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First Results from ATLAS on Production of W and Z Bosons in proton-proton Collisions at $\sqrt{s}$ = 7 TeV

on behalf of the ATLAS collaboration

EPIPHANY 2011

Introduction

Outline

This talk is based on:
http://arxiv.org/abs/1010.2130
For the W + jets results overview, see **Sergei Chekanov**'s talk or ATLAS paper:
http://arxiv.org/abs/arXiv:1012.5382

- Motivation & predictions
- Data & MC samples
- Event selection & background estimation for W & Z
- Cross-section & asymmetry measurement with ~320 nb^{-1}
- Outlook – newest results with larger data samples

Motivation & predictions

- **Physics**

- W & Z cross-section measurement in a previously unobserved energy region (known with ~4% precision from theory).
- Test of higher-order QCD corrections and Parton Density Functions
- Important background for New Physics searches (processes with di-leption or lepton + missing energy final states)

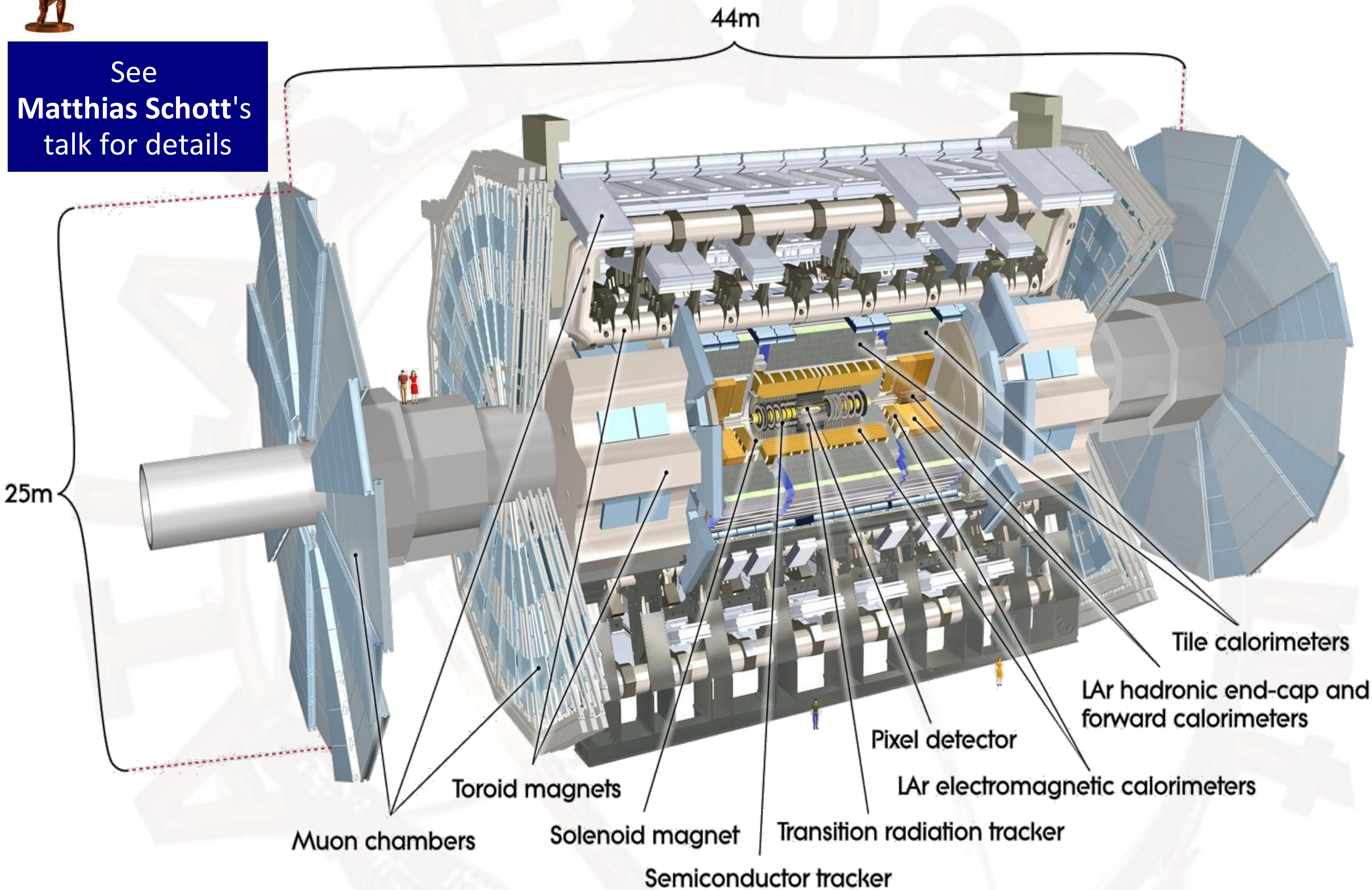
σ(W±)	σ(W+)	σ(W-)	σ(Z)
10.46 nb	6.16 nb	4.30 nb	0.99 nb

- **Commissioning & performance**

- First pure hi-stat sample of isolated leptons with high transverse momentum:
    - Identification, calibration, energy scales, efficiency with tag & probe
    - Missing transverse energy studies

The ATLAS detector

See **Matthias Schott**'s talk for details



Data & MC samples

- ATLAS data from March to July 2010 with a total of **310 - 320 nb^{-1}**

- Trigger**:**
  - Level – 1 **hardware based**
  - **Single lepton**
  - Electrons: **10 GeV** cluster in electromagnetic LAr calorimeter
  - Muons: **6 GeV** track in Muon Spectrometer.

A total of **6.5 x 10^{6}** and **5.1 x 10^{6}** events were collected in electron and muon channels for this analysis

- Electroweak processes generated with **PYTHIA** with MRST LO* PDFs and cross-section normalized to **NNLO**

- **QCD dijet** background determined **from data** (for some comparisons here a PYTHIA LO sample used with cross-section normalized to data)

Event selection & background estimation

Ingredients

- Electrons
  - reconstructed from EM-cluster with matched track
  - 3 sets of identification cuts: *loose* (bkg studies), *medium* (Z selection), *tight* (W selection)

- Muons
  - *Combined* muons use information from Muon Spectrometer matched with Inner Detector
  - Isolation required for efficient selection of signal events

- Missing transverse energy
  - Cell-based algorithm (with cluster filter)
  - In muon channel – a correction for muon momentum added

Event selection – W± cross-section

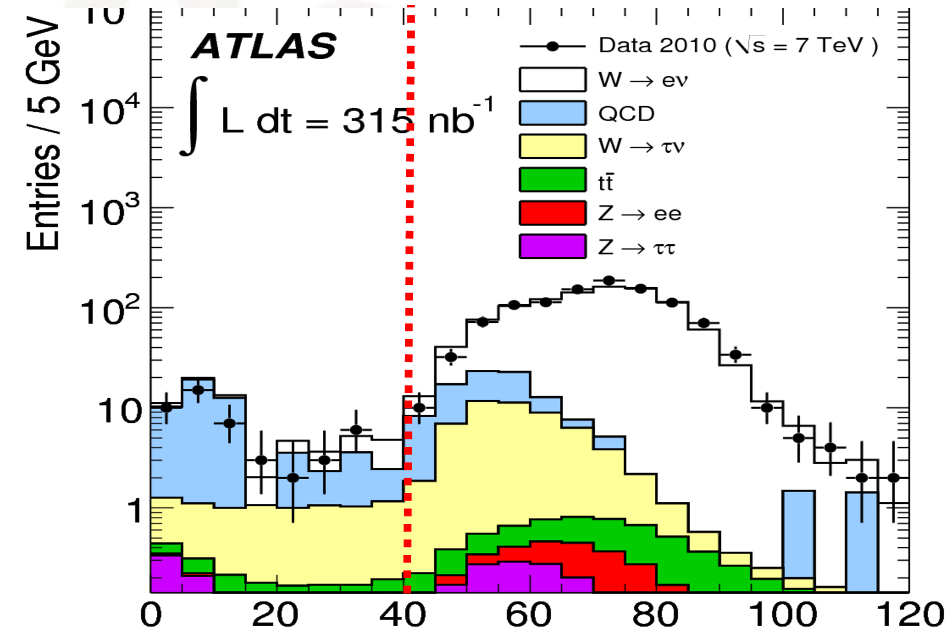
- Electron channel
  - Electron within $|\eta| < 2.47$, without ($1.37<|\eta|<1.52$), $p_T > 20$ GeV and passing tight ID
  - $E_T^{Miss} > 25$ GeV
  - $m_T > 40$ GeV

