W and Z/γ* production in p-p collisions with ATLAS

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on behalf of the ATLAS Collaboration

Measurements of the inclusive W and Z as well as W+jets and Z+jets production cross sections at hadron colliders constitute important tests of the Standard Model

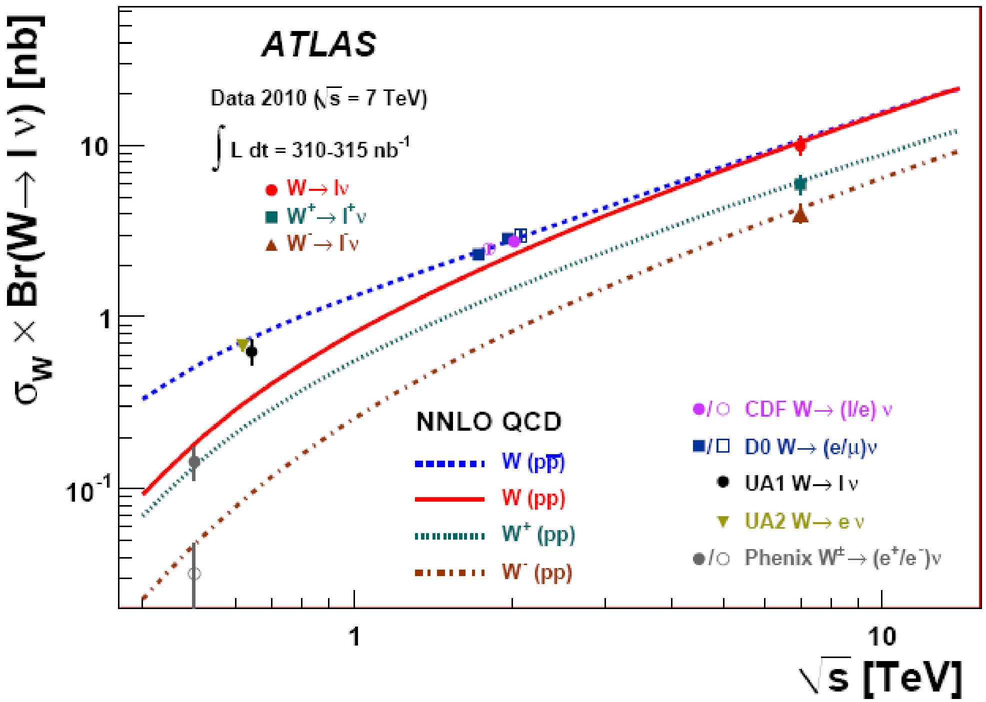
- will provide new constraints on the parton distribution functions
- will allow for precise tests of perturbative QCD

Also constitute significant background in other SM or BSM processes

- Need to measure them well!

This presentation: ATLAS results of leptonic production of

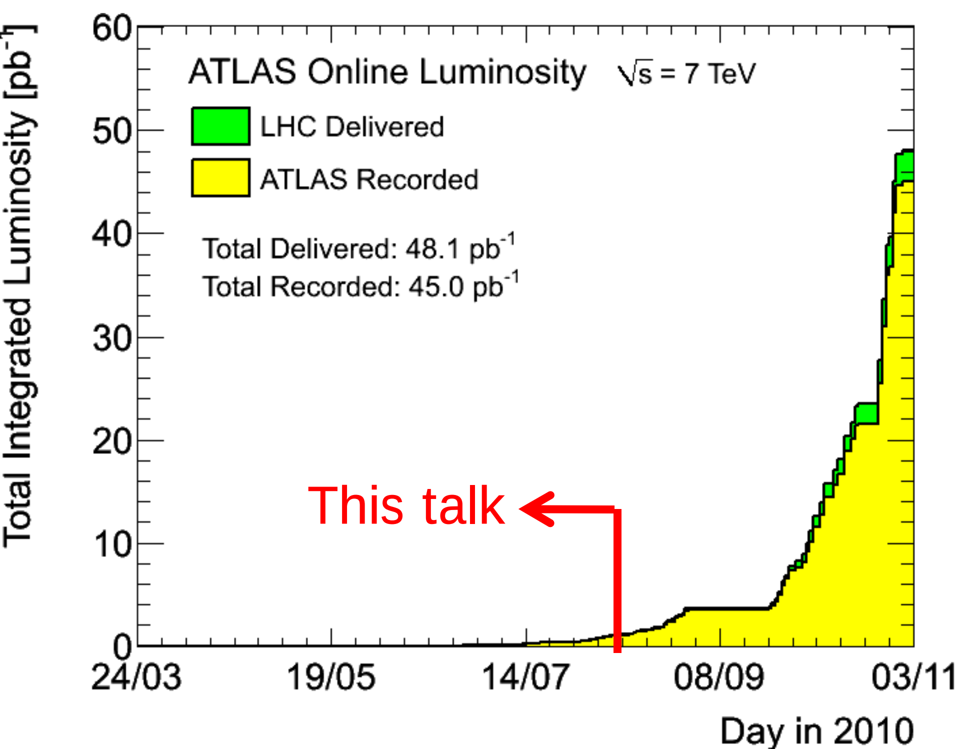
- W^+, W^- and Z/γ* (JHEP12(2010)060)
- W charge asymmetry (JHEP12(2010)060)
- W+jets (arXiv:1012.5382)
- Z /γ*+jets (ATLAS-CONF-2011-001)

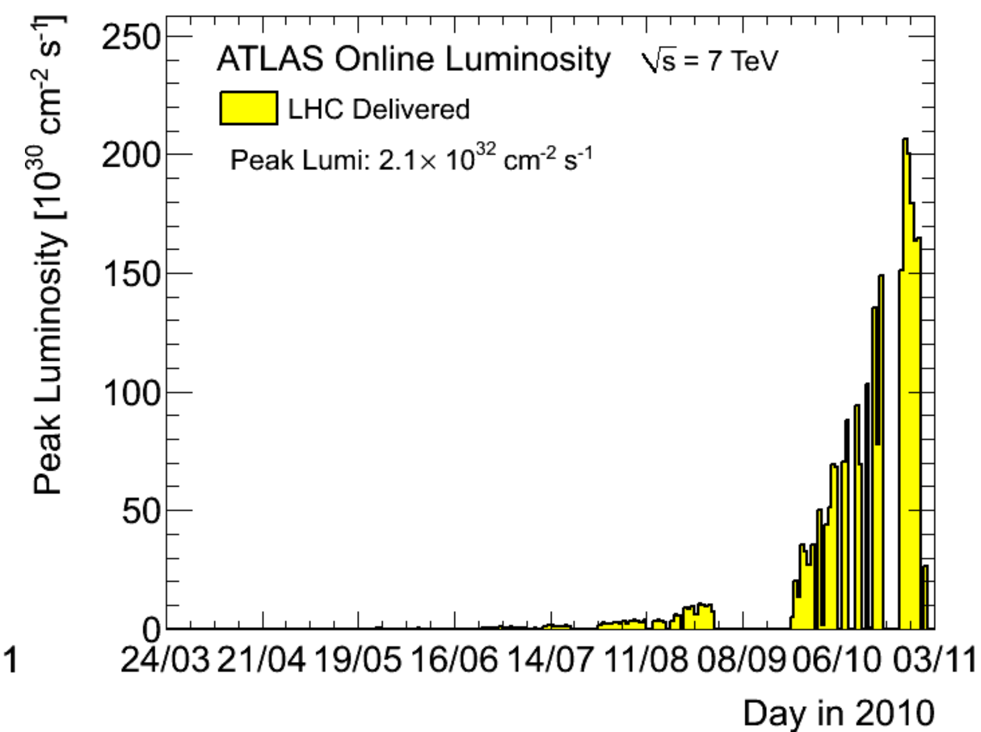


p-p data sample

Data presented here collected over a five-month period, from March to August 2010

- Centre-of-mass energy $\sqrt{s}$ = 7 TeV p-p collisions. Integrated luminosity:
  - 0.32 pb^{-1}: $W \to e\nu$, $W \to \mu\nu$, $Z \to ee$, $Z \to \mu\mu$
  - 1.3 pb^{-1} : $W(\to e\nu)$+jets, $W(\to \mu\nu)$+jets, $Z(\to ee)$+jets, $Z(\to \mu\mu)$+jets
- Hardware-based level-1 trigger: E^{e}_{T}>10GeV (or 14GeV), p^{μ}_{T}>6 GeV (or 10 GeV)
- Pile-up varied from zero to about two extra interactions per event.





Identification/reconstruction of leptons and jets

Electron and muon identification criteria similar for W incl, W +jets, Z incl, Z+jets

- Some further optimisations in W,Z+jets analysis to reduce QCD background
- e: $E_T>20$ GeV, $|\eta|<2.47$ (excluding overlap region 1.37-1.52)
  - Identified using both calorimeter and inner (tracking) detector
- μ: $p_T>20$ GeV, $|\eta|<2.4$
  - Identified using both inner detector and muon spectrometer
  - Additional track-based isolation requirements to further suppress QCD bkg

Jets (W,Z+jets analyses only):

