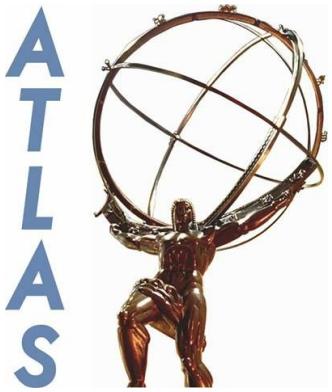
Vector boson production on ATLAS



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On behalf of the ATLAS Collaboration

Physics at the LHC, Perugia, Italy
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Outline

- Motivation for analyses
- Data sample
- Common analysis components

  - object and event selection

  - background estimation

  - corrections
- *W, Z* total cross-section measurement
- *W* charge asymmetry measurement
- *Z* P_T spectrum measurement
- Summary

Motivation

- *W, Z* production leads to important benchmark processes on ATLAS

  - establish robustness of detector hardware & software before we look for new physics

  - allow measurement of lepton trigger and reconstruction efficiencies, resolution, energy scales

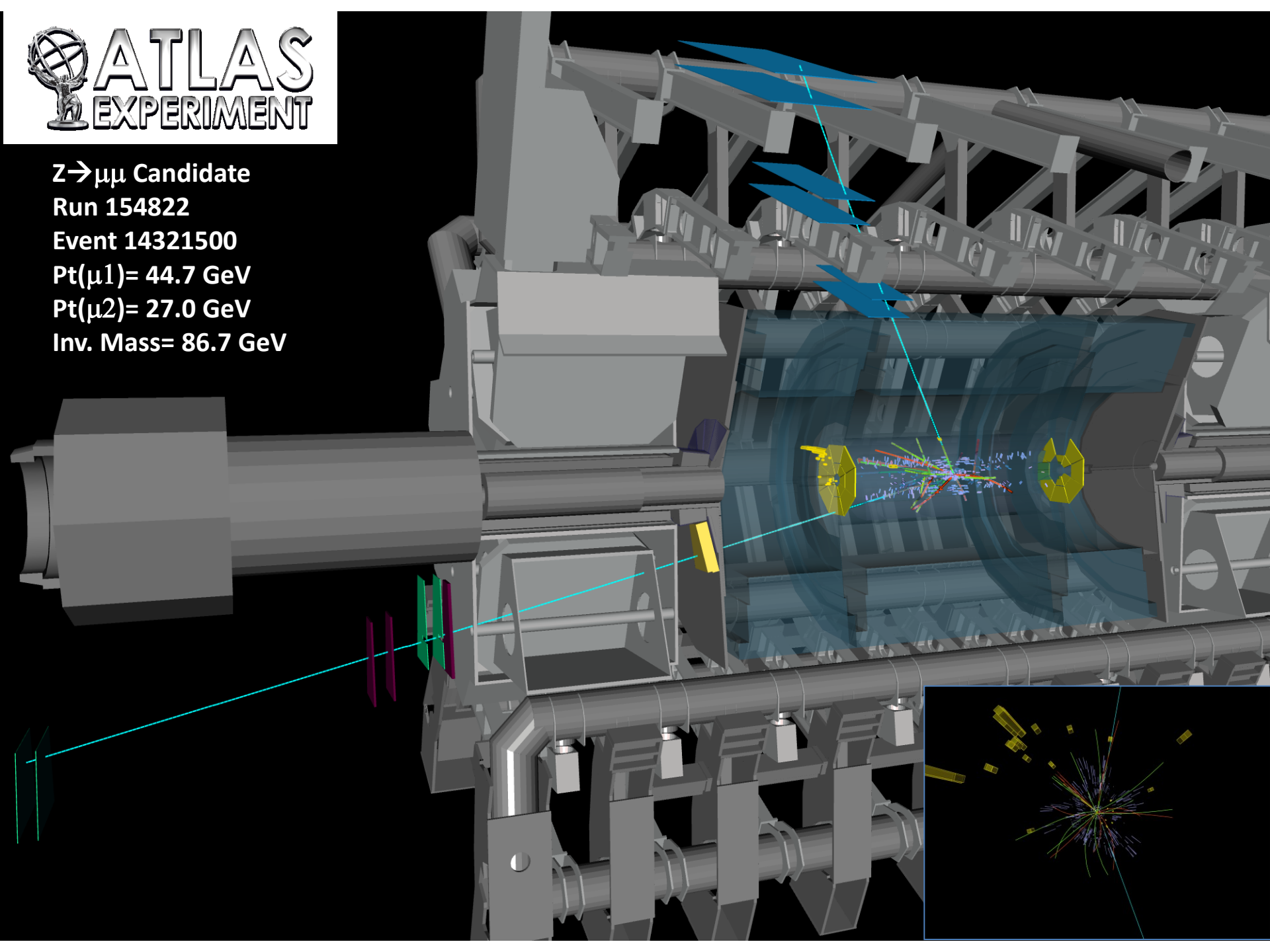
- Theory validation: QCD predictions can be tested in both high- and low-Q^2 regimes by comparing with measured total/differential cross-sections

- PDF constraint: *W* charge asymmetry, *Z* rapidity spectrum measurements help constrain proton PDFs

