Forward physics at ATLAS

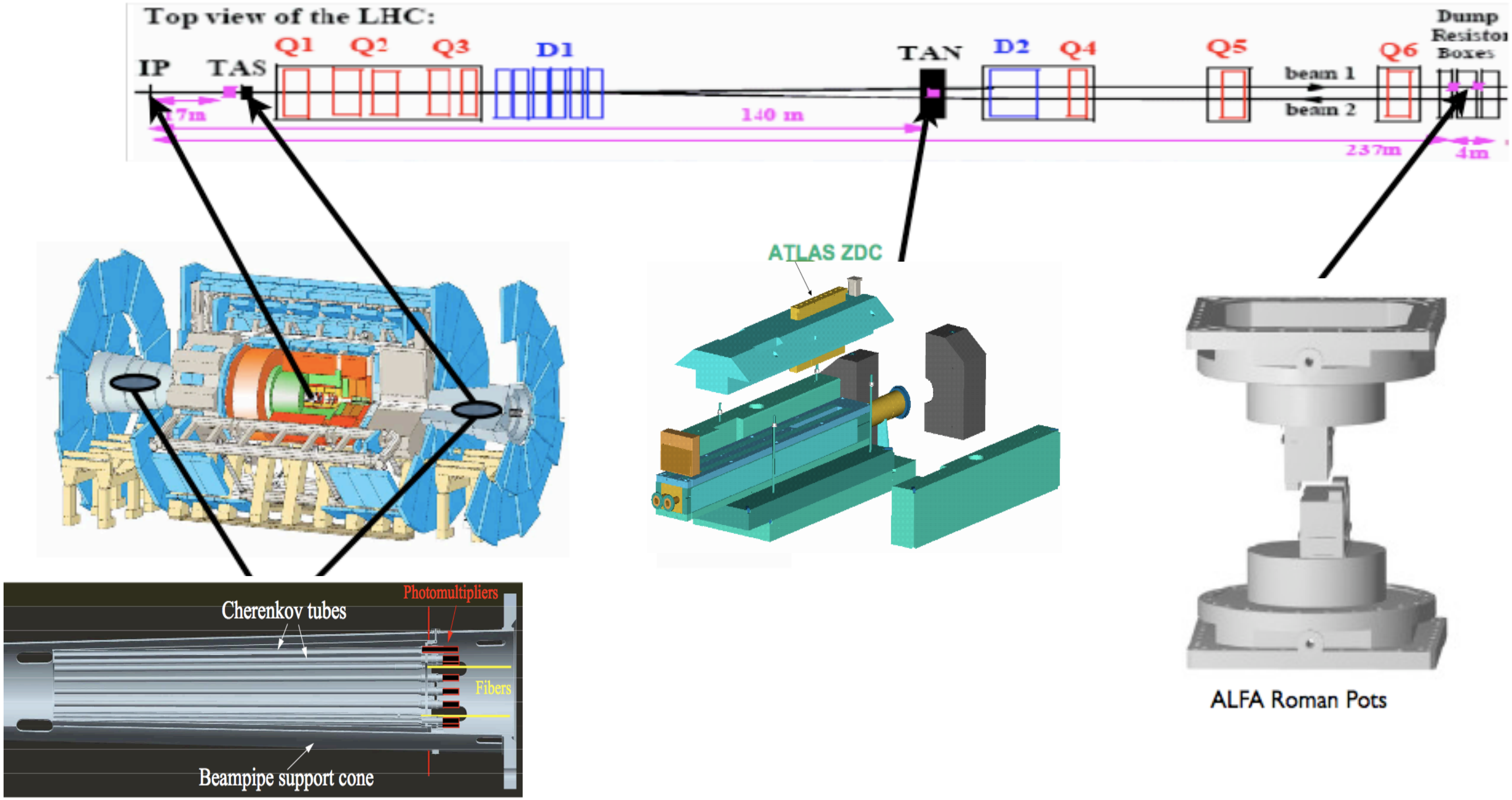
Andy Pilkington – IPPP Durham and Manchester

Presented at LISHEP 2011, Rio De Janiero, Brazil, 7th July 2011

Soft-QCD measurements:
1) Inelastic cross section
2) Forward rapidity gap cross section

Perturbative-QCD measurements:
3) Forward jet cross section
4) Dijet production with a central jet veto

ATLAS – the big picture



LUCID

Total inelastic cross-section

arXiv:1104.0326 (accepted by Nature)

Total pp cross-section

- The total pp cross-section is traditionally measured in two ways
  - Measuring the elastic component (optical theorem, ALFA)
  - Cosmic ray measurements

- The inelastic part of the cross-section in pp collisions is usually divided into diffractive (SD,DD) and non-diffractive (ND) components:

$$\sigma_{\mathbf{inel}} = \sigma_{\mathbf{nd}} + \sigma_{\mathbf{sd}} + \sigma_{\mathbf{dd}}$$

- All experiments have incomplete acceptance for inelastic events.

- In the case of diffractive events, a large fraction events go undetected, specifically the *low-mass* part of the cross-section.
  - This also happens to be the part of the cross-section that has particularly large uncertainty from the theoretical perspective

The inelastic cross-section

- The inelastic cross-section measurement at ATLAS is defined for relatively high mass events, using the variable ξ = M^2/s :

$$\sigma_{inel}(\xi > 5 \times 10^{-6}) = \frac{(N - N_{BG})}{\epsilon_{trig} \times \int L dt} \times \frac{1 - f_{\xi < 5\times 10^{-6}}}{\epsilon_{sel}}$$

Number of selected events

Number of estimated background events

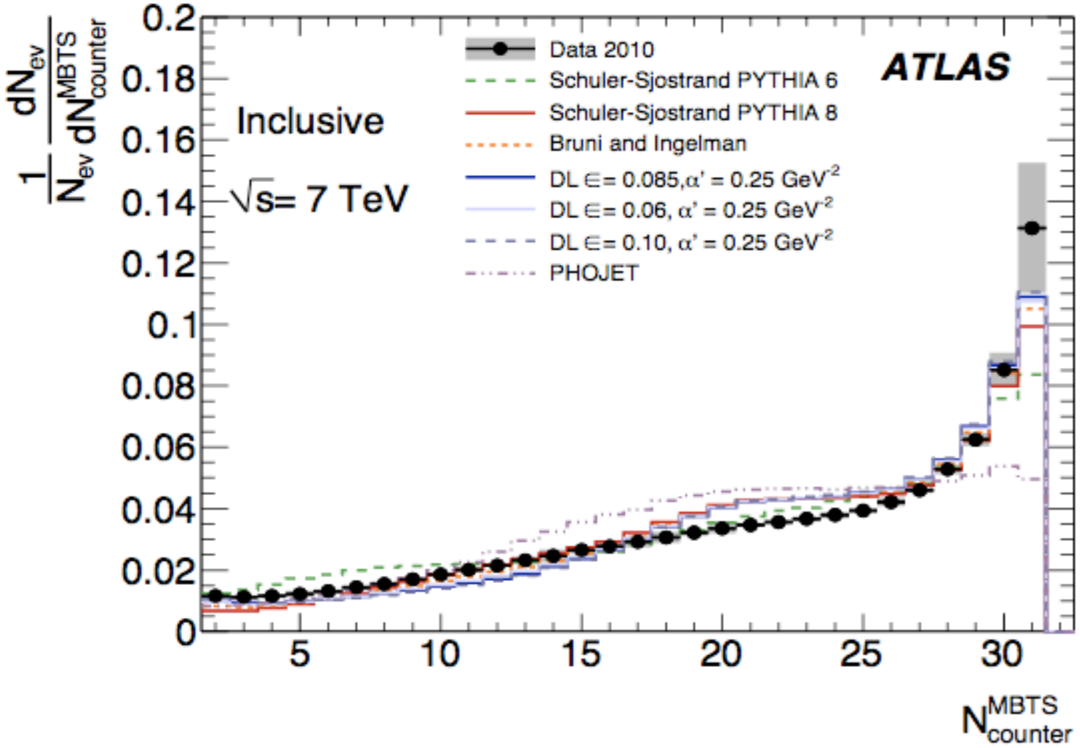
Integrated luminosity from Van Der Meer scans

MC-dependent correction factors

- Events selected using a minimum bias trigger requiring at least one MBTS scintillator counter above threshold (MBTS: 2.1 < |η| <3.8).
- Offline selection requires at least two MBTS counters above a threshold.

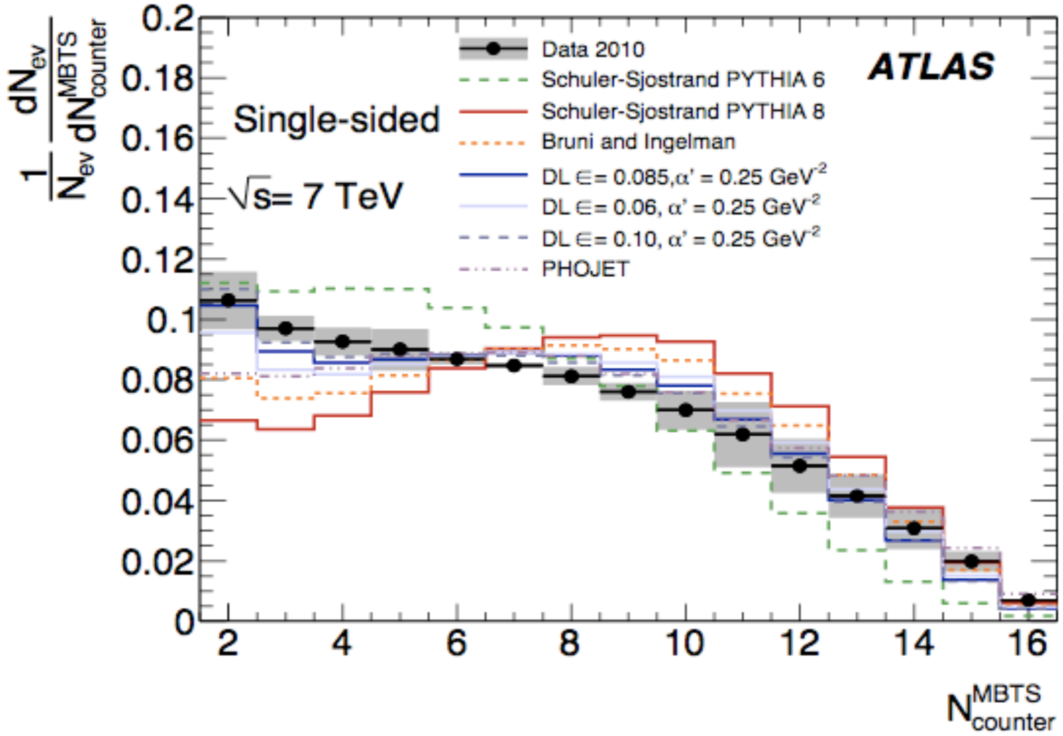
- For ξ >5.10^{-6} , the MBTS acceptance is greater than 50%.
  - MC based correction for fraction of events passing selection from low-mass events

