Determination of integrated Luminosity via W/Z Boson Production at the ATLAS Detector

CERN 2011
Matthias Schott (CERN)
On behalf of the ATLAS Collaboration

Content

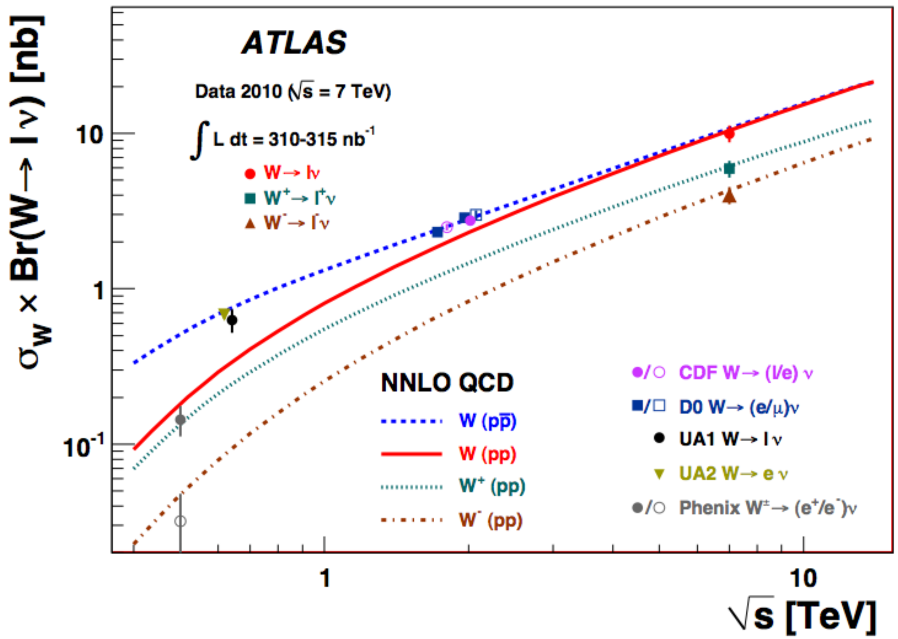
- Current Results and their systematics
- Expected Precision of fiducial cross-sections for $1fb^{-1}$
- Improving Theoretical Uncertainties on Acceptance
- Conclusion

Theoretical Prediction of W/Z Production Cross-Sections

- ATLAS Central values from QCD NNLO calculations by FEWZ with ~5% systematic uncertainty (based on 90% CL, including PDF and α_S uncertainties)

$$\begin{aligned}
\sigma(W^+ \to \ell^+\nu) &= 6.16 \pm 0.31 \text{ nb} \\
\sigma(W^- \to \ell^-\nu) &= 4.30 \pm 0.21 \text{ nb} \\
\sigma(W^\pm \to \ell^\pm\nu) &= 10.46 \pm 0.52 \text{ nb} \\
\sigma(Z(\gamma^*) \to \ell\ell) &= 0.964 \pm 0.048 \text{ nb} \quad (66 < M_{\ell\ell} < 116\,\text{GeV})
\end{aligned}$$

http://arxiv.org/pdf/1011.6259v1



- PDF uncertainties: uncertainties of NLO and NNLO calculations from 68% CL error sets vary between ±(1.6 − 2.0)%
  - Found to be about a factor of two larger using 90%CL error sets,
  - suggesting non-Gaussian distributions of the cross section variations.

- α_s value and its uncertainties
  - using MSTW2008 fits which include PDF sets with α_s values corresponding to ±1σ
  - 68% CL leads to 1.1%, 90% leads to 2.6% relative uncertainty
- Electroweak Radiative Corrections assumed to be negligible

Methodology

- The production cross sections for the W and Z bosons times the branching ratios for decays into leptons can be expressed as

$$\sigma^{\text{tot}}_{W(Z)} \cdot BR(W(Z) \rightarrow \ell\nu\ (\ell\ell)) = \frac{N^{\text{sig}}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

- N^{sig} denote the numbers of background-subtracted signal events passing the selection criteria of the analyses in the W and Z channels

- A_W and A_Z denote the acceptances for the W and Z-boson decays

$$A = \frac{N^{\text{Generated}}_{\text{in Fiducial Region}}}{N^{All}_{Generated}}$$

- C_W and C_Z denote the ratios between the total number of generated events which pass the final selection on reco. level and the number of generated events within the fiducial acceptance