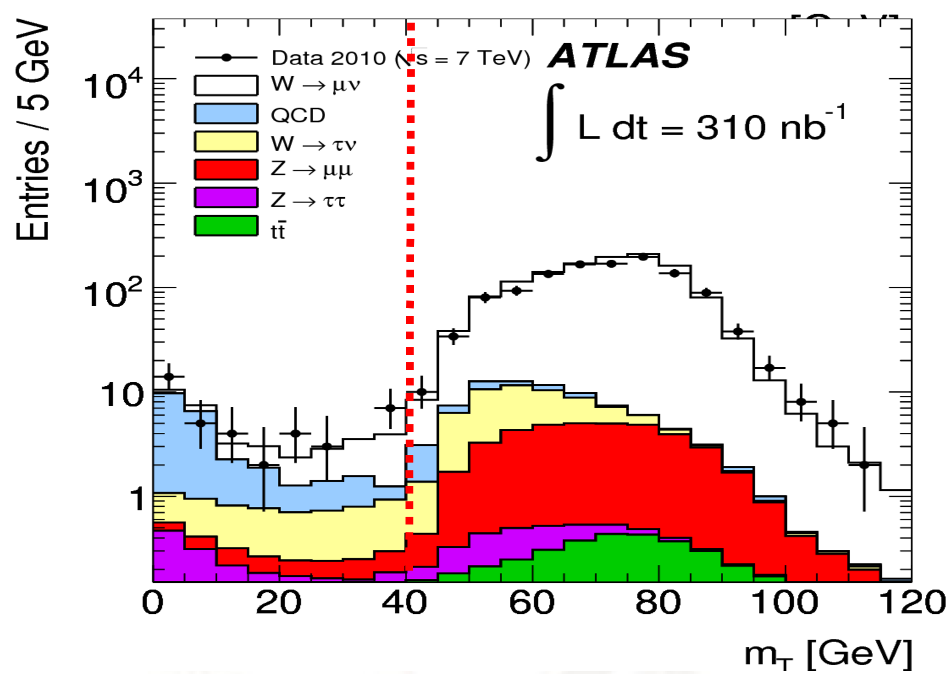
  #selected events: **1069** (in 315 nb^{-1})

- Muon channel
  - Combined muon with $p_T > 20$ GeV within $|\eta| < 2.4$ with track isolation
  - $E_T^{Miss} > 25$ GeV
  - $m_T > 40$ GeV

  #selected events: **1181** (in 310 nb^{-1})

$$m_T = \sqrt{2 p_T^e \, p_T^\nu \left(1 - \cos\left(\phi^e - \phi^\nu\right)\right)}$$

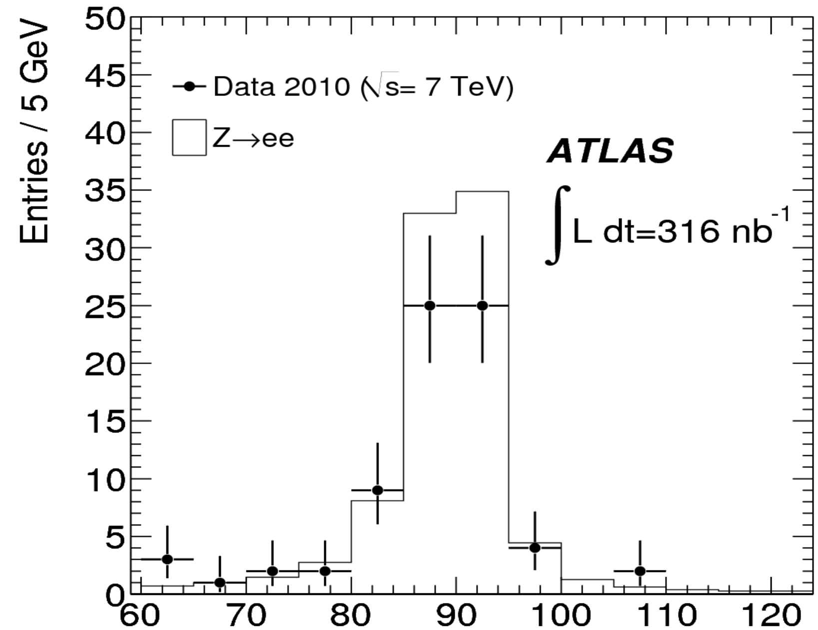




Event selection – Z

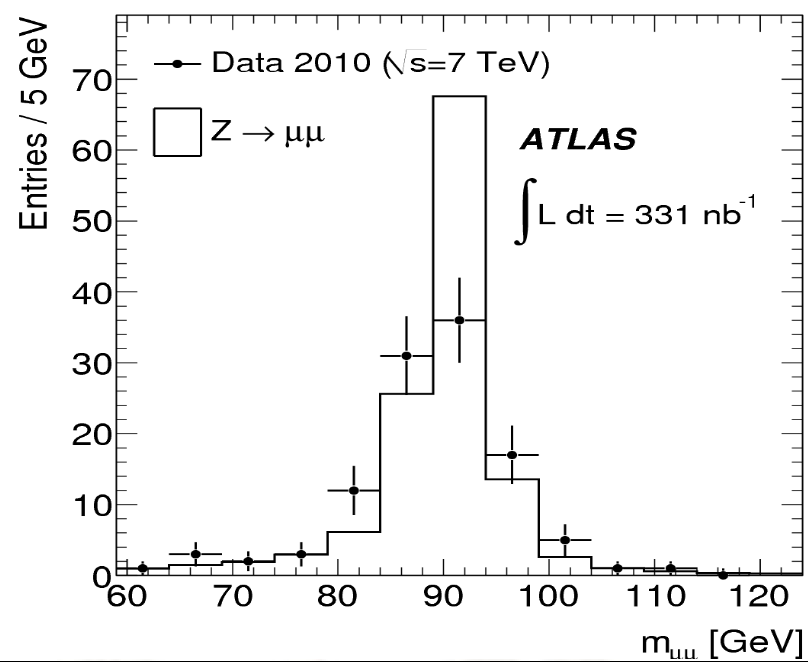
- Electron channel
  - Two oppositely-charged electrons $|\eta| < 2.47$ without($1.37<|\eta|<1.52$) , $p_T > 20$ GeV and medium ID
  - Invariant mass $66 < m < 116$ GeV

  #selected events: **70** (for 316 nb^{-1})



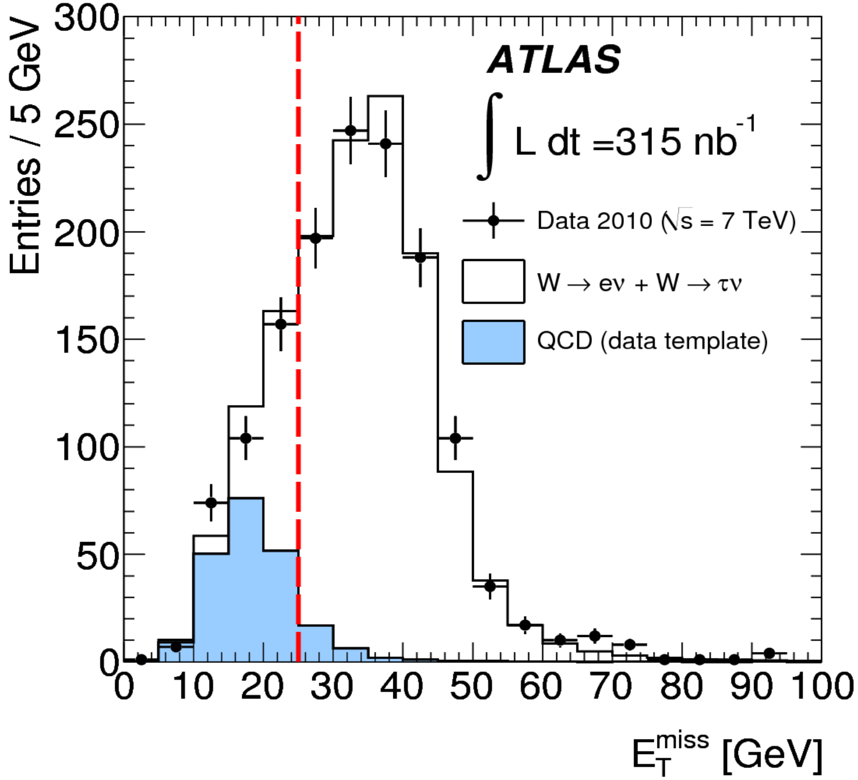
- Muon channel
  - Two combined muons with $p_T > 20$ GeV within $|\eta| < 2.4$ with track isolation
  - Invariant mass $66 < m < 116$ GeV

  #selected events: **109** (for 331 nb^{-1})



Background estimation

- Contributions from **electroweak** processes is estimated from Monte Carlo.
- Number of **QCD** events must be obtained with data-driven methods:
  - W→eν: Template fit to E_T^{Miss} distribution (see plot)
  - W→μν: Isolation requirement -- relaxed versus full
  - Z→ee: Relaxed electron ID to get background template & fit
  - Z→μμ: Estimation based on MC: Negligible contribution expected (~10^{-2})



Event yields

	Total events	EW background events	QCD background events	S:B ratio
W→eν	**1069**	**33.5**±0.5±3.0	**28**±3±10	16
W→μν	**1181**	**77.6**±0.3±5.4	**23**±5±9	11
Z→ee	**70**	**0.27**±0.00±0.03	**0.9**±0.1±0.4	59
Z→μμ	**109**	**0.21**±0.01±0.01	**0.04**±0.01±0.04	435

Cross-section measurement

Cross-section measurement

- The cross-section is calculated as follows:

$$\sigma_{W/Z}^{tot} \cdot BR(channel) = \frac{N_{obs} - N_{bkg}}{A_{W/Z} C_{W/Z} L_{\text{int}}}$$

  - $\boldsymbol{A_{W/Z}}$ is the acceptance for W/Z-boson decays, defined as fraction of events satisfying geometrical and kinematical constraints at generator-level

