Recent W,Z and Jet Cross section measurements at ATLAS

Jan Kretzschmar

University of Liverpool

4^{th} July 2011

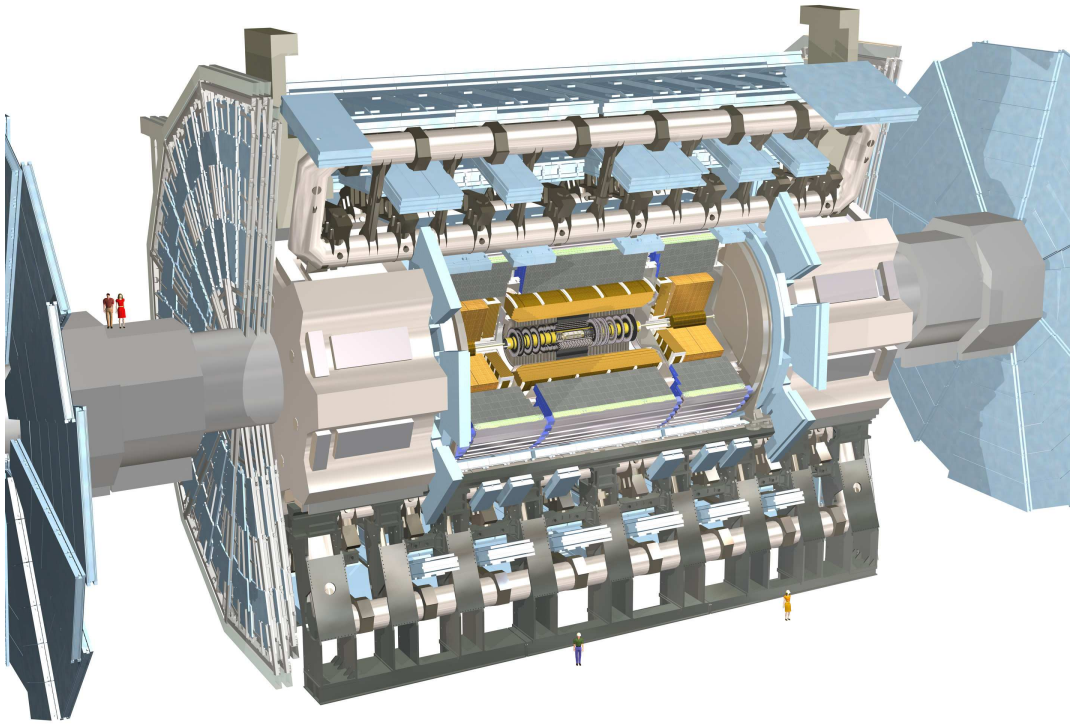
UNIVERSITY OF LIVERPOOL

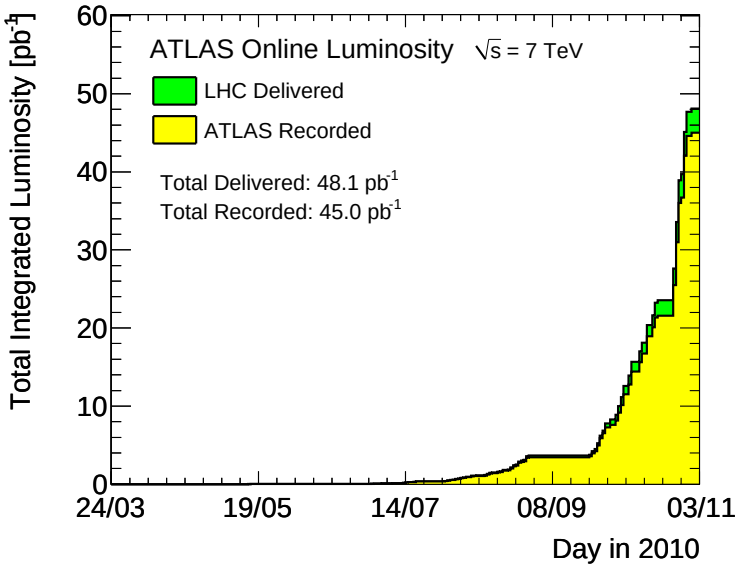
Contents

- Introduction
- Inclusive W&Z Production: total and differential measurements
- W&Z + jets Production
- Inclusive jets and Dijet cross sections

The ATLAS Detector

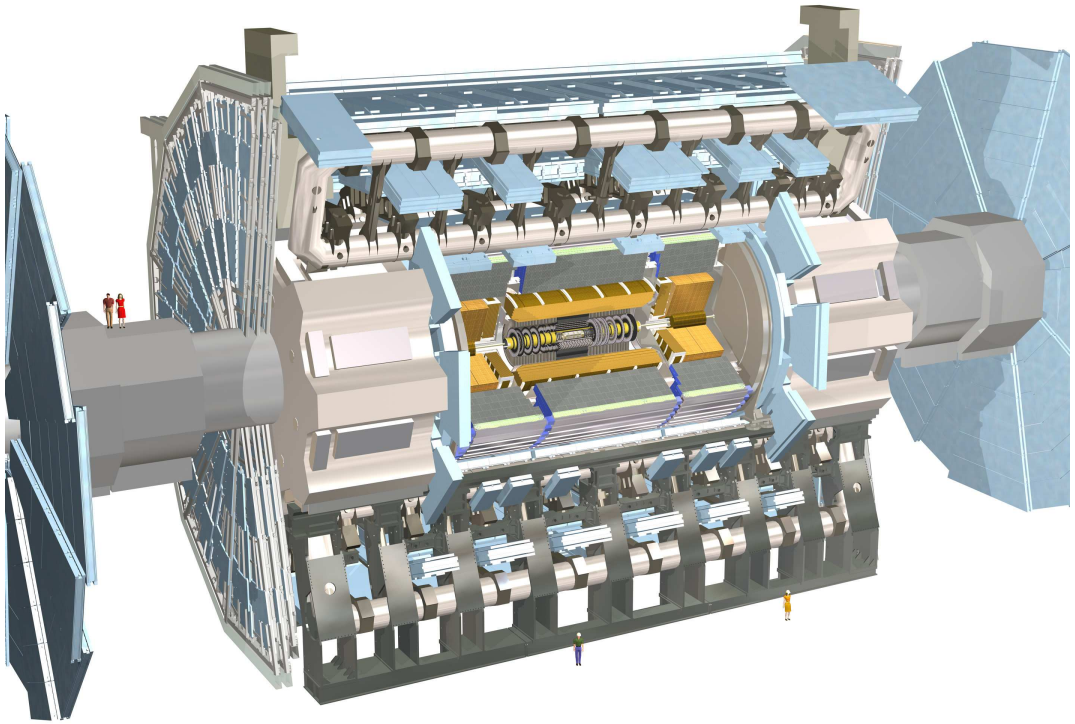
- Precision EM calorimeter and tracking up to $|\eta| < 2.5 \rightarrow$ electrons
- Muon chambers up to $|\eta| < 2.7$, trigger coverage to $|\eta| < 2.4 \rightarrow$ muons
- Calorimetric coverage up to $|\eta| < 4.9 \rightarrow$ jets, $\not\!\!E_T$, “forward electrons”
- Many precision results based on $\sim 35\,\mathrm{pb}^{-1}$ 2010 data

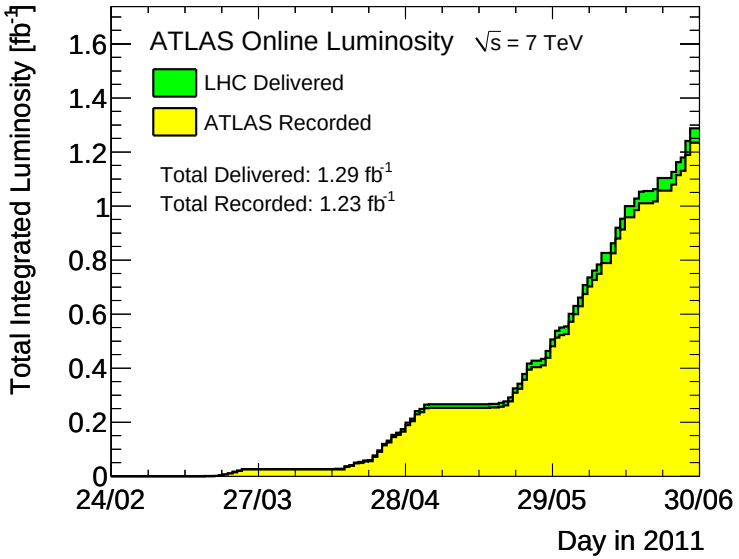




The ATLAS Detector

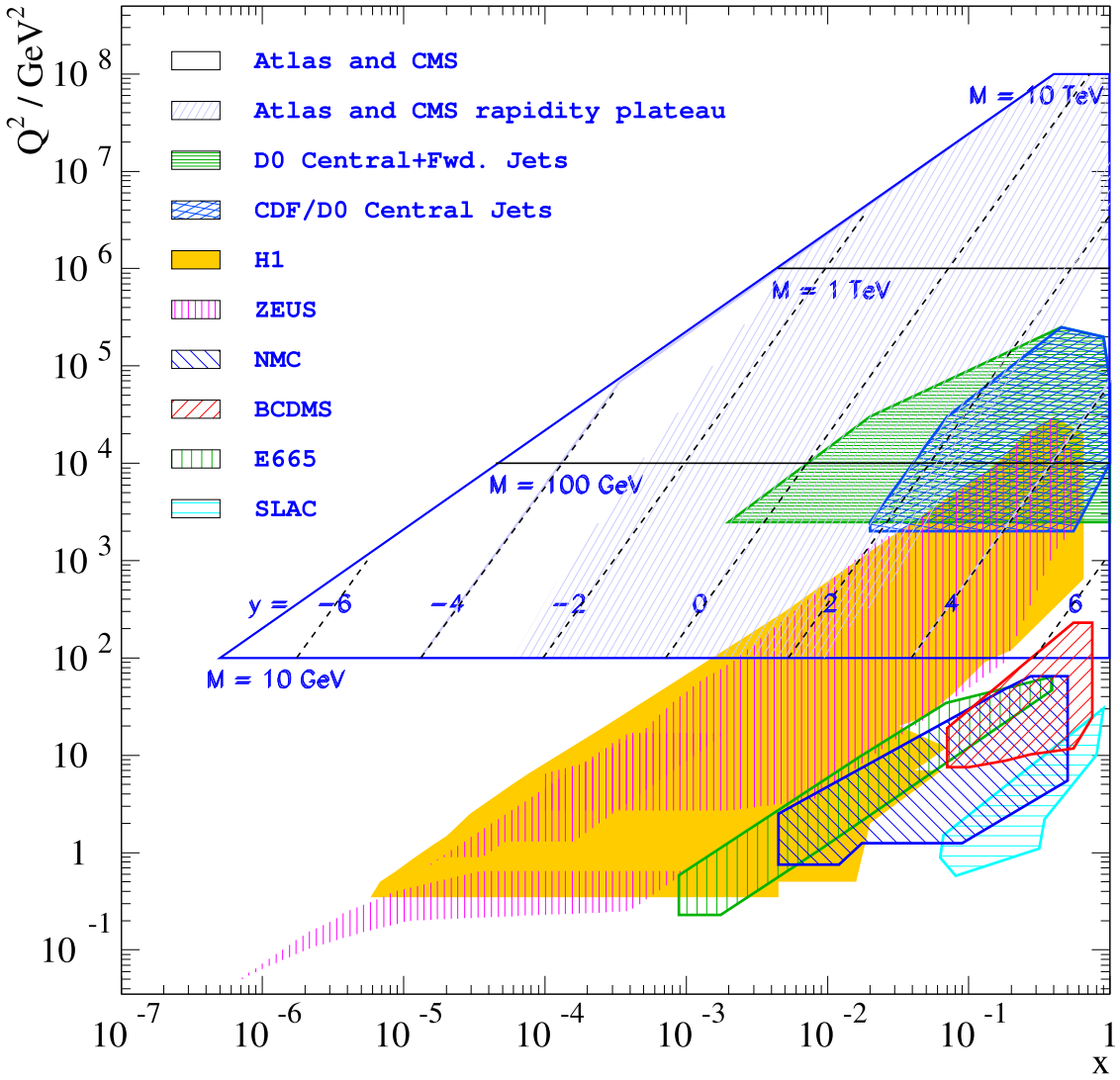
- Precision EM calorimeter and tracking up to $|\eta| < 2.5 \rightarrow$ electrons
- Muon chambers up to $|\eta| < 2.7$, trigger coverage to $|\eta| < 2.4 \rightarrow$ muons
- Calorimetric coverage up to $|\eta| < 4.9 \rightarrow$ jets, $\not\!\!E_T$, “forward electrons”
- Many precision results based on $\sim 35\,\mathrm{pb}^{-1}$ 2010 data
  nearly $100\times$ more data from 2011 already in the pipeline



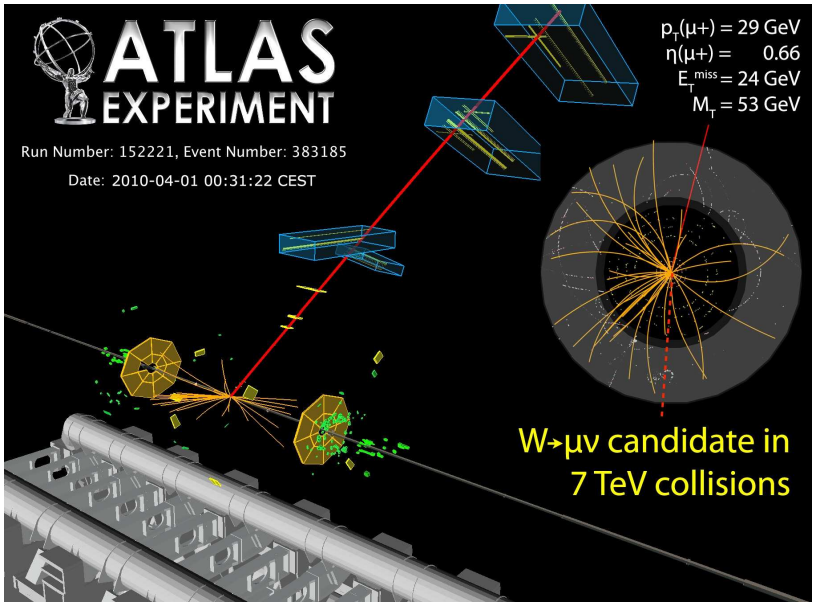


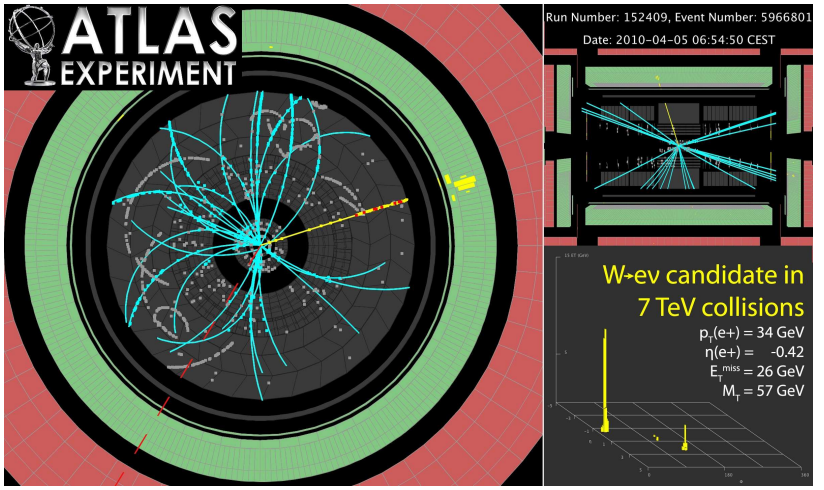
Kinematic Plane

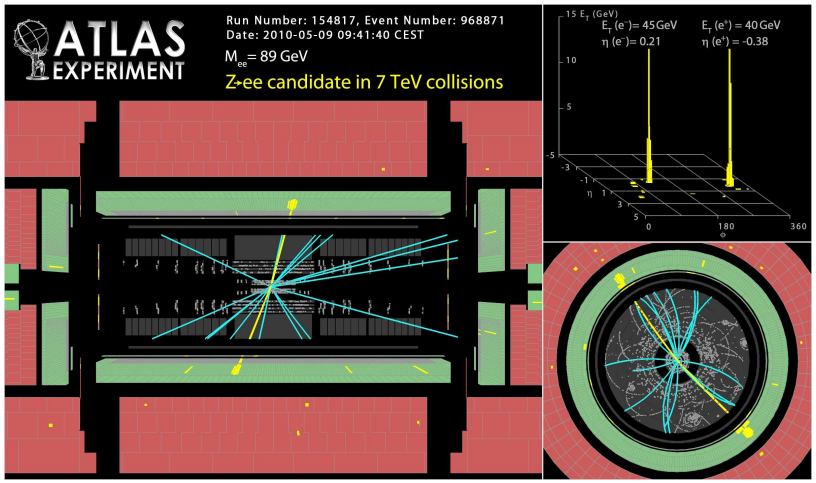
- Inclusive W&Z production
  $Q^2 \sim M^2_{W/Z}$,
  Theory at NNLO,
  exp. precision $\sim 1\%$,
  $|y| < 2.5$ (forward Z up $|y| \lesssim 3.6$)
- W&Z+jets
  $Q^2 \gtrsim M^2_{W/Z}$,
  Theory at NLO,
  exp. precision $\geq 10\%$
- Inclusive jets and dijets:
  wide coverage in x, Q^2,
  Theory at NLO,
  exp. precision $\geq 10\%$