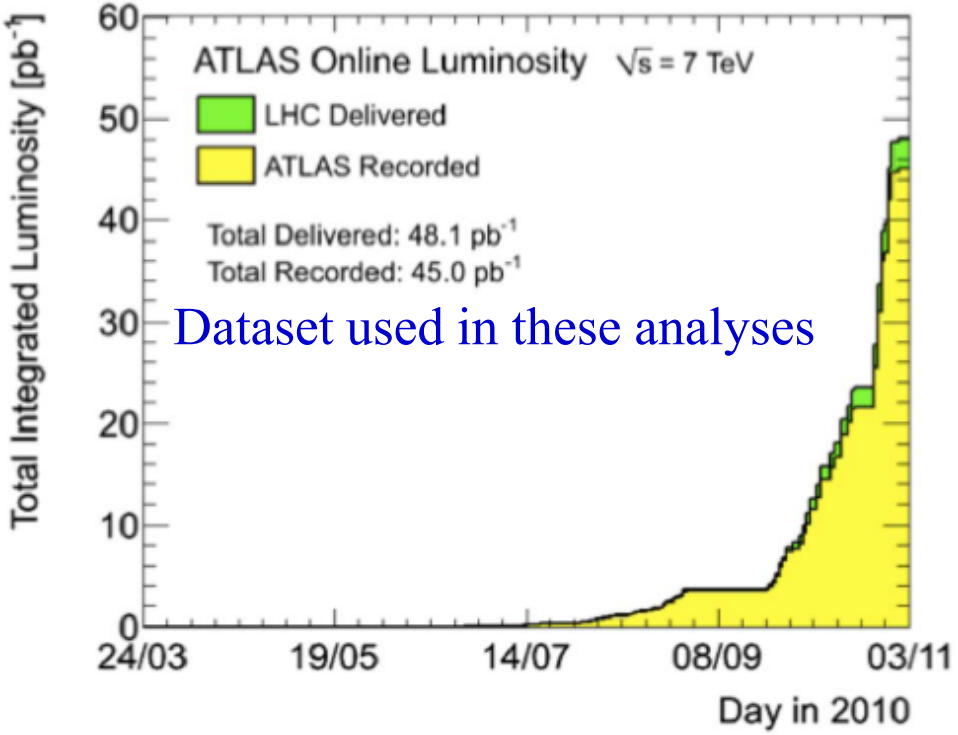
  - some measurements already sensitive to differences among PDF sets

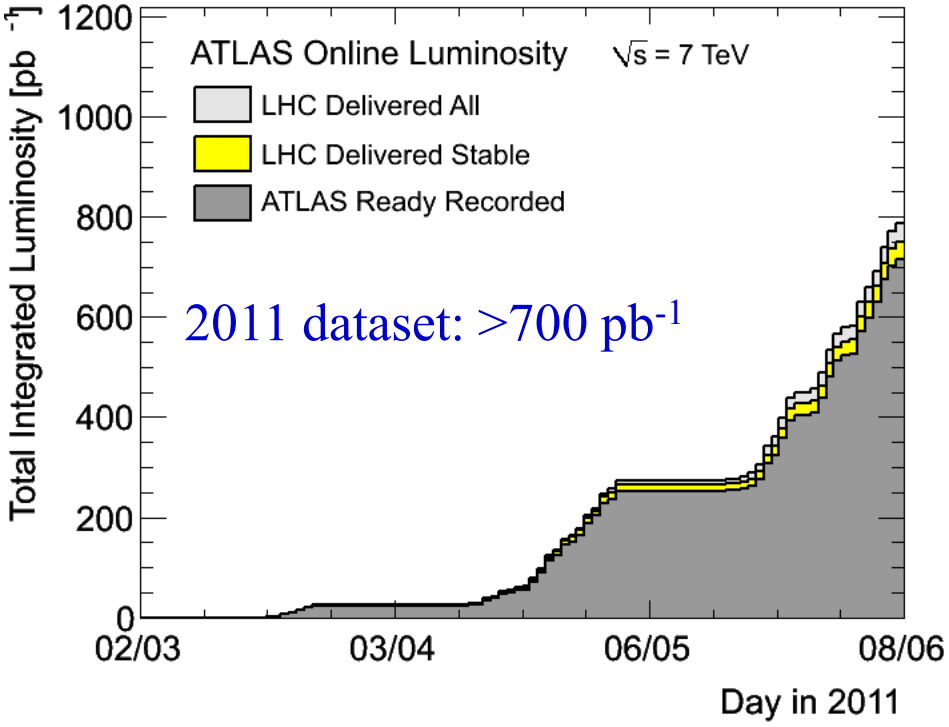
- Particles in many new physics scenarios decay into high-P_T *W/Z* bosons

  –> hint of new physics can show up in tails of P_T spectra


ATLAS
EXPERIMENT
Z→μμ Candidate
Run 154822
Event 14321500
Pt(μ1)= 44.7 GeV
Pt(μ2)= 27.0 GeV
Inv. Mass= 86.7 GeV

Data sample





- These analyses based on the total 7 TeV *pp* collision dataset from 2010
- Integrated luminosity: 31-40 pb^{-1} depending on analysis
- Error on luminosity: 3.4%

Ingredients of a cross-section measurement

$$\sigma_{W,Z} = \frac{N_{Obs} - N_{BG}}{A_{W,Z} C_{W,Z} L_{\text{int}}}$$

- N_{Obs}: observed events
- N_{BG}: estimated background events
- $A_{\text{W,Z}}$: kinematic acceptance

  - measured at generator level in Monte Carlo
- $C_{\text{W,Z}}$: event detection efficiency

  - ratio of events passing all reconstuction-level cuts to those passing truth-level kinematic cuts
- L_{int}: integrated luminosity

- For differential cross-section $\frac{d\sigma}{dx_i}$, all quantities in the expression except L_{int} are determined per bin i