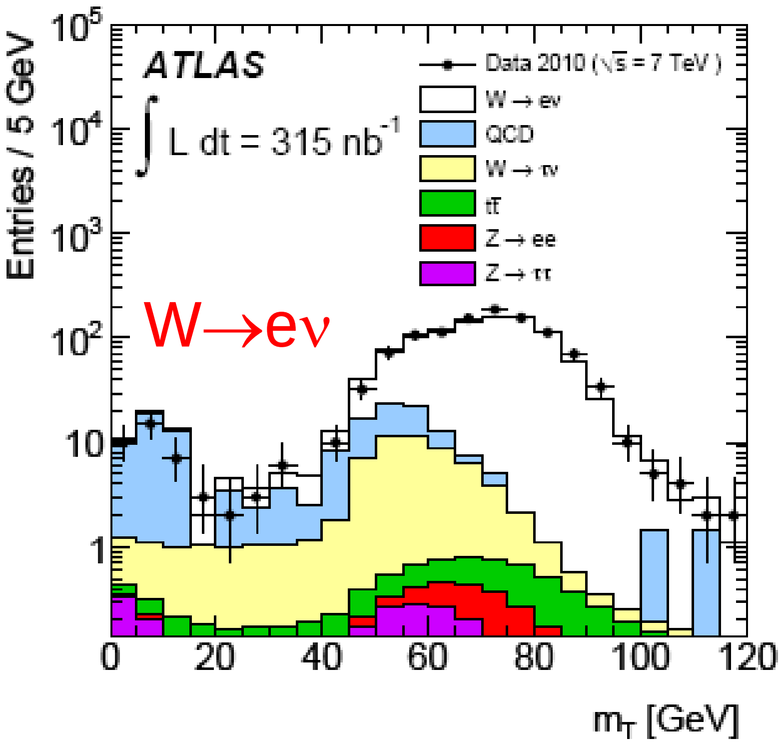
- Anti-kT algorithm with R=0.4
- $p_T>20$ GeV, $|\eta|<2.8$
- p_T, η-dependent corrections for difference in calo response between e & hadrons
- Jets within $\Delta R<0.5$ of lepton were removed
- Jets from pile-up interactions removed
  - Compare tracks associated to primary vertex to all vertices inside jet

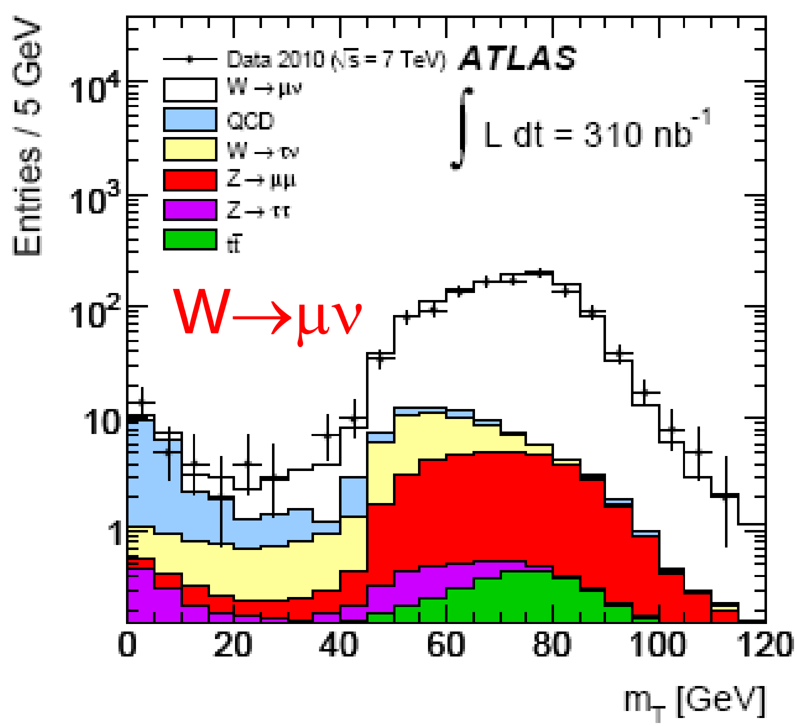
Missing transverse energy (W incl and W+jets)

Missing transverse energy: E_T^{miss}>25GeV

- calorimeter energy inside 3D topological clusters, corrected for difference in response of calorimeter to hadrons and electrons, dead-material losses, out of cluster corrections
  - Muon channel also corrects for muon momentum

Transverse mass of the lepton-E_T^{miss} system: m_T>40GeV





Backgrounds

Leptonic backgrounds

- W→τν→lννν, Z→ll, Z→ττ, semi-leptonic decays of ttbar   (l=e,μ)
  - from MC, normalised to integrated luminosity, using NNLO or NLO+NNLL σ

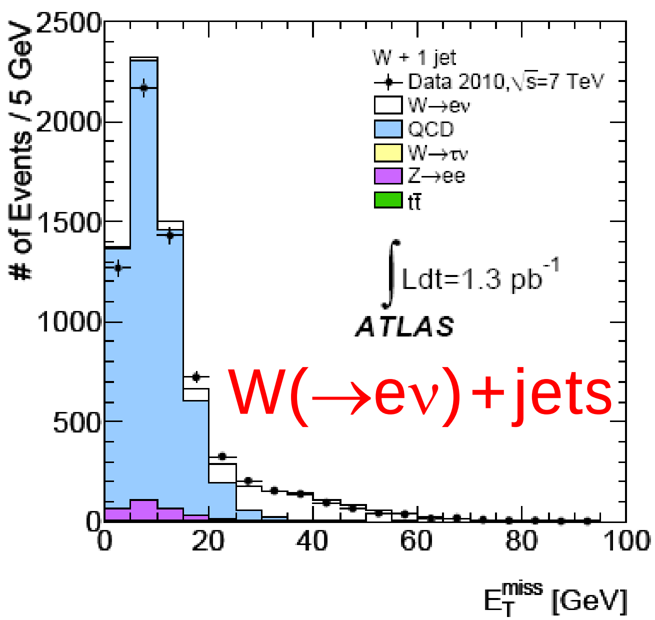
QCD background

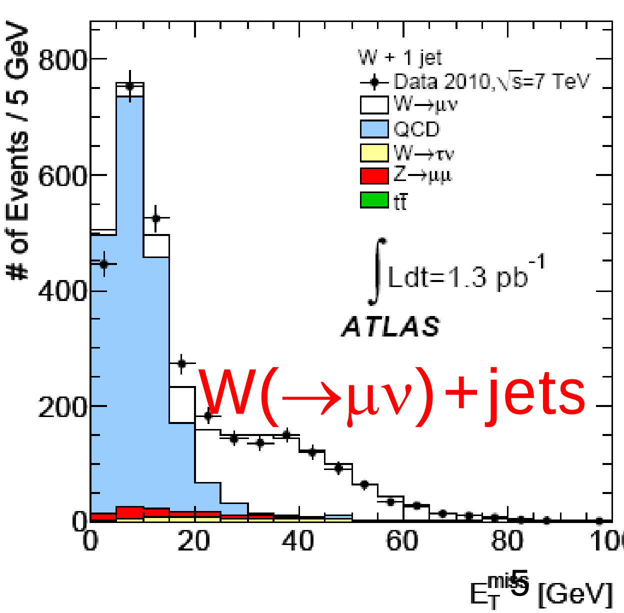
- e: hadrons faking electrons, conversions, semi-leptonic heavy quark decays
- μ: semi-leptonic heavy quark decays

e.g. W+jets: fit E_T^{miss} to sum of two templates (E_T^{miss}>10GeV for e) per jet multiplicity

1) Signal+leptonic background template (from MC)
2) QCD background
   - μ: from MC
   - e: from data

   (using looser and some inverted e ID criteria)





Yield of signal events: W,Z inclusive (L ≅ 0.32pb^{-1})

- Yield of signal events $N^{sig} = N^{observed} - N^{background}$

W incl: N^{sig}~2100 events

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 incl: N^{sig}~180 events (within $66 < M_{ll} < 116$ GeV)

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	$0.21 \pm 0.01 \pm 0.01$	$0.04 \pm 0.01 \pm 0.04$	$108.8 \pm 10.4 \pm 0.0$

Cross-section formalism: W,Z inclusive

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

- $N^{sig}_{W(Z)}$: number of background-subtracted events passing final selection
- $L_{W(Z)}$: integrated luminosity of channel (uncertainty of 11%)
- $C_{W(Z)}$: from PYTHIA (with some data-derived corrections). It gives the fraction of signal events surviving the selections, normalized to the signal that passes the kinematic and m_T or m_{ll} cuts at the generator (Born) level.
  - It corrects for efficiency, resolution, and QED radiation effects.
- $A_{W(Z)}$: fraction of the signal that passes the kinematic and m_T or m_{ll} cuts at the generator level, normalized to the total sample.
  - It corrects to the total cross section.
  - This is a pure Monte Carlo quantity and is estimated using PYTHIA

Systematic uncertainties on $C_{W(Z)} \cong 0.65$ [e], 0.77 [μ]

Apart from luminosity uncertainty of 11%, dominant systematic uncertainties due to:

- Electron channel:
  - material effects in the detector, reconstruction and ID of electrons

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

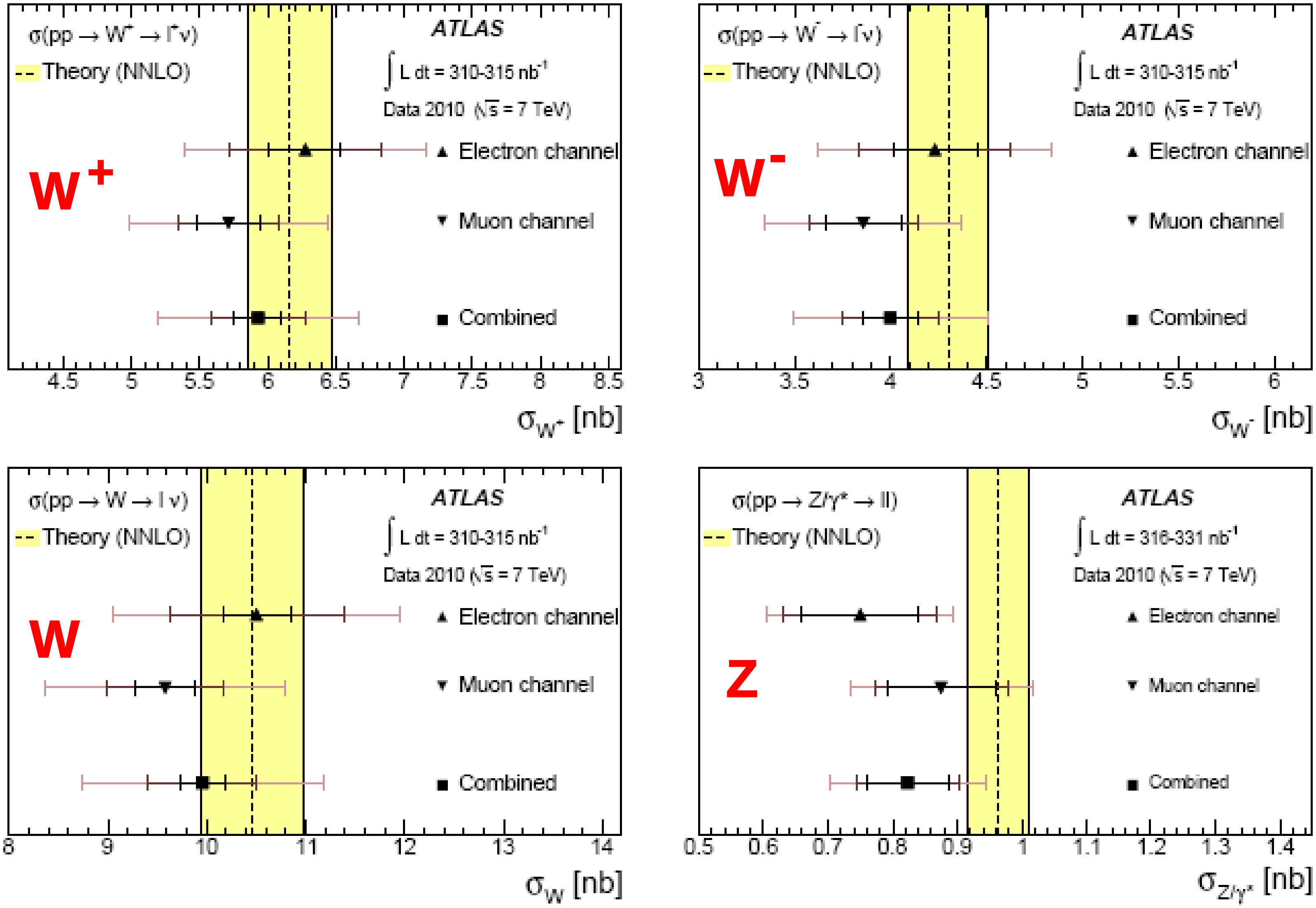
- Muon channel:
  - muon reco efficiency
  - trigger efficiency