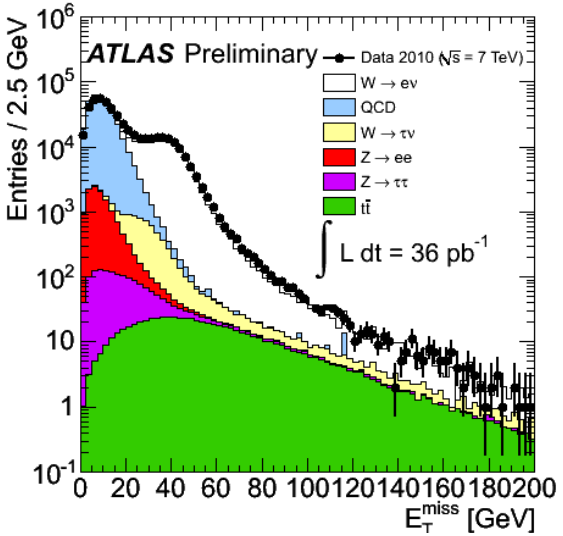
$$C_W = \varepsilon^W_{\text{event}} \cdot \alpha^W_{\text{reco}} \cdot \varepsilon^W_{\text{lep}} \cdot \varepsilon^W_{\text{trig}}$$

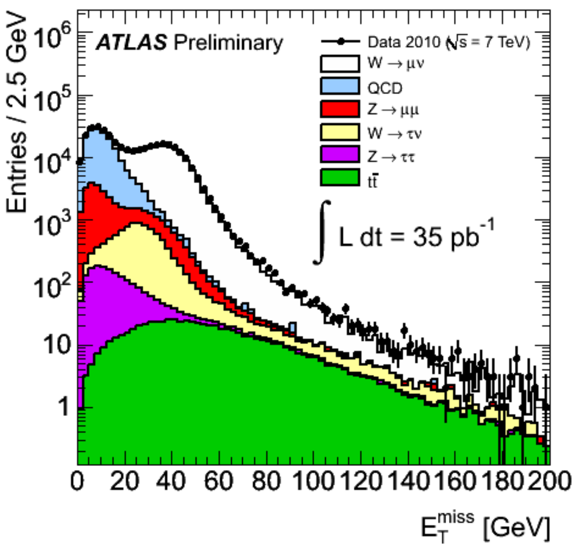
$$C_Z = \varepsilon^Z_{\text{event}} \cdot \alpha^Z_{\text{reco}} \cdot (\varepsilon^Z_{\text{lep}})^2 \cdot [1-(1-\varepsilon^Z_{\text{trig}})^2]$$

- Remarks
  - Acceptance Factor A and detector effect correction factors C can be treated as independent factors
  - Theoretical uncertainties affect dominantly the factor A

W Boson Selection

- Electron Selection
  - E_T > 20 GeV
  - "tight" identification
  - events containing an additional electron are vetoed
- Muon Selection
  - p_T > 20 GeV
  - Combined Muon
  - Track Isolation: $\sum p^{ID}/p_T < 0.2$
- Missing transverse energy
  - E_t^{miss}>25 GeV;
- Transverse mass of the lepton-E_t^{miss} system
  - m_T > 40 GeV;

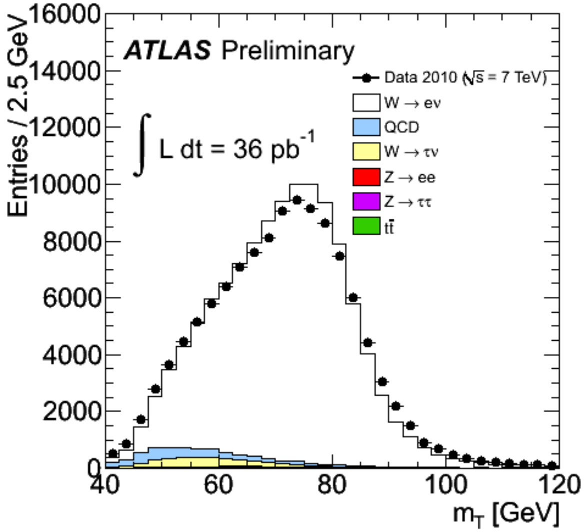


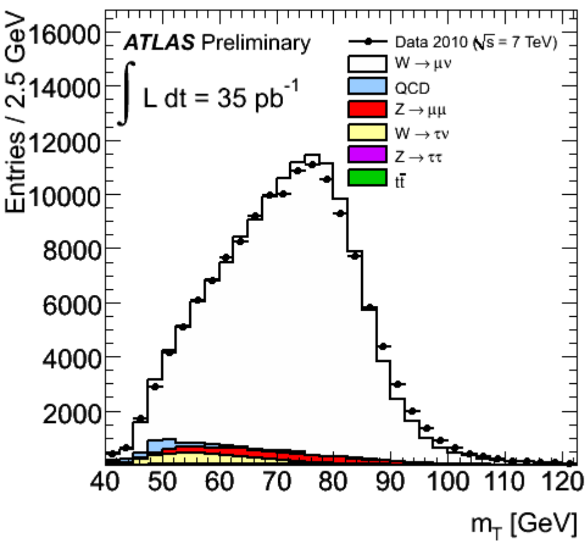


W-Boson Background Estimation

- Overall background contribution
  - Electron Channel: 5.7%
  - Muon Channel: 8.6%
- Data-Driven QCD background estimations for both channels
  - Relative systematic uncertainty ~1%
- Electroweak background estimated by Monte Carlo simulations