Common selection criteria for the analyses

Cosmic muon rejection

- at least one primary vertex in event with >=3 associated tracks
- $|z_0(l) - z^{vtx}| < 1$ cm

Muon

- Combined muon, formed by matching muon spectrometer (MS) track with inner detector (ID) track
- $P_T > 20$ GeV, $|\eta| < 2.4$
- Cuts on matching quality, impact parameter, isolation

Electron

- Information combined from cluster in calorimeter and track in ID
- $P_T > 20$ GeV
- $|\eta| < 2.47$, excluding transition region between barrel and endcap calorimeter
  - for $Z \rightarrow ee$, require one electron with $2.5 < |\eta| < 4.9$
- Cuts on impact parameter, isolation

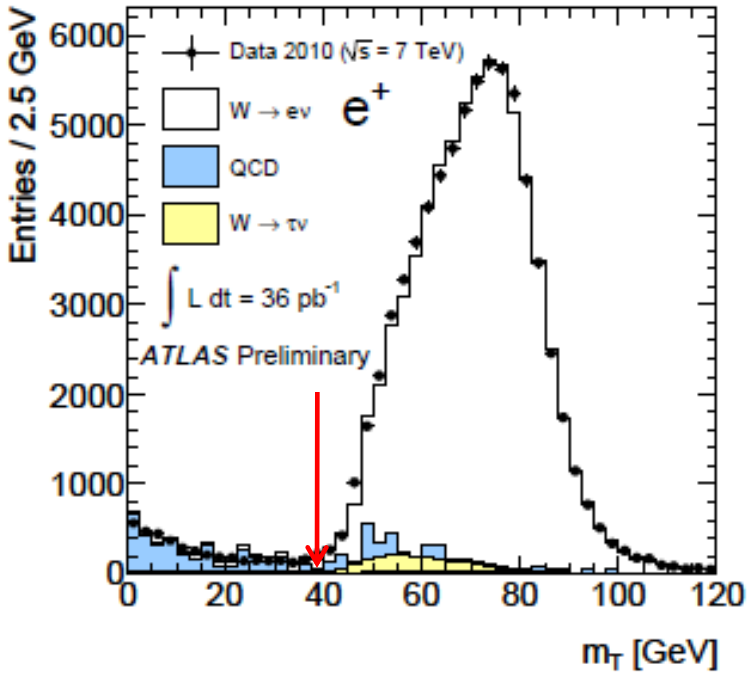
Topological selection

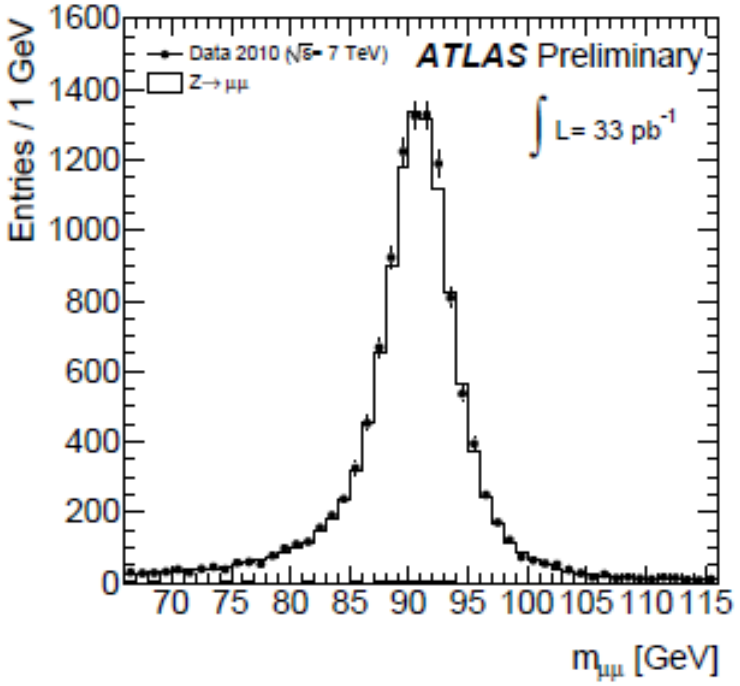
- These cuts reduce background and define signal region

➢ $W \rightarrow l\nu$ analyses: $E_T^{miss} > 25$ GeV,

transverse mass $m_T > 40$ GeV

➢ $Z \rightarrow ll$ analyses : 66 GeV < m_{ll} < 116 GeV





Backgrounds

- In all analyses, QCD background is estimated from data

➢ $W \rightarrow e\nu$: using template fit to E_T^{miss} distribution

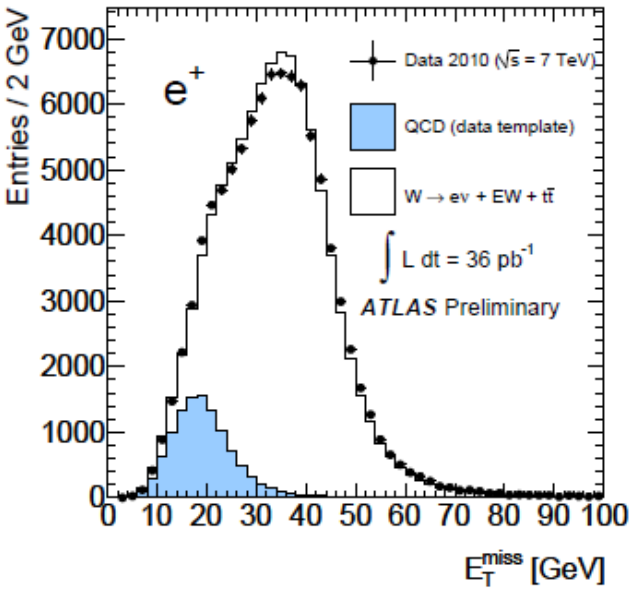
➢ $W \rightarrow \mu\nu$: from control region defined by isolation and E_T^{miss}