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

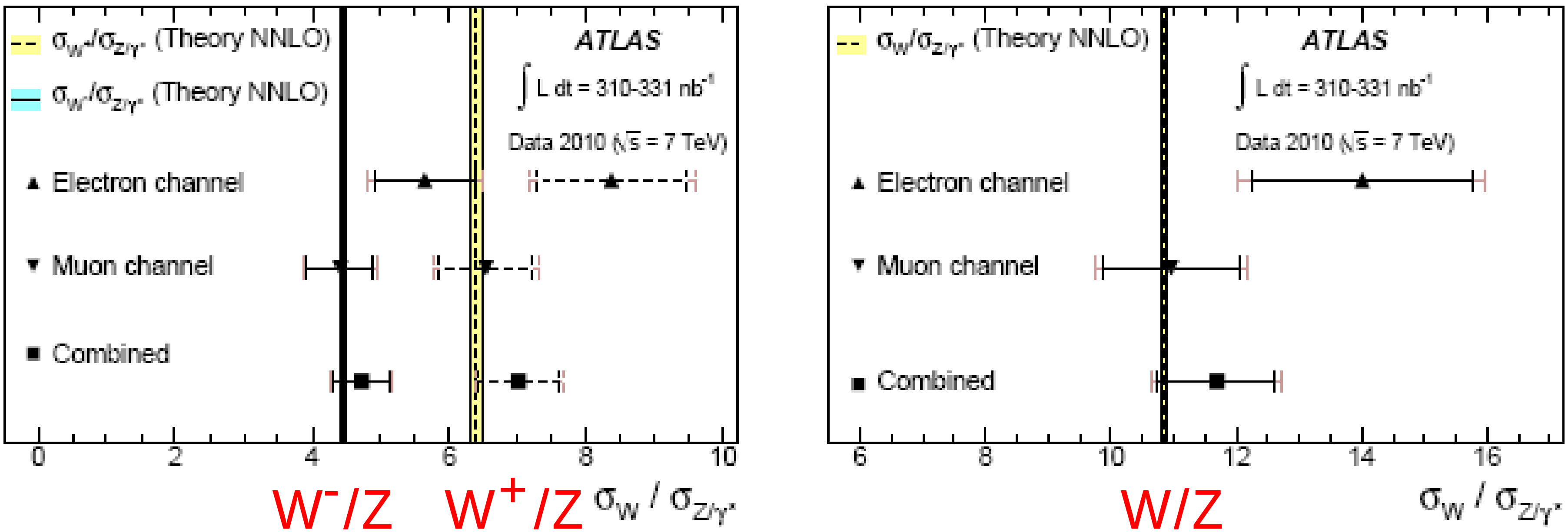
Systematic uncertainties on $A_{W(Z)}$

- The acceptances from PYTHIA with the modified leading order parton distribution function set MRST LO* and the corresponding ATLAS MC09 tune
- Systematic uncertainties dominated by the limited knowledge of the proton PDFs and the modelling of the W and Z boson production at the LHC.
- Looked at:
  - Uncertainties within one PDF set: CTEQ 6.6 PDF error eigenvector sets at 90% C.L. with MC@NLO acceptance calculation
  - Compared MRST LO* with CTEQ 6.6 PDF and HERAPDF 1.0 sets
  - Compared PYTHIA vs MC@NLO with one PDF set (CTEQ 6.6)
- Estimate uncertainties on A_W is 3% and A_Z is 4%

Total inclusive cross section results (L ≅ 0.32 pb^{-1})

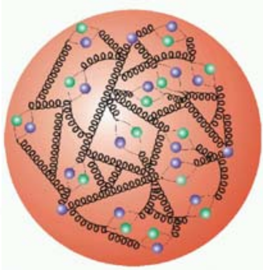


W/Z inclusive cross-section ratios (L ≅ 0.32 pb^{-1})



- Results are dominated by statistical uncertainty

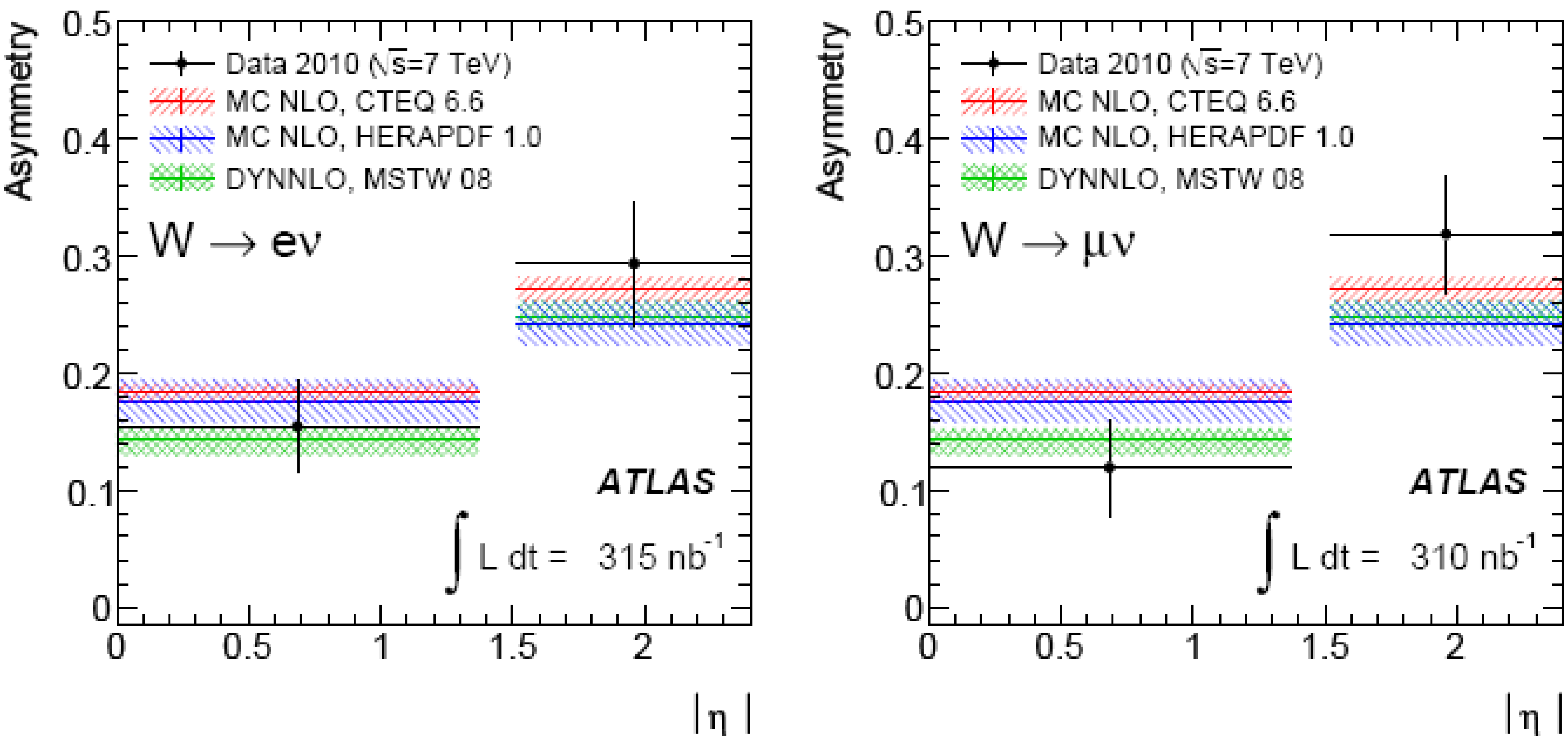
W-charge asymmetry (L ≅ 0.32 pb^{-1})



- In contrast to p-pbar collisions, cross sections for W^+ and W^- production are expected to be different in p-p collisions due to different valence quark distributions
- W-boson charge asymmetry derived from inclusive cross sections prior to acceptance (A_W) correction: fiducial cross section σ^{fid}

$$A_\ell = \frac{\sigma^{\rm fid}_{W^+} - \sigma^{\rm fid}_{W^-}}{\sigma^{\rm fid}_{W^+} + \sigma^{\rm fid}_{W^-}}$$

- Compared to various models
  - Asymmetry confirmed but data don't have discriminating power between models



Yield of events: W,Z+jets (L ≅ 1.3 pb^{-1})