ℓ	Observed candidates	Background (EW+$t\bar{t}$)	Background (QCD)	Background-subtracted signal N_W^{sig}
e^+	637	$18.8 \pm 0.2 \pm 1.7$	$14.0 \pm 2.1 \pm 7.1$	$604.2 \pm 25.2 \pm 7.6$
e^-	432	$14.7 \pm 0.2 \pm 1.3$	$14.0 \pm 2.1 \pm 7.1$	$403.2 \pm 20.8 \pm 7.5$
$e^\pm$	1069	$33.5 \pm 0.2 \pm 3.0$	$28.0 \pm 3.0 \pm 10.0$	$1007.5 \pm 32.7 \pm 10.8$
μ^+	710	$42.5 \pm 0.2 \pm 2.9$	$12.0 \pm 3.0 \pm 4.6$	$655.6 \pm 26.6 \pm 6.2$
μ^-	471	$35.1 \pm 0.2 \pm 2.4$	$10.9 \pm 2.4 \pm 4.1$	$425.0 \pm 21.7 \pm 5.4$
$\mu^\pm$	1181	$77.6 \pm 0.3 \pm 5.4$	$22.8 \pm 4.6 \pm 8.7$	$1080.6 \pm 34.4 \pm 11.2$



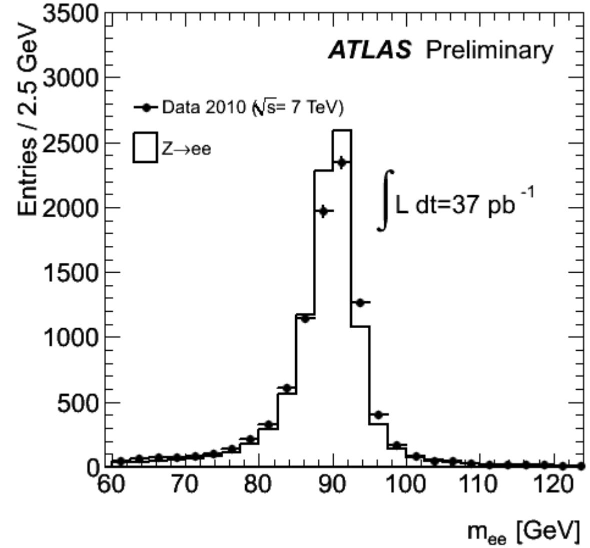


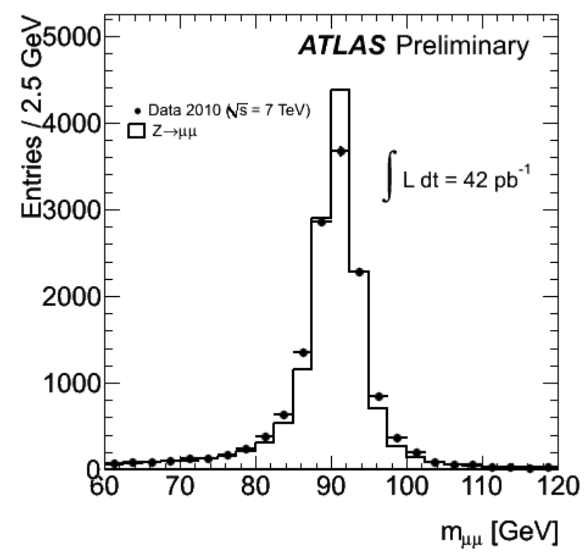
Z/γ* Boson Selection

- A pair of oppositely-charged leptons of the same flavour
  - Electron
    - "Medium" identification, $p_T > 20$ GeV
    - Veto on events with >2 "medium" electrons
  - Muon
    - Combined track, $p_T > 20$ GeV
    - Track Isolation: $\sum p^{ID}/p_T < 0.2$
- Invariant mass window of lepton pair
  - $66 < m_{ll} < 116$ GeV

- Data-Driven QCD background estimate for electron channel, MC prediction for channel
  - Background electron channel: ~1.5%
  - Background muon channel: ~0.2%