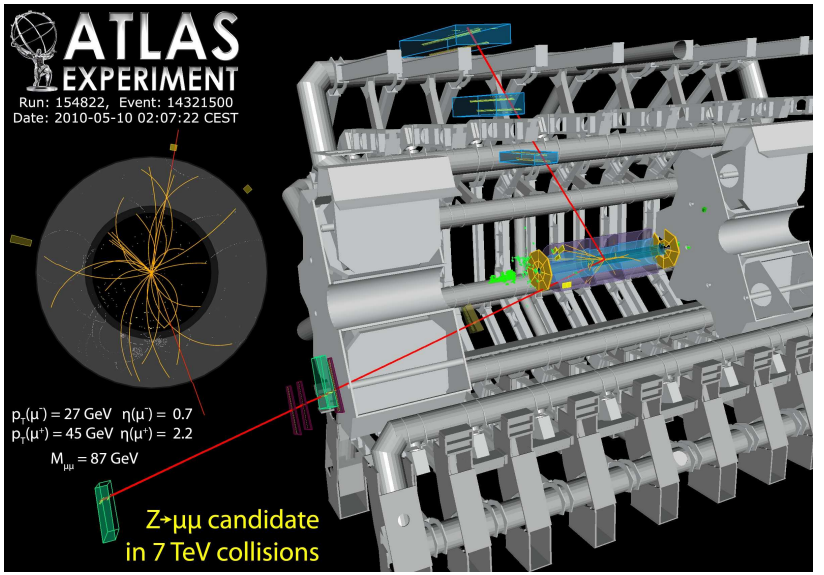


Inclusive W&Z Production





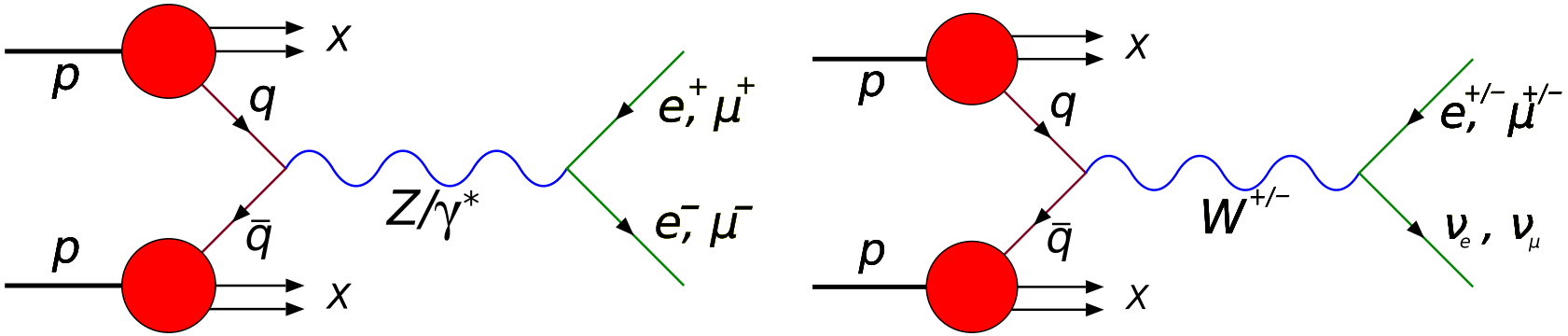




JHEP 12 (2010) 060, Phys. Lett. B 701 (2011) 31, ATLAS-CONF-2011-041

Inclusive W&Z Production

- Drell-Yan production of $W^{\pm}$ and Z bosons with decay in the electron and muon decay channels reach already now $\sim 1\%$ level accuracy



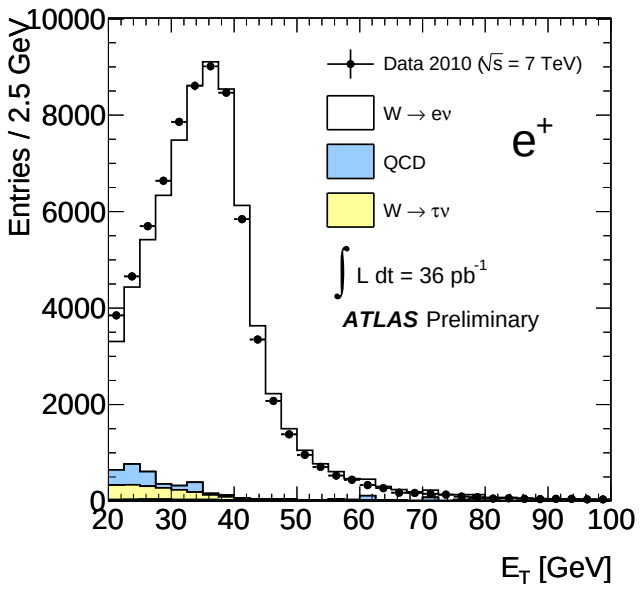
- Need most accurate theory predictions at NNLO to match experimental precision, e.g. total cross sections calculated with FEWZ using MSTW2008NNLO

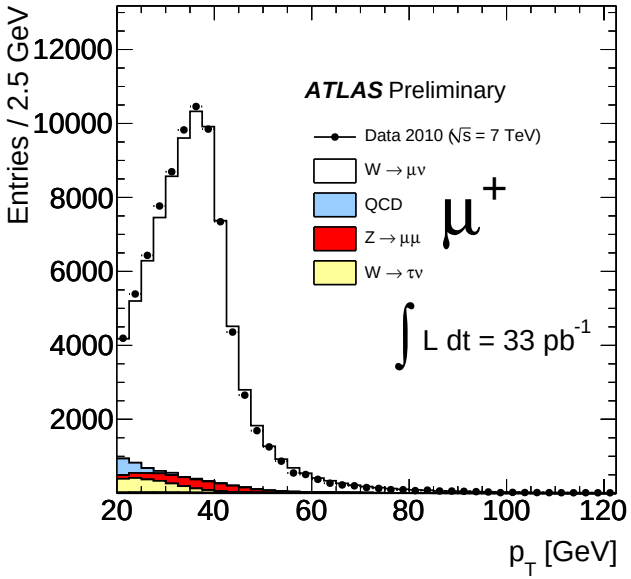
$$\sigma^{NNLO}_{W^+\to\ell^+\nu} = 6.16 \text{ nb} \qquad \sigma^{NNLO}_{W^-\to\ell^-\bar{\nu}} = 4.30 \text{ nb} \qquad \sigma^{NNLO}_{Z/\gamma^*\to\ell\ell} = 0.96 \text{ nb}$$

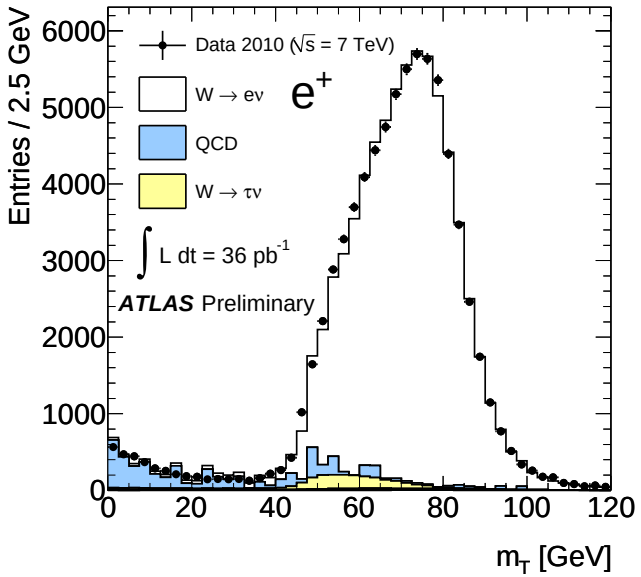
- Error estimate from PDF@90%CL, α_s and scale uncertainties is $\sim 5\%$; only considering PDF@68%CL gives $\sim 2\%$
- Measurement differential in boson rapidity $y \to x$ dependence: $x_{1,2} = M/\sqrt{s} \cdot \exp(\pm y)$

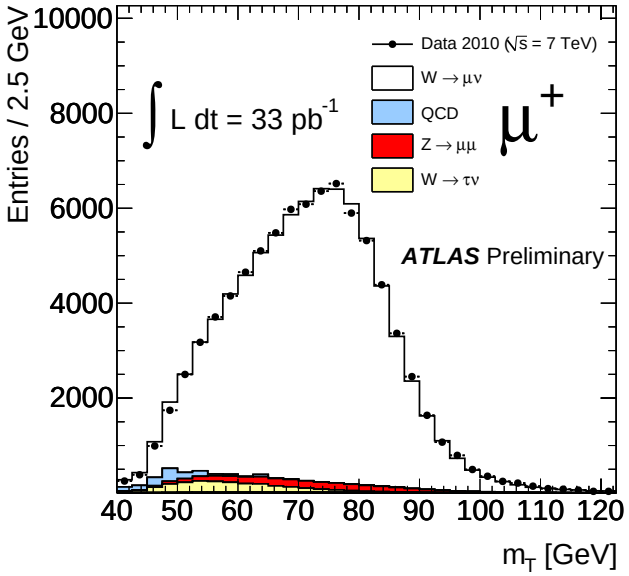
W Selection

- Efficient single lepton triggers (for all W&Z measurements)
- $p_{T,\ell} > 20\,\mathrm{GeV}$
- $|\eta_e| < 2.47$ excluding calo crack; $|\eta_\mu| < 2.4$
- $\not{E}_T > 25\,\mathrm{GeV}$
- $m_T > 40\,\mathrm{GeV}$
- Significant “QCD background” reduction achieved by lepton isolation/identification cuts
- $120 - 140k$ candidates with $\sim 7\%$ background



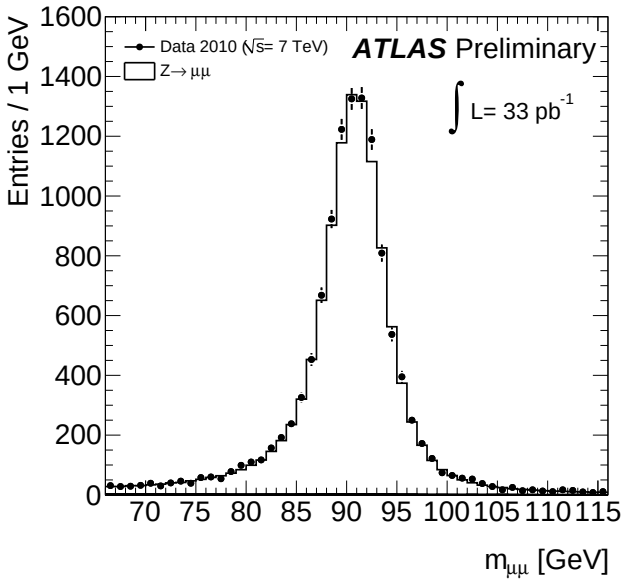


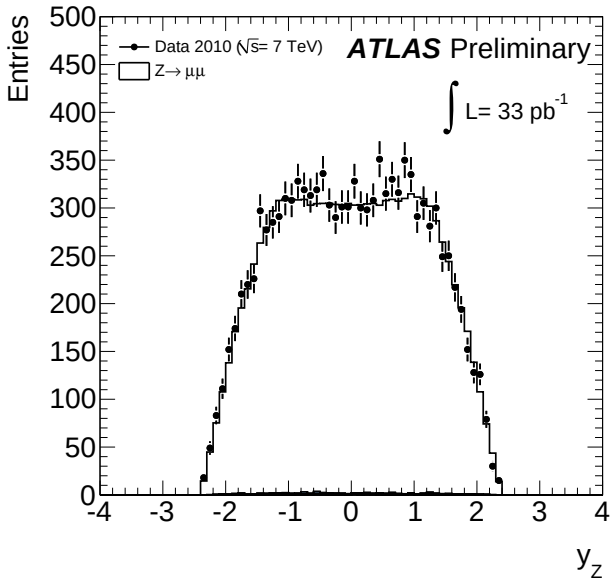


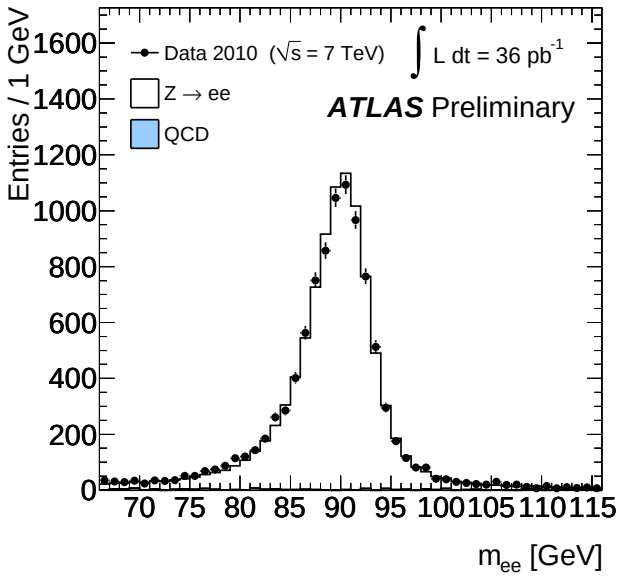


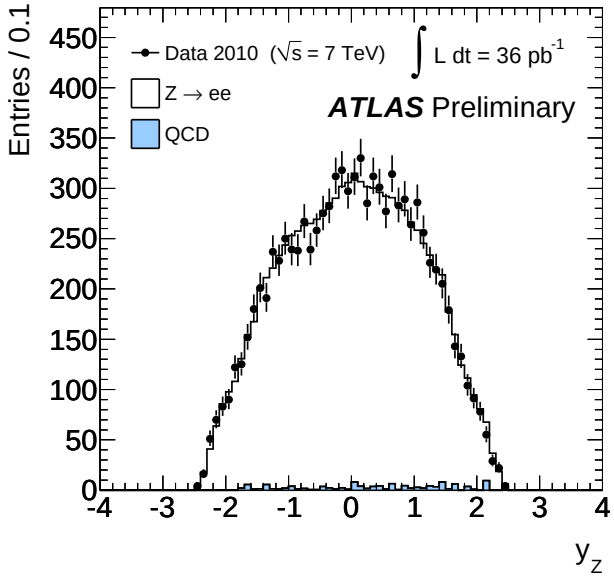
Z Selection

- $p_{T,\ell} > 20\,\mathrm{GeV}$
- $|\eta_e| < 2.47$
  excluding calo crack;
  $|\eta_\mu| < 2.4$
- $66 < m_{ee} < 116\,\mathrm{GeV}$
- $10{-}12k$ candidates with
  $\sim 0 - 2\%$ background