  - $\boldsymbol{C_{W/Z}}$ denotes the ratio between number of events passing final selection and number of generated events within acceptance. It accounts for trigger, reconstruction and selection efficiency

  - $\boldsymbol{L_{int}}$ is the total integrated luminosity of the sample

Cross-section measurement

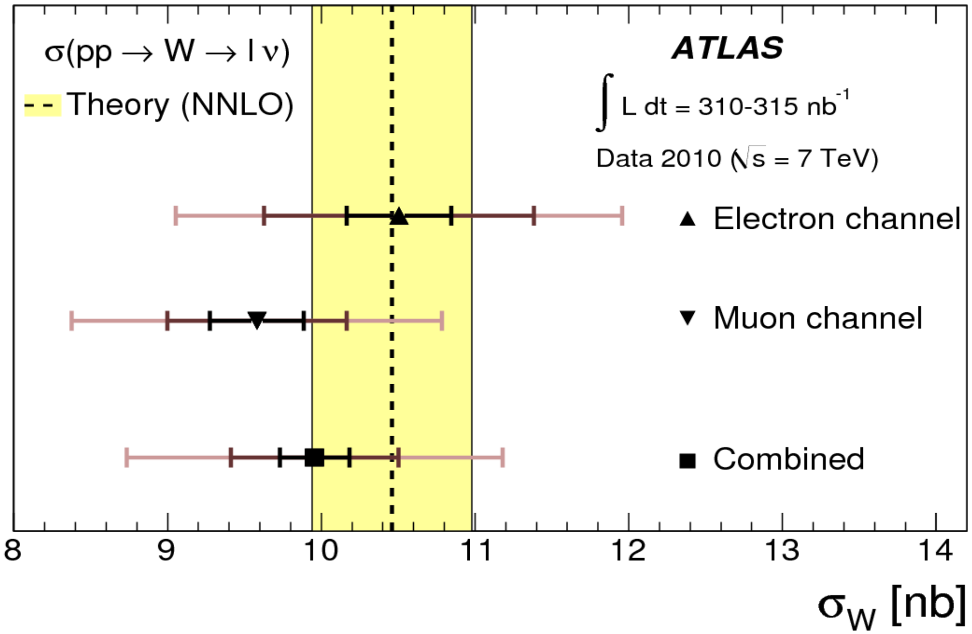
	$W \rightarrow e\nu$		$Z \rightarrow ee$		$W \rightarrow \mu\nu$		$Z \rightarrow \mu\mu$	
	Central value	Relative uncertainty	Central value	Relative uncertainty	Central value	Relative uncertainty	Central value	Relative uncertainty
C_W, C_Z	0.659	7.0%	0.651	9.4%	0.758	4.0%	0.773	5.5%

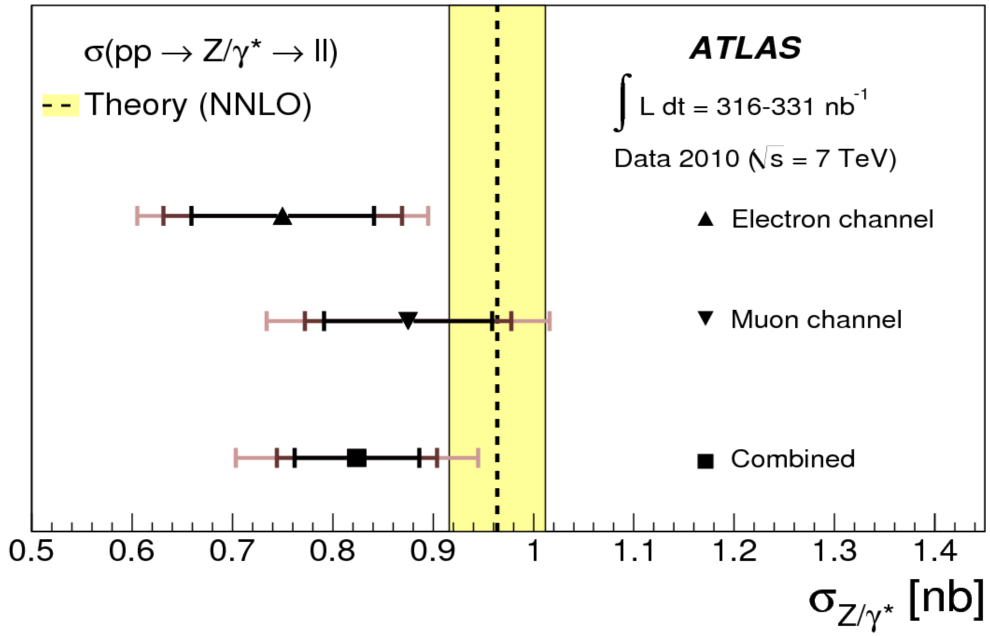
Electron channel →

Muon channel →

MC	A_{W^+} $W^+ \rightarrow e^+\nu$	A_{W^-} $W^- \rightarrow e^-\nu$	A_W $W \rightarrow e\nu$	A_Z $Z \rightarrow e^+e^-$	A_W/A_Z
PYTHIA MRST LO*	0.466	0.457	0.462	0.446	1.036
	A_{W^+} $W^+ \rightarrow \mu^+\nu$	A_{W^-} $W^- \rightarrow \mu^-\nu$	A_W $W \rightarrow \mu\nu$	A_Z $Z \rightarrow \mu^+\mu^-$	A_W/A_Z
PYTHIA MRSTLO*	0.484	0.475	0.480	0.486	0.988

Cross-section - results



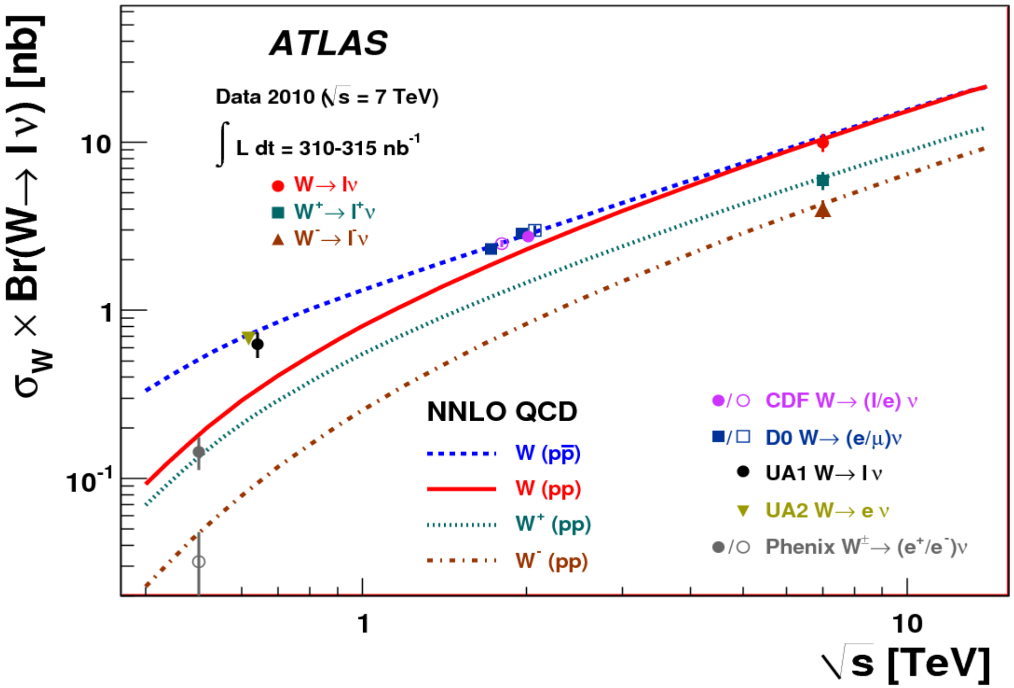


	$\sigma_W^{tot} \cdot BR(W \to e\nu)$ [nb]	$\sigma_W^{tot} \cdot BR(W \to \mu\nu)$ [nb]
W^+	$6.27 \pm 0.26(stat) \pm 0.48(syst) \pm 0.69(lumi)$	$5.71 \pm 0.23(stat) \pm 0.30(syst) \pm 0.63(lumi)$
W^-	$4.23 \pm 0.22(stat) \pm 0.33(syst) \pm 0.47(lumi)$	$3.86 \pm 0.20(stat) \pm 0.20(syst) \pm 0.42(lumi)$
W	$10.51 \pm 0.34(stat) \pm 0.81(syst) \pm 1.16(lumi)$	$9.58 \pm 0.30(stat) \pm 0.50(syst) \pm 1.05(lumi)$