ℓ	Observed candidates	Background (EW+$t\bar{t}$)	Background (QCD)	Background-subtracted signal N_Z^{sig}
$e^{\pm}$	70	$0.27 \pm 0.00 \pm 0.03$	$0.91 \pm 0.11 \pm 0.41$	$68.8 \pm 8.4 \pm 0.4$
$\mu^{\pm}$	109	$0.21 \pm 0.01 \pm 0.01$	$0.04 \pm 0.01 \pm 0.04$	$108.8 \pm 10.4 \pm 0.0$





Experimental Uncertainties

- Current experimental uncertainties dominated by lepton identification
- Given the small statistics which was used for this measurement the current numbers are already impressively small
  - Expect large improvements for reprocessed data and full statistics

Parameter	$\delta C_W/C_W(\%)$	$\delta C_Z/C_Z(\%)$
Trigger efficiency	<0.2	<0.2
Material effects, reconstruction and identification	5.6	8.8
Energy scale and resolution	3.3	1.9
E_T^{miss} scale and resolution	2.0	-
Problematic regions in the calorimeter	1.4	2.7
Pile-up	0.5	0.2
Charge misidentification	0.5	0.5
FSR modelling	0.3	0.3
Theoretical uncertainty (PDFs)	0.3	0.3
Total uncertainty	7.0	9.4

Parameter	$\delta C_W/C_W(\%)$	$\delta C_Z/C_Z(\%)$
Trigger efficiency	1.9	0.7
Reconstruction efficiency	2.5	5.0
Momentum scale	1.2	0.5
Momentum resolution	0.2	0.5
E_T^{miss} scale and resolution	2.0	-
Isolation efficiency	1.0	2.0
Theoretical uncertainty (PDFs)	0.3	0.3
Total uncertainty	4.0	5.5

Theoretical Uncertainties

- Acceptance correction factors extrapolate fiducial cross-sections to full cross-sections
  - Predicted by Monte Carlo event generators
  - Negligible impact on experimental factors C_W and C_Z

MC	A_{W^+} $W^+ \to e^+\nu$	A_{W^-} $W^- \to e^-\nu$	A_W $W \to e\nu$	A_Z $Z/\gamma^* \to e^+e^-$	A_W/A_Z
PYTHIA MRST LO*	0.466	0.457	0.462	0.446	1.036
PYTHIA CTEQ6.6	0.479	0.458	0.471	0.455	1.035
PYTHIA HERAPDF1.0	0.477	0.461	0.470	0.451	1.042
MC@NLO HERAPDF1.0	0.475	0.454	0.465	0.440	1.057
MC@NLO CTEQ6.6	0.478	0.452	0.465	0.445	1.045
	A_{W^+} $W^+ \to \mu^+\nu$	A_{W^-} $W^- \to \mu^-\nu$	A_W $W \to \mu\nu$	A_Z $Z/\gamma^* \to \mu^+\mu^-$	A_W/A_Z
PYTHIA MRSTLO*	0.484	0.475	0.480	0.486	0.988
PYTHIA CTEQ6.6	0.499	0.477	0.490	0.496	0.987
PYTHIA HERAPDF1.0	0.496	0.479	0.489	0.492	0.994
MC@NLO HERAPDF1.0	0.494	0.472	0.483	0.479	1.008
MC@NLO CTEQ6.6	0.496	0.470	0.483	0.485	0.996

- Theoretical uncertainty within on PDF-Set (here CTEQ 6.6) in combination with the MC@NLO acceptance calculation
  - ±1.0% for W^+
  - ±1.8% for W^-
  - ±1.6% for $Z/\gamma*$

- Differences between different PDF-Sets (MRST LO*, CTEQ 6.6 and HERAPDF)
  - ±2.7% for W+
  - ±0.9% for W−
  - ±2.0% for $Z/\gamma*$

- Uncertainties due to the modelling of W and Z production by comparing PYTHIA and MC@NLO with same PDF-Set
  - ±0.4% for W+
  - ±1.4% for W−
  - ±2.3% for $Z/\gamma*$