The inelastic cross-section (II)



Inclusive MBTS hit multiplicity

Used for inelastic measurement



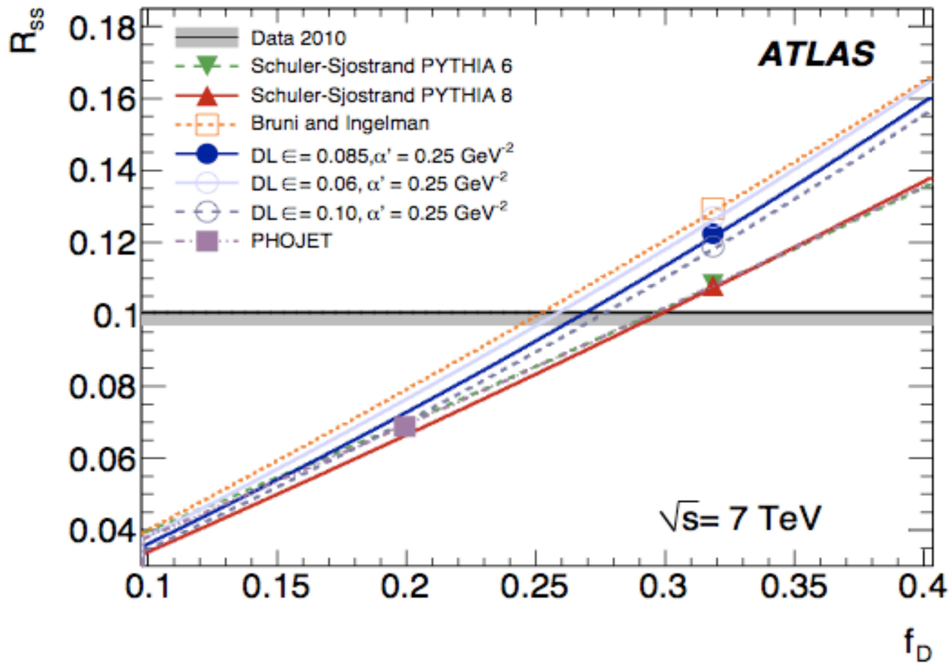
Single-sided MBTS hit multiplicity

Defined as events with one side of MBTS empty

Used to constrain the diffractive component

- DL model with ε=0.085 and α'=0.25 GeV^{-2} used as default parameterisation for MC-based corrections
- Other MC models used to assess uncertainties.

The inelastic cross-section (III)



- Ratio of single-sided events compared to generator level predictions (points)
- Diffractive fraction in each generator varied to produce R_{ss} vs f_D
- Using default DL parameterisation:

$$f_D = 26.9^{+2.5}_{-1.0}\%$$

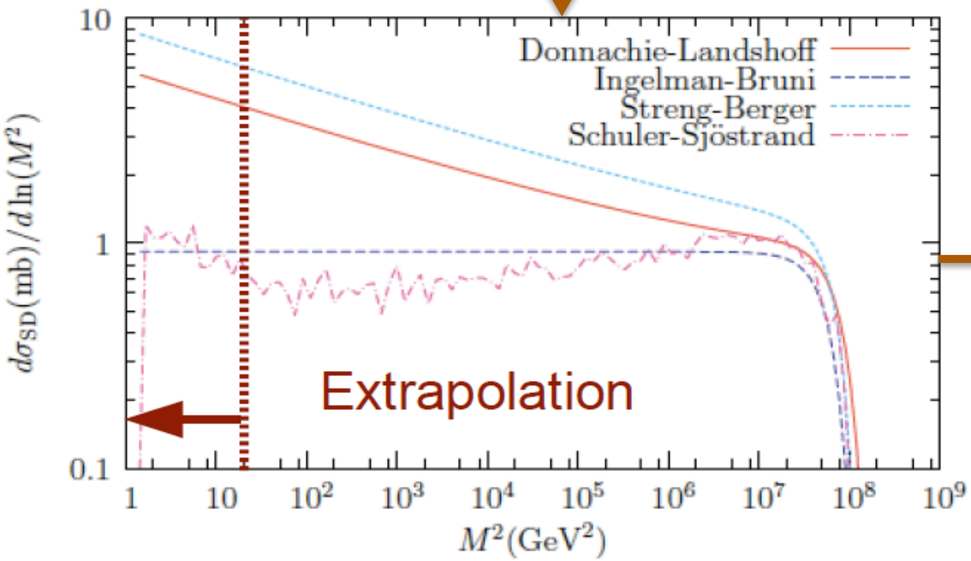
- Constraining the diffractive component reduces systematic uncertainty on inelastic cross-section
- Various other systematics studied, covering:
  - physics modelling,
  - detector simulation and response.
  - luminosity

Source	Uncertainty (%)
Trigger Efficiency	0.1
MBTS Response	0.1
Beam Background	0.4
f_D	0.3
MC Multiplicity	0.4
ξ-Distribution	0.4
Material	0.2
Luminosity	3.4
Total	3.5

The inelastic cross-section (IV)

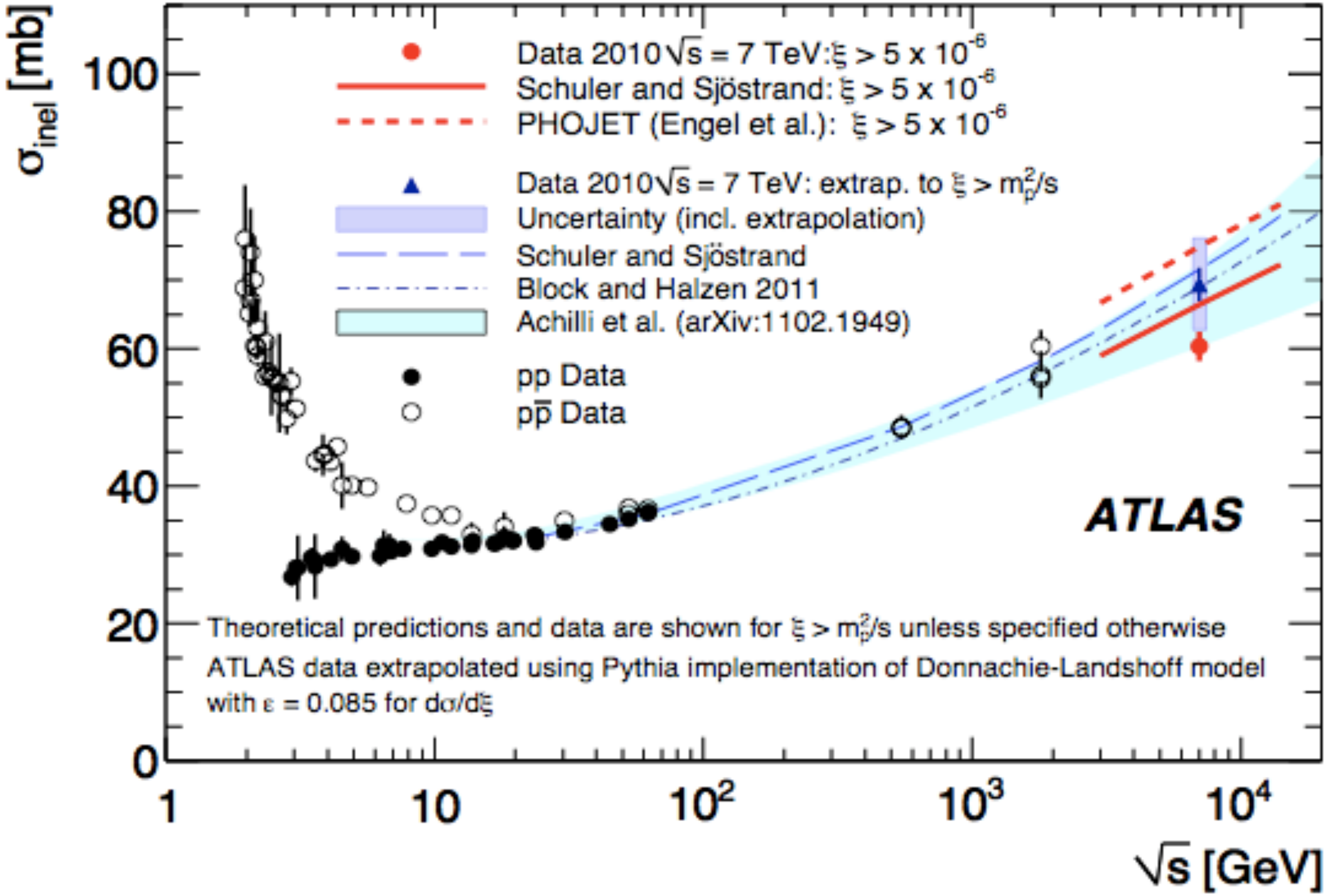
$\sigma(\xi > 5 \times 10^{-6})$ [mb]	
ATLAS Data 2010	60.33 ± 2.10(exp.)
Schuler and Sjöstrand	66.4
PHOJET	74.2
Ryskin *et al.*	51.8 – 56.2

- Final result can be extrapolated to the full inelastic cross-section: $\xi > m_p^2/s$
  - Allows comparison with previous results
  - But a large modelling uncertainty!