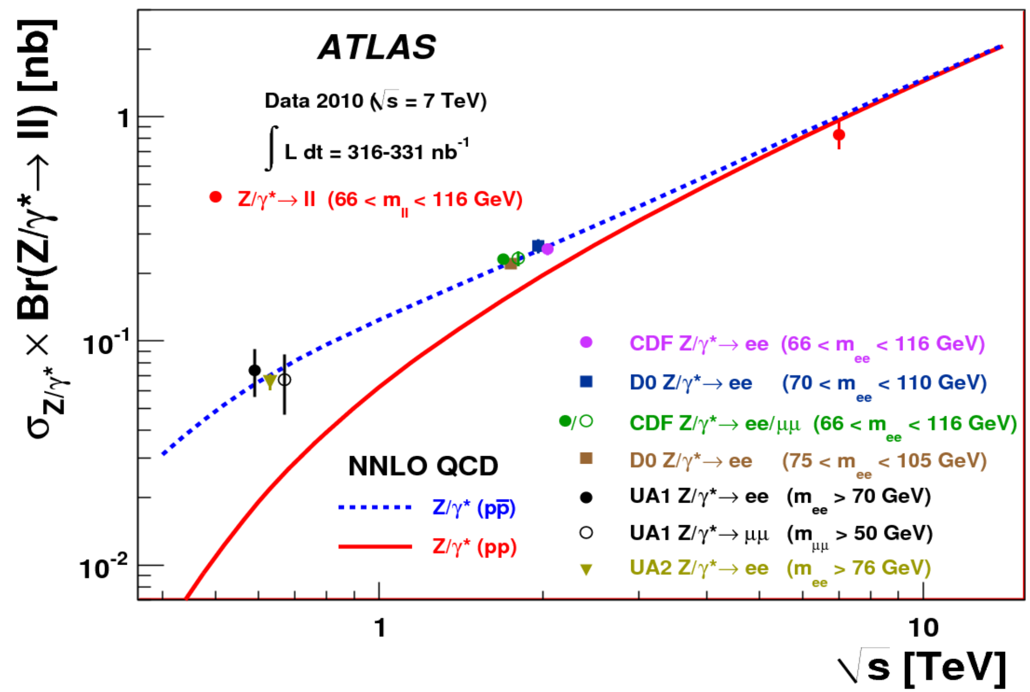
	$\sigma_{Z/\gamma^*}^{tot} \cdot BR(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV	$\sigma_{Z/\gamma^*}^{tot} \cdot BR(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.75 \pm 0.09(stat) \pm 0.08(syst) \pm 0.08(lumi)$	$0.87 \pm 0.08(stat) \pm 0.06(syst) \pm 0.10(lumi)$

Cross-section - results

W cross-section in context of previous measurements

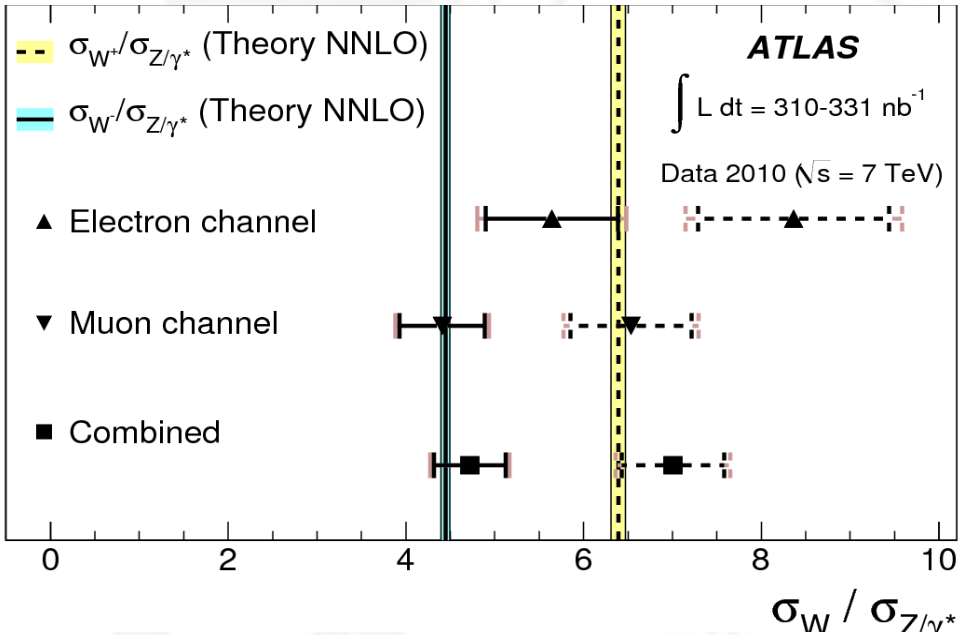


Z cross-section in context of previous measurements

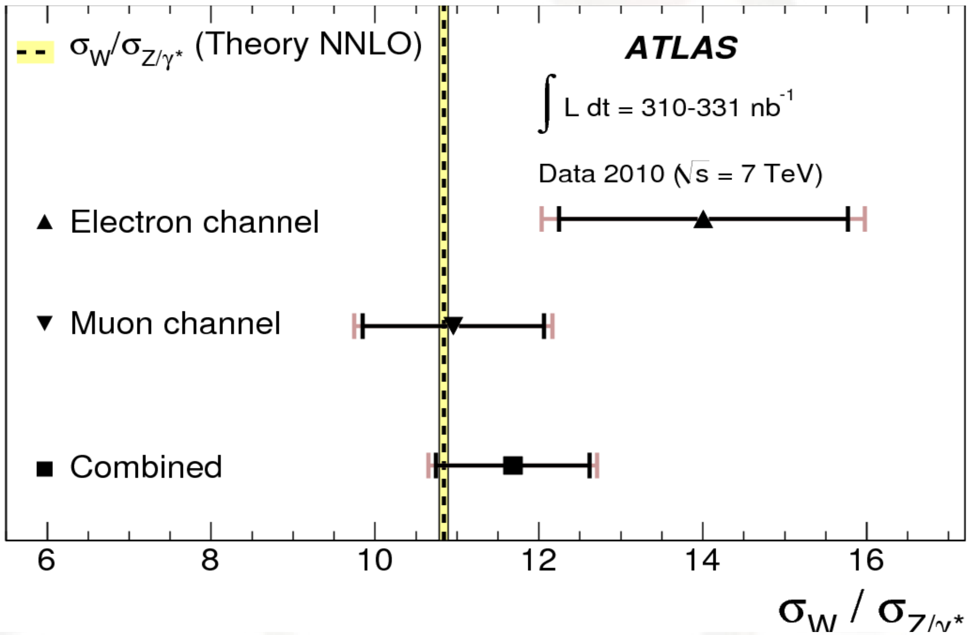


Cross-section - results

Ratios of W+/Z and W-/Z cross-sections



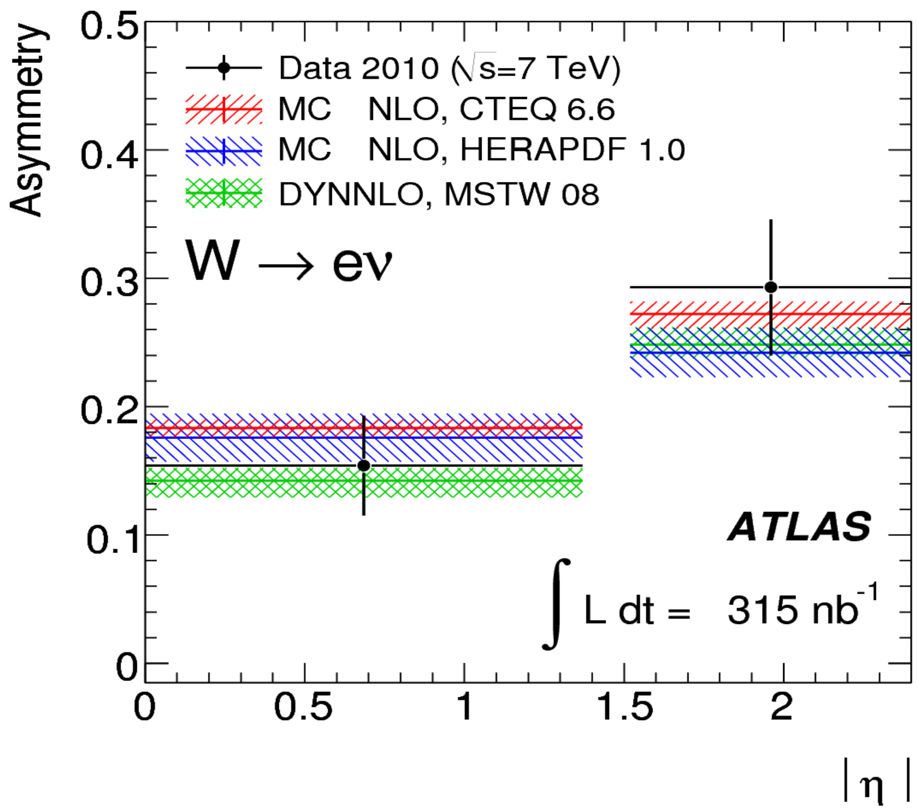
Ratios of W(both signs)/Z cross-sections