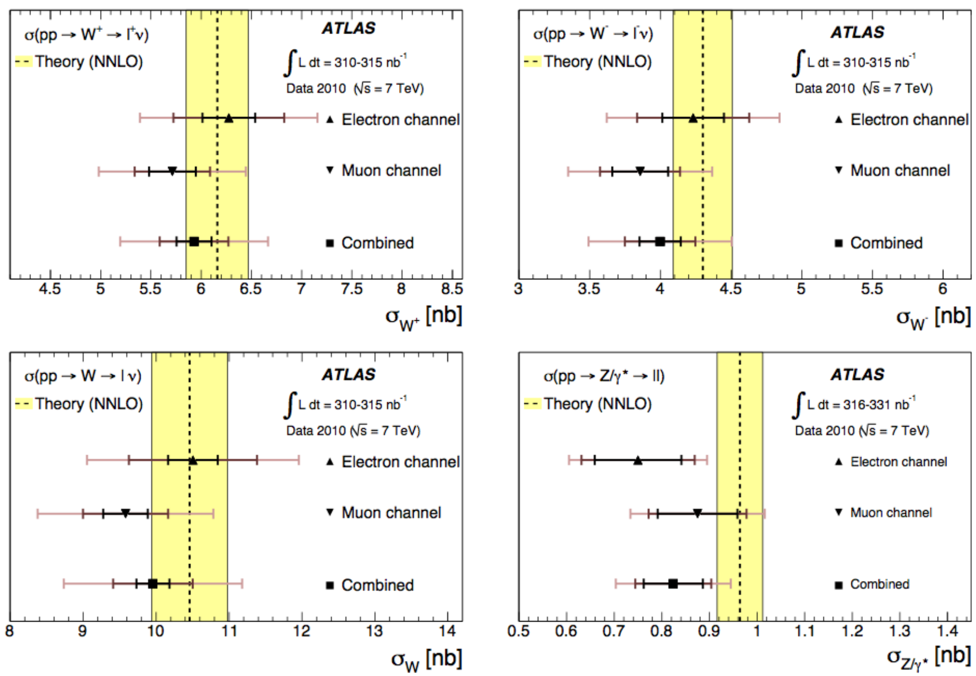
Final Results for 300nb^{-1}

- Measured W and Z/γ* production cross-sections agree with theoretical predictions

- Why 300nb^{-1}?
  - Already dominated by uncertainty on luminosity

- Measurement of individual cross-sections is only from minor physical importance when luminosity uncertainty is larger than 2-3% (see following discussion)
  - Near Future: Focus on measurement of cross-section ratios and differential cross-sections

	$\sigma^{\text{tot}}_{W(\pm)} \cdot \text{BR}(W \to e\nu)$ [nb]	$\sigma^{\text{tot}}_{W(\pm)} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$6.27 \pm 0.26(\text{stat}) \pm 0.48(\text{syst}) \pm 0.69(\text{lumi})$	$5.71 \pm 0.23(\text{stat}) \pm 0.30(\text{syst}) \pm 0.63(\text{lumi})$
W^-	$4.23 \pm 0.22(\text{stat}) \pm 0.33(\text{syst}) \pm 0.47(\text{lumi})$	$3.86 \pm 0.20(\text{stat}) \pm 0.20(\text{syst}) \pm 0.42(\text{lumi})$
W	$10.51 \pm 0.34(\text{stat}) \pm 0.81(\text{syst}) \pm 1.16(\text{lumi})$	$9.58 \pm 0.30(\text{stat}) \pm 0.50(\text{syst}) \pm 1.05(\text{lumi})$
	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.75 \pm 0.09(\text{stat}) \pm 0.08(\text{syst}) \pm 0.08(\text{lumi})$	$0.87 \pm 0.08(\text{stat}) \pm 0.06(\text{syst}) \pm 0.10(\text{lumi})$



Expected Statistics in 2011 and consequences

- Assuming an integrated luminosity of ~1fb^{-1} in 2011 at 7TeV
  - ~300k reconstructed Z Boson candidates per lepton channel
  - ~3.000k reconstructed W Boson Events
  - This means 1k-10k Z/W Boson events per day which might enable to have an luminosity estimate on a daily bases
    - Not sensitive to pile-up
- Statistical precision <0.2% for the Z/γ^* Boson channel
  - No statistical advantage of measuring the W Boson cross-section

- Further Experimental Advantages of Z/γ^* cross-section measurement
  - No dependence on missing energy
  - Lepton reconstruction performance can be determined in signal sample
  - Rather Clean Signal selection even in forward region
    - see discussion of theoretical uncertainties
  - Two identical leptons in the selection allows reduction of experimental uncertainties

$$N \sim \varepsilon^2 + 2\varepsilon(1-\varepsilon)$$

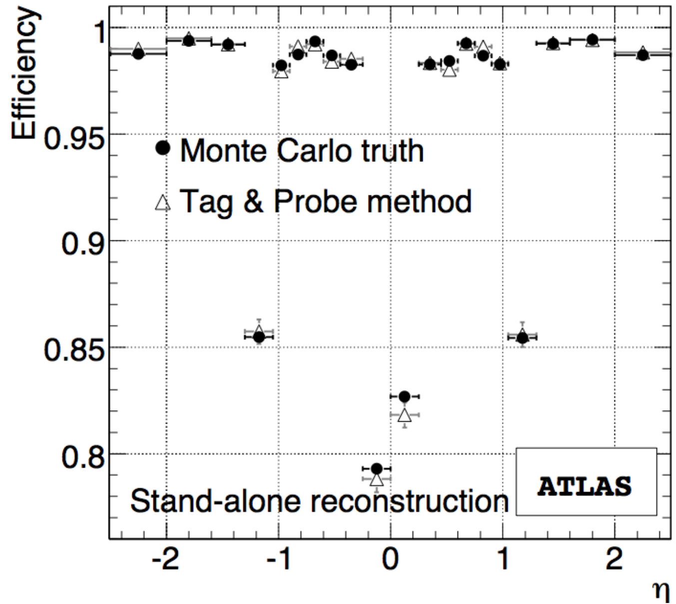
$$\Delta N \sim 2(1-\varepsilon)\Delta\varepsilon$$