$\sigma(\xi > m_p^2/s)$ [mb]	
ATLAS Data 2010	69.4 ± 2.4(exp.) ± 6.9(extr.)
Schuler and Sjöstrand	71.5
PHOJET	77.3
Block and Halzen	69
Ryskin *et al.*	65.2 – 67.1
Gotsman *et al.*	68
Achilli *et al.*	60 – 75

The inelastic cross-section (V)



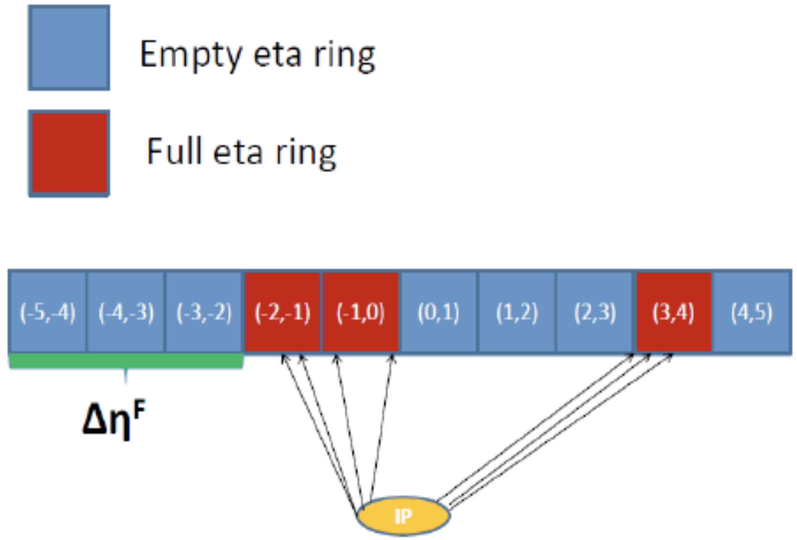
Forward rapidity gap cross-section

ATLAS-CONF-2011-059

Forward rapidity gap cross section

Detector-level gap algorithm

- Detector divided into 49 η-rings spanning the region $-4.9 < \eta < 4.9$.
- Ring is empty if it does not contain
  - Any track with p_T>200MeV (for $|\eta|<2.5$)
  - Any calorimeter cell above threshold $E/\sigma > S_{th}(\eta)$ (for $|\eta|<4.9$)

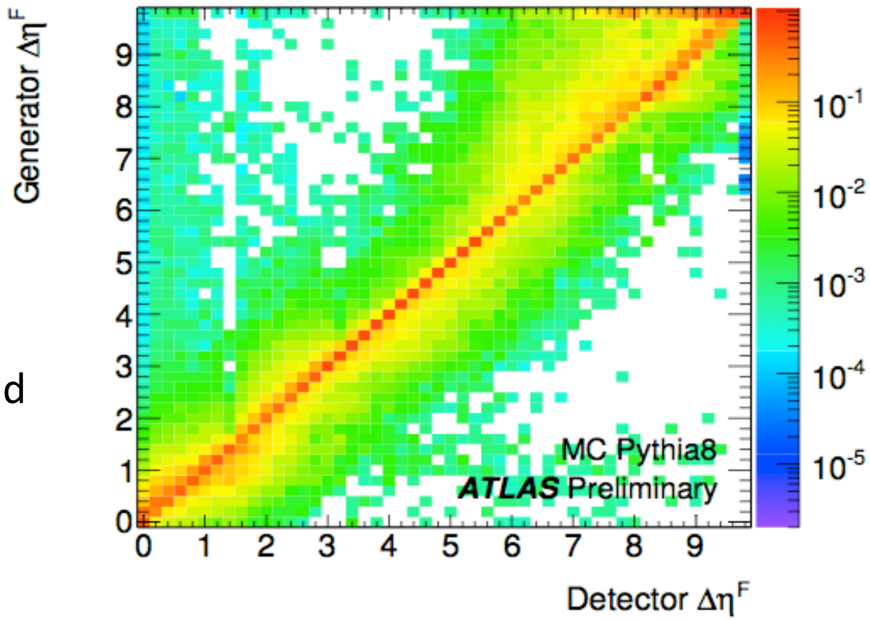


Hadron-level gap-definition

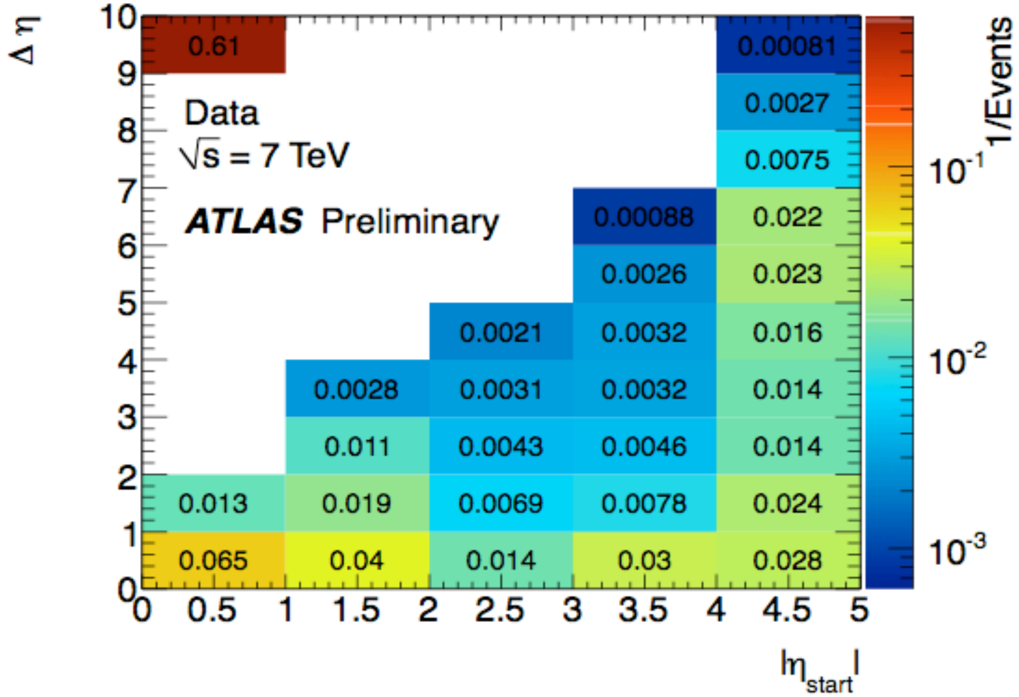
- Phase space divided into same η-rings
- No stable particle with p_T>200MeV and $|\eta|<4.9$
  - Approximates threshold cut due to noise rise in forward regions

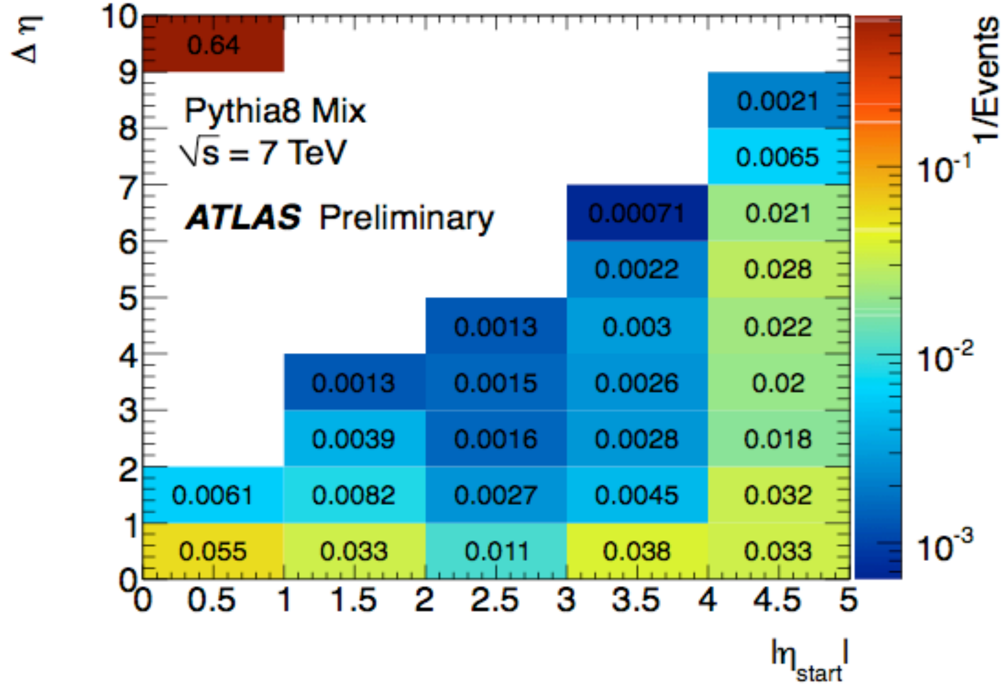
Forward rapidity gap cross-section ($d\sigma/d\Delta\eta_F$)

- Data corrected back to hadron-level using Migration Matrix and Bayesian unfolding method.



Rapidity gap cross section (II)