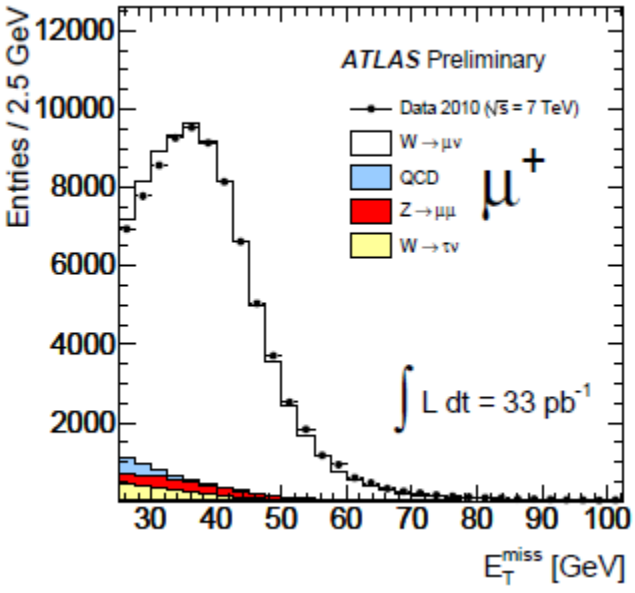
➢ $Z \rightarrow ee$: from fit to ee invariant mass distribution obtained by loosening some electron identification criteria

➢ $Z \rightarrow \mu\mu$: from control region defined by isolation and $\mu\mu$ invariant mass

- Non-QCD backgrounds include tt and electroweak channels

  - estimated from simulation





Corrections

- Lepton trigger, reconstruction efficiencies: estimated using tag-probe method with $Z \rightarrow \mu\mu$ and $Z \rightarrow ee$ events

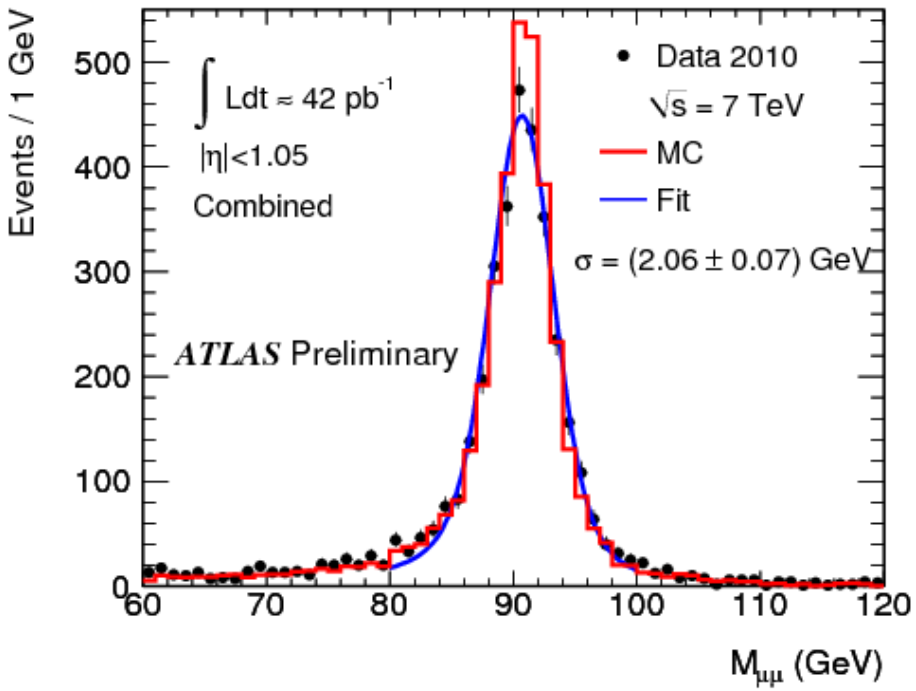
  - scale factors derived to correct for differences between data, Monte Carlo

- Lepton P_T resolution: determined from fits to invariant mass distributions in $Z \rightarrow \mu\mu$, ee events

  - resolution in data worse than in MC
  - MC P_T smeared to match data resolution

- Lepton P_T scale: P_T scale derived using peak positions of invariant mass spectra in $Z \rightarrow \mu\mu$, ee events