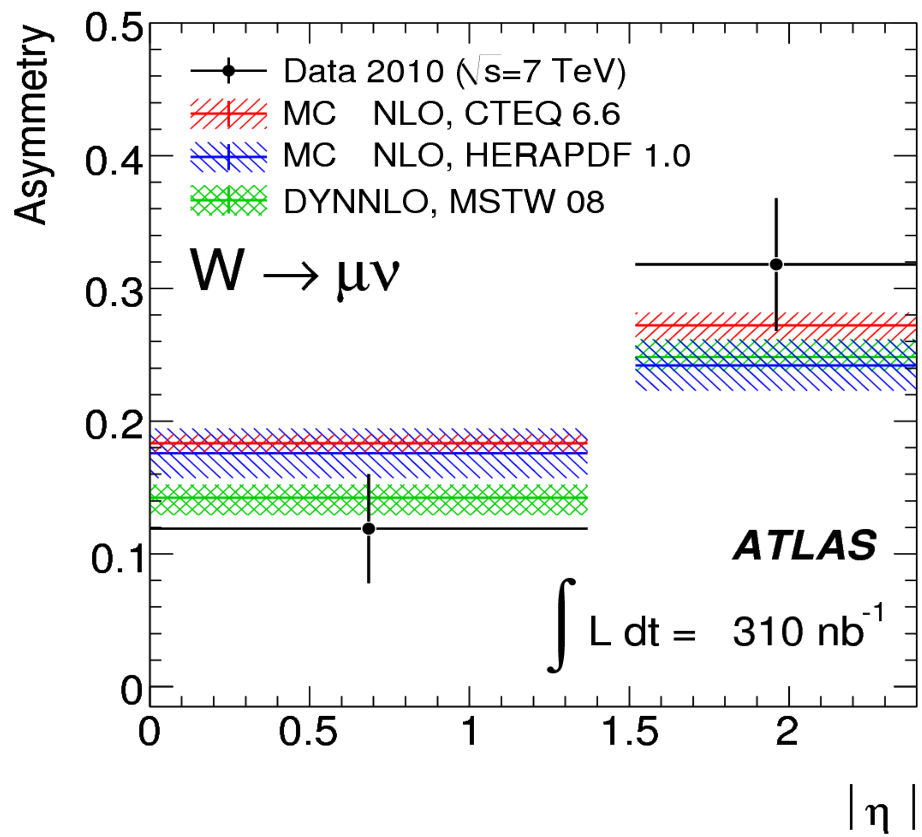


W^+/W^- asymmetry

- Expected to be non-zero, increasing with η
- Is sensitive to valence quarks distribution
- Provides constraints on PDF's

$$A_l = \frac{\sigma(W+)A_{W+} - \sigma(W-)A_{W-}}{\sigma(W+)A_{W+} + \sigma(W-)A_{W-}}$$