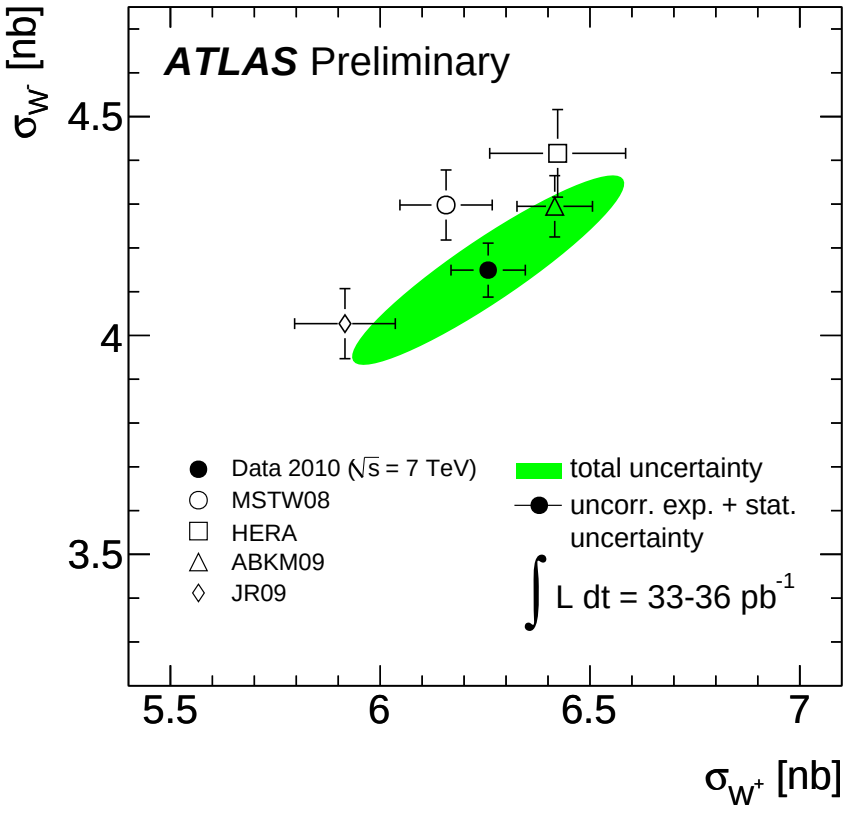


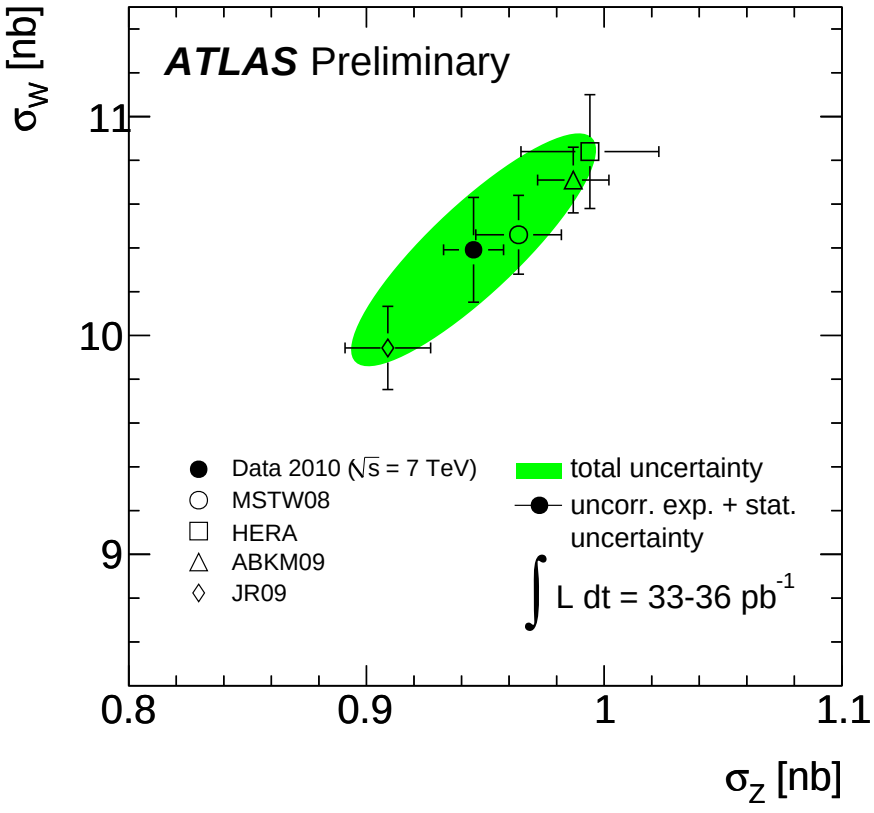
Total W&Z Cross Sections

- Factor ~ 2 extrapolation from measured region to total needed:
  - Initial determination of $3-4\%$ uncertainty using Pythia with MRST LO* PDF
    - Compare Pythia to MC@NLO with same PDF
    - Compare MRST LO*, CTEQ 6.6 and HERAPDF 1.0 in Pythia
    - Evaluate effect of CTEQ 6.6 error sets
  - To be improved using only NLO generators (MC@NLO, PowHeg)
- Preliminary $\not\!\!E_T$ systematics have largest effect on W (2%)
- Luminosity uncertainty of 3.4%

	$\sigma^{\mathrm{tot}}_{W^{(\pm)}} \cdot$ BR$(W \to \ell\nu)$ [nb]
W^+	$6.257 \pm 0.017(\mathrm{sta}) \pm 0.152(\mathrm{sys}) \pm 0.213(\mathrm{lum}) \pm 0.188(\mathrm{acc})$
W^-	$4.149 \pm 0.014(\mathrm{sta}) \pm 0.102(\mathrm{sys}) \pm 0.141(\mathrm{lum}) \pm 0.124(\mathrm{acc})$
W	$10.391 \pm 0.022(\mathrm{sta}) \pm 0.238(\mathrm{sys}) \pm 0.353(\mathrm{lum}) \pm 0.312(\mathrm{acc})$
	$\sigma^{\mathrm{tot}}_{Z/\gamma^*} \cdot$ BR$(Z/\gamma^* \to \ell\ell)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^*	$0.945 \pm 0.006(\mathrm{sta}) \pm 0.011(\mathrm{sys}) \pm 0.032(\mathrm{lum}) \pm 0.038(\mathrm{acc})$

Total W&Z Cross Sections

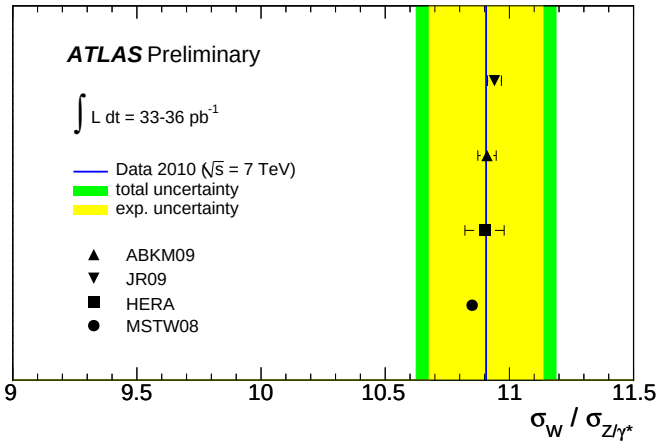


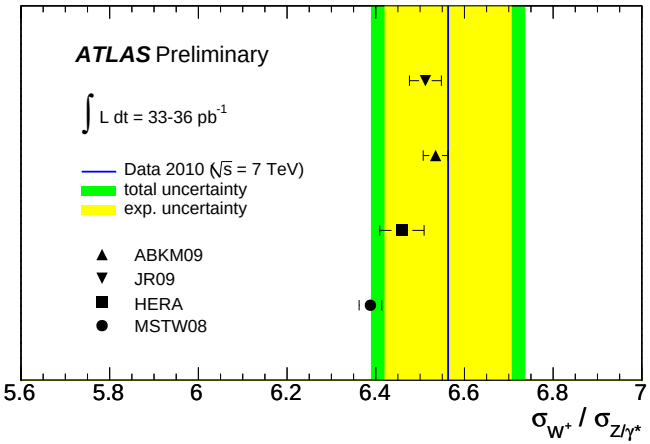


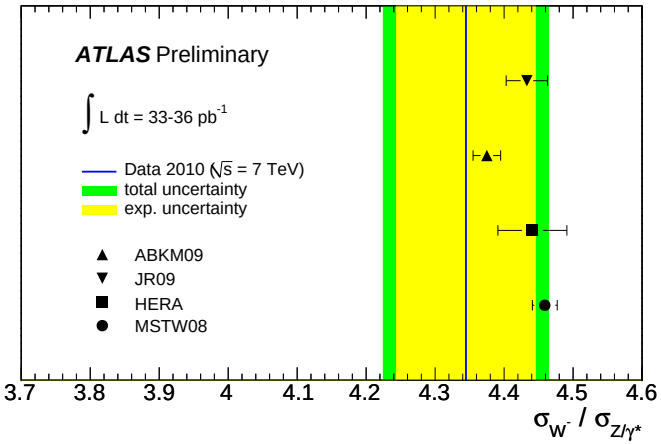
- Overall remarkable agreement between measurement and predictions
- A few differences between different PDFs, when considering only their own uncertainties @68%CL
- Note: correlations between $W^+ - W^-$ only approximate, theory correlations not considered

Total W&Z Cross Section Ratios

- Ratios profit from cancellations of experimental as well as theoretical uncertainties
- Good agreement for all PDFs, “canonical W/Z ratio” confirmed to 2%



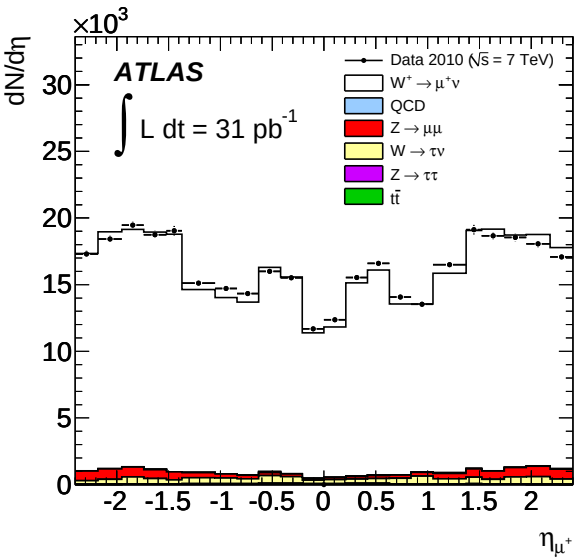


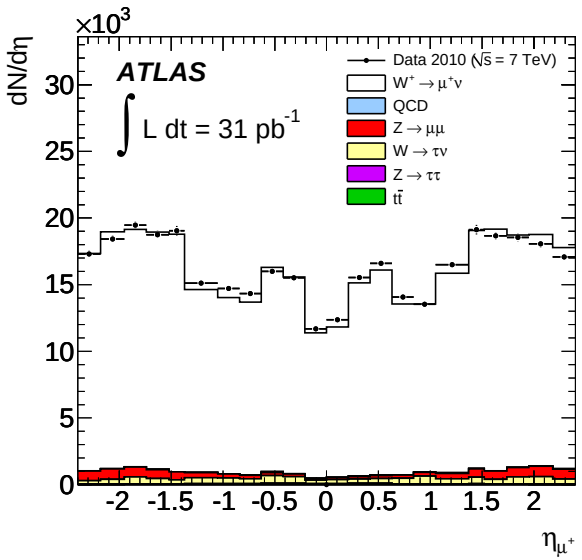


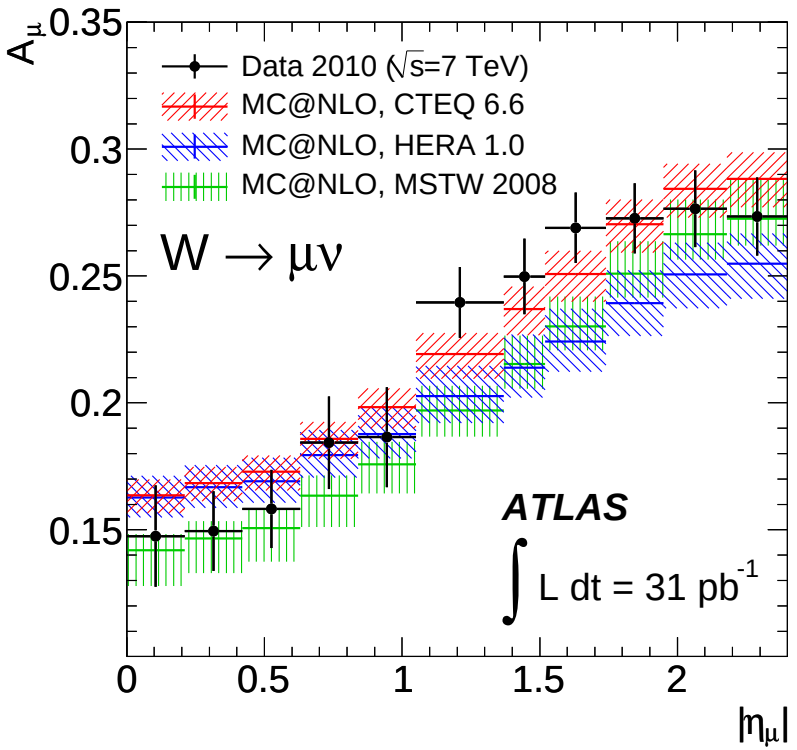
Ratio	Data
W^+/Z	$6.563 \pm 0.049(\text{sta}) \pm 0.134(\text{sys}) \pm 0.098(\text{acc})$
W^-/Z	$4.345 \pm 0.034(\text{sta}) \pm 0.095(\text{sys}) \pm 0.065(\text{acc})$
W/Z	$10.906 \pm 0.079(\text{sta}) \pm 0.215(\text{sys}) \pm 0.164(\text{acc})$