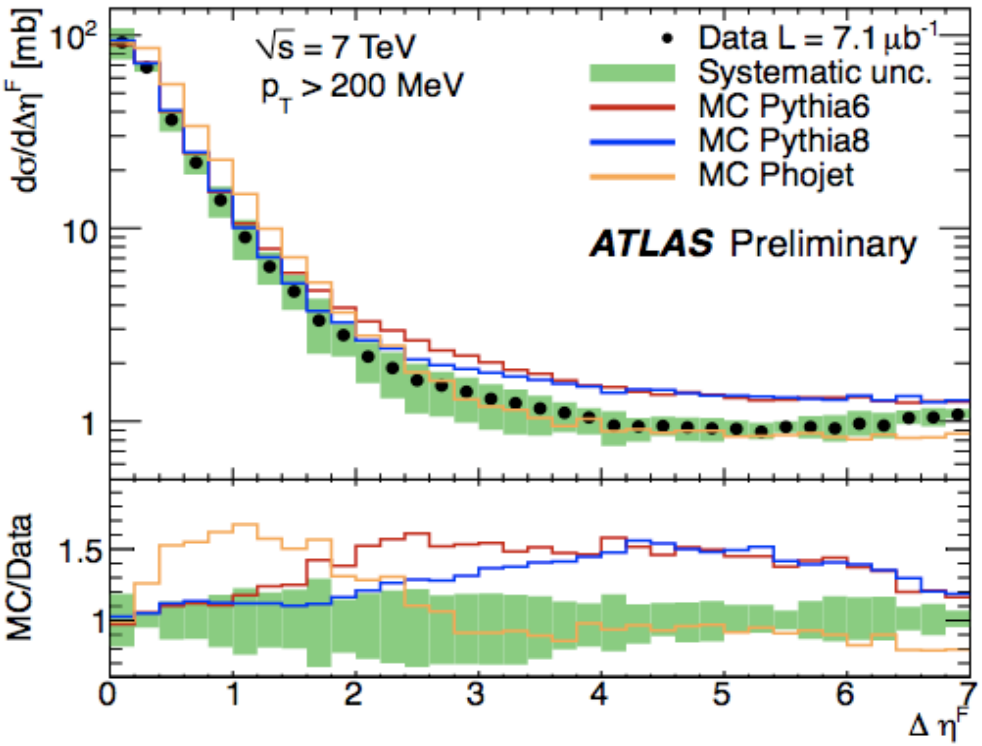


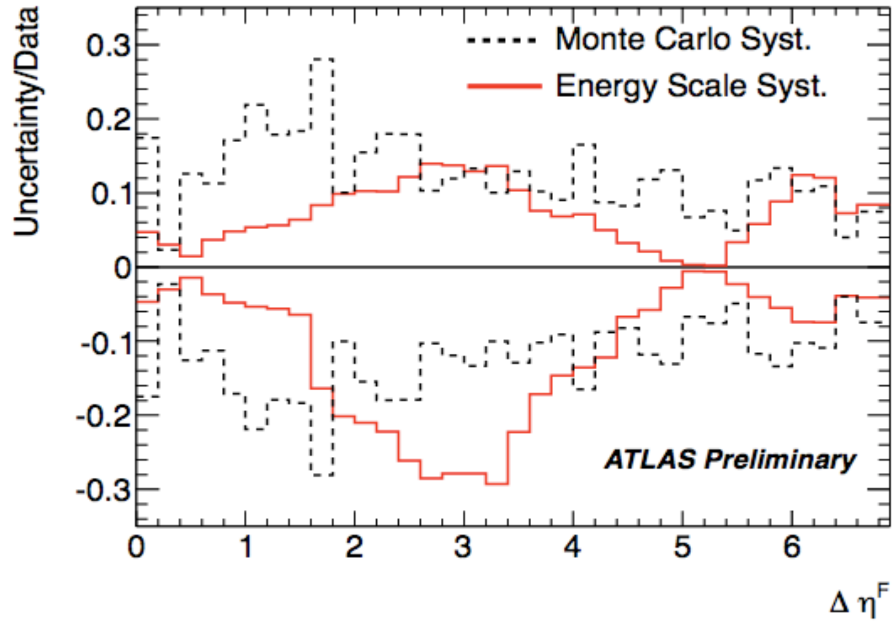


- To constrain diffractive modelling in MC use a ***floating gap*** approach
  - Rapidity gap defined as the largest successive span of empty η-rings
  - Events classified by the size of the rapidity gap and the starting point of the gap (defined relative to the edge of the detector)
- ND, SD and DD relative fractions allowed to vary in MC
  - Determine diffractive fraction to be 30.2 ± 0.3 ± 3.8 % [central value from PYTHIA 8]
  - Constrained MCs used in detector correction procedure to reduce model dependence

Rapidity gap cross section (III)

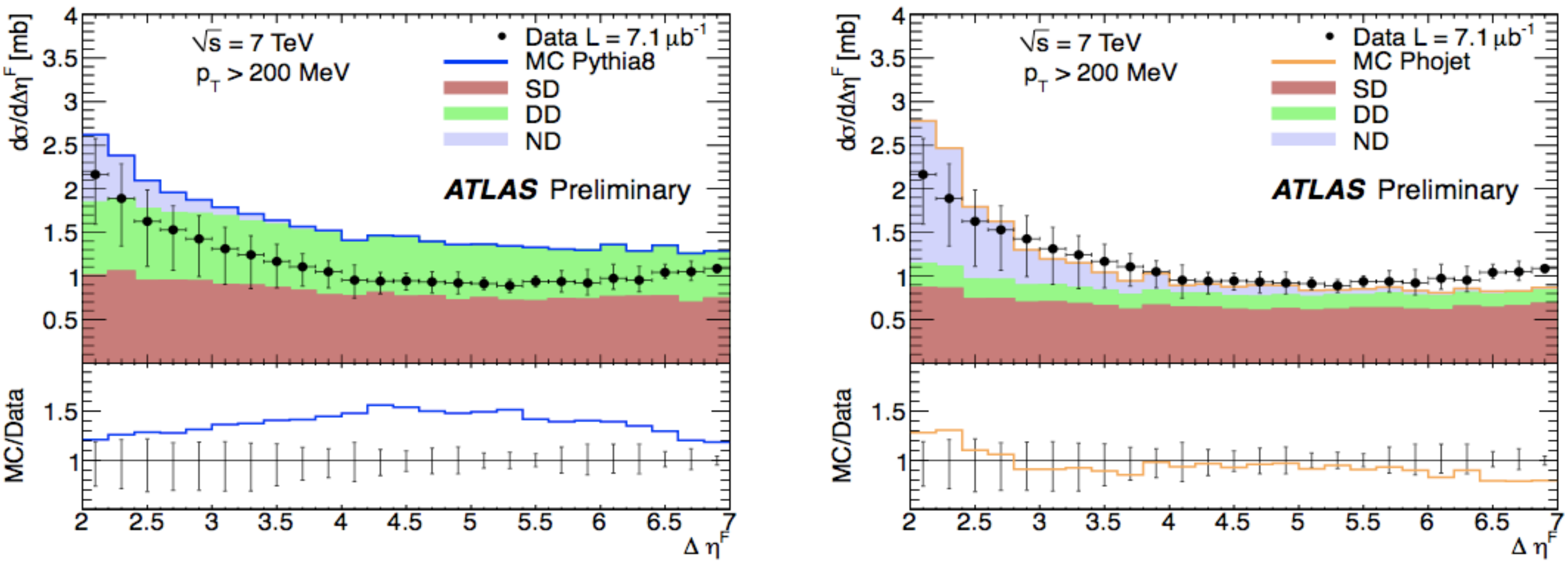
Inelastic cross-section measured as a function of a ***forward rapidity*** gap, $\Delta\eta_F$, defined as starting at the edge of the calorimeter ($\eta=\pm4.9$)





- Data shown against default PYTHIA 6, PYTHIA 8 and PHOJET predictions
- Largest systematic uncertainties from unfolding and low-E_T energy scale
- No MC can describe both small and large $\Delta\eta_F$ regions
- Diffractive cross-section of ~1mb per unit rapidity is predicted by KMR in arXiv: 1102.2844.

Rapidity gap cross-section (IV)

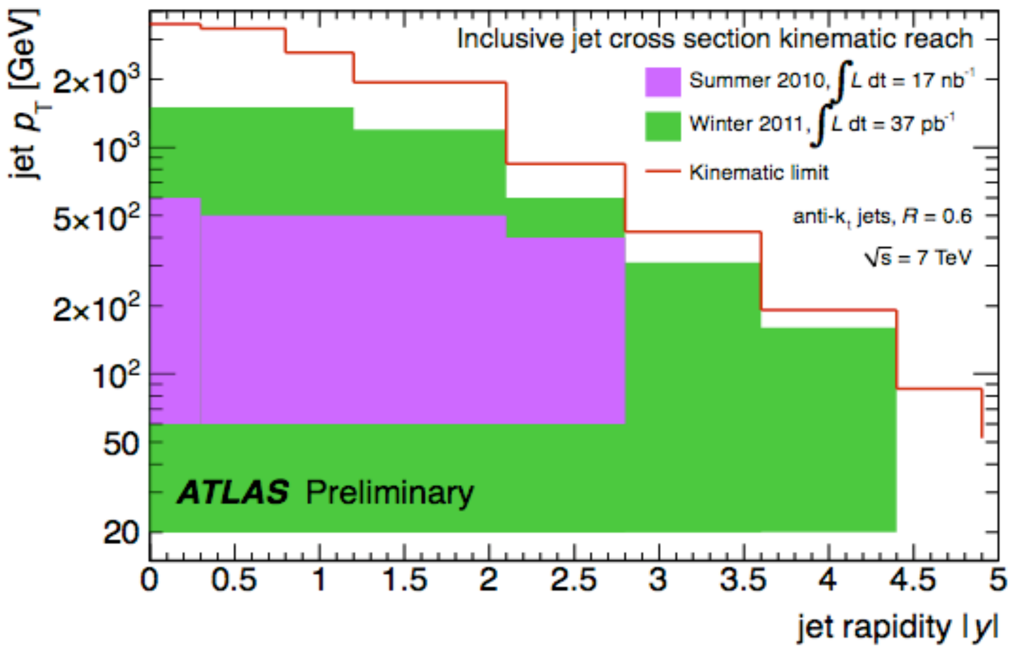


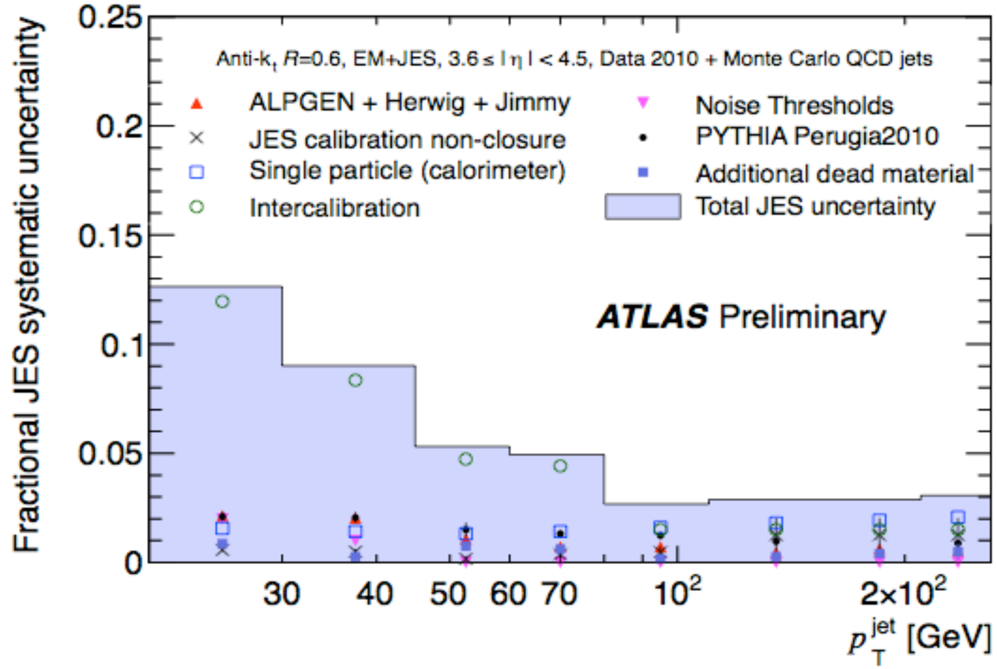
- In the large $\Delta\eta_F$ regions, scrutinise the PYTHIA 8 and PHOJET contributions:
  - Both have similar SD prediction
  - PYTHIA 8 overshoots the data due to a very large DD contribution

