HERWIG all have difficulty describing the full range of $\Delta\eta_F$ and p_T^{cut} dependences.
  - Central jet veto analysis of fraction of events with gaps and <Njets>
  - Data shows expected reduction in gap fraction with large average dijet p_T and Δy.
- ATLAS has studied the underlying event in jet events
  - Increasing transverse activity vs. p_T^{lead} inclusive jet events
  - Constant to decreasing activity in exclusive dijet events, due to veto of tails of high p_T jet distribution
  - MC models describe behavior well, with some discrepancies.
    - HERWIG/JIMMY better than PYTHIA for inclusive jet topology
    - PYTHIA 6 tunes generally better for exclusive dijet topology
- ATLAS has measured the inclusive jet cross section at 2.76 and 7 Ted and the ratios of cross sections vs. p_T and x_T.
  - Cross section at 2.76 TeV shows good agreement with NLO pQCD
  - Ratio of cross sections at 2.76 and 7 TeV compared to NLO and MC models as functions of jet x_T and p_T.

BACKUP SLIDES

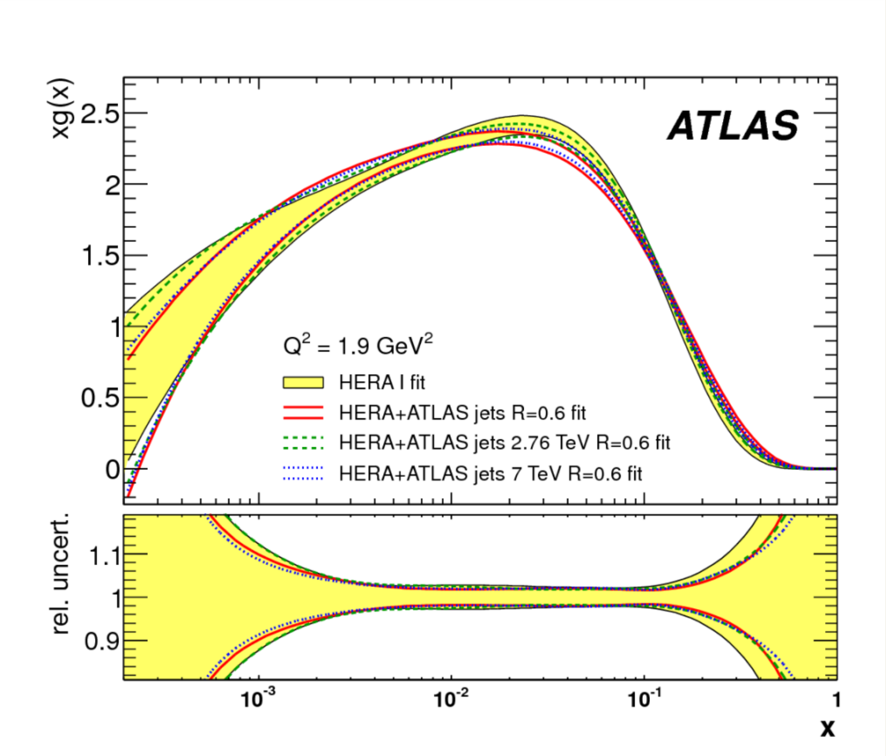
Eur. Phys. J. C (2011) 71: 1763

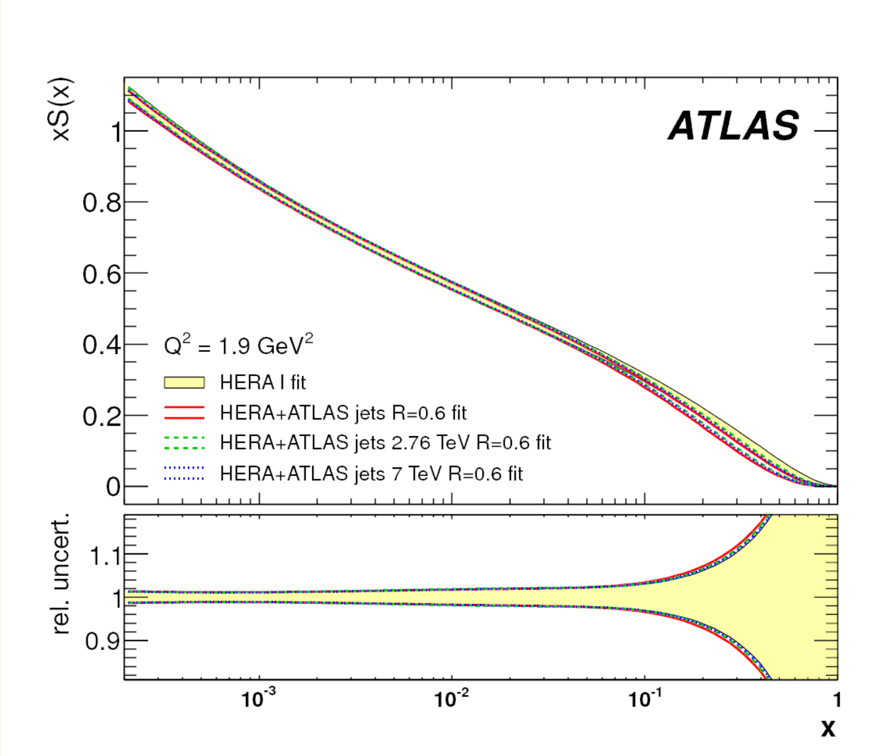
Jet Multiplicities





HERAFitter* PDF Results





-PDF fits using HERA 1 data and HERAFITTER

-HERA results combined with ATLAS inclusive jet cross section measurements at 2.76 and 7 TeV

-Fit performed for each separately and combined.

- Constraints on the gluon contribution