W/Z boson production in muonic final states at the ATLAS experiment

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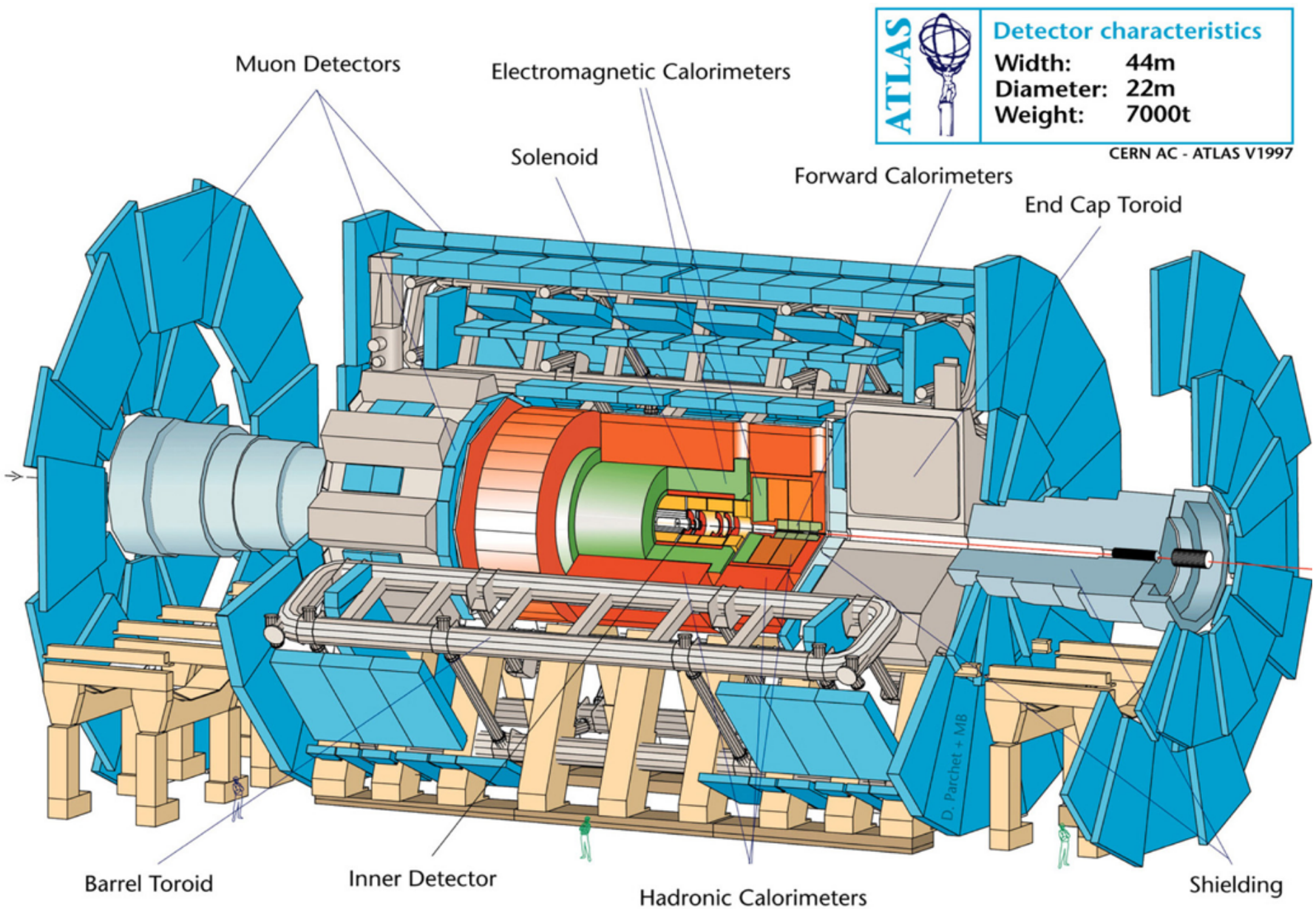
Motivations

- studying DY production of W and Z bosons is a strong benchmark for QCD
  - test perturbative calculations
  - constrain proton PDFs
- W, Z are standard high-p_T candles
  - study lepton reconstruction performances
  - production rate can be used for luminosity measurement
- necessary step towards new physics searches
  - detector and physics must be fully understood
  - electroweak signatures are starting point to chase new physics signatures