$W \to \mu\nu$ differential Asymmetry

- First differential cross section ratio: $A = \frac{\sigma^{W+}(\eta_l) - \sigma^{W-}(\eta_l)}{\sigma^{W+}(\eta_l) + \sigma^{W-}(\eta_l)}$
- Measured as function of lepton η, no extrapolations done
- Needs detailed control of charge dependent efficiency effects and momentum biases
- Detailed discussion at PDF4LHC meeting in March by A. Belloni

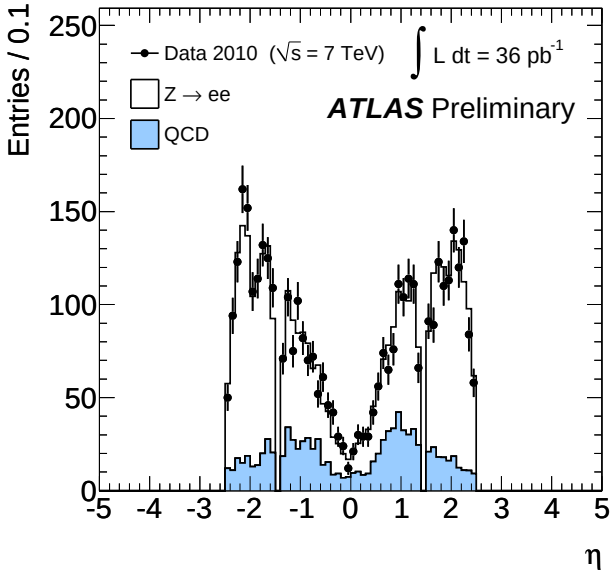


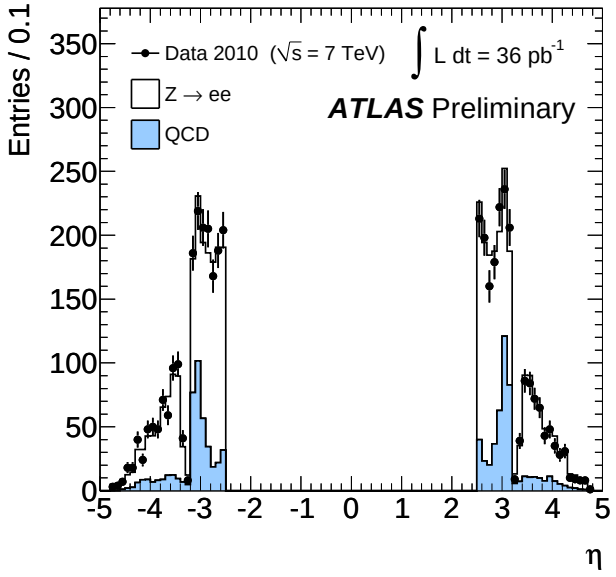


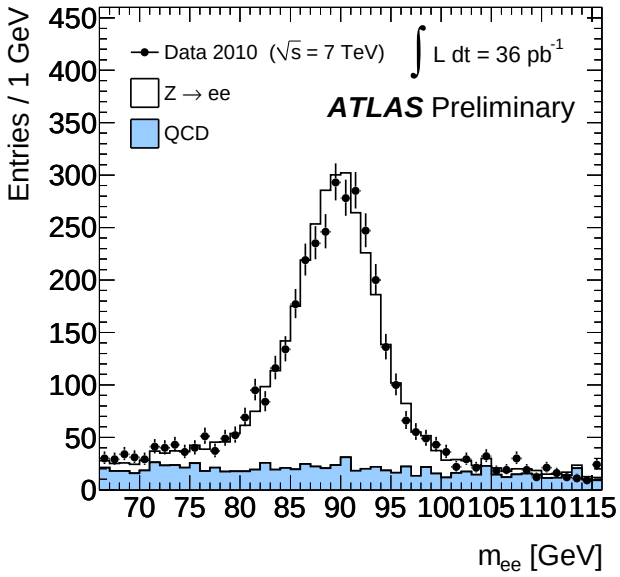


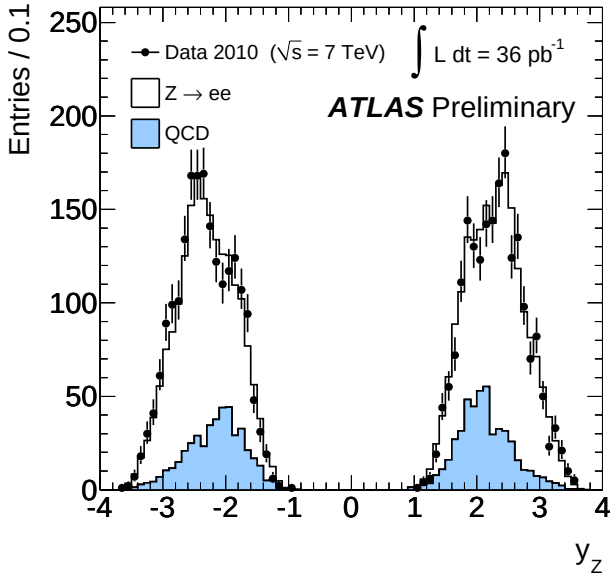
Forward $Z \to ee$ Measurement

- One electrons in forward calorimeters $2.5 < |\eta_e| < 4.9$, other central (as before)
- $p_{T,\ell} > 20\,\mathrm{GeV}$
- $66 < m_{ee} < 116\,\mathrm{GeV}$
- $4k$ candidates with $\sim 25\%$ background
- Extension of rapidity range to $y_Z \sim 3.6$
- Cross section extrapolated to total is in agreement with expectation within $\sim$ 10% measurement uncertainty







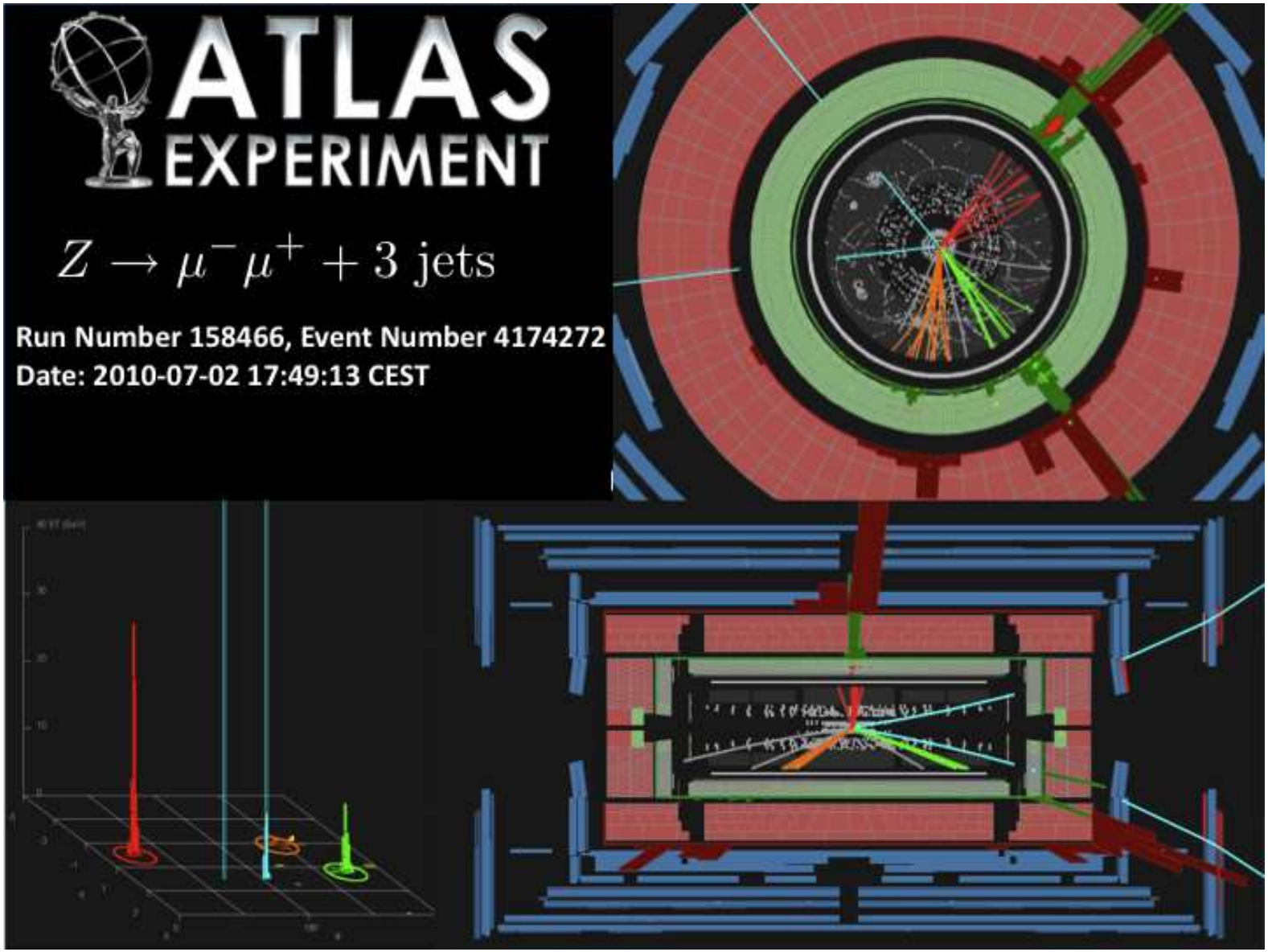


Coming Inclusive W & Z Measurements

Publication based on 2010 data will be available in a few weeks

- Update of “total” cross sections, integrated cross sections with minimal extrapolation
- $W^{\pm}$ cross sections as function of lepton η_{ℓ}
- Z cross section as function of boson rapidity y_Z
- Combination of e and μ results in common phase space
- Containing the full W, Z “package” with correlation information between channels and bins
- Differential NNLO theory calculations performed with tools like FEWZ2 and DYNNLO1.1 (NNLO very time consuming, very fast NLO calculations possible with MCFM+APPLGRID)

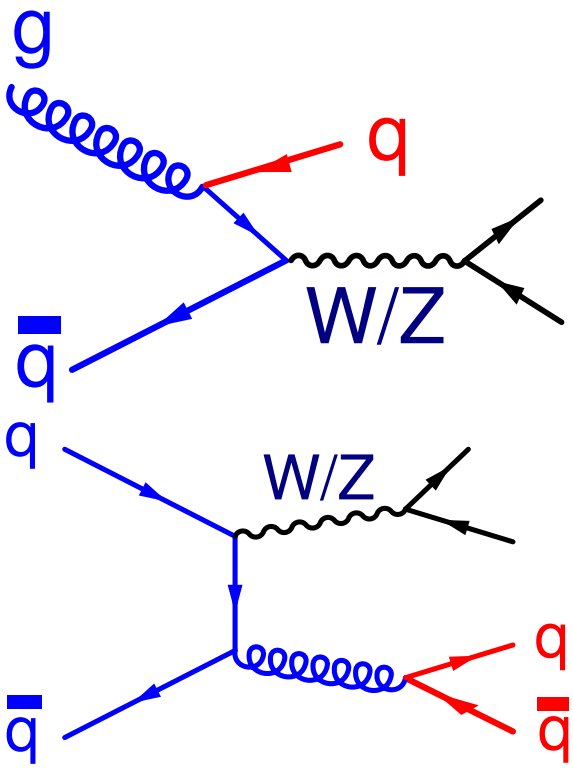
W&Z+jets Production

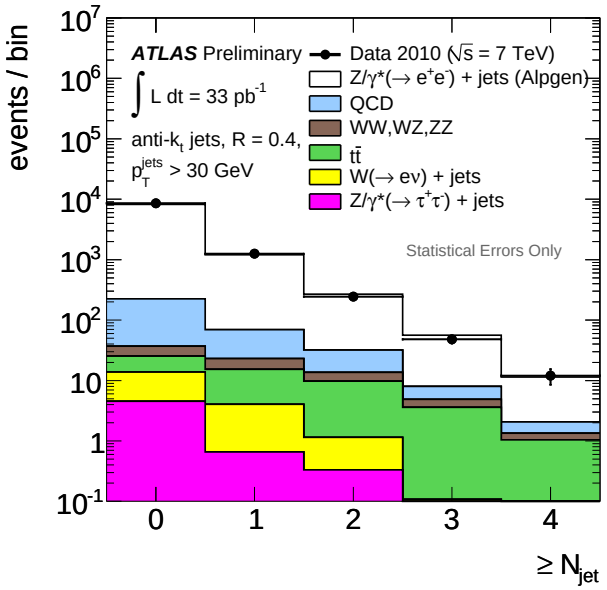


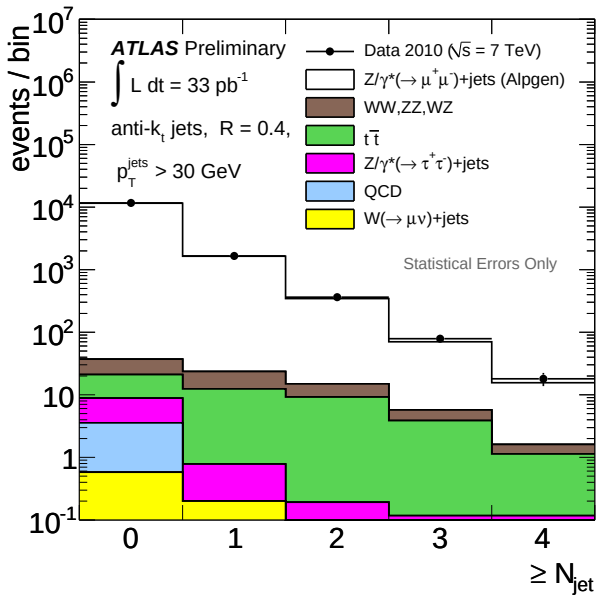
ATLAS-CONF-2011-042, ATLAS-CONF-2011-060

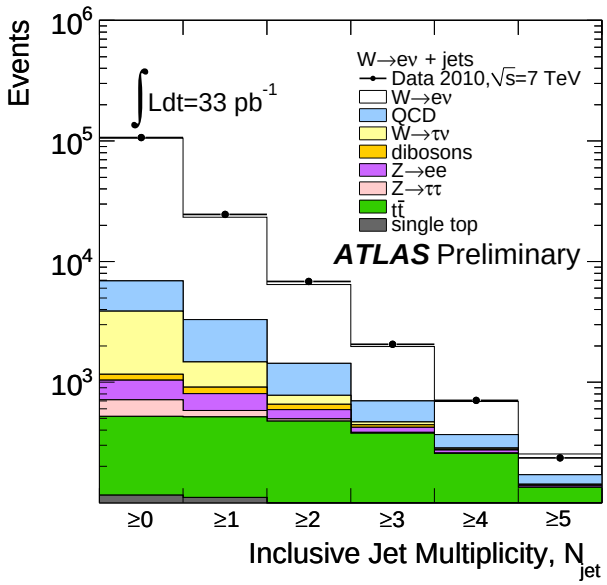
W/Z+jets

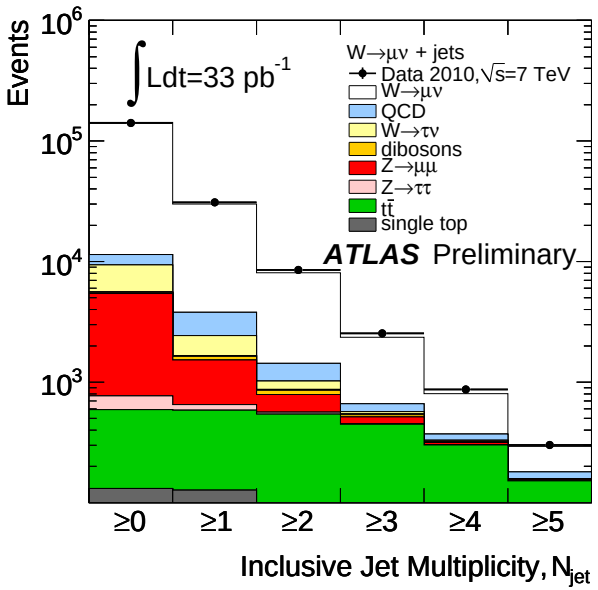
- In addition to standard Z/W selection, measure jets (Anti-k_T R=0.4) with $|y| < 2.8$ and $p_T > 20(30)\,\mathrm{GeV}$ for W(Z)