Inclusive forward jet cross-section

ATLAS-CONF-2011-047

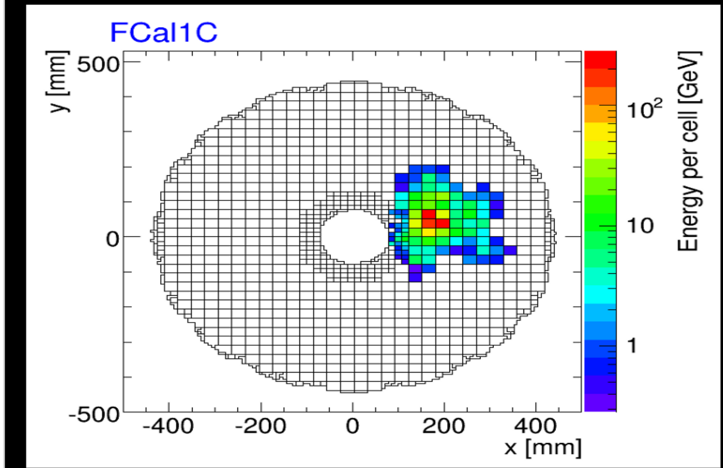
Inclusive forward jet cross section

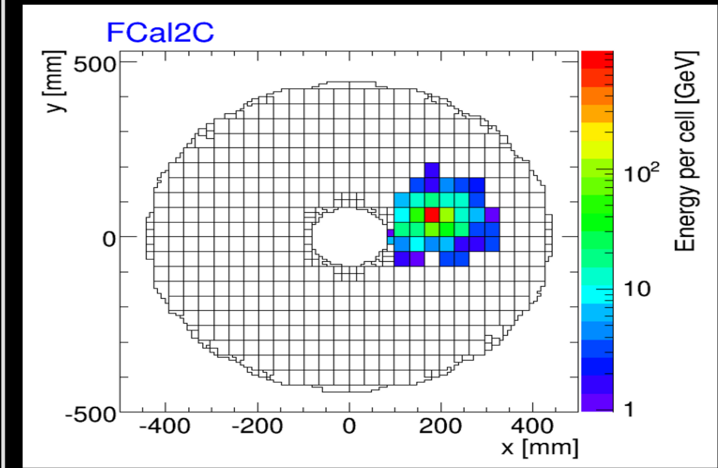


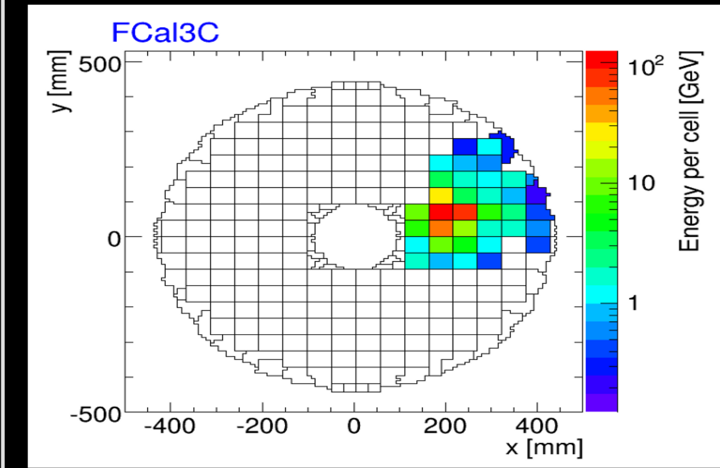


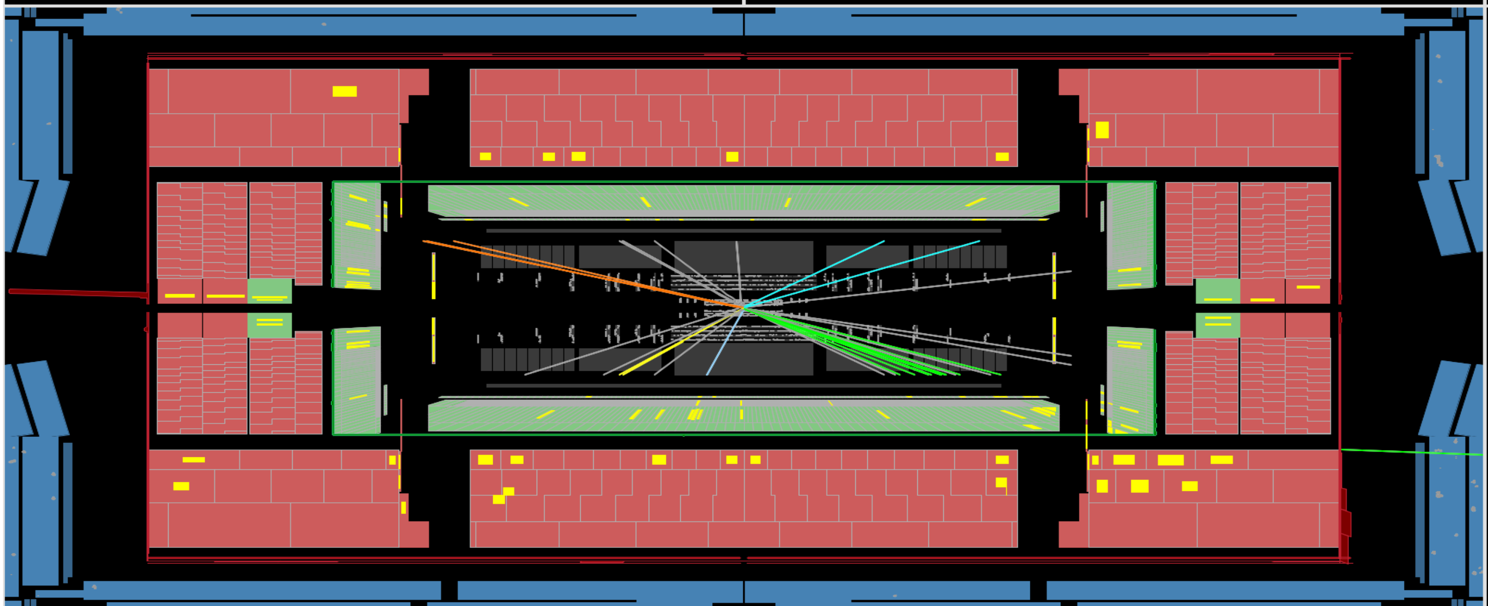
- Inclusive jet cross-section is defined for all jets with a given p_T and y
  - High p_T –forward jets are sensitive to PDFs at high-x and low-x
- Latest measurement is for anti-k_T jets [R=0.4,0.6] with p_T > 20 GeV and y < 4.4
- Measuring forward jets significantly more challenging than central jets due to increasing Jet Energy Scale uncertainty