The ATLAS experiment



[ID]
B = 2 T, up to $|\eta| < 2.5$
$\sigma/pT \sim 3.4 \times 10^{-4}\ pT \oplus 0.015$

[ECAL]
up to $|\eta| < 3.2$
$\sigma/E \sim 10\%/\sqrt{E}$

[HCAL]
up to $|\eta| < 3.2$ (FCAL: 4.9)
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

[MS]
up to $|\eta| < 2.7$
$\sigma/p_T < 10\%$ up to 1 TeV

Measurement strategy

measuring W and Z/γ* $\sigma_{\text{tot}} = \sigma_{W/Z} \times BR(W/Z \to l\nu/ll) = \frac{N - B}{A_{W/Z} \cdot C_{W/Z} \cdot L_{\text{int}}}$

full 2010 pp data sample @ 7 TeV [~35 pb^{-1}]

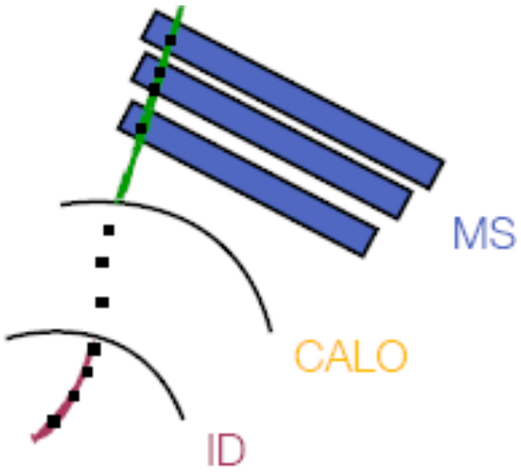
* $C_{W/Z}$: efficiency in the fiducial region (from data)
* $A_{W/Z}$: extrapolation to the full kinematic region (PYTHIA)
* background estimated from MC (EW) and data (QCD)

fiducial regions: [W] $p_{T,\mu} > 20$ GeV, $|\eta_\mu| < 2.4$, $p_{T,\nu} > 25$ GeV, $m_T > 40$ GeV
[Z/γ*] $p_{T,\mu} > 20$ GeV, $|\eta_\mu| < 2.4$, $66 < m_{\mu\mu} < 116$ GeV

→ 84103 W^+ (55162 W^-) candidates
→ 11669 Z candidates

(see http://cdsweb.cern.ch/record/1338570)