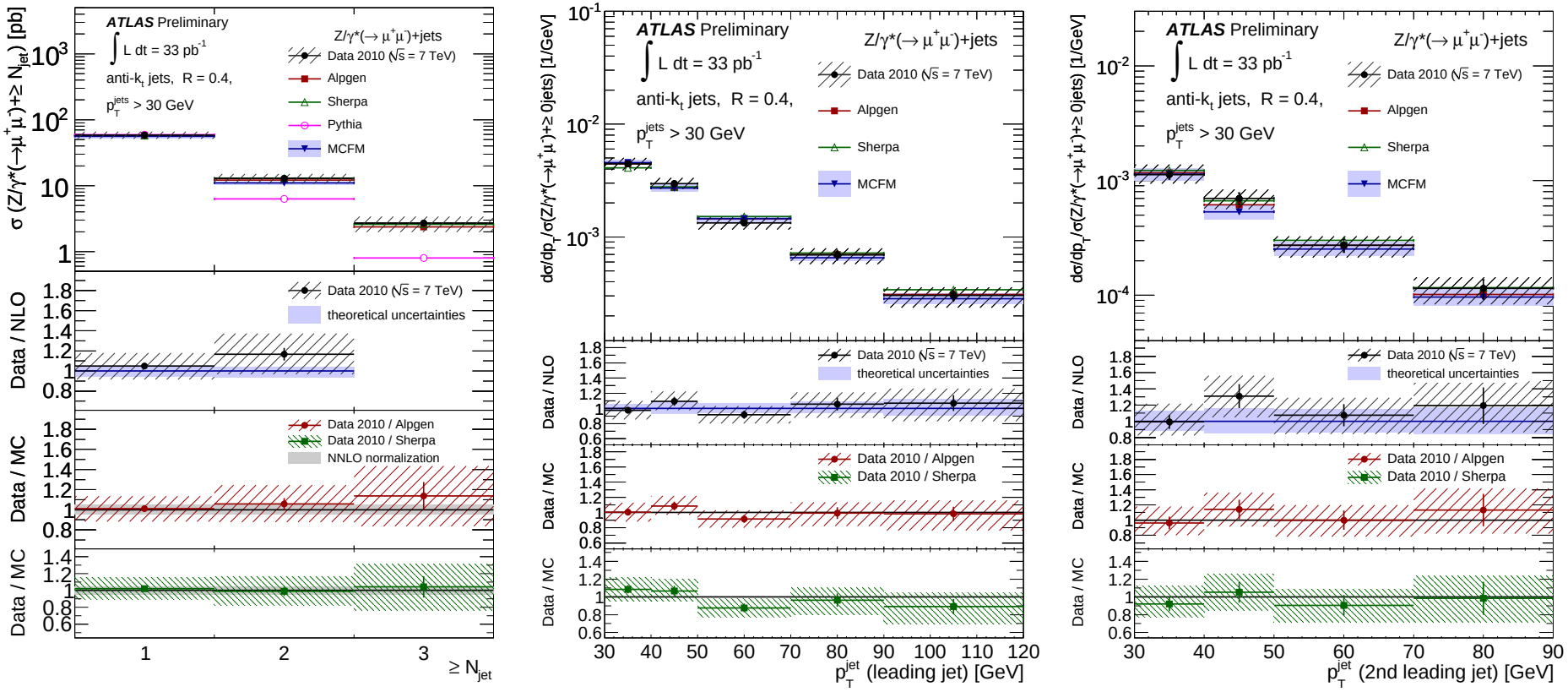








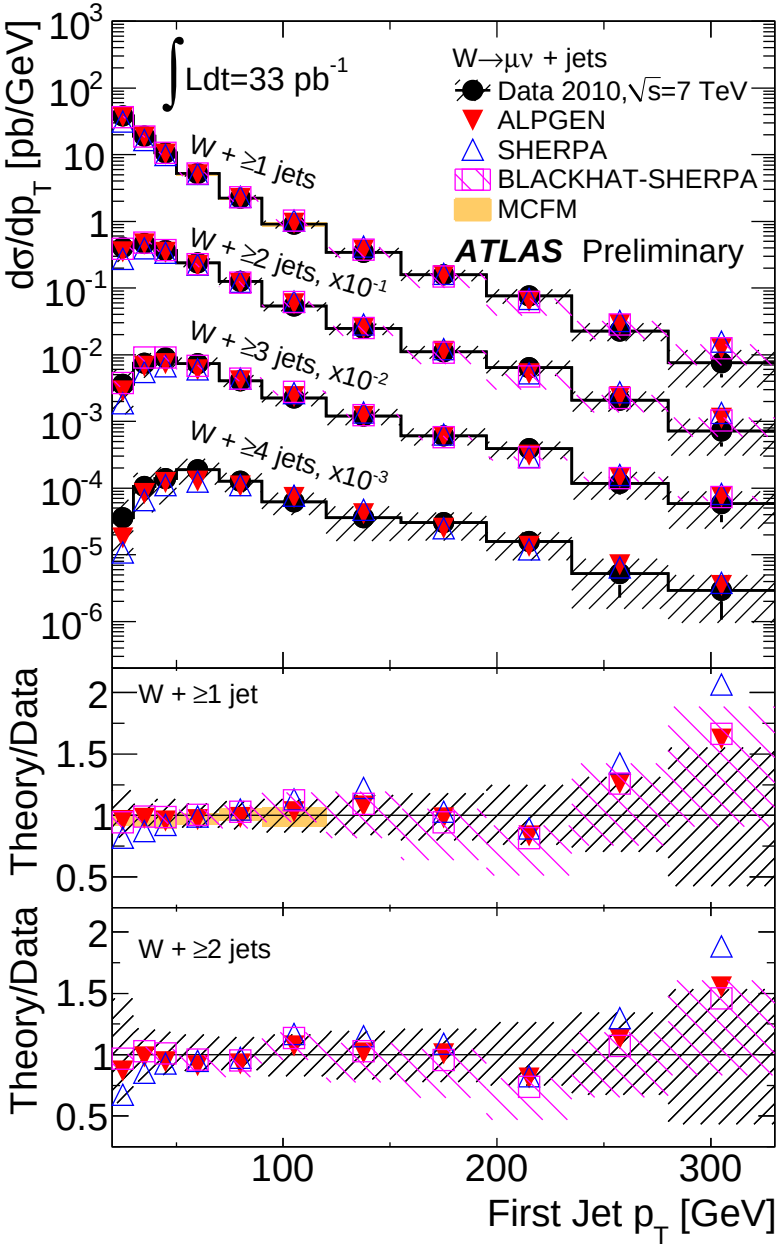
Results Z+jets



- Experimental precision limited by jet understanding to $\geq 10\%$
- Theory predictions at NLO using MCFM for $N_{\mathrm{jet}} \leq 2$ using CTEQ6.6 PDF and $\mu_r = \mu_f = H_T/2 \rightarrow$ good agreement
- Tree-level ME generators ALPGEN and SHERPA give a good description as well

Results W+jets

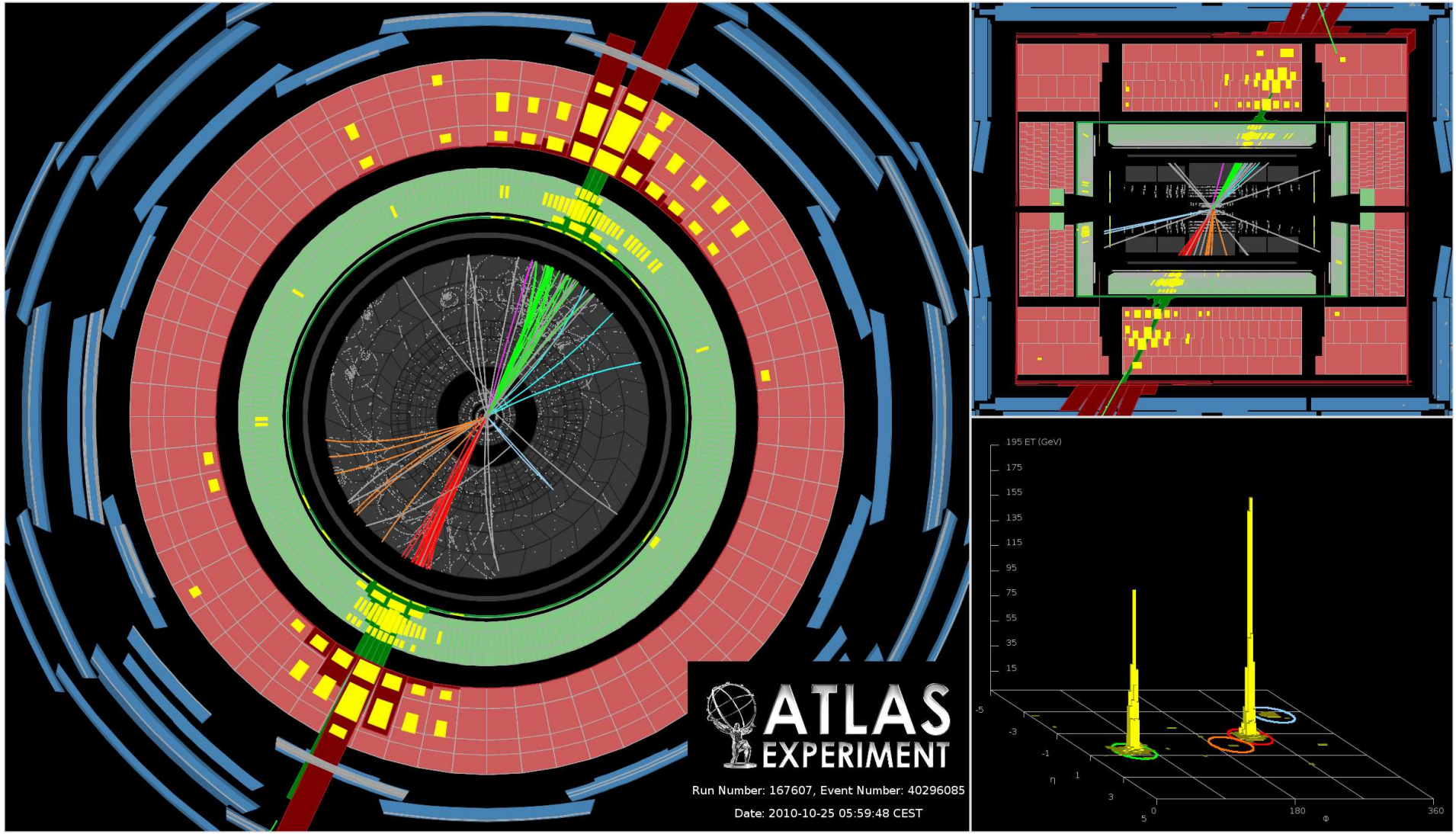
- Experimental precision limited by jet understanding to $\geq 10\%$
- Theory predictions at NLO give good agreement (CTEQ6.6 PDF and $\mu_r = \mu_f = H_T/2$)
  - MCFM for $N_{\text{jet}} \leq 2$
  - Blackhat+Sherpa for $N_{\text{jet}} \leq 3$
- Tree-level ME generators ALPGEN and SHERPA give a good description as well



Coming W & Z + Jets Measurements

- Publications based on 2010 data will be available in a few weeks: Improved jet uncertainties (see later), wider jet coverage $|y| < 4.4$ as for inclusive jet measurements (see later)
- Future: measure "W Asymmetry" as function of jet variables/kinematics? Integrate MCFM W+jets into APPLGRID for fast calculations?

Inclusive Jets and Dijets



ATLAS-CONF-2011-047, ATL-PHYS-PUB-2011-005, ATLAS-CONF-2011-032

Jet cross sections

- Inclusive jet cross-sections in bins of rapidity y and transverse momentum p_T

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T \mathrm{d}|y|} \quad \text{with} \quad p_T > 20\,\mathrm{GeV}, |y| < 4.4$$

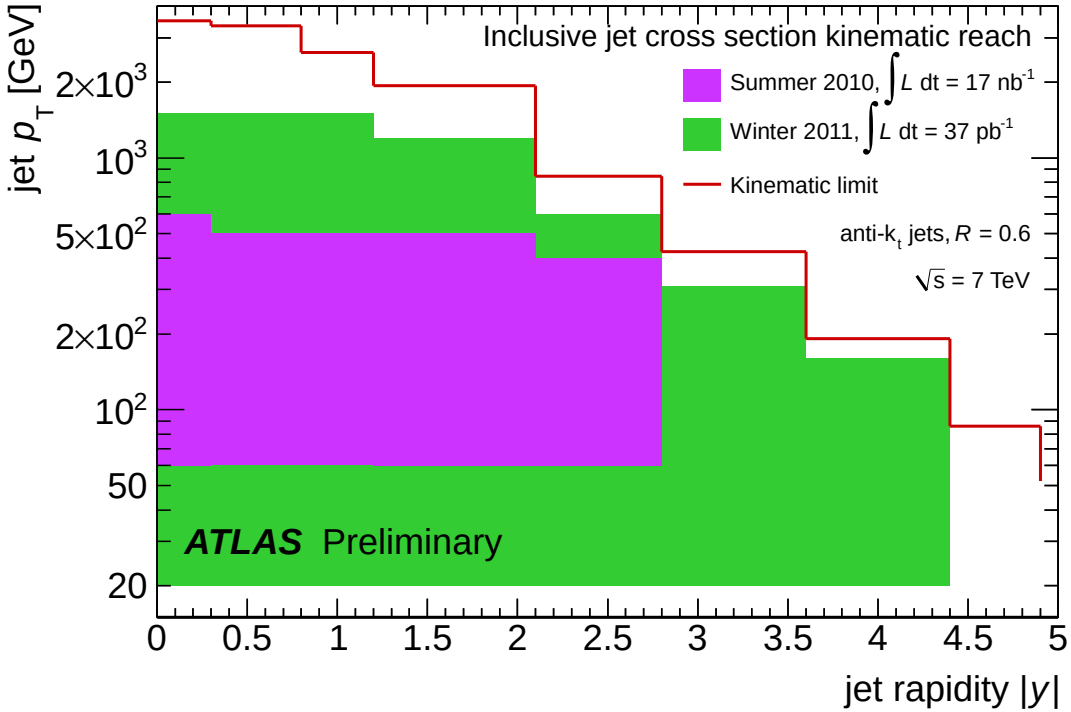
- Dijet cross-section in bins of mass m_{12} and $|y|_{\max} = \max(|y_1|, |y_2|)$:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}m_{12} \mathrm{d}|y|_{\max}} \quad \text{with} \quad p_{T1} > 30\,\mathrm{GeV}, p_{T2} > 20\,\mathrm{GeV}, |y|_{\max} < 2.8$$