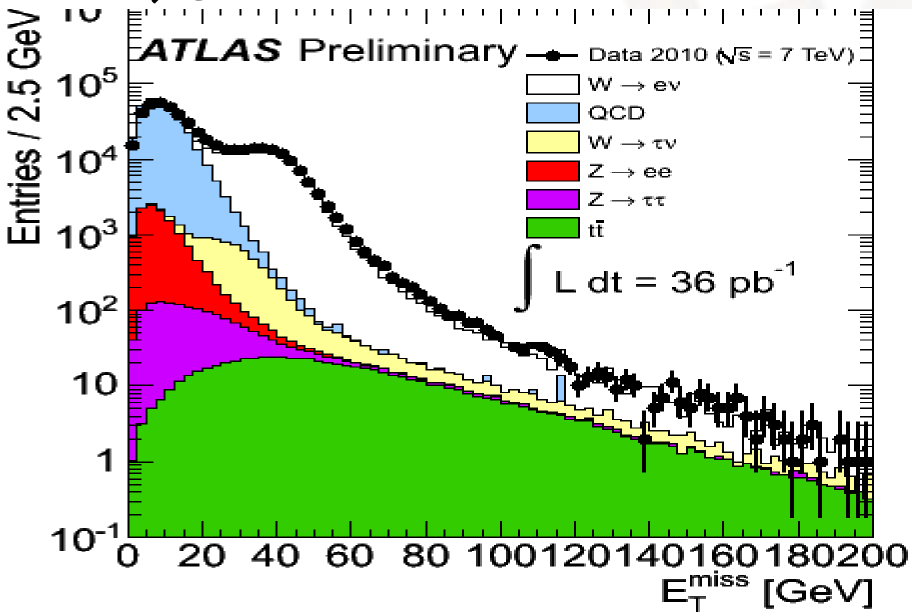




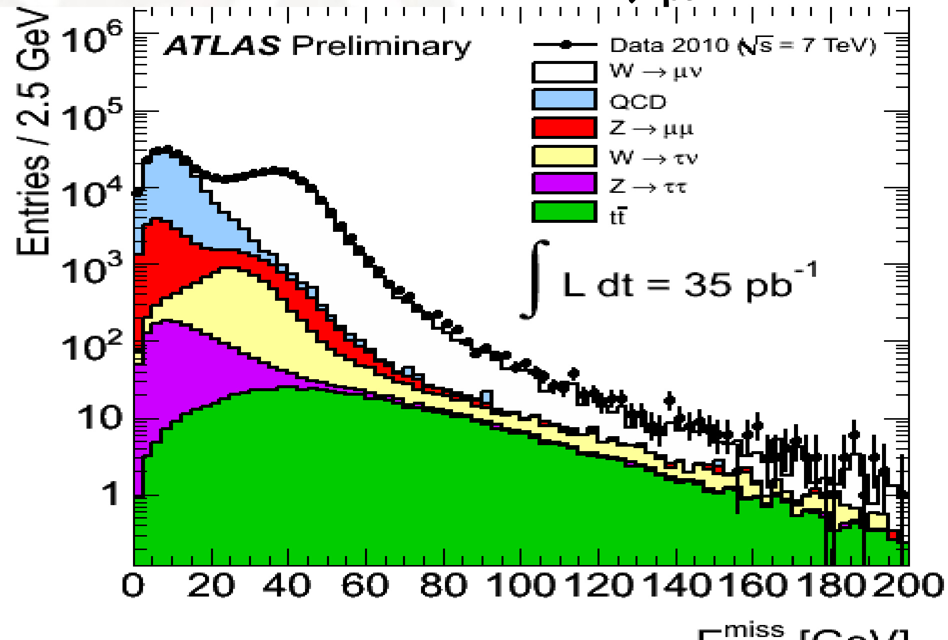
Outlook

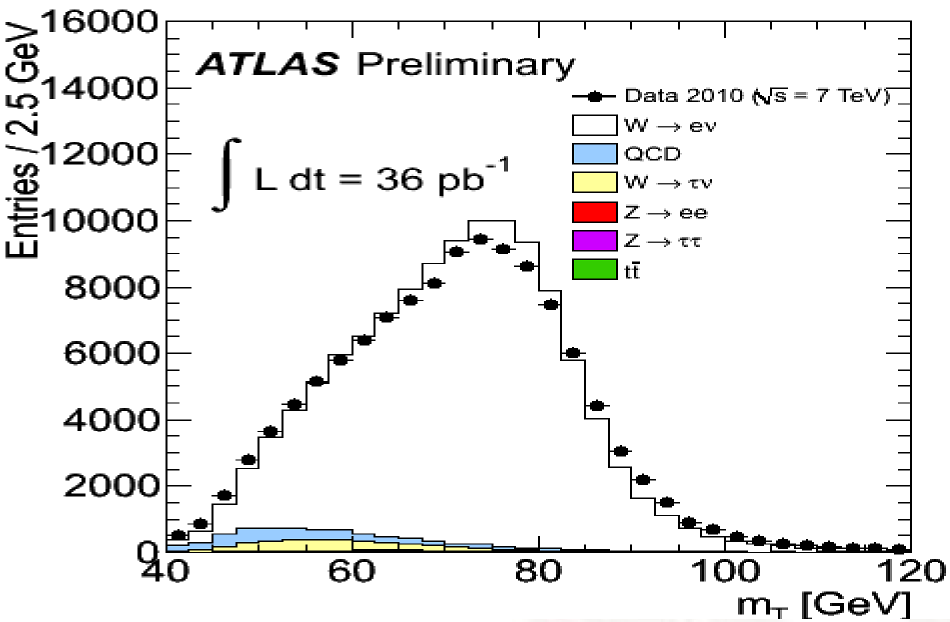
The story goes on: $35 pb^{-1}$

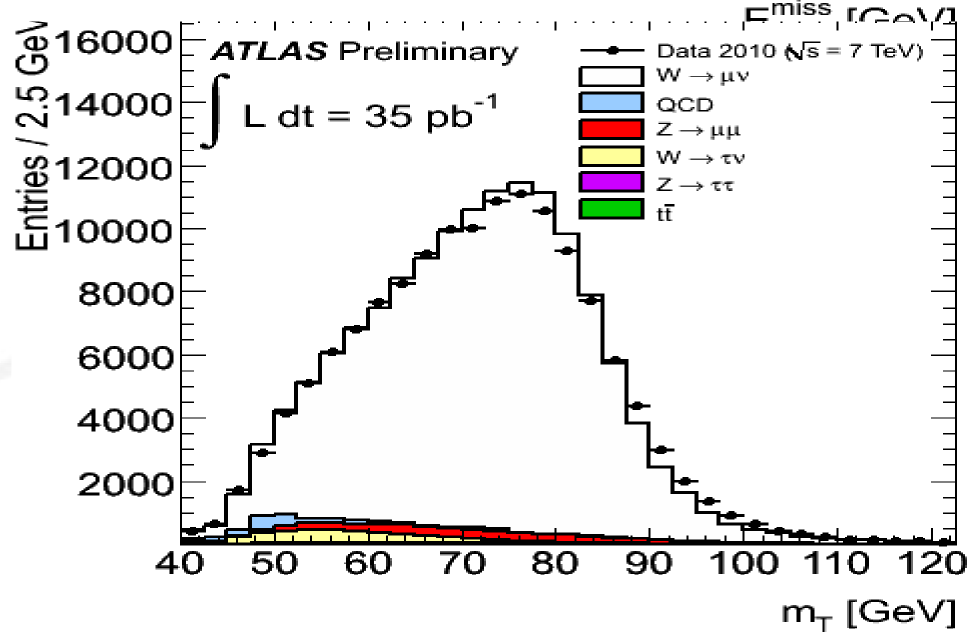
$W \to e\nu$



$W \to \mu\nu$

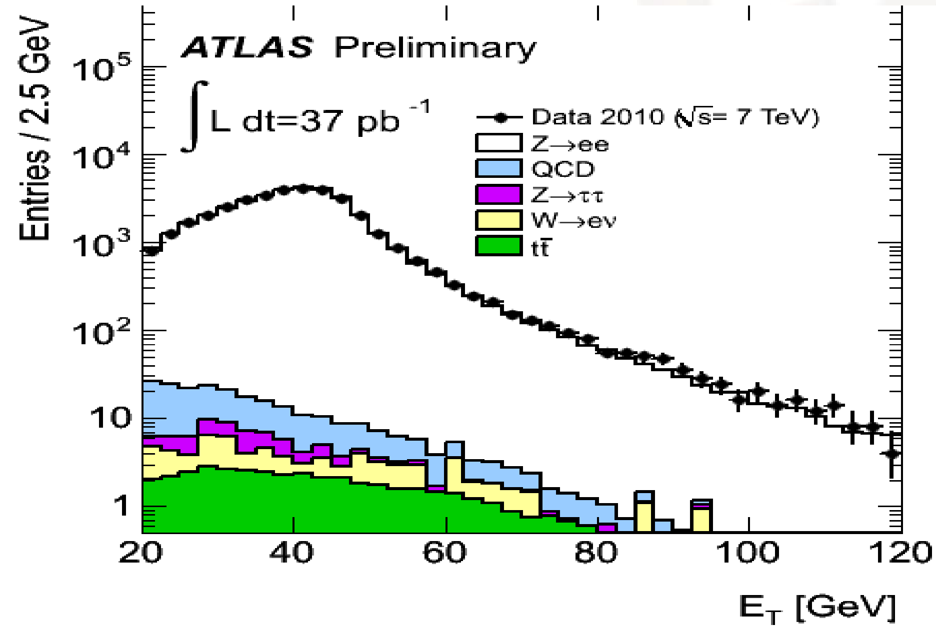


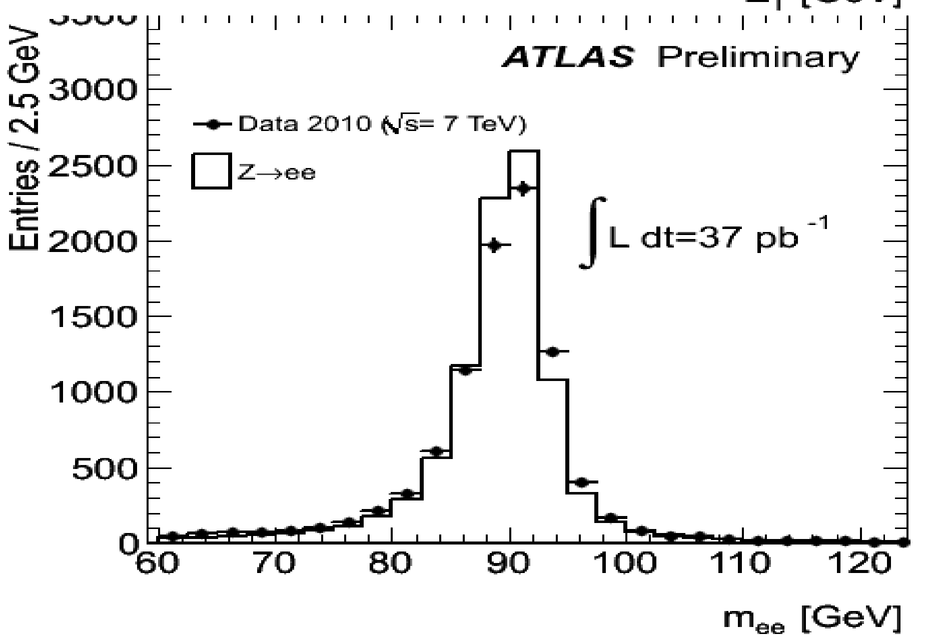




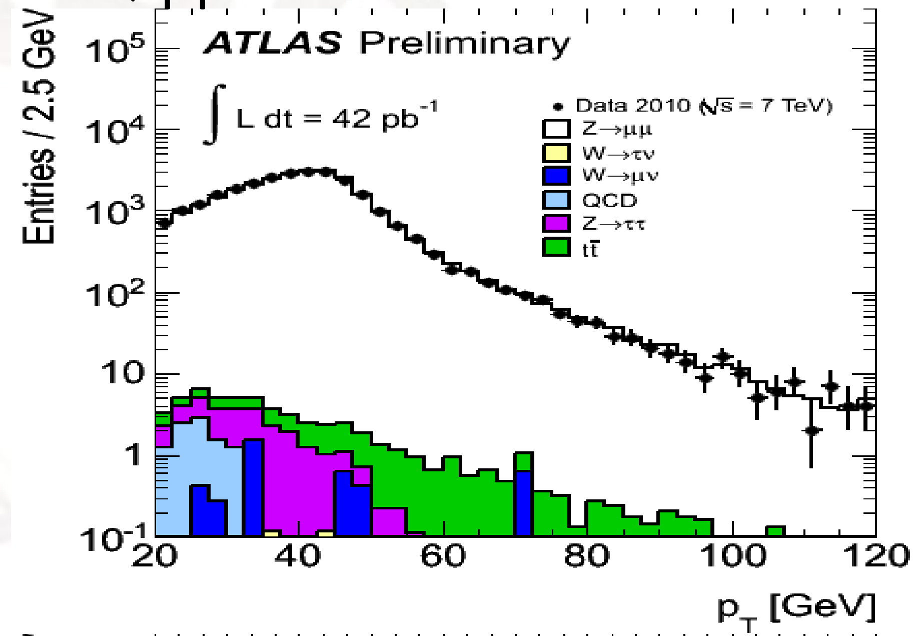
The story goes on: $35pb^{-1}$

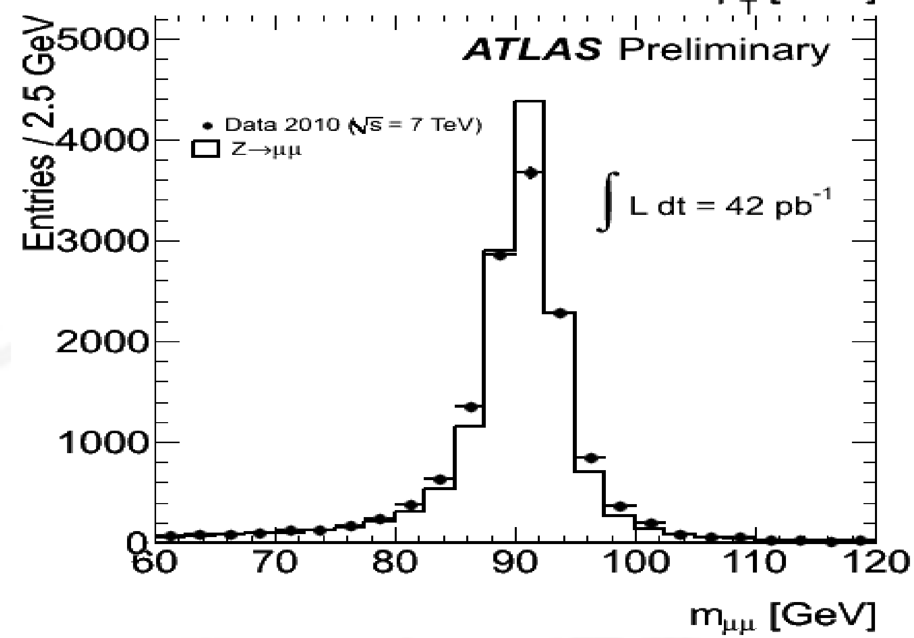
Z→ee





Z→μμ





Summary

- Basic object reconstruction and identification procedures well understood
- Measurement of $W \rightarrow l\nu$ and $Z \rightarrow ll$ cross-sections and their ratios – results consistent with expectations (first data points at 7 TeV !)
- First measurement of W charge asymmetry at 7 TeV
- Uncertainty already (at 320 nb^{-1}) dominated by systematics & lumi
- Higher statistics will also greatly reduce systematic errors on energy scale, reconstruction & identification efficiencies.
- Ready for $W \rightarrow \tau\nu$ & $Z \rightarrow \tau\tau$

BACKUP

Data & MC samples

Process	Generator	σ x BR [nb]	Order
W → eν	PYTHIA	10.46 ± 0.52	NNLO
W → μν	PYTHIA	10.46 ± 0.52	NNLO
W → τν	PYTHIA	10.46 ± 0.52	NNLO
Z → ee	PYTHIA	0.99 ± 0.05	NNLO
Z → μμ	PYTHIA	0.99 ± 0.05	NNLO
Z → ττ	PYTHIA	0.99 ± 0.05	NNLO
ttbar	MC@NLO	0.16 ± 0.01	NLO + NNLL
QCD dijets (e channel) p_T > 15 GeV	PYTHIA	1.2×10^6	LO
QCD dijets (μ channel) p_T > 8 GeV	PYTHIA	10.6×10^6	LO
bb (μ channel) p_T > 18 GeV, p_T(μ)> 15 GeV	PYTHIA	73.9	LO
bb (μ channel) p_T > 18 GeV, p_T(μ)> 15 GeV	PYTHIA	28.4	LO

- W → τν contributes mostly via leptonic τ decay.
- In Z-processes one lepton may be lost outside of acceptance, generating, in addition, a missing transverse energy.
- In the ttbar process an electron from W decay in t→Wb may be found.