Muon reconstruction

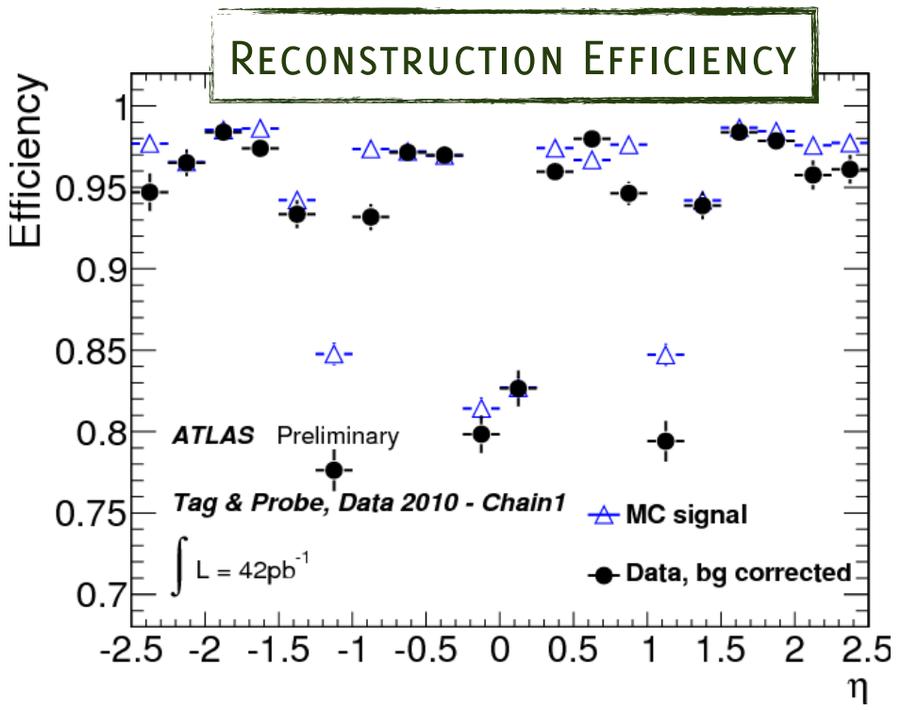


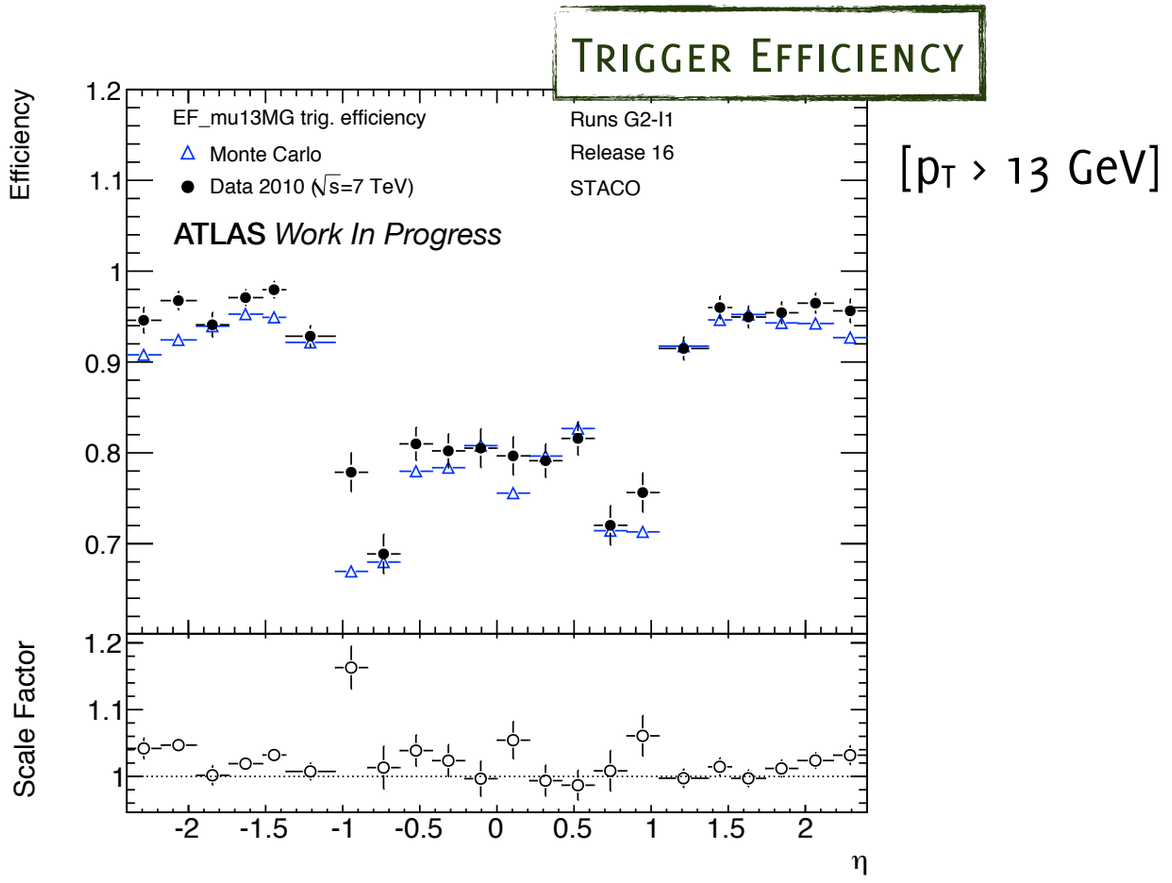
combination of tracks measured from ID and MS

for this analysis we restrict to $p_T > 20$ GeV, $|\eta| < 2.4$

requesting isolated muons ($\Sigma_{\Delta R<0.4} p_T(\text{tracks})/p_T(\mu) < 0.2$)

MC efficiencies are corrected to reproduce data

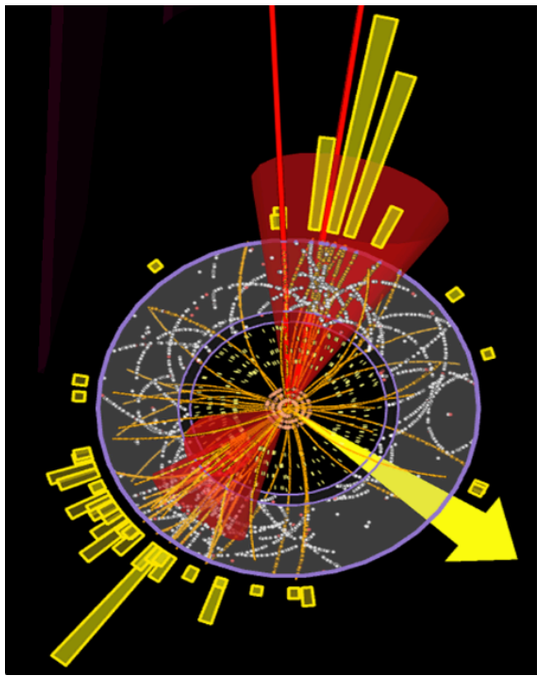




[$p_T > 13$ GeV]