- W+jets: observed events and background: $N^{observed}$~2000 events for $N_{jet}\geq1$

e

Electron channel process	$N_{jet}\geq 0$	$N_{jet}\geq 1$	$N_{jet}\geq 2$	$N_{jet}\geq 3$	$N_{jet}\geq 4$
QCD	130^{+20}_{-60}	100^{+20}_{-40}	45^{+7}_{-20}	18^{+3}_{-8}	-
$W\to\tau\nu$	113 ± 11	25 ± 5	4 ± 2	0.5 ± 0.4	-
$Z\to ee$	10 ± 8	7 ± 6	3 ± 2	1 ± 1	-
$t\bar{t}$	17 ± 2	17 ± 2	17 ± 2	14 ± 2	-
Observed in Data	4216	987	276	83	-

μ

Muon channel process	$N_{jet}\geq 0$	$N_{jet}\geq 1$	$N_{jet}\geq 2$	$N_{jet}\geq 3$	$N_{jet}\geq 4$
QCD	30 ± 20	20 ± 13	4^{+10}_{-4}	2 ± 2	1 ± 1
$W\to\tau\nu$	133 ± 12	24 ± 6	5 ± 2	0.9 ± 0.5	0.4 ± 0.3
$Z\to\mu\mu$	170 ± 14	30 ± 4	8 ± 1	2 ± 0.5	0.6 ± 0.2
$t\bar{t}$	18 ± 2	18 ± 2	18 ± 2	16 ± 2	11 ± 1
Observed in Data	4911	1049	292	95	36

- Z+jets: observed events: $N^{observed}$~190 events for $N_{jet}\geq1$ (within $71<M_{ll}<111$ GeV)

	$N_{jet}\geq1$	$N_{jet}\geq2$	$N_{jet}\geq3$	$N_{jet}\geq4$
$Z/\gamma^*(\to ee)$+jets	82	26	9	2
$Z/\gamma^*(\to\mu\mu)$+jets	110	31	8	2

W,Z+jets cross section

e.g. W+jets: Yield of signal events corrected back to particle level

- Take into account detector and reconstruction efficiencies
- Use ALPGEN, restricting to same phase-space as data
- Particle-level jets constructed using jet-finder on all “long-lived” particles
- Correction factors calculated as 1D functions of jet multiplicity and p_T of leading and next-to-leading jets
  - Some data-derived correction factors e.g. for trigger efficiency

- Biases in the procedure for correcting for detector effects (compare ALPGEN and SHERPA) found to be negligible in comparison to experimental systematics

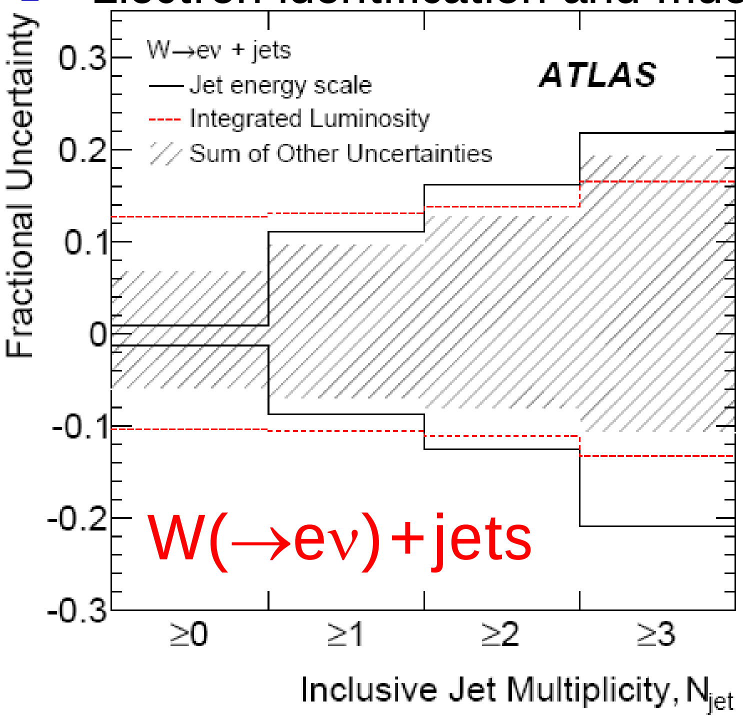
- Similar procedure for Z+jets
  - See systematic uncertainty table for unfolding systematic

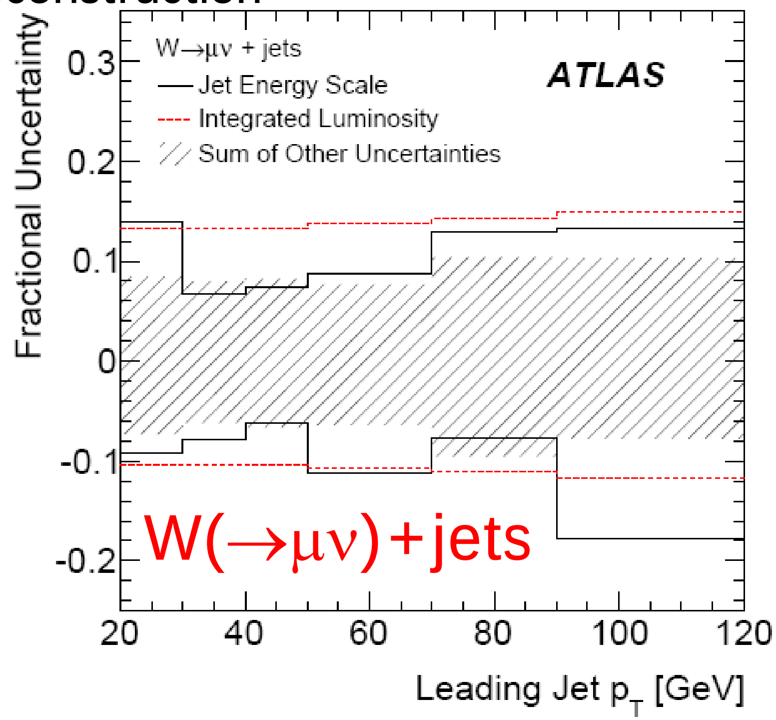
W+jets: experimental systematic uncertainties

Dominant systematic uncertainties

- Luminosity determination (11%)
- Jet energy scale uncertainty
  - 10% at 20 GeV to 8% at 100 GeV plus 5% for difference in calorimeter response to quark and gluon-initiated jets
- QCD template in the electron channel
- Electron identification and muon reconstruction

See backup slides for table of uncertainties



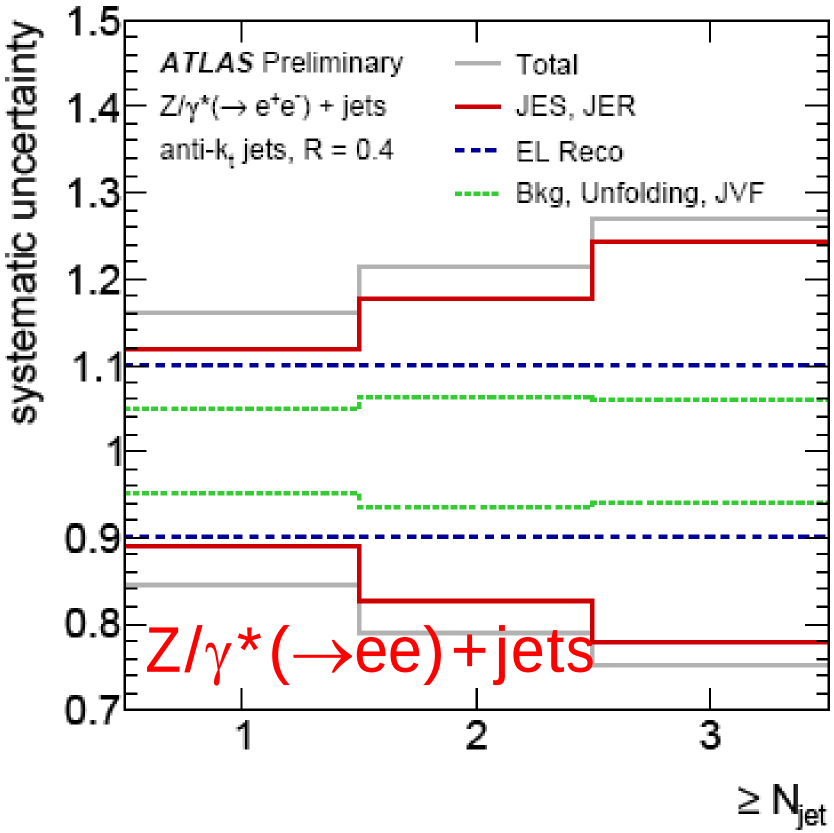


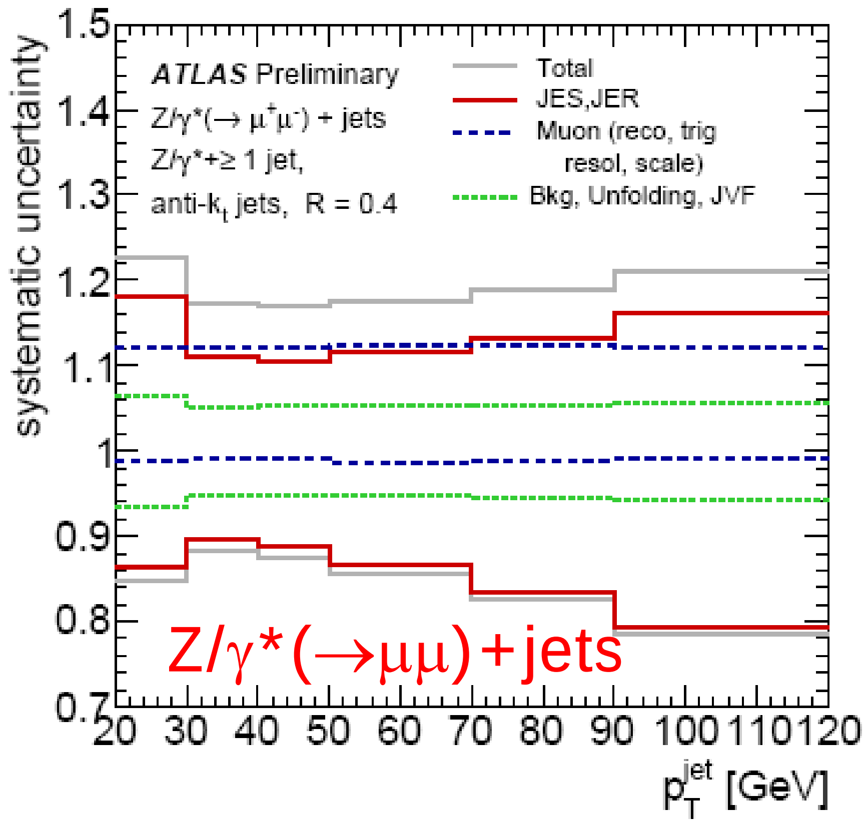
Z+jets: experimental systematic uncertainties