QCD dijets contain genuine leptons from semi-leptonic heavy quark decays, misidentified hadrons, electrons from photon conversions. For the Z→μμ channel, dedicated bb and cc samples were produced to increase statistics.

Electron reconstruction & identification

- A central electron candidate is seeded with **electromagnetic cluster** with $|\eta| < 2.47$ and $E_T > 2.5$ GeV in the second layer of EM calorimeter.
- An Inner Detector **track** needs to be loosely matched with the cluster of the electron candidate. Overall reconstruction efficiency: **97%**
- A ***loose*** identification involves examination of shower shapes in the 2nd sampling layer of LAr calorimeter and hadronic leakage.
- In ***medium*** selection the energy deposits in the first calorimeter layer are used, as well as track-quality variables (number of hits in Si, impact parameter) and more restrictive track-cluster matching. Relative efficiency: **94.3%** with **5.7×10^3** rejection against QCD jets.
- The ***tight*** cuts require in addition E/p matching, a hit in first pixel layer for conversion rejection and e/π discrimination with TRT high threshold hits. Relative efficiency: **74.9%** with **7.7×10^4** rejection power.

Muon reconstruction

• **Standalone** muons are reconstructed based on Muon Spectrometer information only. A minimum of 2 track segments pointing to the interaction point are required. Track parameters are corrected for multiple interactions and energy losses in calorimeters (typically 3 GeV).

• **Combined** reconstruction utilizes also the information from Inner Detector combining standalone tracks with ID tracks either statistically or by refitting the whole track. Reconstruction efficiency of **93%** has been measured.

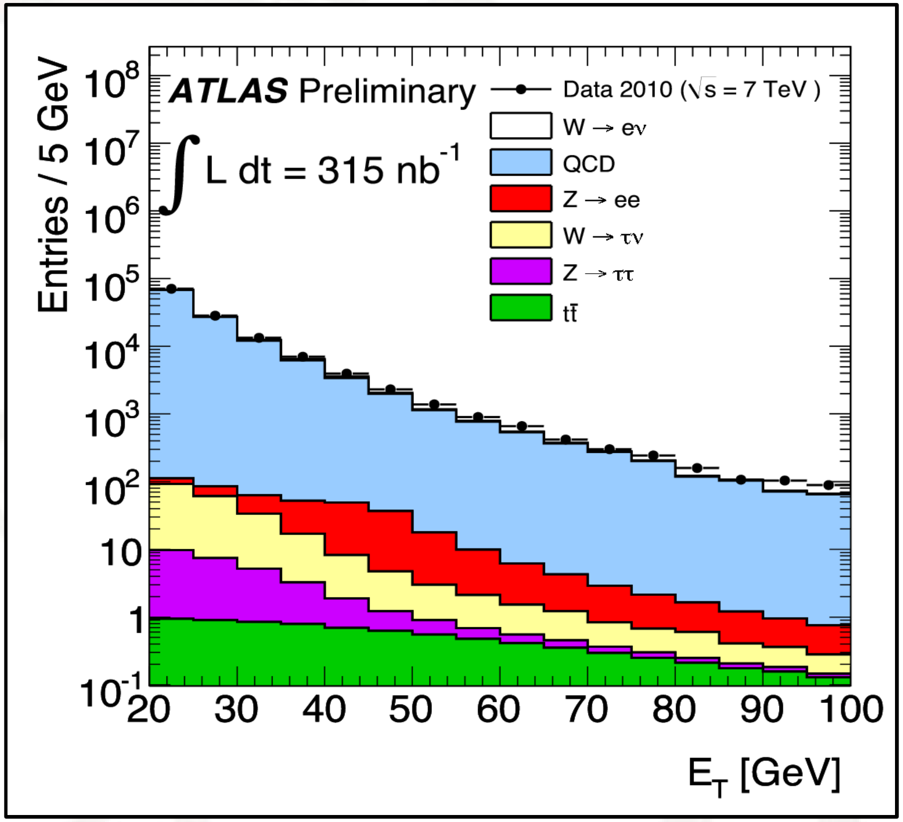
• Muon **isolation** cut is applied, with **98.4%** efficiency, rejecting **84%** of QCD background.

Missing transverse energy

- Missing transverse energy, E_T^{Miss} computed with cell-based algorithm with **topological clusters**.
- Clusters constructed from cells with $E > 4\sigma_{noise}$ seed, $E > 2\sigma_{noise}$ secondary cells and all their direct neighbors (**420**).
- Energy measured with assumption of purely-electromagnetic nature of contributing processes and corrected for hadron response, dead material and out-of-cluster losses.
- Components of E_T^{Miss} calculated as sums of energy components of cells belonging to clusters (an additional term is required in muon channel):
  – In electron channel: $E_{x,y}^{Miss} = -\Sigma_i E_{x,y}^i$
  – In muon channel: $E_{x,y}^{Miss} = -\left(\Sigma_i E_{x,y}^i + \Sigma_i^{Muons} p_{x,y}^i\right)$

Event preselection - electrons

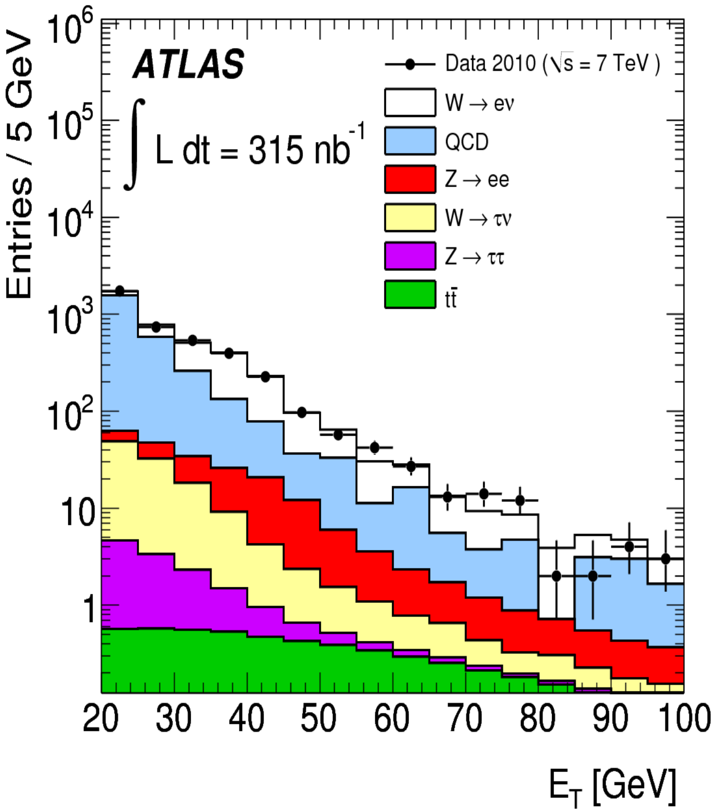
- Electron candidate within Inner Detector acceptance:
$|\eta| < 2.47$
and outside of calorimeter transition region between barrel and end-caps:
$|\eta| < 1.37$ or **$|\eta| > 1.52$**
- Electron candidate cluster transverse energy **$E_T > 20$ GeV**
- **Loose** identification
- Note: QCD scaled by 0.4 to match data



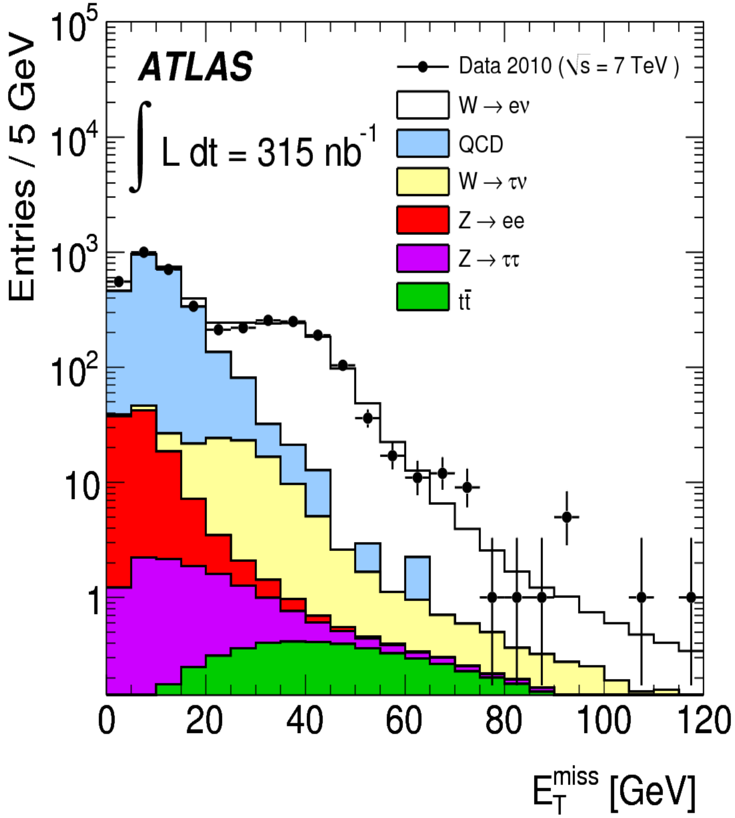
- Sample after preselection dominated by QCD events