- Large increase of covered phase space w.r.t. publication using early data

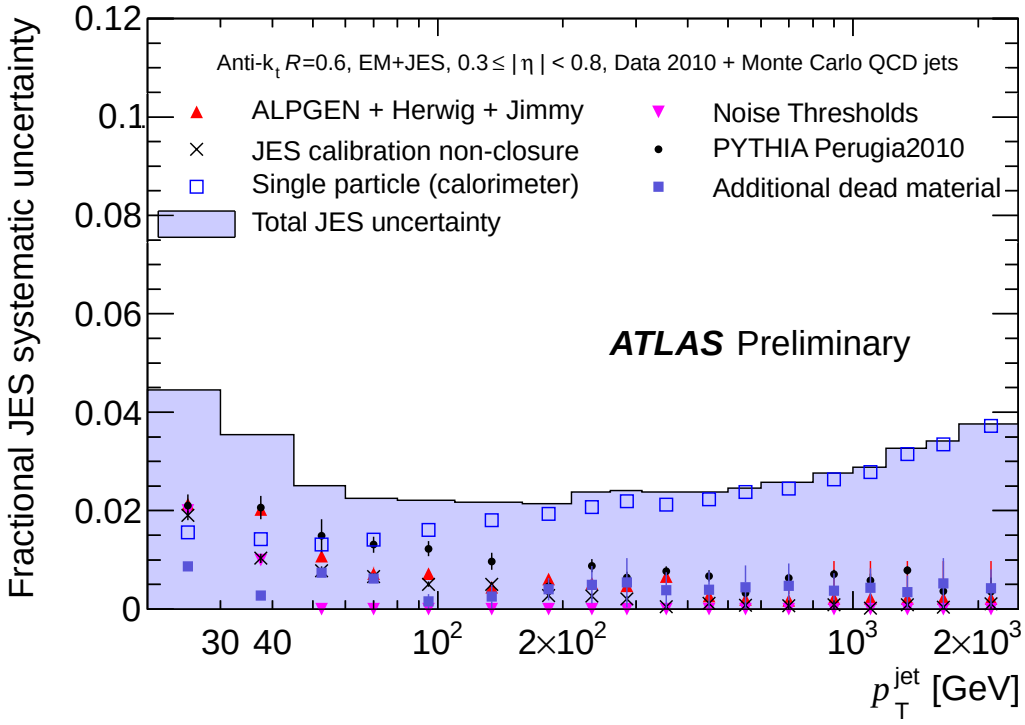
  Eur. Phys. J. C71 (2011) 1512

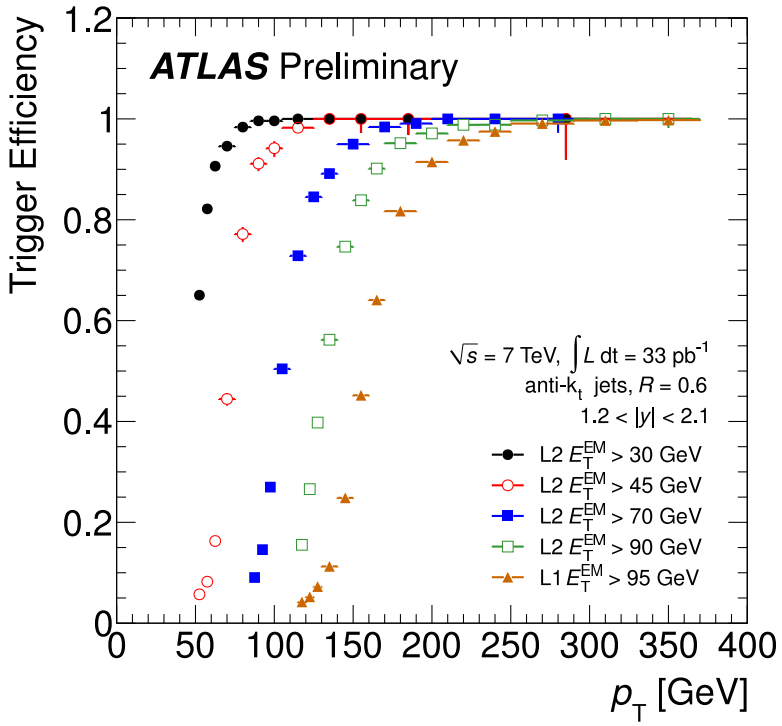
- Publication will contain full uncertainty correlation information



Jets: Experimental details

- Jets are identified using the Anti-k_T algorithm with cone size parameters of R=0.4/0.6 (hadronisation vs. underlying event)
- Pileup energy removed and jets calibrated to correct energy scale
- Efficient cleaning cuts remove fakes from e.g. noise or cosmics
- Jets with $20 < p_T < 60\,\mathrm{GeV}$ triggered with MinBias scintillators, for $p_T > 60\,\mathrm{GeV}$ calorimeter triggers (using plateau, corr. for prescales)



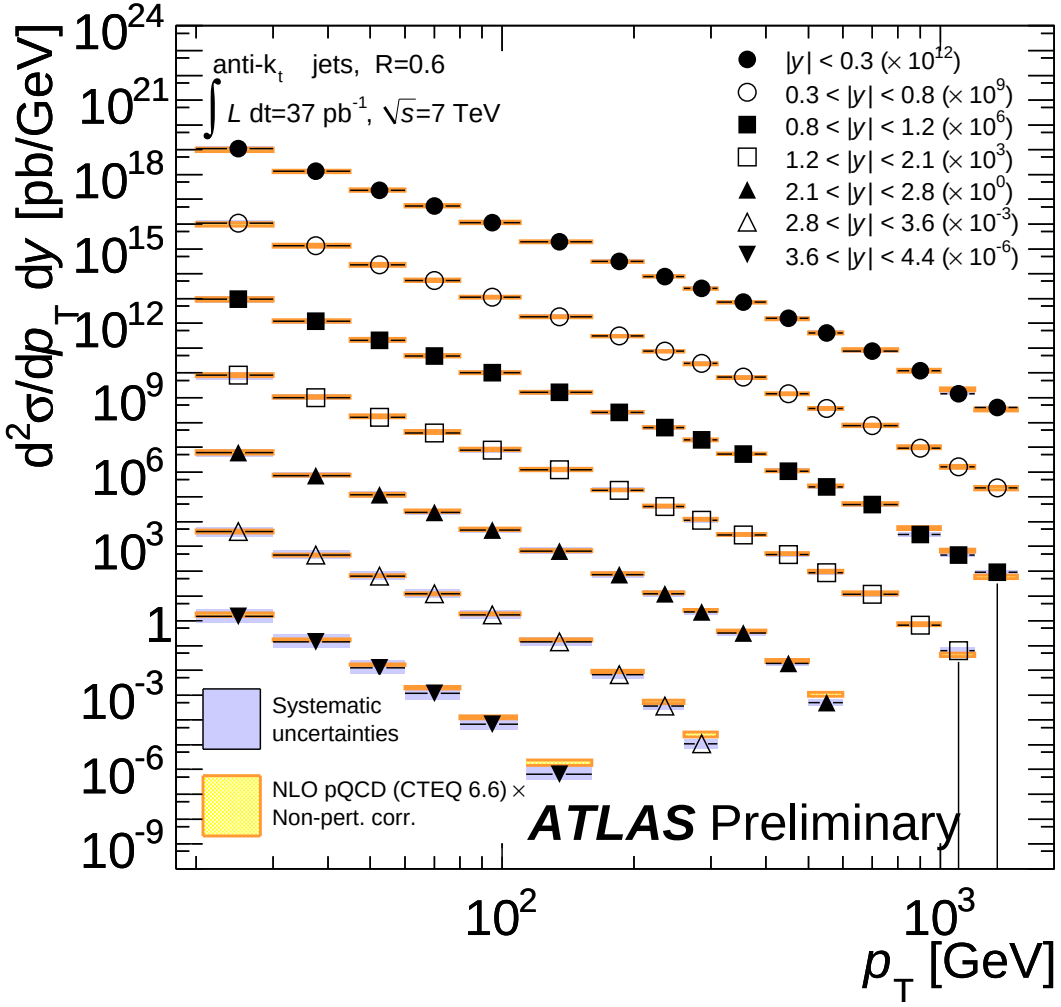


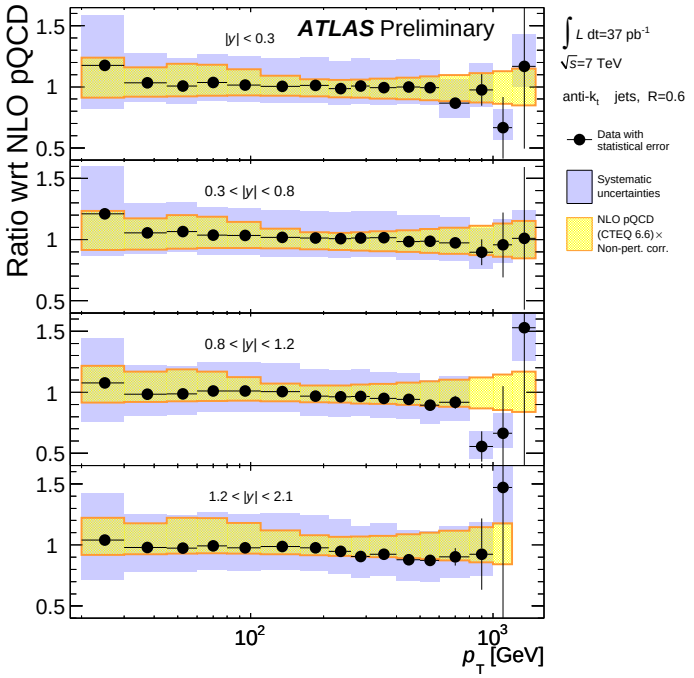
Jet NLO Predictions

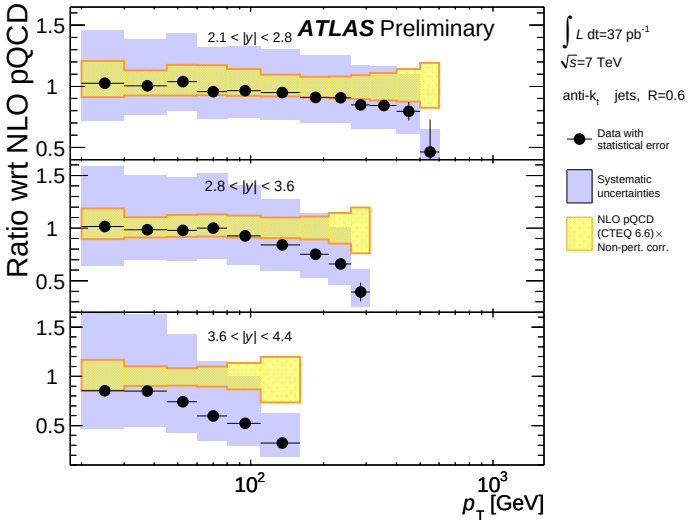
- fixed order QCD predictions at NLO parton level using NLOJet++
- Corrections for non-perturbative effects (hadronisation and underlying event) obtained with PYTHIA (AMBT1 tune) and applied to predictions
- Baseline: CTEQ 6.6 with $\mu_r = \mu_f = p_T^{\mathrm{lead}}$; Variations evaluated using APPLGRID:
  - PDF uncertainties and different PDF sets
  - Scale variations μ_r, μ_f by factor 2
  - α_s
- In addition: NLO Matrix Element + Parton Shower using PowHeg, showered by either Pythia or Herwig (including non-perturbative effects)

Inclusive Jet results

- Good agreement over wide $p_T - y$ range
- ~ 10 orders of magnitude in cross sections
- Precision $10 \sim 50\%$, mainly jet energy scale

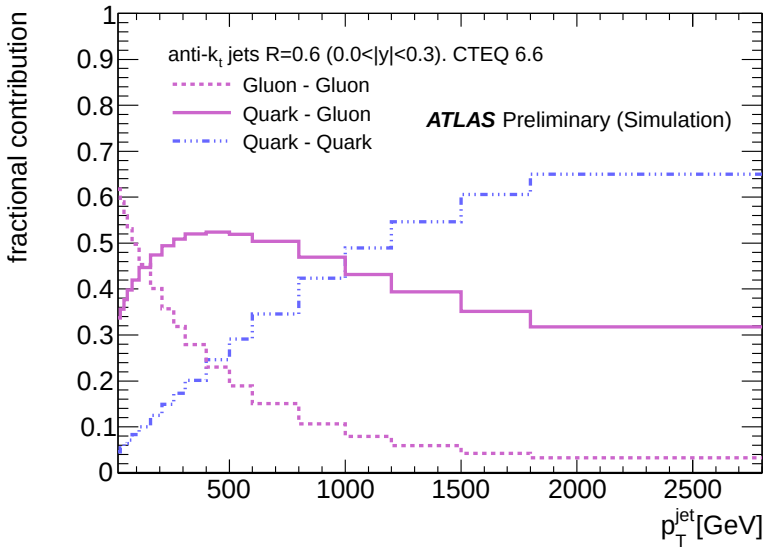


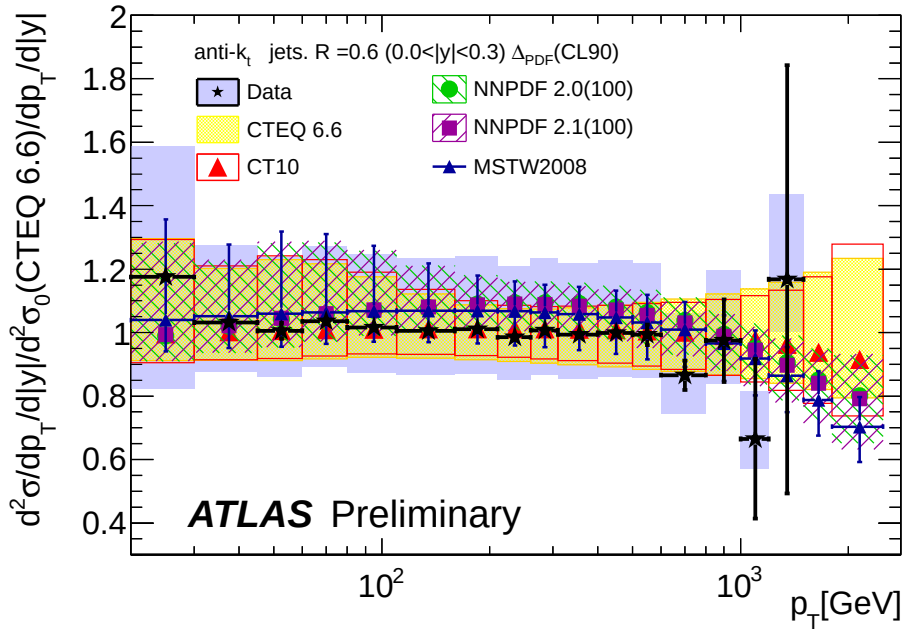


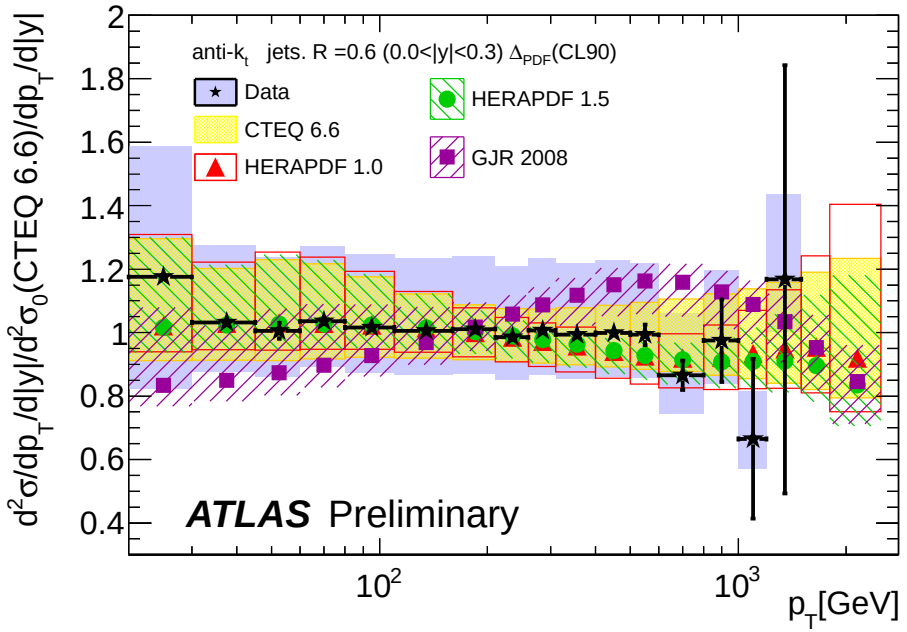


Inclusive Jet results: Central

- Detailed comparisons to many NLO PDF sets: broad agreement within experimental uncertainties for nearly all sets