Dominant systematic uncertainties

- Luminosity determination (11%)
- Jet energy scale and resolution uncertainty
- QCD background in the electron channel
- Lepton reconstruction/identification

See backup slides for table of uncertainties





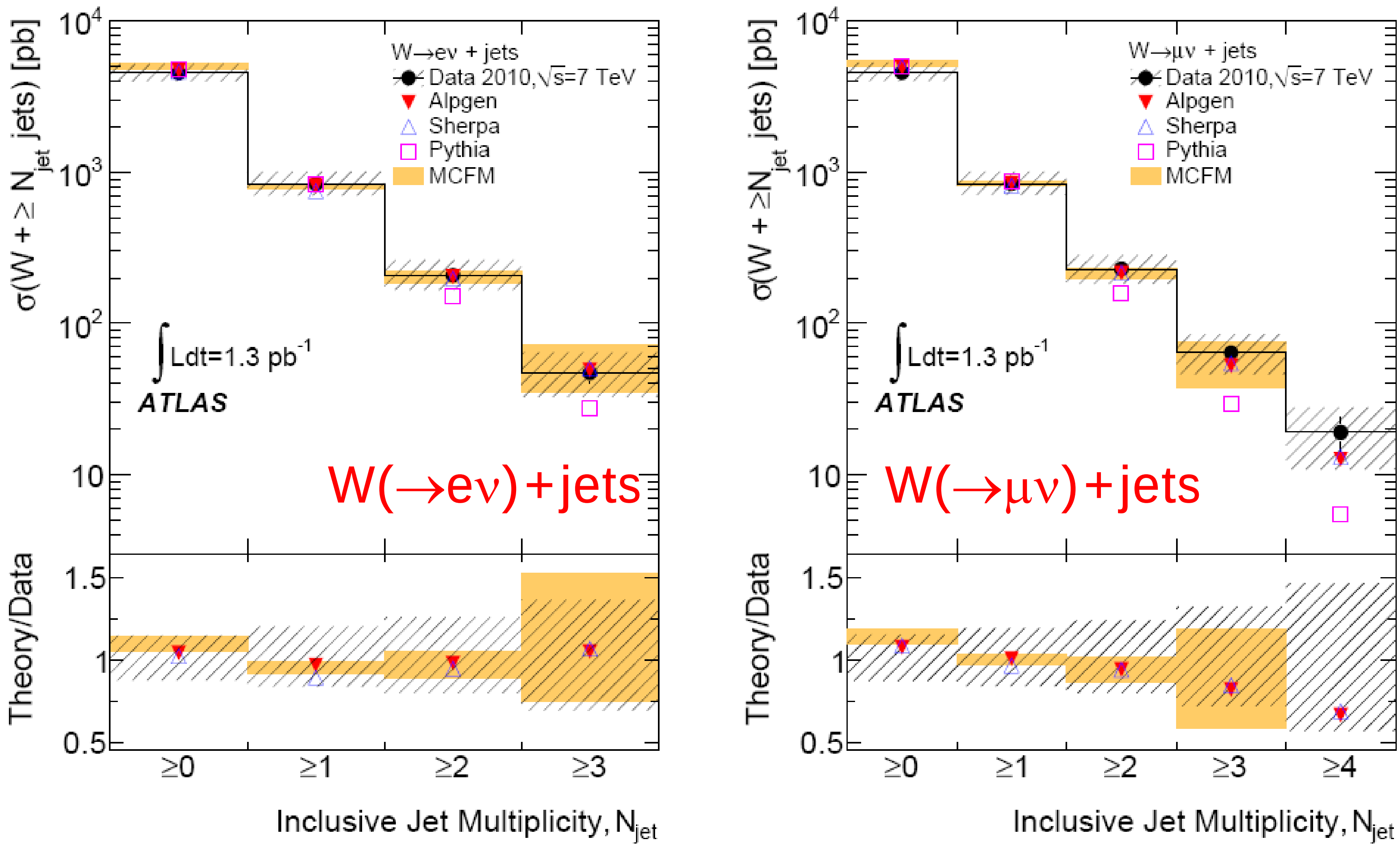
Comparison of results with predictions

Results shown in comparison to

- PYTHIA (LO)
- ALPGEN & SHERPA (match higher mult matrix elements to a LL parton shower)
- MCFM (provides NLO predictions for Njet≤2, LO for 3 jets)
  - Systematic uncertainties for W+jets:
    - Fragmentation: compare PYTHIA to HERWIG
    - Underlying event: compare AMBT1 tune to JIMMY tune and vary AMBT1 tune to increase underlying event activity by 10%
    - Normalisation&factorisation: vary scales by factor of 2
    - PDF: use 22 eigenvectors of CTEQ6.6, use MSTW2008
  - Systematic uncertainties for Z+jets:
    - Fragmentation& underlying event: turn off both interactions between proton remnants and the string fragmentation, use HERWIG+JIMMY and PYTHIA MC with different UE tunes (ATLAS-MC09, DW and AMBT1).
    - Normalisation&factorisation: vary scales by factor of 2
    - PDF: Hessian method

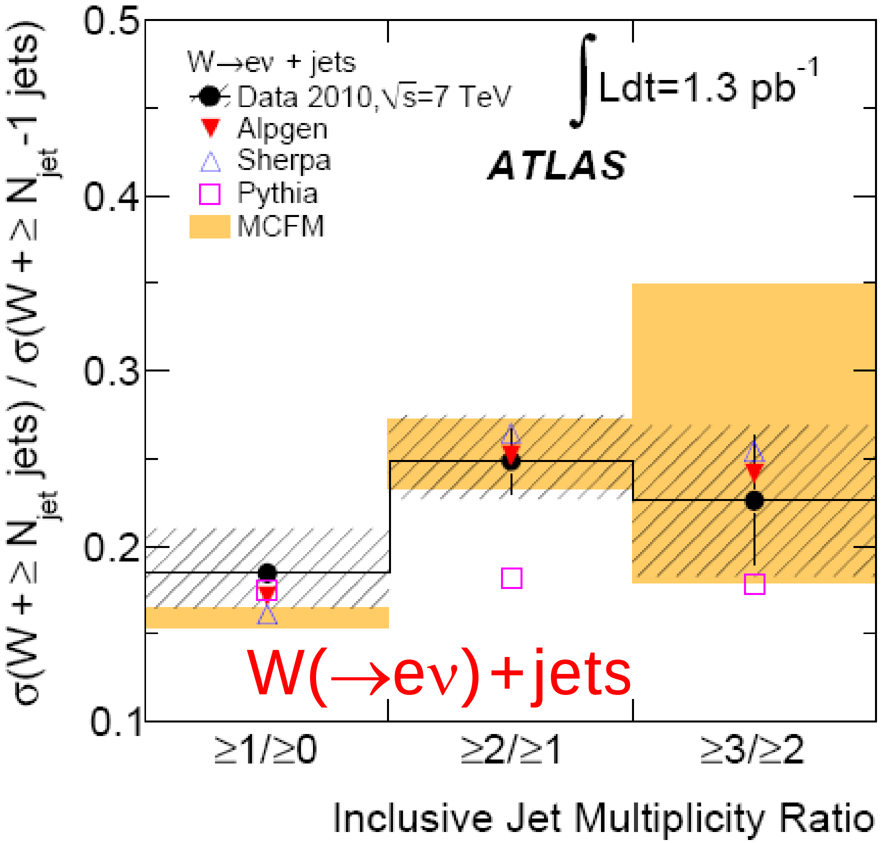
AMBT1 (ATLAS Min Bias Tune 1): tuning PYTHIA6 to LHC data at $\sqrt{s}$=0.9&7 TeV, ATLAS-CONF-2010-031 (2010).

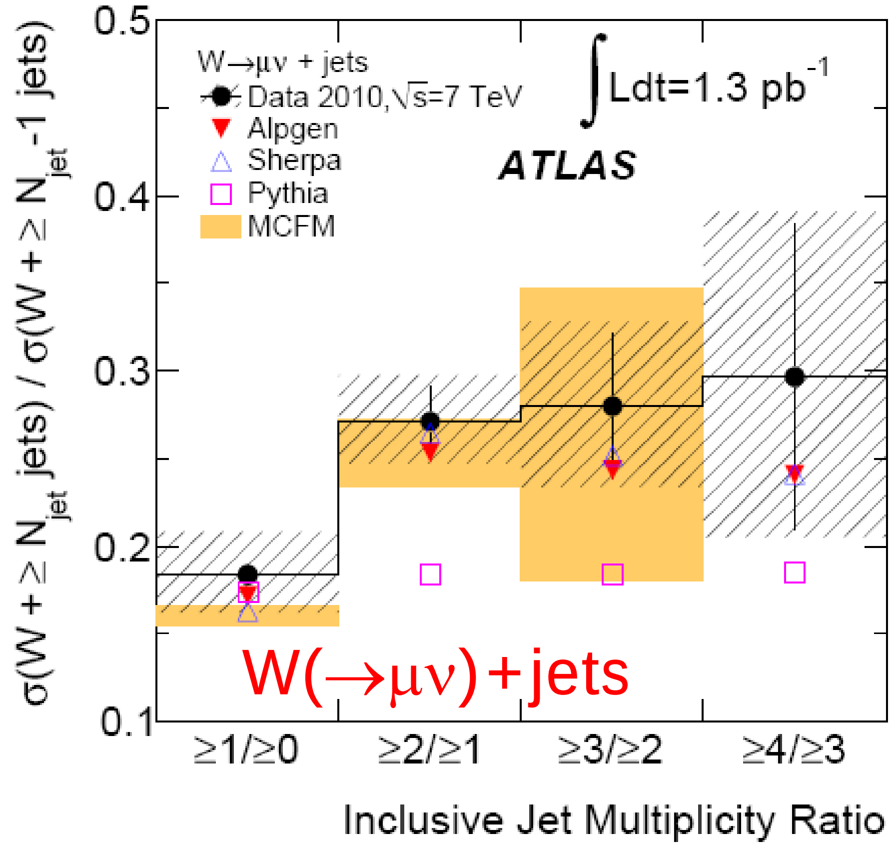
W+ ≥N_{jet} cross sections (L ≅ 1.3 pb^{-1})