Forward jet with E=3.37TeV, η=4







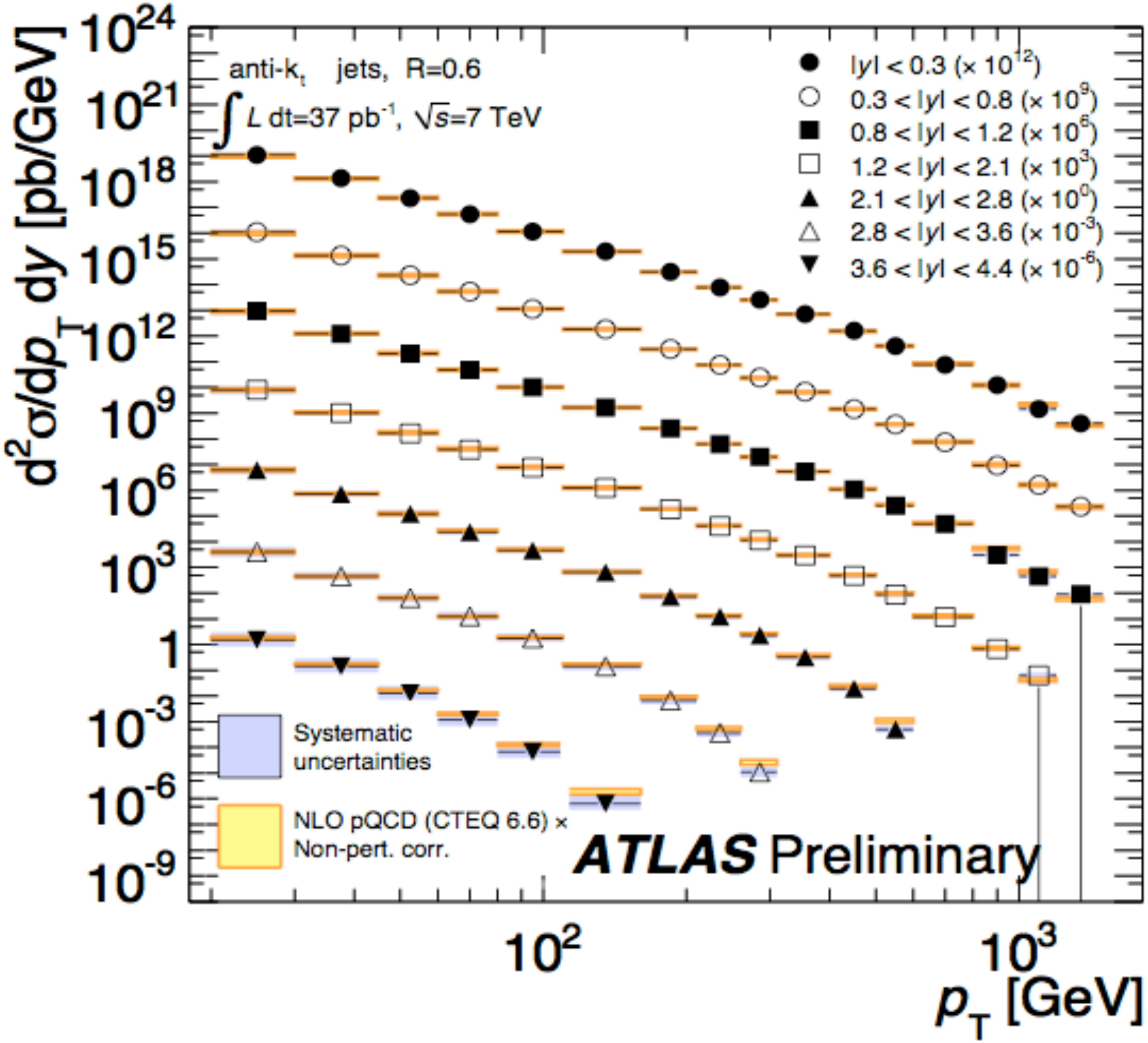


ATLAS EXPERIMENT

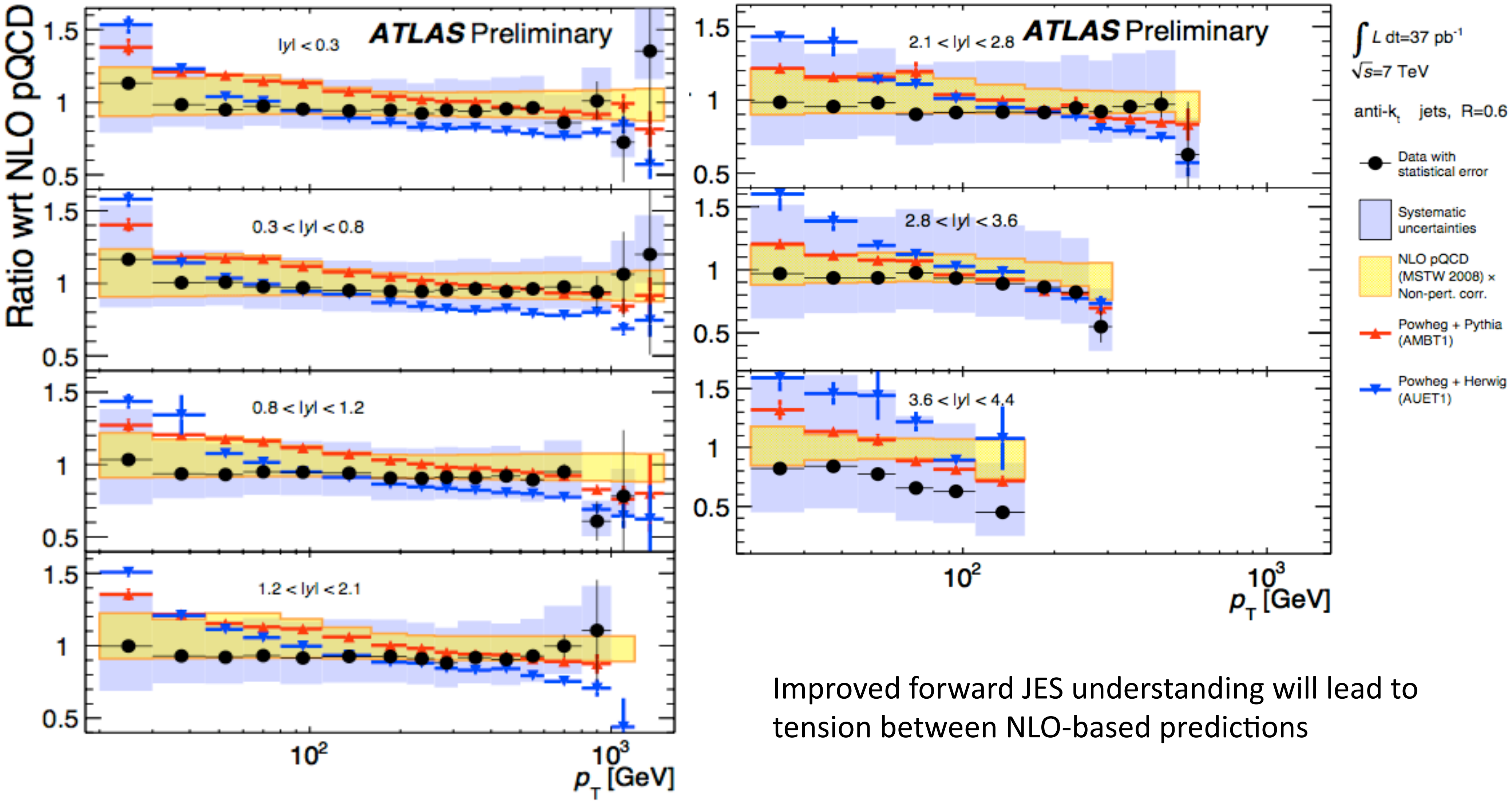
Run Number: 167607, Event Number: 36526763

Date: 2010-10-25 05:40:24 CEST

Inclusive forward jet cross section (II)

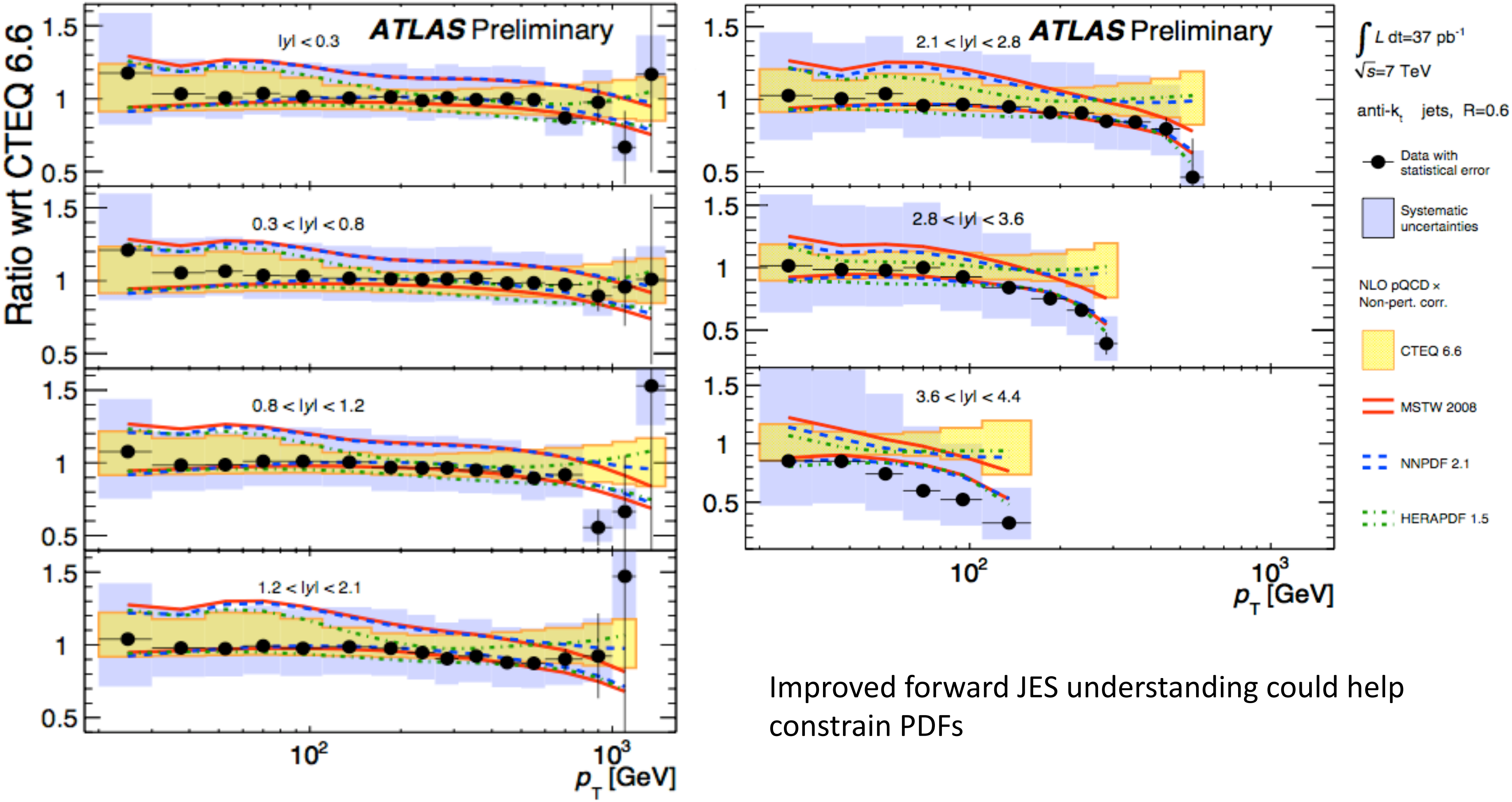


Inclusive forward jet cross section (III)



Improved forward JES understanding will lead to tension between NLO-based predictions

Inclusive forward jet cross section (IV)