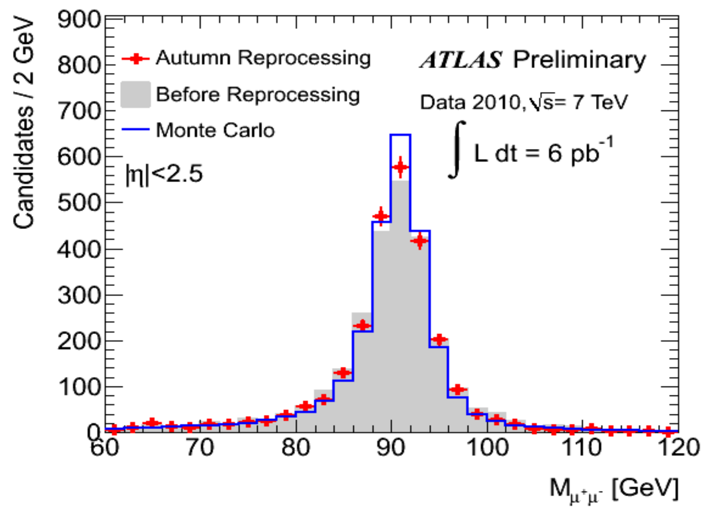
    - Does not help for ratio measurements

Understanding Muons with 1fb^{-1}

- Tag and Probe techniques on the Z-Boson can be used to determine the lepton reconstruction, trigger and cut-efficiencies on fine binning (e.g 50 bins) with statistical precision far below 1%
  - Systematic uncertainties of offline muon reconstruction ~0.5%
  - Systematic uncertainties of muon trigger efficiency w.r.t. offline <0.5%
  - Isolation Cut efficiency ~1%

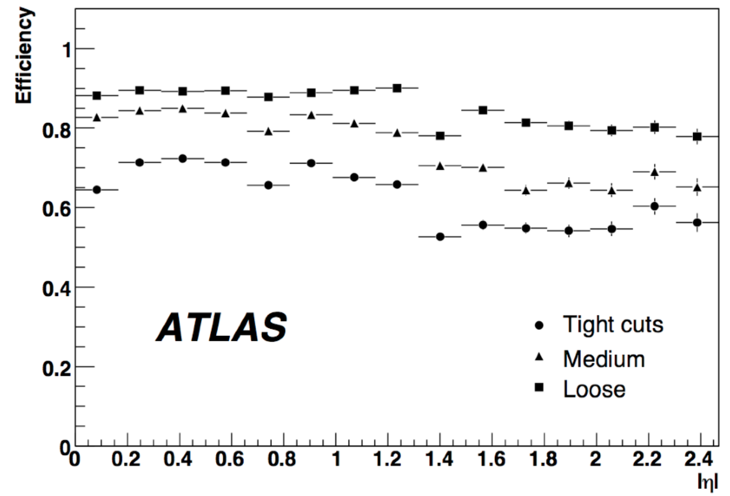
- Muon Momentum Scale and Resolution
  - Scale already now known to ~1% level
  - Resolution expected to be known to <5%
  - No significant impact on cross-section measurement