  - $J/\psi \rightarrow ee$ events used to check linearity

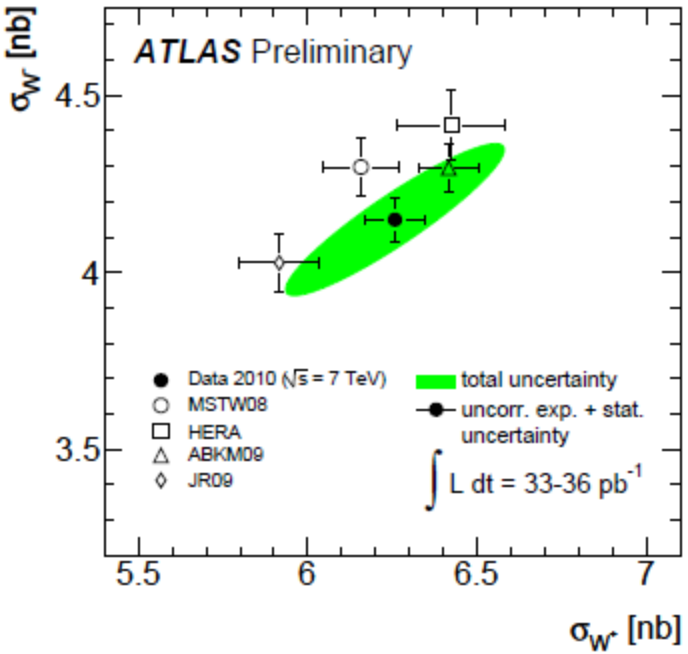


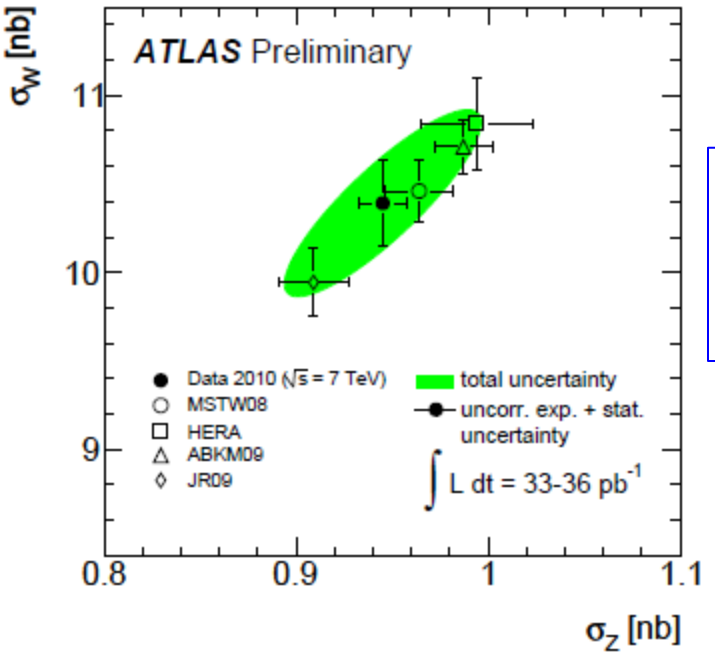
W, Z total cross-section

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

Acceptance uncertainty already ~largest error

- owing to extrapolation from fiducial region to full phase space

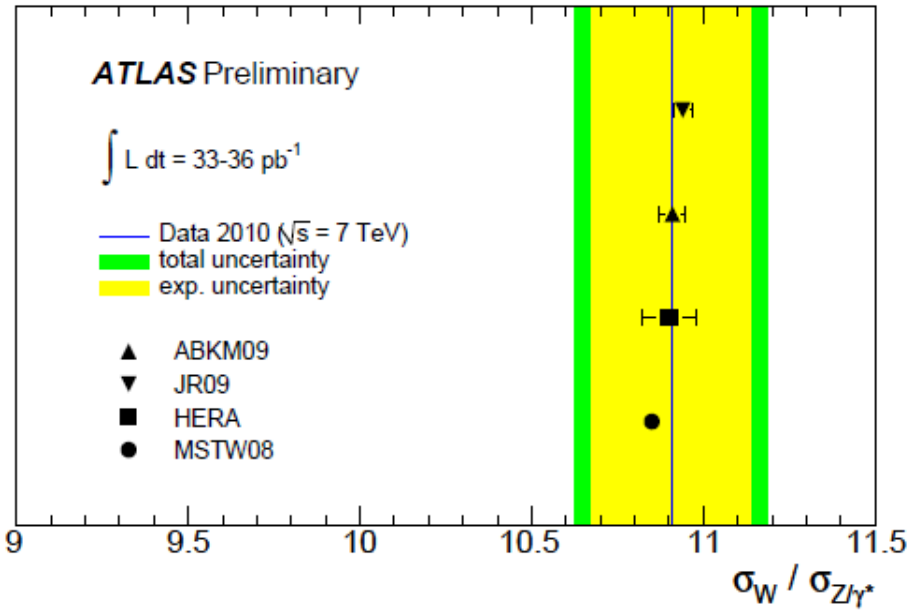




Close agreement with NNLO QCD predictions

W/Z cross-section ratio

- Luminosity uncertainty cancels out in cross-section ratios
- Object ID-related uncertainties are reduced, since correlated between numerator and denominator



- Ratio is insensitive to PDFs provided that the light quark sea is flavor-independent at $x \sim 10^{-2}$

  - close agreement of predictions from different PDFs with measurement is evidence for this flavor-symmetry

Charge asymmetry of muons from *W* decay

$$A_W = \frac{W^+ - W^-}{W^+ + W^-} = \frac{u_v - d_v}{u_v + d_v + \bar{u} + \bar{d}}$$

- Decay muon charge asymmetry varies as a function of muon η owing to correlation with parton momentum fraction x
- Define $A_\mu = \frac{d\sigma_{W\mu^+}/d\eta_\mu - d\sigma_{W\mu^-}/d\eta_\mu}{d\sigma_{W\mu^+}/d\eta_\mu + d\sigma_{W\mu^-}/d\eta_\mu}$