Event selection – W (e channel)

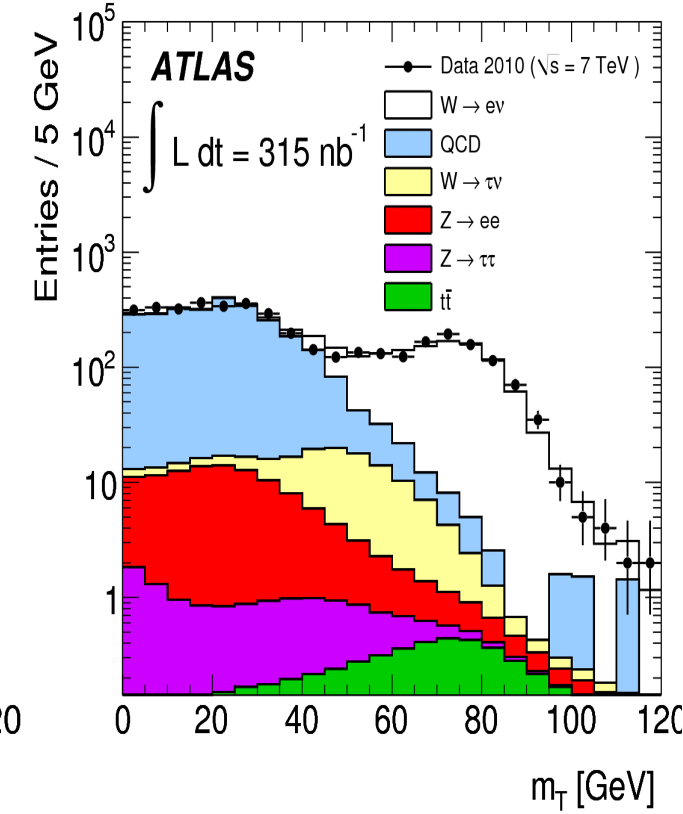
- Fake leptons suppressed by adding **tight** identification requirements



Electron transverse energy

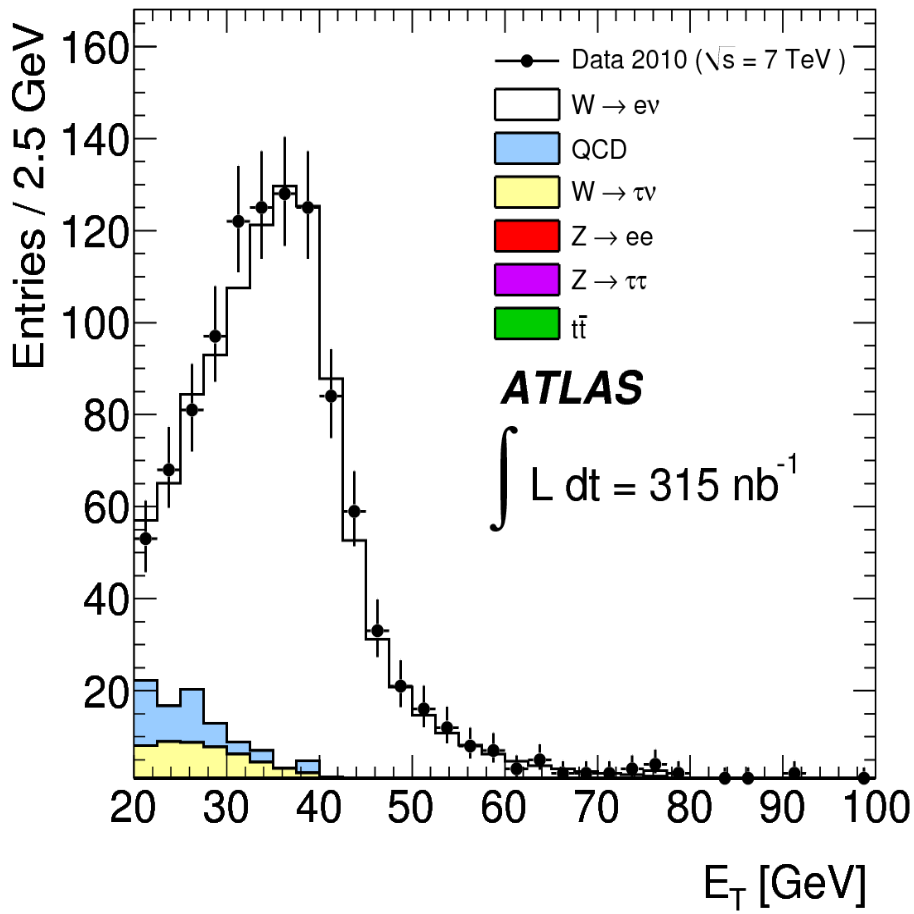


Missing transverse energy

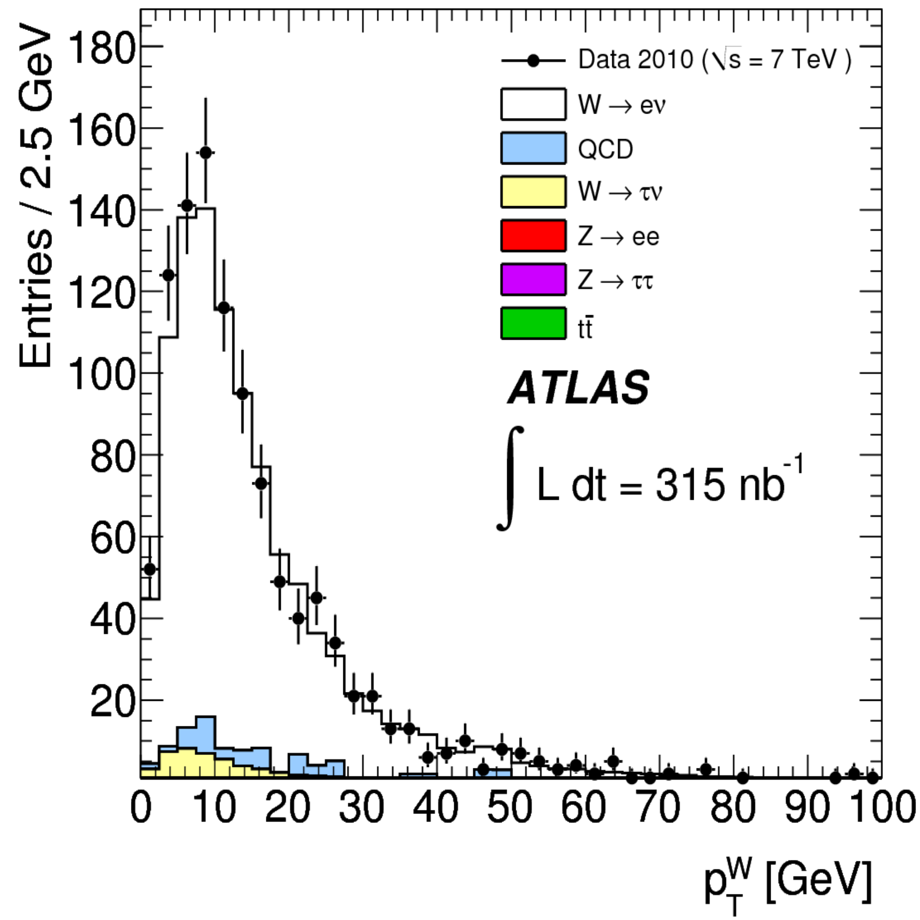


Transverse mass

Kinematics of selected candidates



Transverse energy of electron clusters after final selection



Transverse momentum of W candidates after final selection

W – μν background

$$N_{\mathrm{loose}} = N_{\mathrm{nonQCD}} + N_{\mathrm{QCD}}$$

$$N_{\mathrm{iso}} = \epsilon^{\mathrm{iso}}_{\mathrm{nonQCD}} N_{\mathrm{nonQCD}} + \epsilon^{\mathrm{iso}}_{\mathrm{QCD}} N_{\mathrm{QCD}},$$

Events without isolation requirement

“Isolated” events

Known from Z-μμ data

Known from MC

Estimated with data sample of muons with $15 < p_T < 20$ GeV (strongly background-dominated)

Systematic uncertainties

- Systematic uncertainty on the C_W correction factor is a combination of terms from various contributions:

Electron channel

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

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