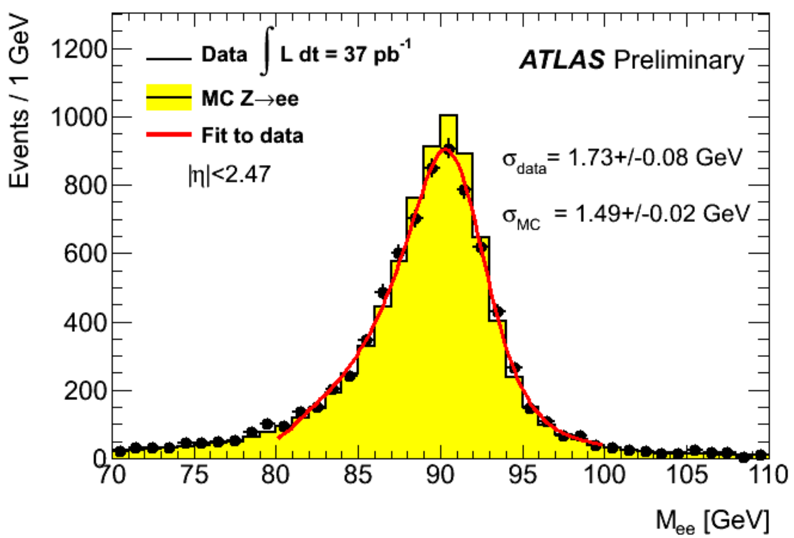




Understanding Electrons with $1fb^{-1}$

- Tag and Probe technique in electron decay channel more difficult (expected QCD background is significantly higher, charge misid, …)
  - Electron reconstruction efficiency (i.e. electron container) already known to at 1% level and will significantly decrease
  - MC studies show that the electron identification efficiency can be determined to ~1%
  - Uncertainty on trigger efficiency negligible
- Impact of Electron energy scale and resolution uncertainties in measurement can be assumed to be below 0.5%





Precision of Z-Boson Fiducial Cross-Sections with $1fb^{-1}$

- Assuming only one lepton identification for $1fb^{-1}$ analyses
  - Conservative estimate for enhanced bkg uncertainty 1% and 0.5% for e and μ
- Electron channel
  - $\Delta\sigma_Z^{fid}/\sigma_Z^{fid} = 1.9\%$
- Muon channel
  - $\Delta\sigma_Z^{fid}/\sigma_Z^{fid} = 1.4\%$
- Combination of electron and muon channel
  - $\Delta\sigma_Z^{fid}/\sigma_Z^{fid} = 1.2\%$

Electron Channel	**$\Delta C_Z/C_Z$ (0.3 pb^{-1})**	**$\Delta C_Z/C_Z$ (1 fb^{-1})**
Trigger	<0.2 %	<0.2%
Electron ID	8.8 %	1 %
Scale and Resolution	1.9 %	0.5 %
Problematic Regions in Calo.	2.7 %	1 %
Pile-Up	0.2 %	0.4 %
FSR-Modelling	0.3 %	0.3 %
Total Uncertainty	**9.4 %**	**1.6 %**

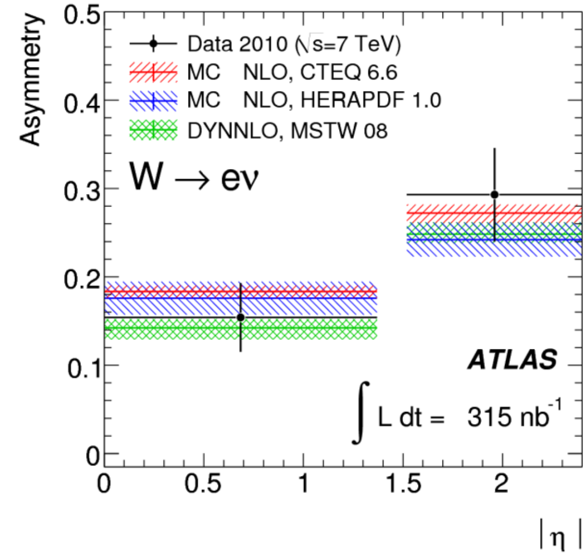
Muon Channel	**$\Delta C_Z/C_Z$ (0.3 pb^{-1})**	**$\Delta C_Z/C_Z$ (1 fb^{-1})**
Trigger	0.7 %	0.2 %
Muon ID	5.0 %	0.5 %
Scale and Resolution	0.7 %	0.5 %
Isolation Efficiency	2.0 %	1.0 %
Total Uncertainty	**5.5 %**	**1.3 %**

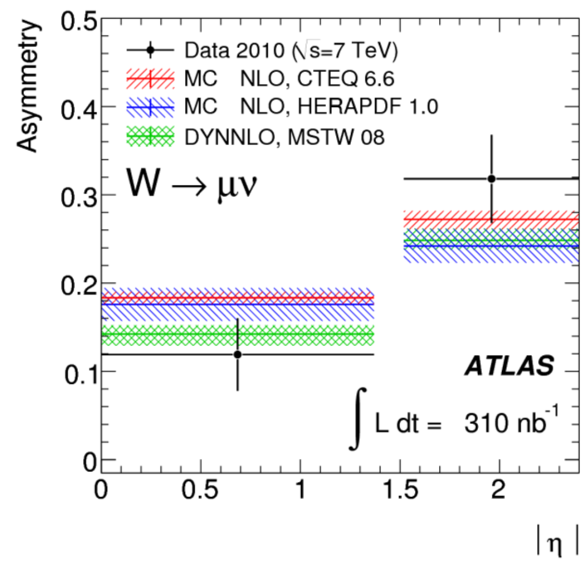
Improving theoretical uncertainties (1/2)