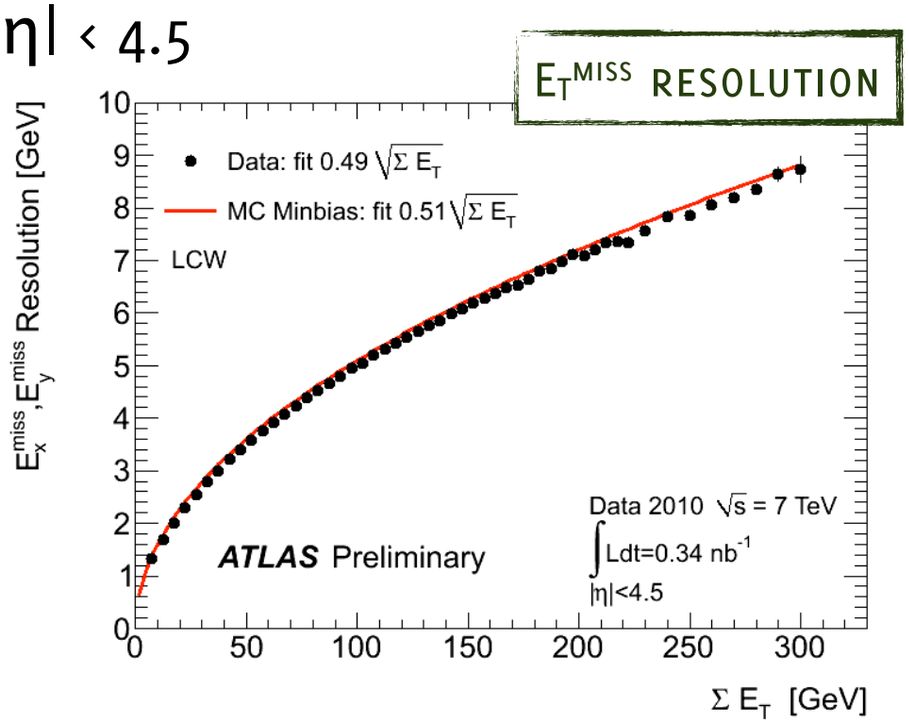
	trigger	reco	isolation
average efficiency	~85%	~92%	~99%