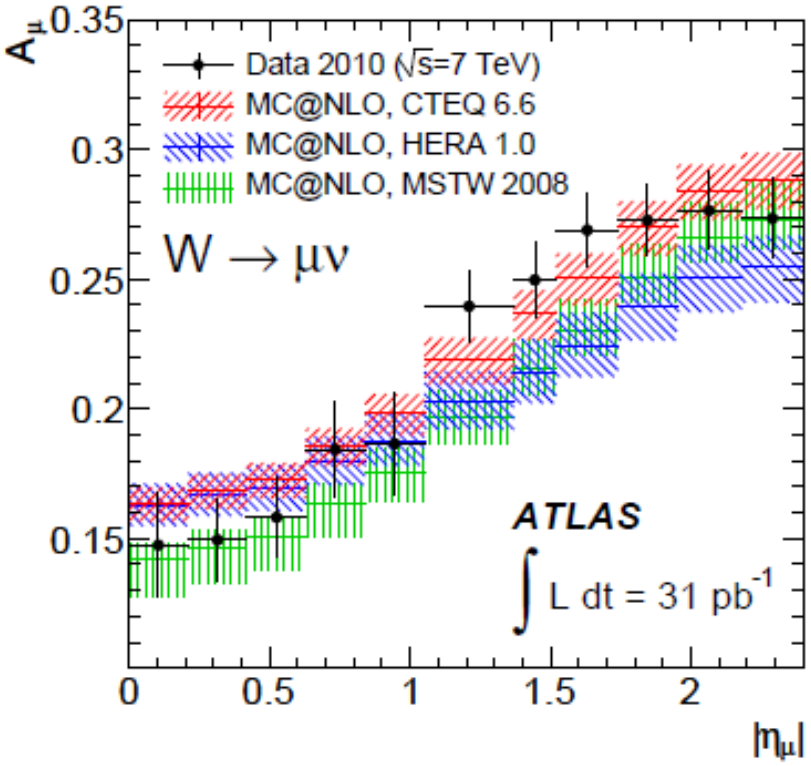
➢ At LHC energies, A_μ probes PDFs in low and medium x

- Many systematics, including those for luminosity, cancel in A_μ
- Detector effects that are different for the two muon charges can bias results

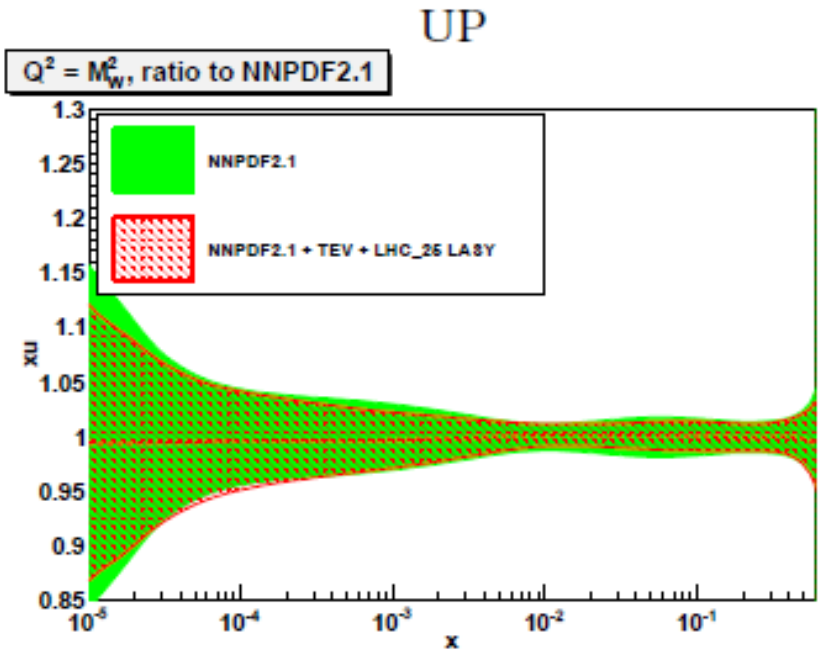
  - muon trigger & reconstruction efficiencies, P_T scale, resolution

  - these must be studied carefully

W charge asymmetry: results



- PDF uncertainty bands are 90% C.L.
  - estimated using error eigenvectors of each PDF set
- Data compatible with all 3 sets, but most closely with CTEQ6.6

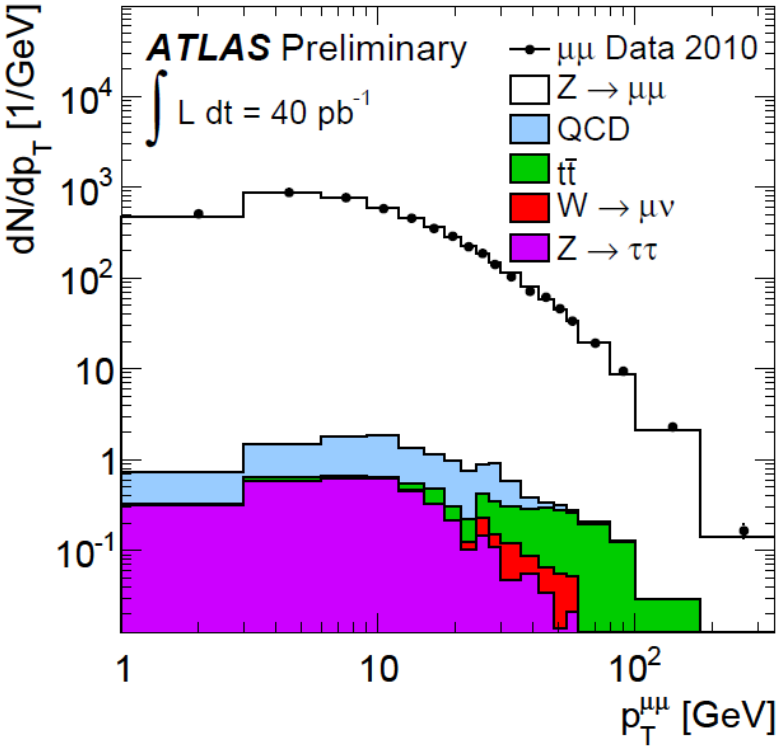


- Results already used in latest NNPDF versions (S. Forte's talk this morning)
  - uncertainties on light quark PDFs reduced