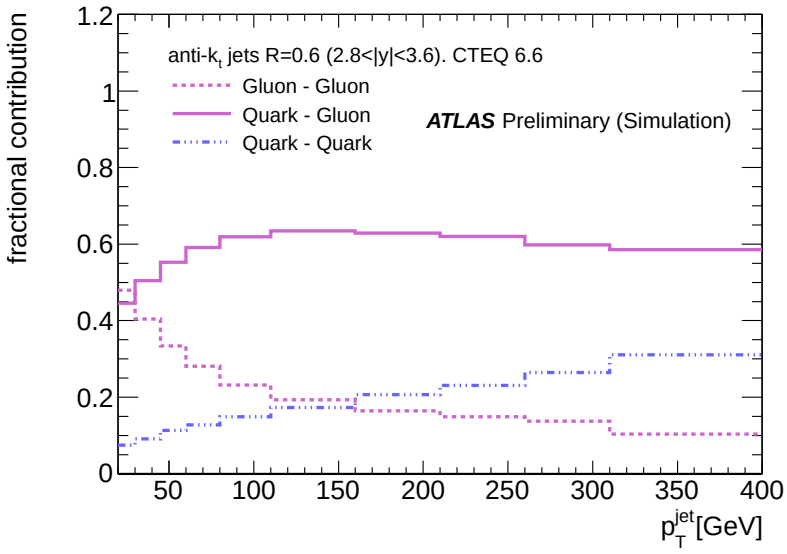


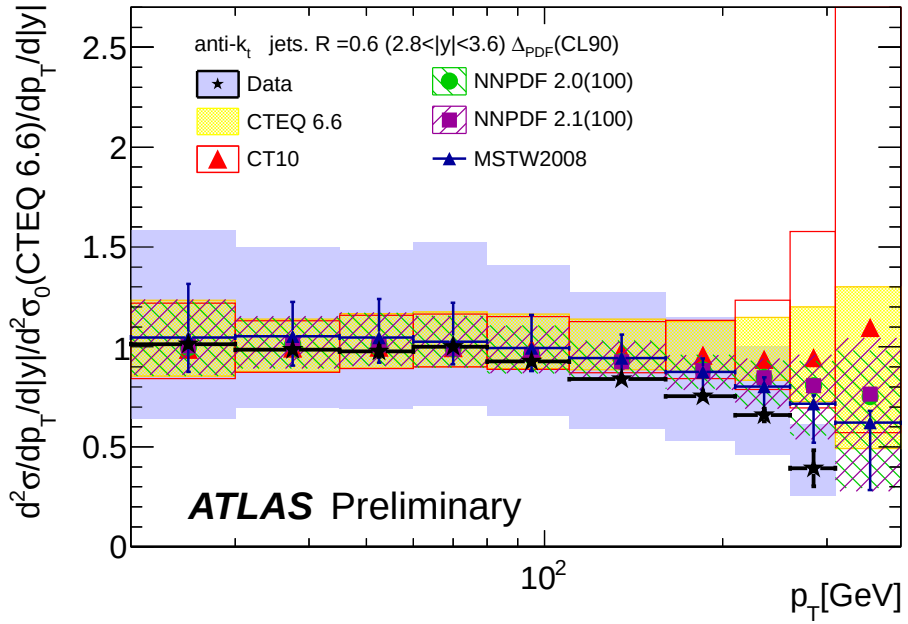


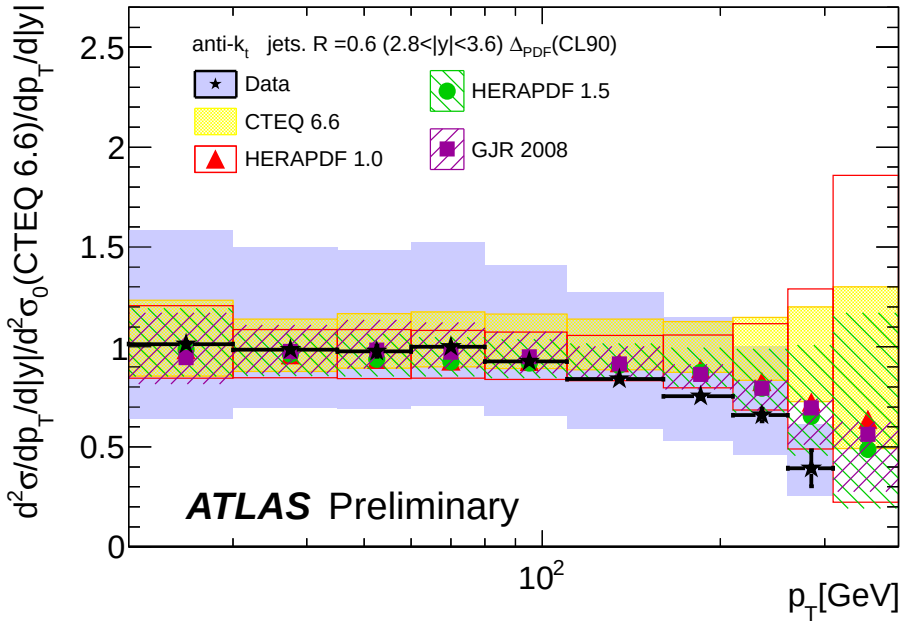


Inclusive Jet results: Forward

- Detailed comparisons to many NLO PDF sets: broad agreement within experimental uncertainties for all sets, some tendency for non CTEQ sets to describe high p_T end better

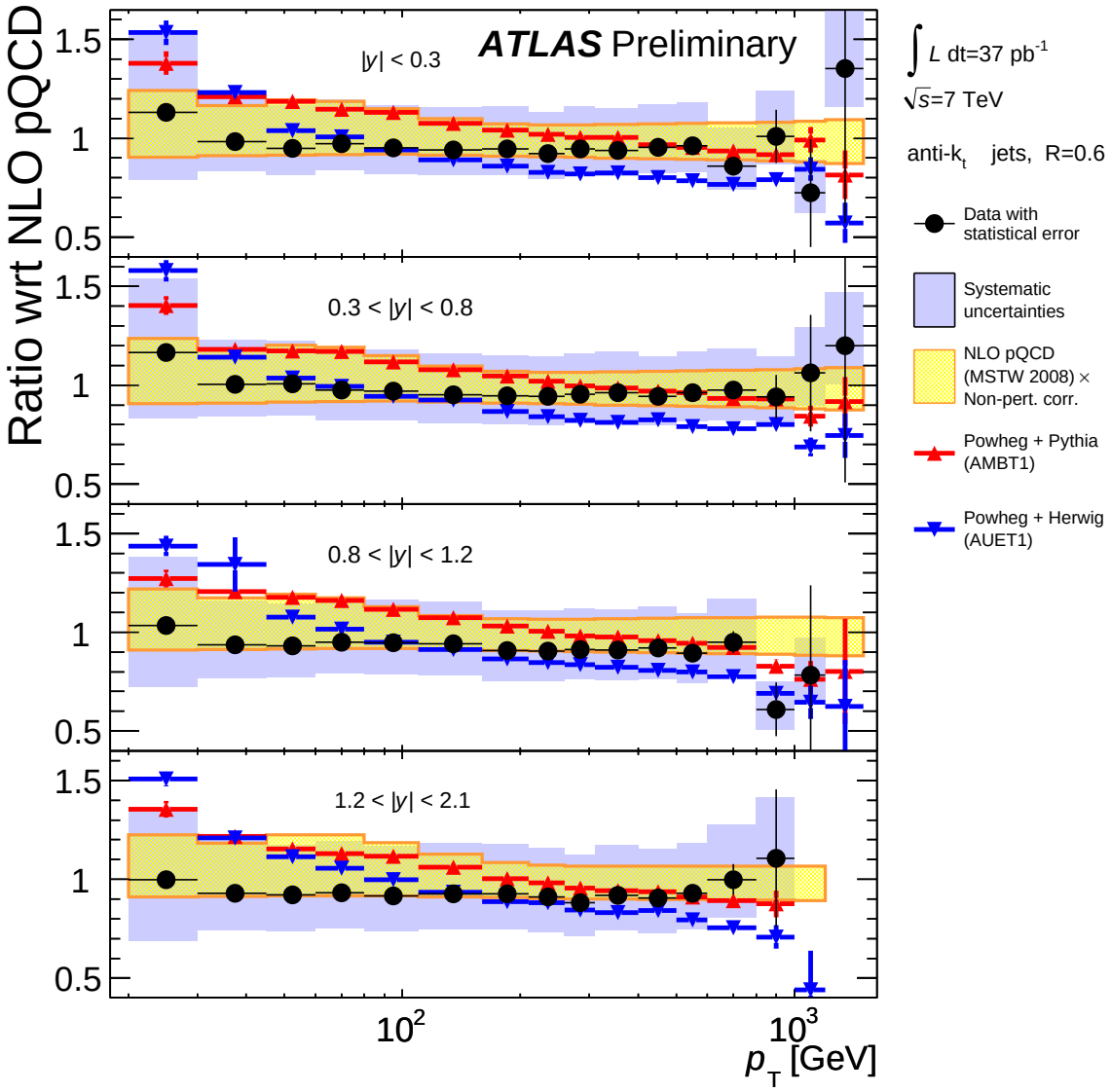






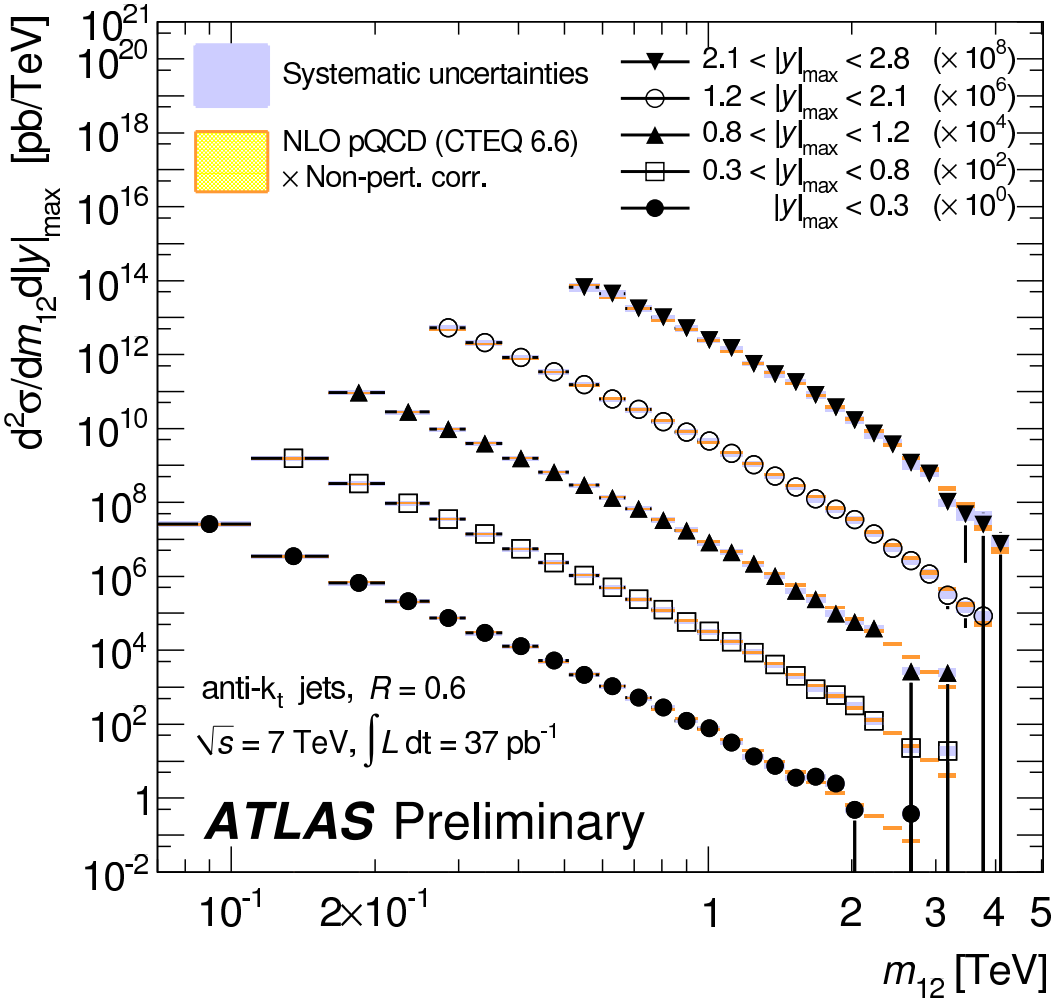
Inclusive Jets: NLOJET++ vs. PowHeg

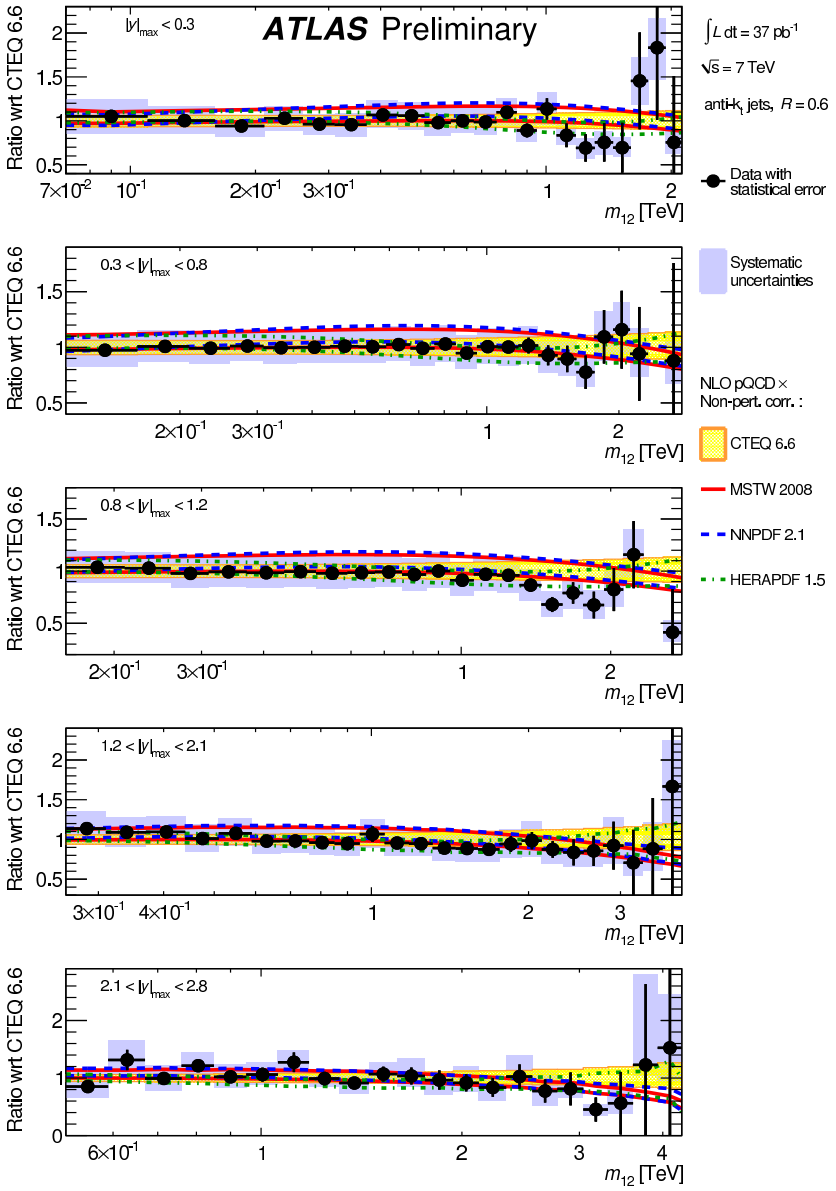
- A significant difference between NLOJET++, PowHeg+Pythia and PowHeg+Herwig was observed
- NLO Matrix Element in good agreement between NLOJET++ and PowHeg
- Indication of uncertainties due to non-perturbative effects?