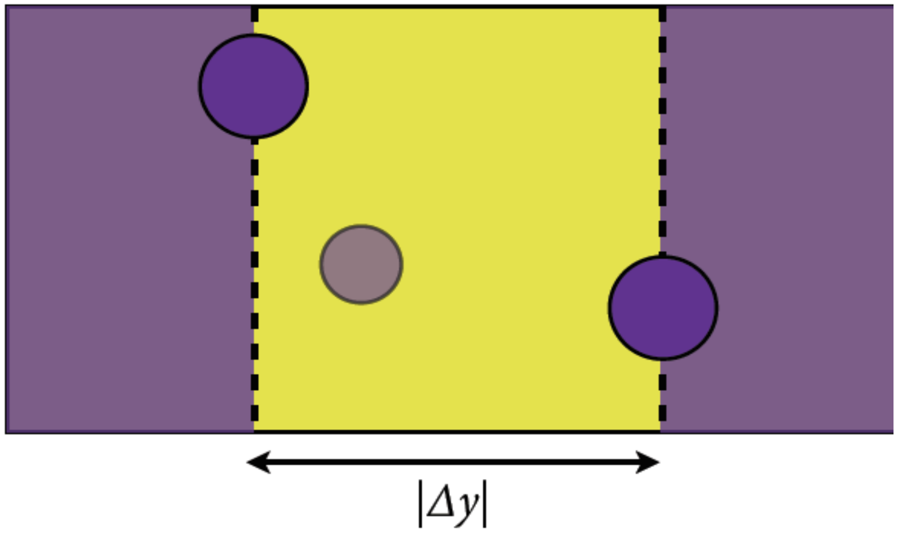


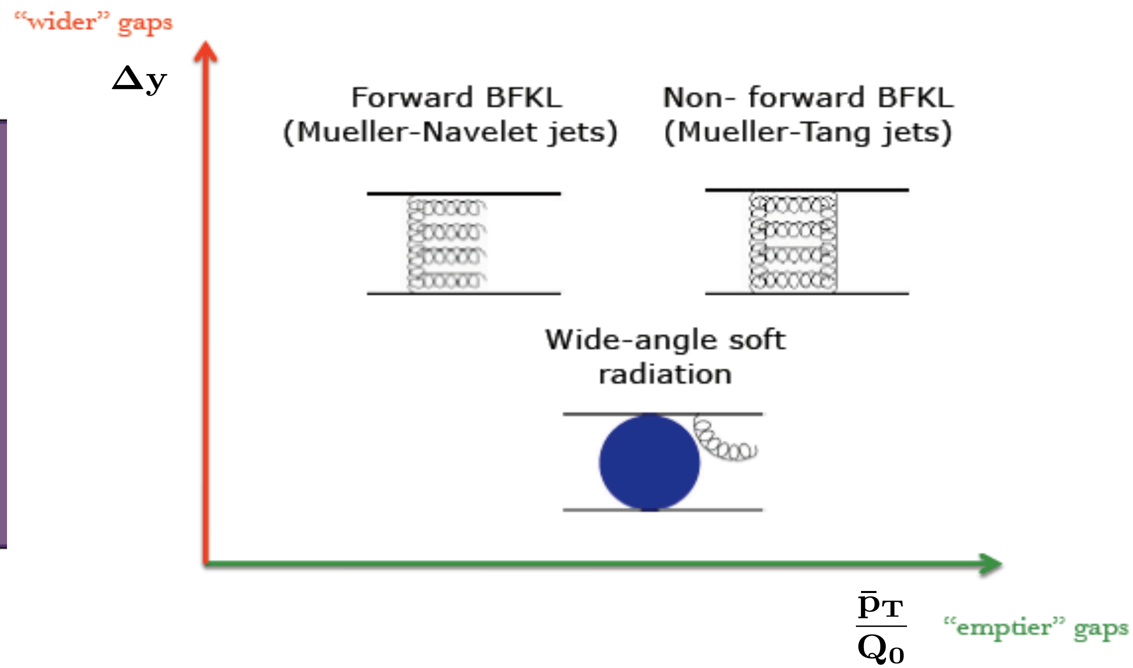
Improved forward JES understanding could help constrain PDFs

Dijet production with a central jet veto

ATLAS-CONF-2011-038

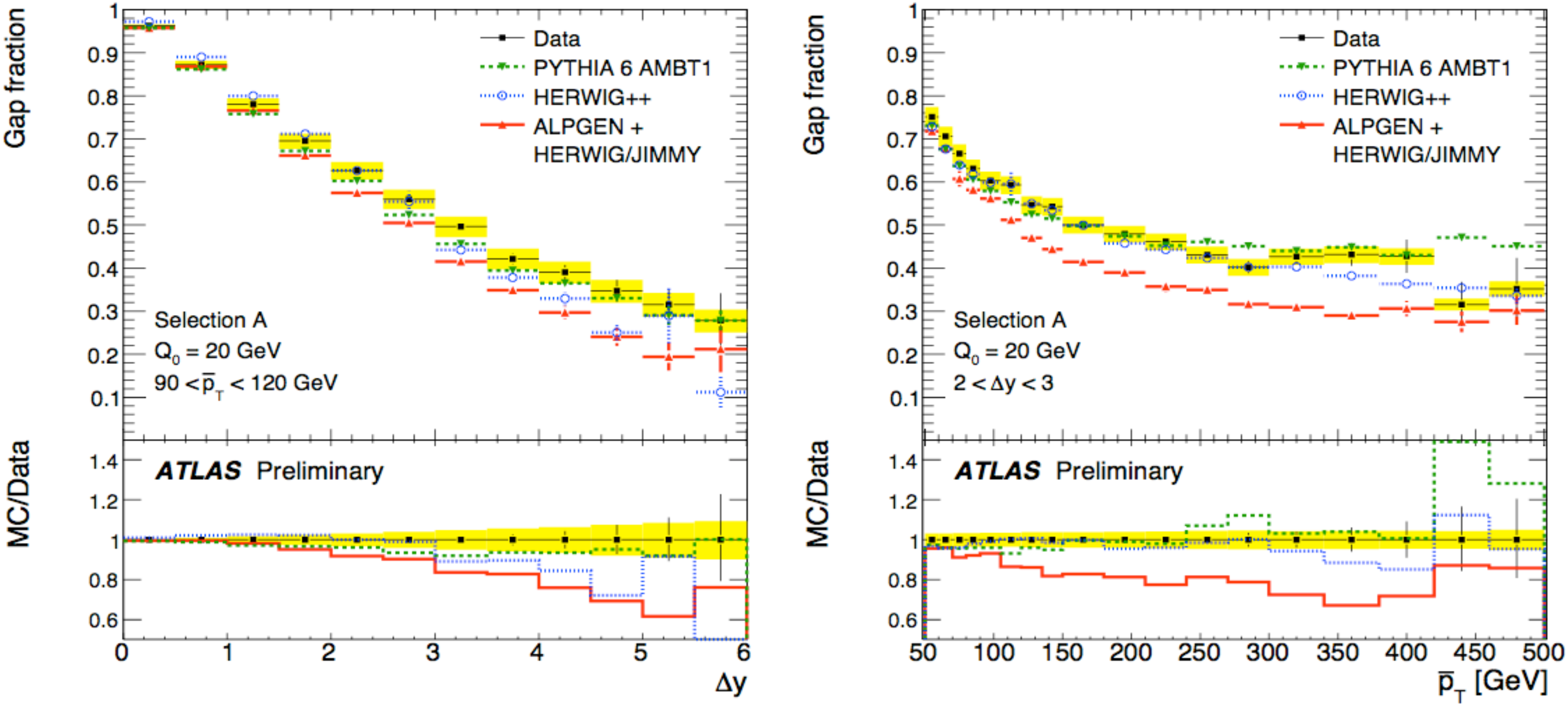
Dijet production with a central jet veto





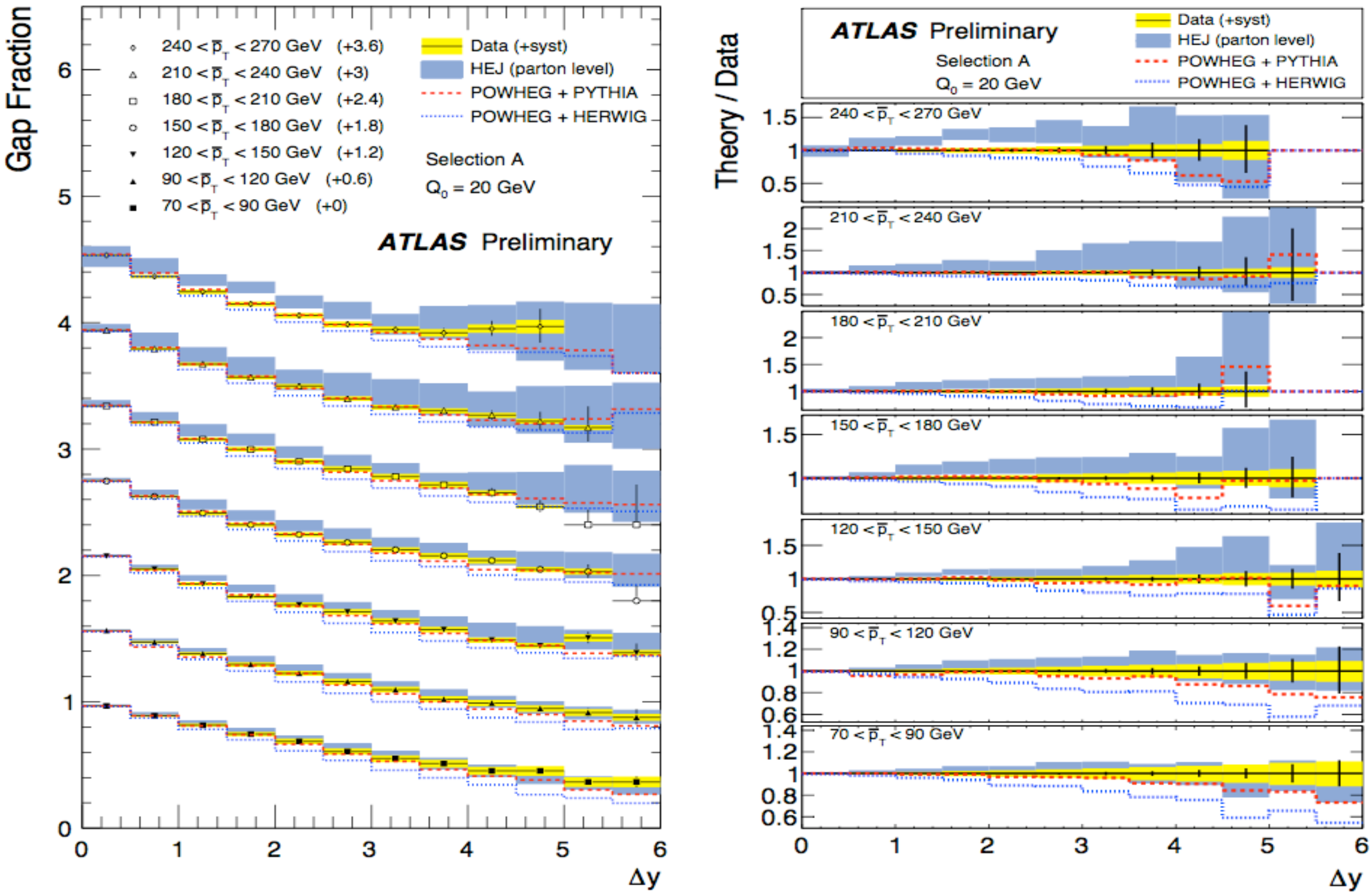
- ***Dijet system*** identified as the two highest p_T jets in the event with $|y| < 4.5$
- ***Gap events*** defined as the subset of events that do not contain an additional jet with $p_T > 20$ GeV in the rapidity interval bounded by the dijet system
- ***Gap fraction*** sensitive to all-order QCD phenomena, such as
  - BFKL-dynamics [when Δy is large]
  - Wide-angle soft-gluon radiation [when $\bar{p}_T/Q_0$ is large]
- ***Data corrected*** for experimental effects (i.e to hadron level)