- Expected largest systematic at $1fb^{-1}$: theoretical uncertainty on kinematic acceptance correction
  - Current theo. unc. on acceptance: 3.4%

- Possible ways to improve this uncertainty
  - Large uncertainty arise mainly from the extrapolation in |η| (while p_T has a minor effect)
    - Extend measurement using the ATLAS forward calorimeter which allows an electron identification up to |η|<4.9
      - Reduce significantly needed extrapolation
      - Constrain unc. on A also for μ-channel
  - Measure double differential cross-sections for W^+, W^- and Z and provide new PDF-Fits
    - Long term

- Assumed uncertainty on acceptance A for $1fb^{-1}$: 1-2%



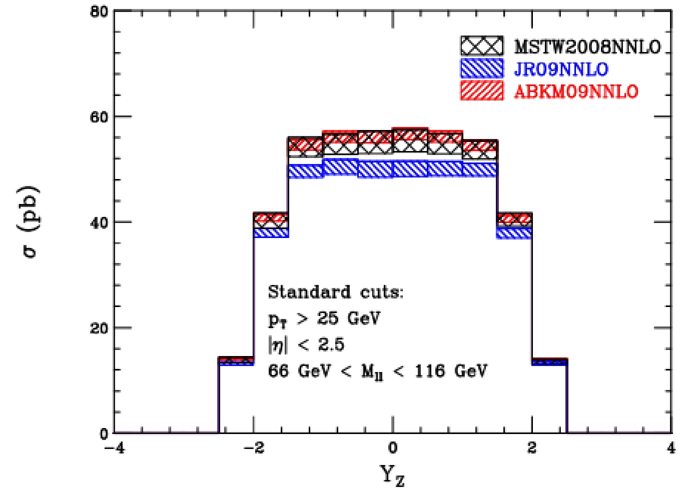


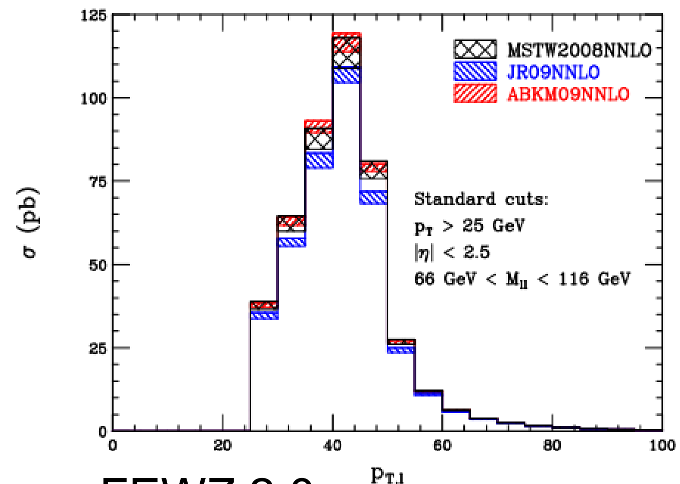
Improving theoretical uncertainties (2/2)

- Other path: Avoid uncertainties in A from the beginning on
- New versions of NNLO cross-section programs allow the calculation of fiducial cross-sections, i.e. cross-sections within the detector acceptance
  - See for example FEWZ 2.0
    - http://arxiv.org/pdf/1011.3540v1
    - Problem: no parton shower/resummation included: leads to an unrealistic p_T distribution
  - Still preliminary a not studied in detailed by ATLAS
- Cross-Section predictions for fiducial cuts (p_T>25, |η|<2.5) by FEWZ 2.0

$$\text{MSTW 2008:} \quad \sigma_{standard} = 436.0^{+15.4}_{-13.9}(\text{PDF})\ \text{pb};$$
$$\text{ABKM 2009:} \quad \sigma_{standard} = 445.6^{+7.6}_{-7.6}(\text{PDF})\ \text{pb};$$
$$\text{JR 2009:} \quad \sigma_{standard} = 404.3^{+7.9}_{-11.0}(\text{PDF})\ \text{pb}.$$

  - 2-3% systematic uncertainty due to PDFs





FEWZ 2.0
http://arxiv.org/pdf/1011.3540v1

Target Precision for 2011

- Combining the experimental uncertainties on C_Z and the improved theoretical uncertainties on A lead to an estimated precision of **~2%** on the measured Z/γ^* cross-section

- Using measured cross-section to predict integrated luminosity requires the theoretical predicted cross-section
  - Using 68% confidence limit leads to a theoretical uncertainty of 2%
    - We know that this is too optimistic
  - Larger improvements expected when using LHC data to constrain PDFs
  - Lower bound on cross-section prediction given by renormalisation and factorisation scale uncertainties: 0.6-0.8%