Z P_T spectrum & $d\sigma_Z/dP_T$

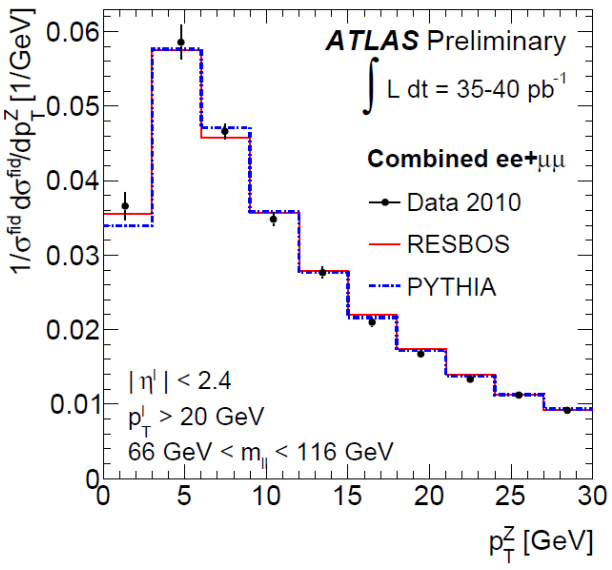
- Raw P_T spectrum must be corrected ('unfolded') for detector effects, QED final state radiation etc
- MC-derived bin-by-bin corrections used for unfolding
- Unfolding using a migration matrix not used owing to limited MC stat

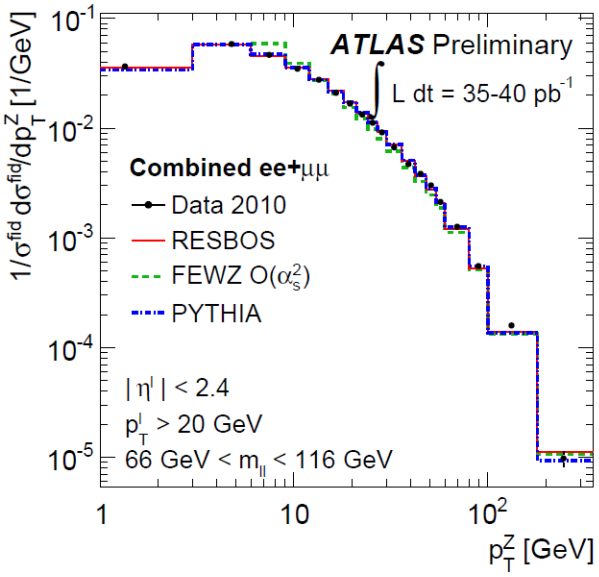
  - used instead to estimate systematics from unfolding
- Systematics for lepton efficiencies, scale, resolution estimated and applied bin-by-bin



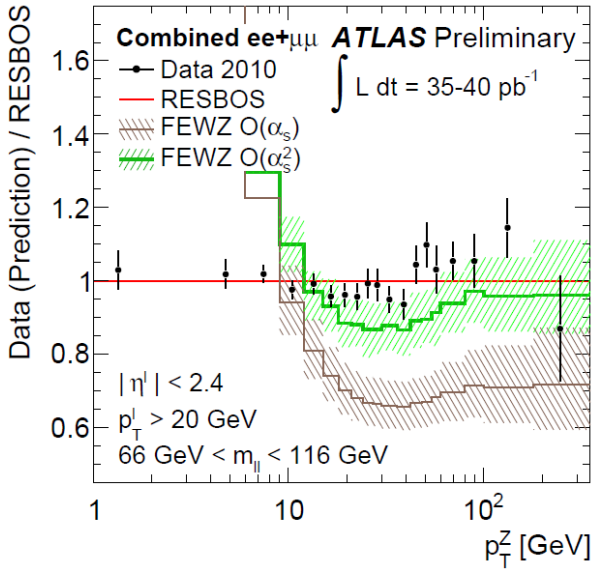
Uncorrected P_T spectrum from $Z \rightarrow \mu\mu$ channel

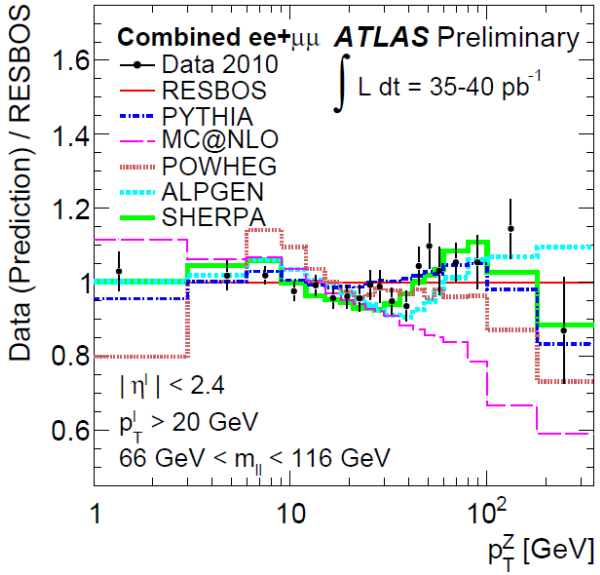
Z P_T spectrum: results





Measurement within fiducial region





Measurement compared with predictions from ResBos, FEWZ (NLO and NNLO), and various event generators