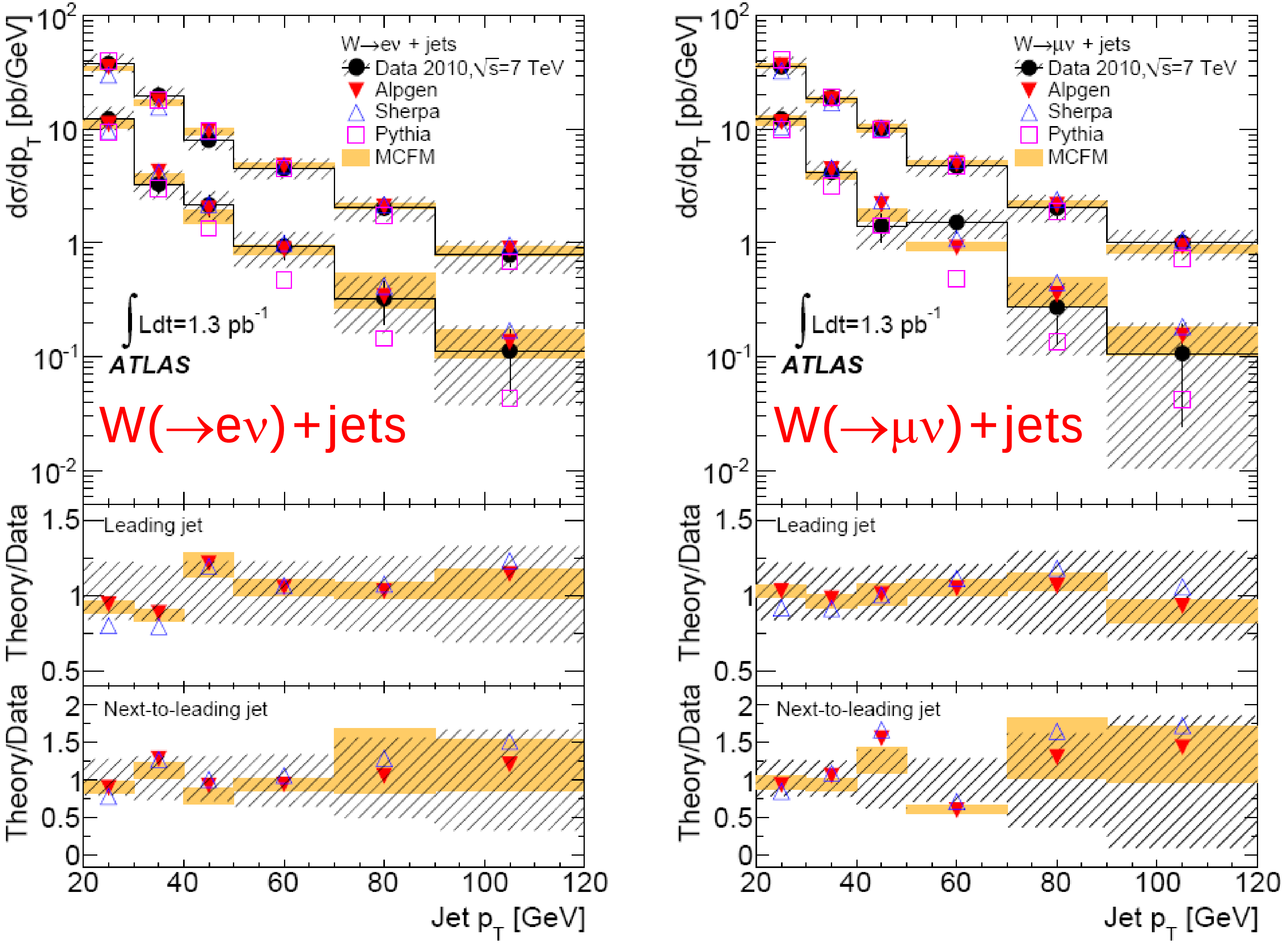
- Cross-sections given in the phase-space of the measurement
  - Kinematic requirements on lepton, jet, E_T^{miss}, m_T