Dijet production with a central jet veto (II)

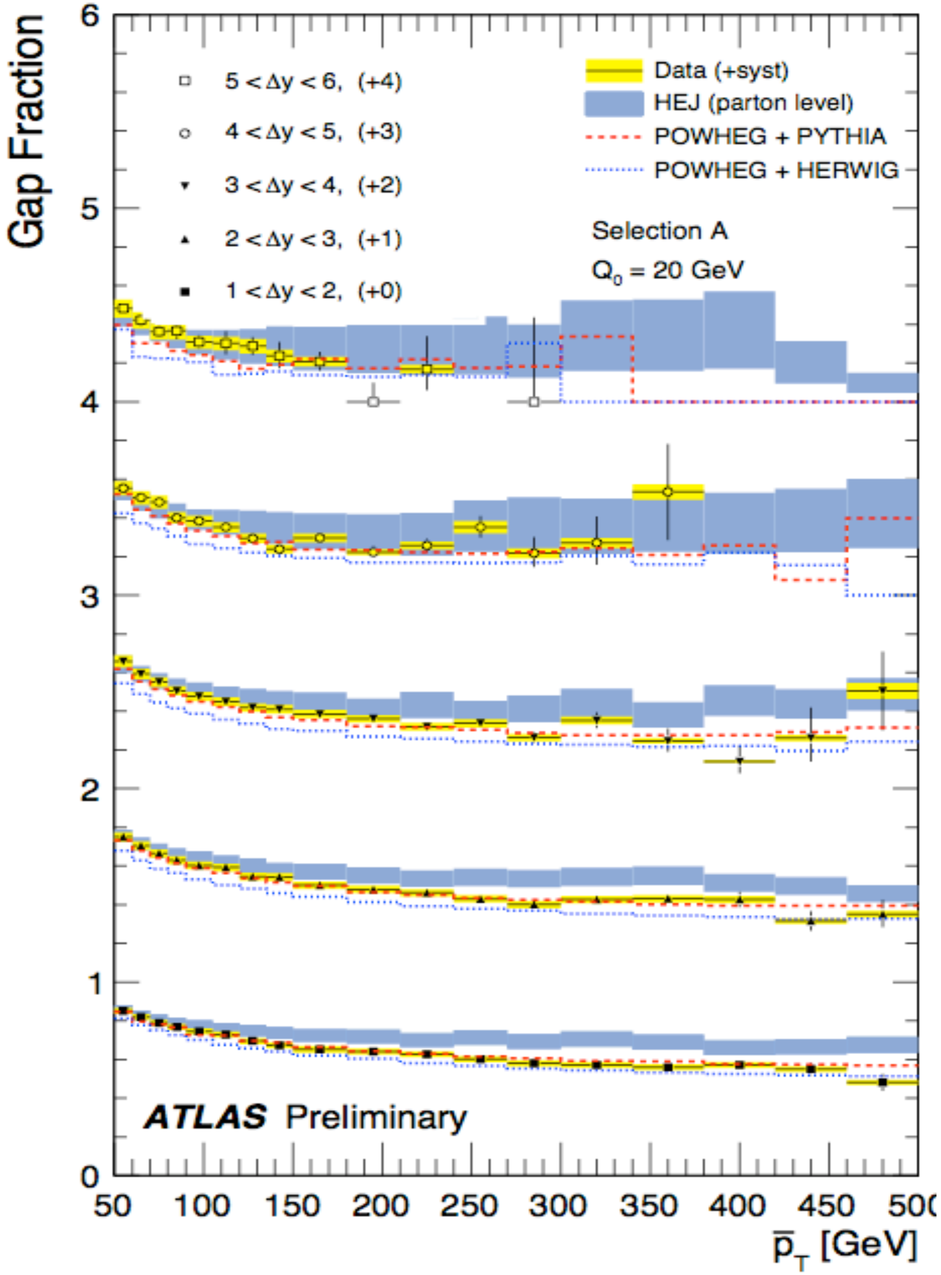


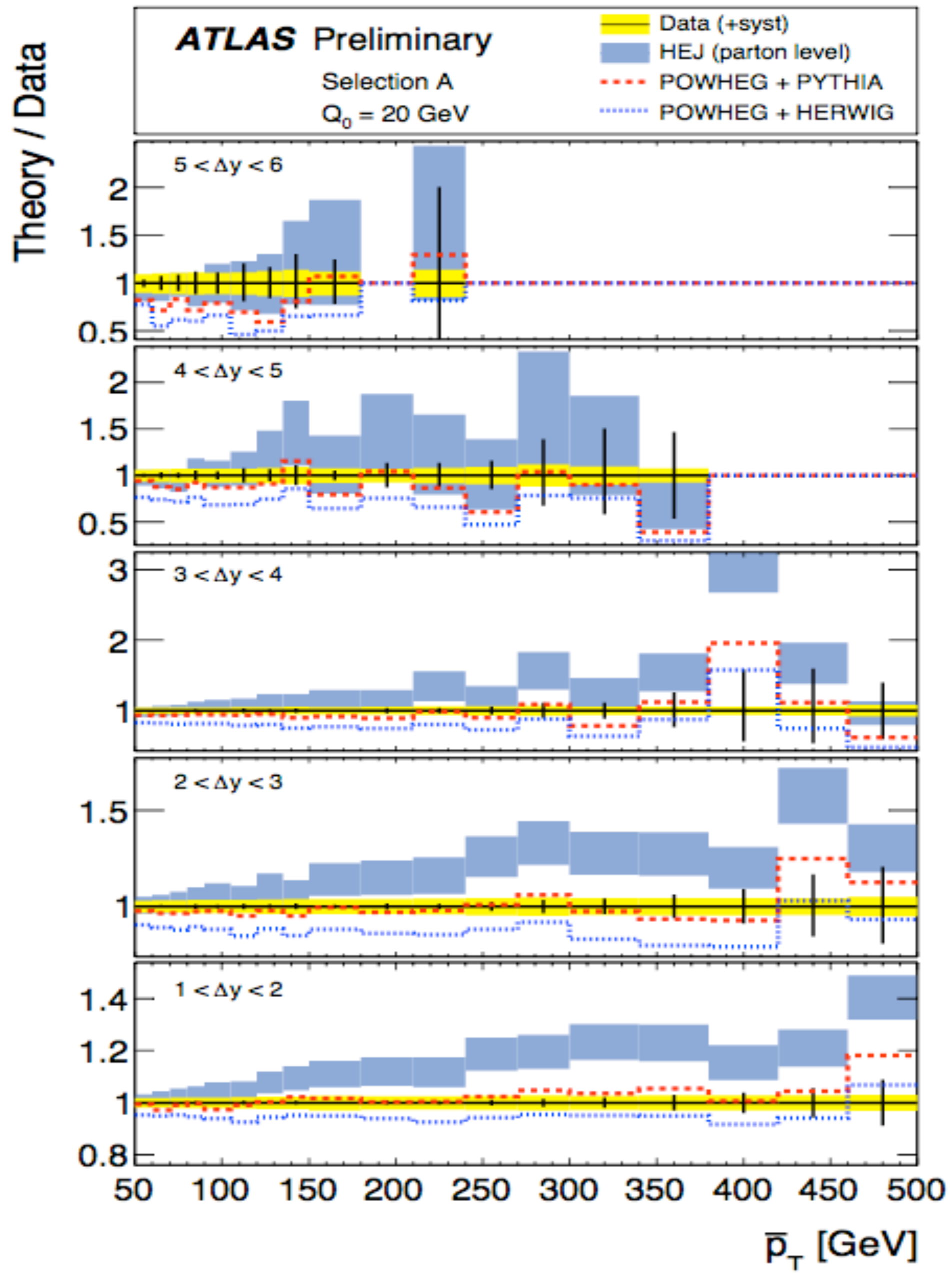
- Spread of LO+PS generators is indicative of the theoretical uncertainty associated with applying a jet veto
- ALPGEN+HERWI+JIMMY surprisingly far from the data.

Dijet production with a central jet veto (III)



Dijet production with a central jet veto (IV)





Dijet production with a jet veto (V)

- Data compared to POWHEG predictions
  - NLO-plus-parton-shower (for soft and collinear resummation)
  - POWHEG describes data well as $\bar{\mathbf{p}}_\mathrm{T}/\mathbf{Q_0}$ increases, but not as Δy increases.

- Data compared to HEJ predictions
  - All-order prediction for hard wide-angle emissions
  - HEJ describes data well as Δy increases, but not as $\bar{\mathbf{p}}_\mathrm{T}/\mathbf{Q_0}$ increases.

- Remember that VBF topology includes two reasonably high-p_T jets with large rapidity separation, plus a veto on a third jet!
- None of the theory predictions shown here do particularly well in this region of phase space

Summary of forward physics at ATLAS

Soft-QCD

1) Inelastic cross-section measured for $\xi > 5.10^{-6}$, and extrapolated to $\xi > m_p^2/s$
   - Large modelling uncertainty in extrapolation, due to low-mass diffraction
2) Forward rapidity gap cross-section measured for $\Delta\eta_F$ up to 7 (measured from calorimeter edge)
   - PYTHIA 6 & 8 both predict too large a gap cross-section; suggests that double diffractive contribution is too large in these models.

Perturbative-QCD

1) Inclusive jet cross-section measured for jets up to rapidities of 4.4
   - Large JES uncertainty covering spread of NLO-based theory predictions
2) Jet vetoes studied for dijet topologies
   - All theory predictions break down, either at large Δy or at large $\bar{p}_T/Q_0$