Dijets

- Good agreement over wide $|y|_{\max} - m_{12}$ range with all PDFs, HERAPDF 1.5 describes the data best



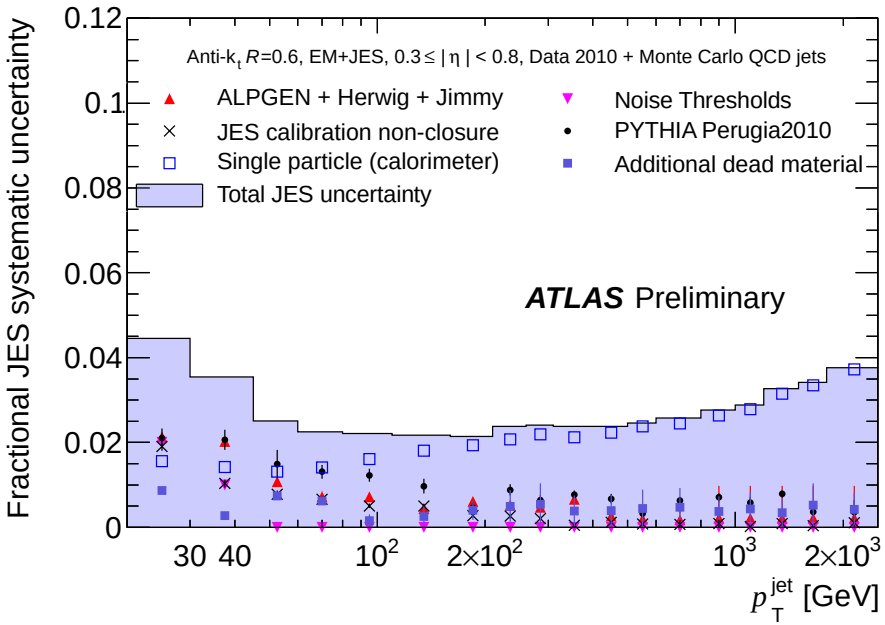


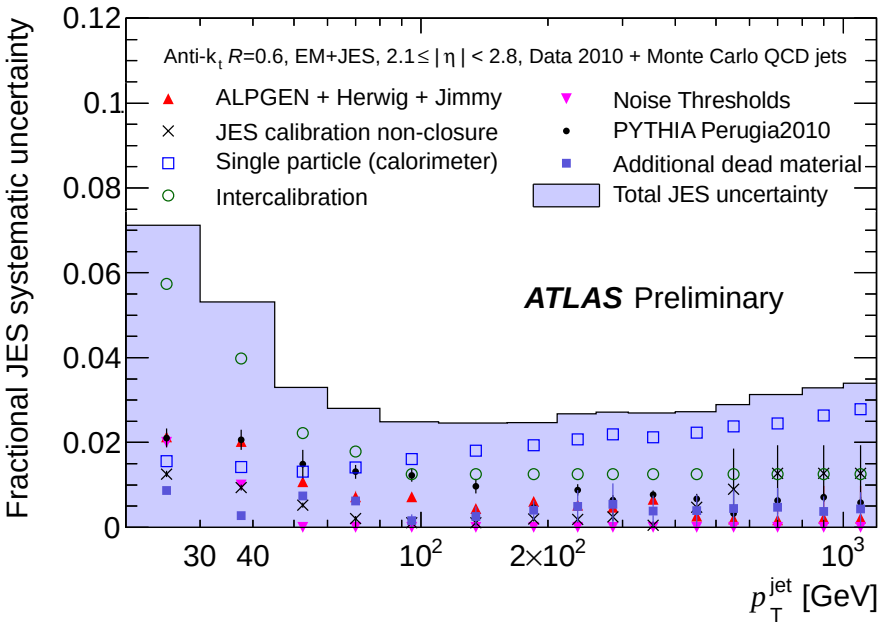
Summary

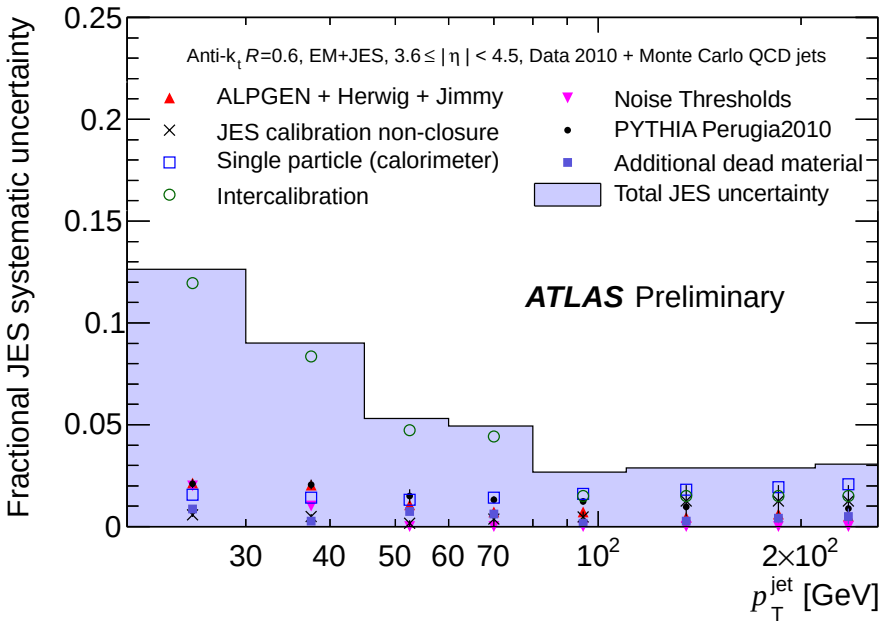
- Presented 2010 ATLAS measurements with largest relevance to PDF determination
- Inclusive W&Z Production, especially W charge asymmetry, can already distinguish between PDF sets
- W&Z + jets Production provides interesting test of QCD, no PDF sensitivity yet
- Inclusive jets and Dijet cross sections show preferences for certain PDF sets partially, theory predictions differ significantly between NLOJET++ and PowHeg
- Final publications on 2010 data are imminent
- Using the large 2011 data set should increase precision further, but need to deal with much more pileup

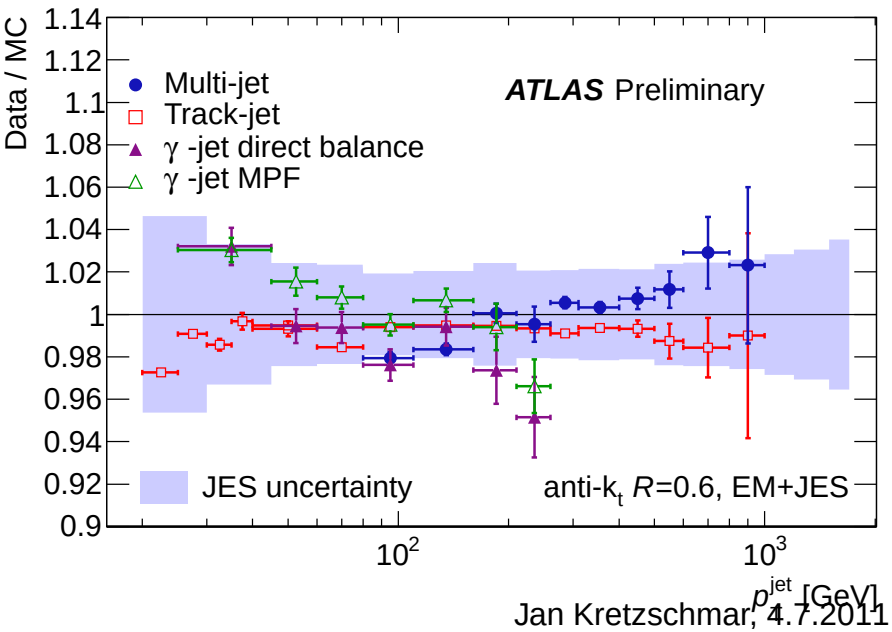
Backup

Jet Energy Scale

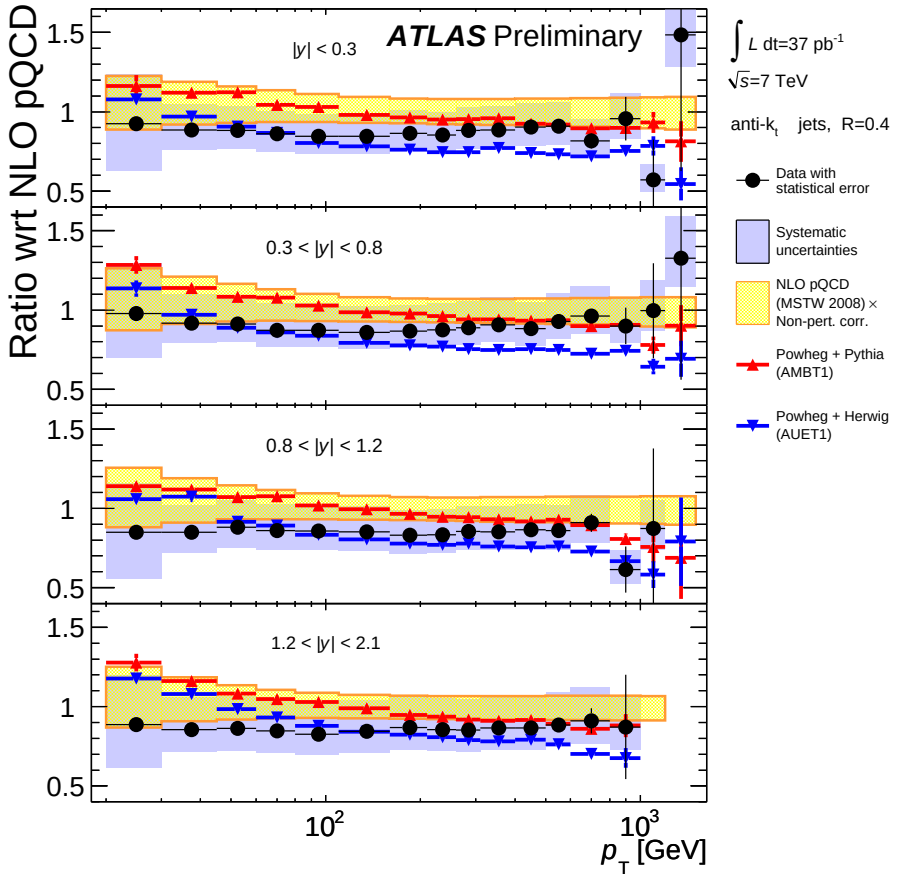


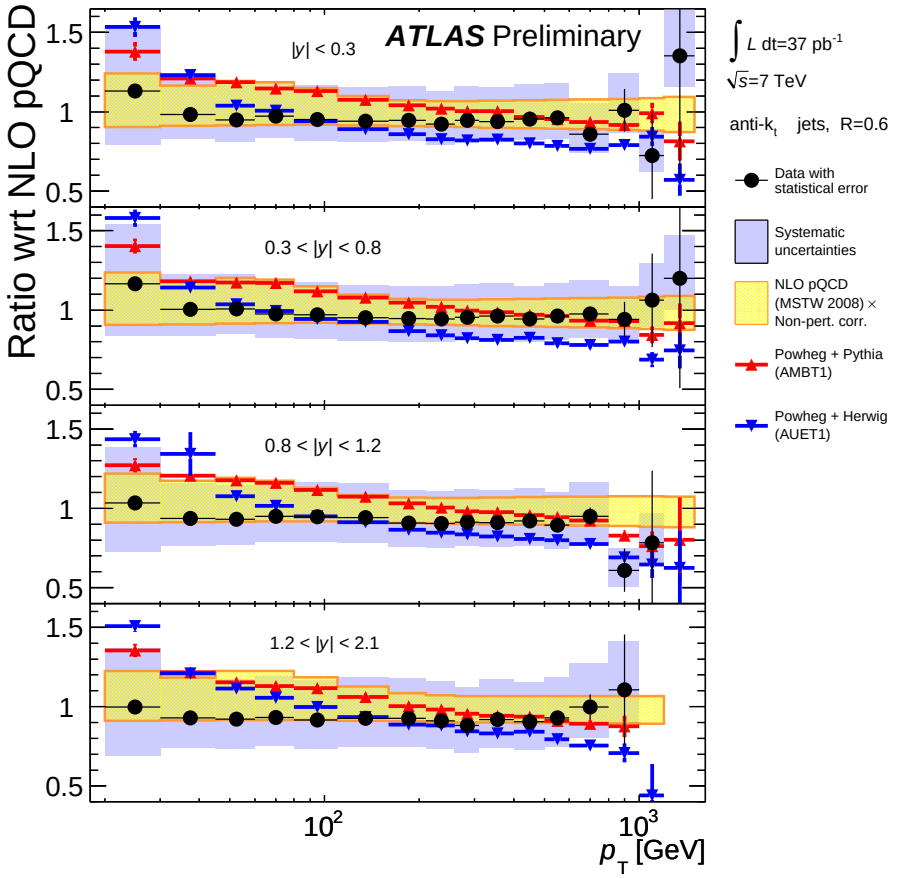






Inclusive Jets: R=0.4 vs. R=0.6





Dijets Jets: R=0.4 vs. R=0.6