$(W+\geq N_{jet})\,/\,(W+\geq N_{jet}-1)$ cross-section ratios

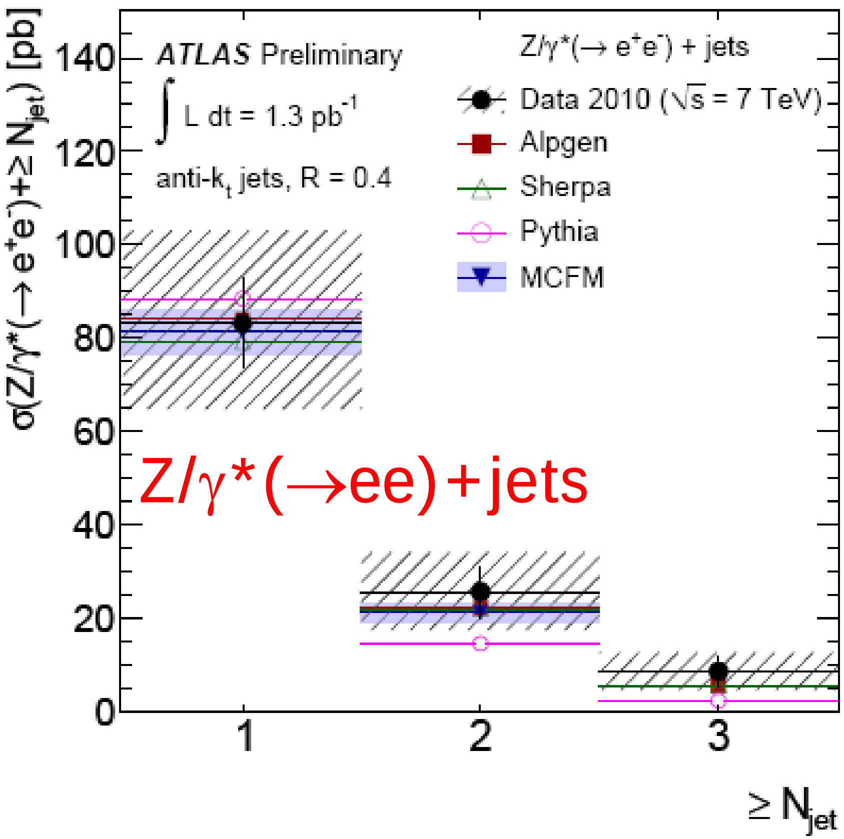


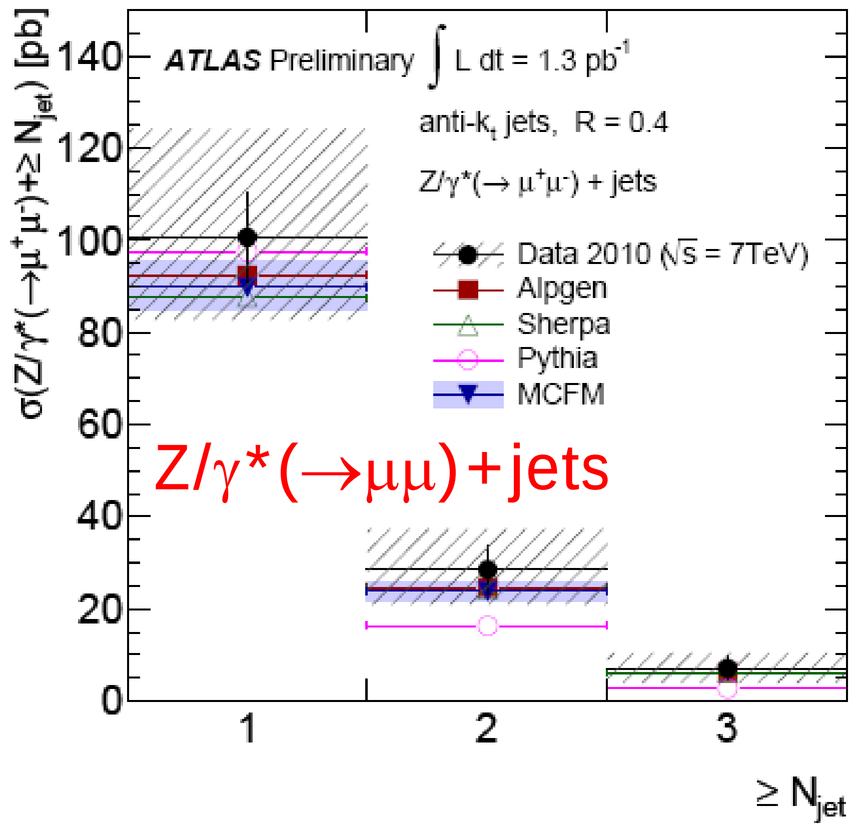


W+jets cross section vs jet p_T



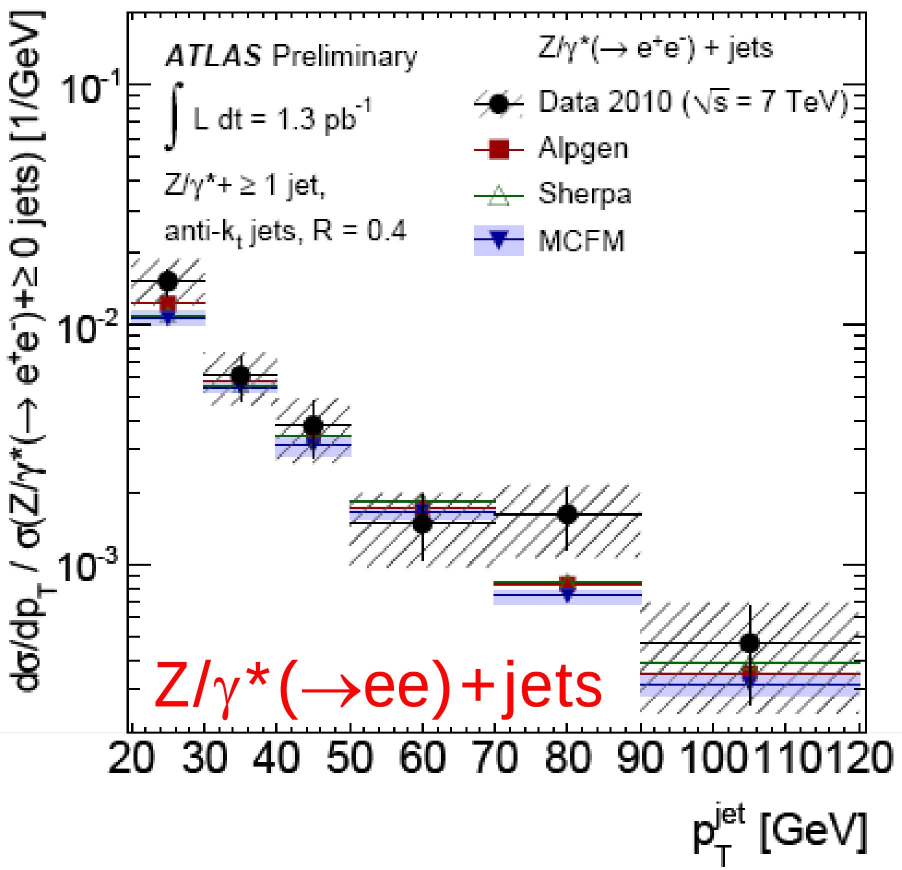
$Z/\gamma^* + \geq N_{jet}$ cross sections ($L \cong 1.3\ pb^{-1}$)

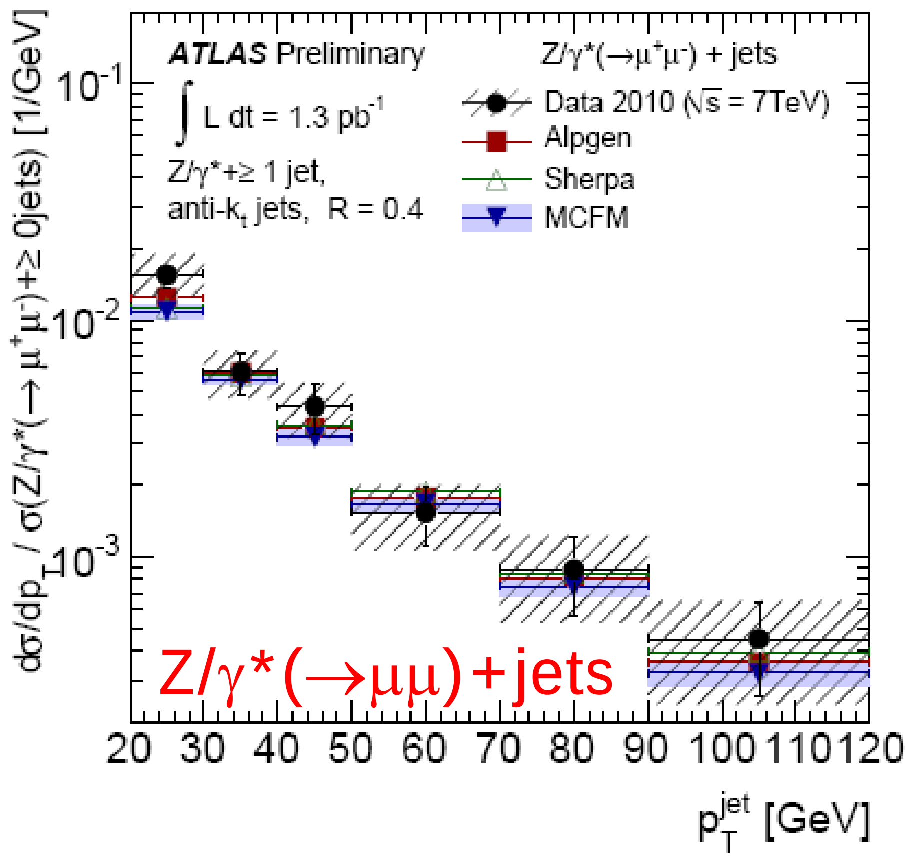




- Cross-sections given in the phase-space of the measurement
  - Kinematic requirements on lepton, jet, M_{ll}

Z/γ^* + jets cross section vs jet p_T

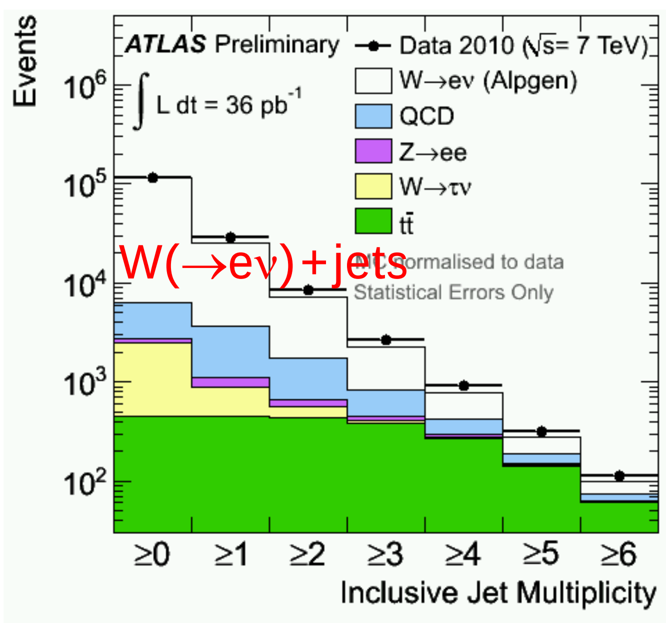


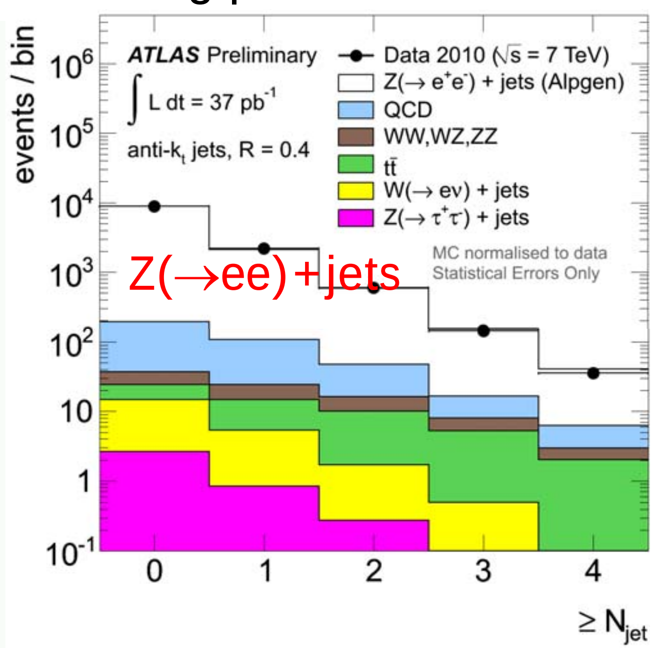


Conclusions and summary

- Presented the very first results from ATLAS on W,Z and W,Z+jets production cross sections in the electron and muon decay channels!
  - Based on 0.32-1.3 pb^{-1} (only ~3% of the available data from 2010 run!)
    - These results have set the stage for the future high statistics analyses
- Experimental uncertainties largely dominate the current results
  - Absolute measurements dominated by lumi and experimental uncertainties
  - Ratios mostly still dominated by statistics
  - Agreement with predictions but no discriminating power with models... yet!

$L \cong 36\ pb^{-1}$





BONUS SLIDES!

Monte-Carlo samples: W,Z inclusive

Need MC samples to simulate both the signal and background

- For the W and Z signal processes:
  - $W \to e/\mu\nu$, $Z \to ee/\mu\mu$ samples (MRST LO*, corrected to NNLO)
- For the backgrounds the following processes were considered:
  - $W \to e/\mu/\tau\nu$, $Z \to ee/\mu\mu/\tau\tau$ (MRST LO*, corrected to NNLO)
  - ttbar (NLO+NNLL)
  - Jet production via QCD processes (di-jet LO MC)
- $W \to l\nu$, $Z \to ll$, QCD di-jet MC: generated with in-time pileup

Physics process	Generator	σ· BR [nb]		
$W \to \ell\nu \quad (\ell = e, \mu)$	PYTHIA [25]	10.46±0.52	NNLO	[5, 8]
$W^+ \to \ell^+\nu$		6.16±0.31	NNLO	[5, 8]
$W^- \to \ell^-\bar{\nu}$		4.30±0.21	NNLO	[5, 8]
$Z/\gamma^* \to \ell\ell \quad (m_{\ell\ell} > 60$ GeV)	PYTHIA	0.99±0.05	NNLO	[5, 8]
$W \to \tau\nu$	PYTHIA	10.46±0.52	NNLO	[5, 8]
$W \to \tau\nu \to \ell\nu\nu\nu$	PYTHIA	3.68±0.18	NNLO	[5, 8]
$Z/\gamma^* \to \tau\tau \quad (m_{\ell\ell} > 60$ GeV)	PYTHIA	0.99±0.05	NNLO	[5, 8]
$t\bar{t}$	MC@NLO [26, 27], POWHEG [31]	0.16±0.01	NLO+NNLL	[28–30]
Dijet (e channel, $\hat{p}_T > 15$ GeV)	PYTHIA	1.2×10^6	LO	[25]
Dijet (μ channel, $\hat{p}_T > 8$ GeV)	PYTHIA	10.6×10^6	LO	[25]
$b\bar{b}$ (μ channel, $\hat{p}_T > 18$ GeV, $p_T(\mu) > 15$ GeV)	PYTHIA	73.9	LO	[25]
$c\bar{c}$ (μ channel, $\hat{p}_T > 18$ GeV, $p_T(\mu) > 15$ GeV)	PYTHIA	28.4	LO	[25]