Data-ResBos agreement quite good

Summary

- Vector boson production in ATLAS is being used to both benchmark the detector and extract important physics
- *W, Z* total cross-sections have been measured with 2010 dataset

  - results agree with NNLO QCD predictions

  - theory (acceptance) systematic already close to dominant
- *W* charge asymmetry *vs* muon pseudorapidity has been measured

  - results with 31 pb^{-1} already start to constrain PDFs
- *Z* differential cross-section in P_T bins shows ResBos to describe P_T spectrum well

  - Sherpa, Alpgen, Pythia also do decent jobs

  - measurement still statistically limited in high-P_T regime
- Higher-stat results using 2011 data already in the pipeline

Backup

W charge asymmetry: corrections

- Muon trigger, reco efficiencies: estimated using *Z* tag-probe separately for μ^+, μ^-

  - very similar between muon charges

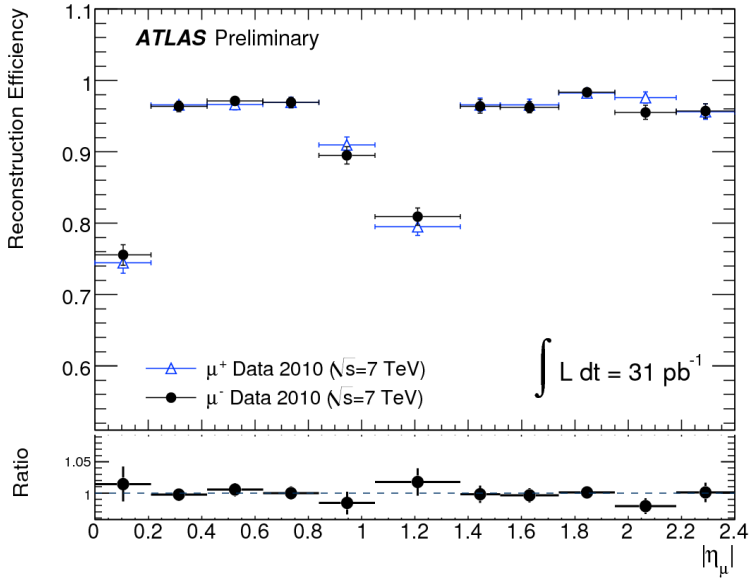
- Muon resolution: determined using two independent methods

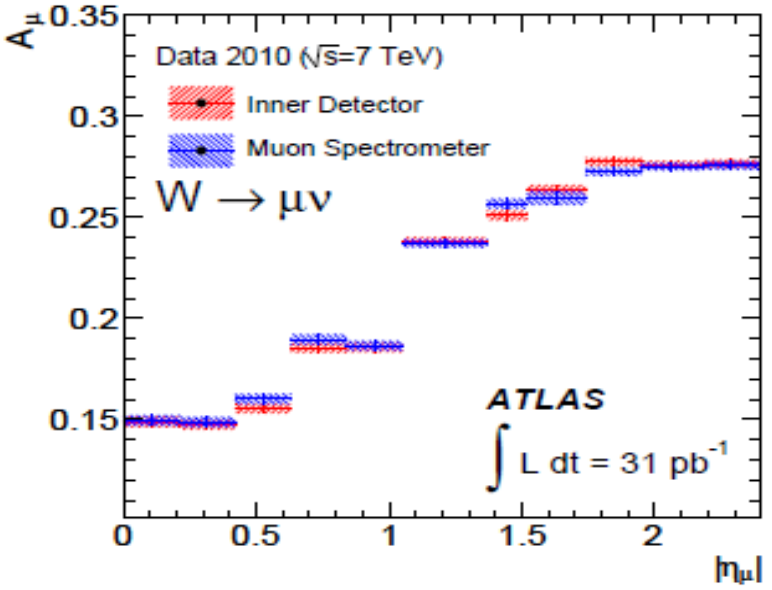
  - results for different muon charges agree within error

- Muon P_T scale: found to be different for μ^+, μ^- by up to 3%

  - corrected in simulation

- Effect of corrected P_T scale on A_μ checked by doing measurement separately using MS tracks and assoc. ID tracks





Z P_T spectrum: uncertainty from unfolding

- Pythia is not expected to model Z P_T distribution well
- P_T spectrum from Pythia is reweighted to those from MC@NLO, ResBos

  - also to P_T spectrum in data reweighted with migration matrix
- Maximum deviation from Pythia Z P_T spectrum taken as a systematic
- To estimate uncertainty from parton shower model & hadronization, derive correction factors from MC@NLO and compare with Pythia

  - to distinguish from difference in P_T spectrum shape, MC@NLO spectrum is reweighted to that from Pythia
- Shape and model uncertainties combined to give total systematic on unfolding

  - dominated by shape uncertainty

Z rapidity spectrum

- $d\sigma^Z/dY$ at high rapidity probes PDFs at small x
- One or both partons are from the sea

  –> gluon PDFs can be constrained using this measurement
- On ATLAS, muon reconstruction limited to $|\eta| \sim 2.7$
- Electrons reconstructed up to $|\eta| = 4.9$ –> Z's to $|\eta| = 3.6$

➢ Work ongoing in both Z –> $\mu\mu$ and Z –> ee channels