Monte-Carlo samples: W,Z + jets

Physics process	Generator	σ · BR (nb)		
$W \to \ell\nu$ inclusive ($\ell = e, \mu, \tau$)	PYTHIA 6.4.21 [21]	10.46	NNLO	[14]
$W^+ \to \ell^+\nu$		6.16	NNLO	[14]
$W^- \to \ell^-\overline{\nu}$		4.30	NNLO	[14]
$W \to \ell\nu$ + jets ($\ell = e, \mu, \tau$)	PYTHIA 6.4.21 [21]			
$W \to \ell\nu$ + jets ($\ell = e, \mu, \tau$, $0 \leq N_{parton} \leq 5$)	ALPGEN 2.13 [22]			
$W \to \ell\nu$ + jets ($\ell = e, \mu, \tau$, $0 \leq N_{parton} \leq 4$)	SHERPA 1.1.3 [23]			
$Z \to \ell\ell$ + jets ($m_{\ell\ell} > 40$ GeV, $0 \leq N_{parton} \leq 5$)	ALPGEN 2.13 [22]	1.07	NNLO	[14]
$t\bar{t}$	POWHEG-HVQ v1.01 patch 4 [24]	0.16	NLO+NNLL	[25]
Dijet (e channel, $\hat{p}_T > 15$ GeV)	PYTHIA 6.4.21 [21]	1.2×10^6	LO	[21]
Dijet (μ channel, $\hat{p}_T > 8$ GeV, $p_T^\mu >$ 8 GeV)	PYTHIA 6.4.21 [21]	10.6×10^6	LO	[21]

Physics process	Generator	σ× Br (nb)
$Z/\gamma^*(\to ll)$+jets, $l = e, \mu, \tau$ ($m_{ll} > 40$ GeV, $0 \leq N_{parton} \leq 5$)	ALPGEN	1.07 (NNLO)
$Z/\gamma^*(\to ll)$+jets, $l = e, \mu$ ($m_{ll} > 60$ GeV, $0 \leq N_{parton} \leq 4$)	SHERPA	0.99 (NNLO)
$Z/\gamma^*(\to ll)$+jets, $l = e, \mu$ ($m_{ll} > 40$ GeV, $\hat{p}_t > 10$ GeV)	PYTHIA	0.47 (LO)
$Z/\gamma^*(\to ll)$+jets, $l = e, \mu$ ($m_{ll} > 40$ GeV, $\hat{p}_t > 10$ GeV)	HERWIG+JIMMY	0.37 (LO)
$W(\to l\nu_l)$+jets, $l = e, \mu$	ALPGEN	10.46 (NNLO)
$t\bar{t}$ (lepton + X final state)	MC@NLO	0.16 (NLO)
$WW + WZ + ZZ$ (2 leptons + X final state, $0 \leq N_{parton} \leq 3$)	ALPGEN	0.007 (NLO)
Dijets (inclusive jets, electron filter $E_T > 17$ GeV)	PYTHIA	97700 (LO)
Dijets ($b\bar{b} + c\bar{c}$, muon filter $p_T > 15$ GeV)	PYTHIA	102.3 (LO)

W+jets: systematic uncertainties for $N_{jet} \geq 1$

e channel		
Effect	Range	Cross Section Uncertainty (%)
Jet energy scale and E_T^{miss}	$\pm 10\%$ (dependent on jet η and p_T) $\oplus 5\%$	+11, -9
Jet energy resolution	14% on each jet	± 1.0
Electron trigger	$\pm 0.5\%$	∓ 0.7
Electron identification	$\pm 5.2\%$	∓ 5.5
Electron energy scale	$\pm 3\%$	+3.9, -4.7
Pile–up removal cut	$4-7\%$ in lowest jet p_T bin	± 1.9
Residual pile-up effects	from simulation	± 2.2
QCD background shape	from template variation	-1.5, +5.2
Luminosity	$\pm 11\%$	-10, +13

μ channel		
Effect	Range	Cross Section Uncertainty (%)
Jet energy scale and E_T^{miss}	$\pm 10\%$ (dependent on jet η and p_T) $\oplus 5\%$	+11, -9
Jet energy resolution	14% on each jet	± 1.8
Muon trigger	$\pm 2.5\%$ in barrel, $\pm 2.0\%$ in endcap	∓ 1.6
Muon reconstruction	$\pm 5.6\%$	-5.4, +5.9
Muon momentum scale	$\pm 1\%$	+2, -0.9
Muon momentum resolution	$\pm 5\%$ in barrel, $\pm 9\%$ in endcap	± 1.4
Pile–up removal cut	$4-7\%$ in lowest jet p_T bin	± 1.7
Residual pile-up effects	from simulation	± 1.4
Luminosity	$\pm 11\%$	-11, +13

Z+jets: systematic uncertainties for $N_{jet} \geq 1$

e channel		
Source	range	uncertainty on cross section (%)
Jet energy scale	7% to 8%, depending on p_T^{jet} and η^{jet} $\oplus$ 5%	10% to 20%
Jet energy resolution	14% per jet	8% to 2%
Pile-up removal	4% in first p_T^{jet} bin	4% at $p_T^{jet} < 30$ GeV
QCD background	100% uncertainty	4% to 6%
$t\bar{t}$, Z/W+jets, dibosons	6%, 5%, 5% on normalization	1%
Lepton reconstruction	4.9% independent on N_{jet} and p_T^{jet}	10%
Unfolding	using SHERPA instead of ALPGEN	2% to 6%

μ channel		
Source	range	uncertainty on cross section (%)
Jet energy scale	7% to 8%, depending on p_T^{jet} and η^{jet} $\oplus$ 5%	10% to 20%
Jet energy resolution	14% per jet	8% to 2%
Pile-up removal	4% in first p_T^{jet} bin	4% at $p_T^{jet} < 30$ GeV
QCD background	100% uncertainty	$< 1\%$
$t\bar{t}$, Z/W+jets, dibosons	6%, 5%, 5% on normalization	$< 1\%$
Lepton reconstruction	7% independent on N_{jet} and p_T^{jet}	12%
Unfolding	using SHERPA instead of ALPGEN	2% to 6%

Inclusive cross-section results + ratios

	$\sigma^{\text{tot}}_{W(\pm)} \cdot \text{BR}(W \to e\nu)$ [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^*	$0.75 \pm 0.09(\text{stat}) \pm 0.08(\text{syst}) \pm 0.08(\text{lumi})$	$0.87 \pm 0.08(\text{stat}) \pm 0.06(\text{syst}) \pm 0.10(\text{lumi})$

	$R^e_{W(\pm)/Z}$	$R^\mu_{W(\pm)/Z}$
W^+	8.4 ± 1.1 (stat) ± 0.6 (syst)	6.5 ± 0.7 (stat) ± 0.3 (syst)
W^-	5.7 ± 0.7 (stat) ± 0.4 (syst)	4.4 ± 0.5 (stat) ± 0.2 (syst)
W	14.0 ± 1.8 (stat) ± 0.9 (syst)	11.0 ± 1.1 (stat) ± 0.5 (syst)

W + jets cross-section results + ratios

Jet multiplicity	$W \to e\nu$ (nb)	MCFM $W \to e\nu$ (nb)	$W \to \mu\nu$ (nb)	MCFM $W \to \mu\nu$ (nb)
≥ 0	$4.53 \pm 0.07\ ^{+0.35}_{-0.30}\ ^{+0.58}_{-0.47}$	$5.08^{+0.11}_{-0.30}$	$4.58 \pm 0.07\ ^{+0.38}_{-0.32}\ ^{+0.61}_{-0.48}$	$5.27^{+0.11}_{-0.32}$
≥ 1	$0.84 \pm 0.03^{+0.13}_{-0.10}\ ^{+0.11}_{-0.09}$	$0.81^{+0.02}_{-0.04}$	$0.84 \pm 0.03\ ^{+0.11}_{-0.09}\ ^{+0.11}_{-0.09}$	$0.84^{+0.02}_{-0.04}$
≥ 2	$0.21 \pm 0.01\ ^{+0.04}_{-0.03}\ ^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$	$0.23 \pm 0.02\ ^{+0.04}_{-0.03}\ ^{+0.03}_{-0.02}$	$0.21^{+0.01}_{-0.02}$
≥ 3	$0.047 \pm 0.007^{+0.014}_{-0.011}\ ^{+0.008}_{-0.006}$	0.05 ± 0.02	$0.064 \pm 0.008\ ^{+0.016}_{-0.014}\ ^{+0.010}_{-0.008}$	0.05 ± 0.02
≥ 4	-	-	$0.019 \pm 0.005 \pm 0.006\ ^{+0.004}_{-0.003}$	-

Jet multiplicity	$W \to e\nu$	MCFM $W \to e\nu$	$W \to \mu\nu$	MCFM $W \to \mu\nu$
$\geq 1/\geq 0$	$0.185 \pm 0.007^{+0.025}_{-0.019}$	$0.159^{+0.006}_{-0.005}$	$0.183 \pm 0.007^{+0.023}_{-0.020}$	$0.160^{+0.006}_{-0.005}$
$\geq 2/\geq 1$	$0.250 \pm 0.019^{+0.019}_{-0.010}$	$0.255^{+0.017}_{-0.022}$	$0.274 \pm 0.020^{+0.018}_{-0.011}$	$0.255^{+0.017}_{-0.021}$
$\geq 3/\geq 2$	$0.224 \pm 0.037 \pm 0.022$	$0.241^{+0.108}_{-0.061}$	$0.278 \pm 0.041^{+0.024}_{-0.020}$	$0.242^{+0.104}_{-0.061}$
$\geq 4/\geq 3$	-	-	$0.297 \pm 0.088^{+0.037}_{-0.026}$	-