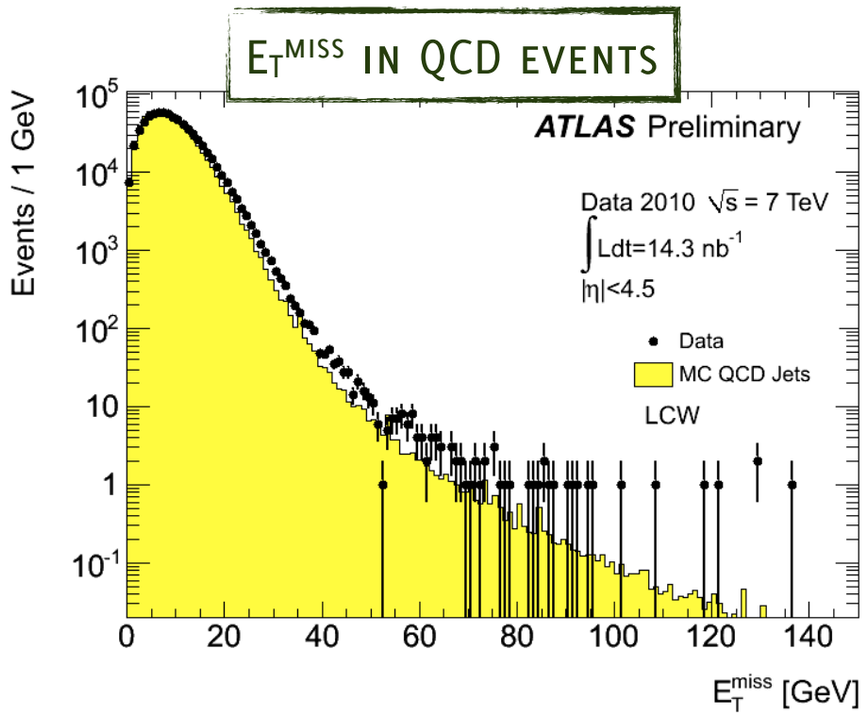
E_T^{miss} reconstruction



missing transverse energy is measured from CALO and MS

- ECAL/HCAL: reconstructed topological clusters
- MS: correction for muons
- calorimeter coverage up to $|\eta| < 4.5$





$$E_x^{miss} = E_x^{miss,\,calo} + E_x^{miss,\,muon}$$

$$E_y^{miss} = E_y^{miss,\,calo} + E_y^{miss,\,muon}$$

$$E_T^{miss} = [(E_x^{miss})^2 + (E_y^{miss})^2]^{1/2}$$

Background estimation

electroweak backgrounds

[W] $Z\to\mu\mu$, $W\to\tau\nu$, $t\bar{t}$, $Z\to\tau\tau$, diboson — ~7%

[Z/γ^*] diboson, $t\bar{t}$, $Z\to\tau\tau$, $W\to\mu\nu$ — ~0.4%

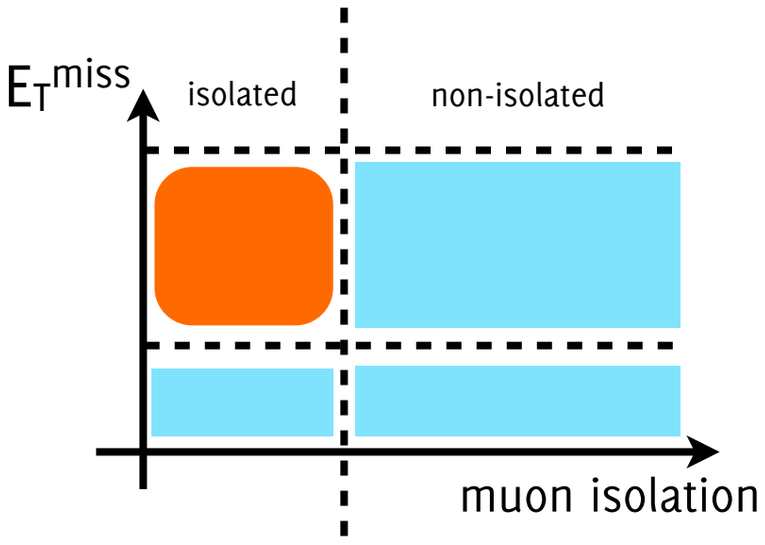
QCD backgrounds

heavy quark decays, π/K, fake muons

theoretical uncertainties: need a data-driven estimate

[W] 1.7±0.2±0.7%

[Z/γ^*] 0.22±0.16±0.09%

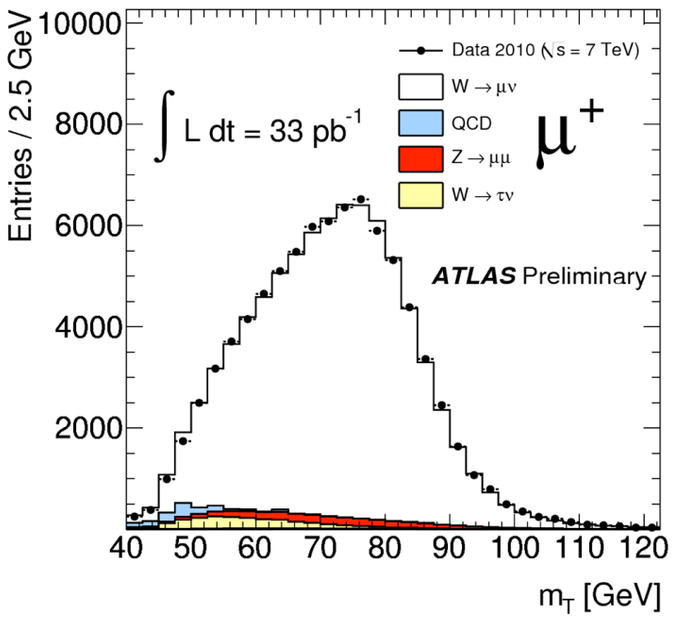


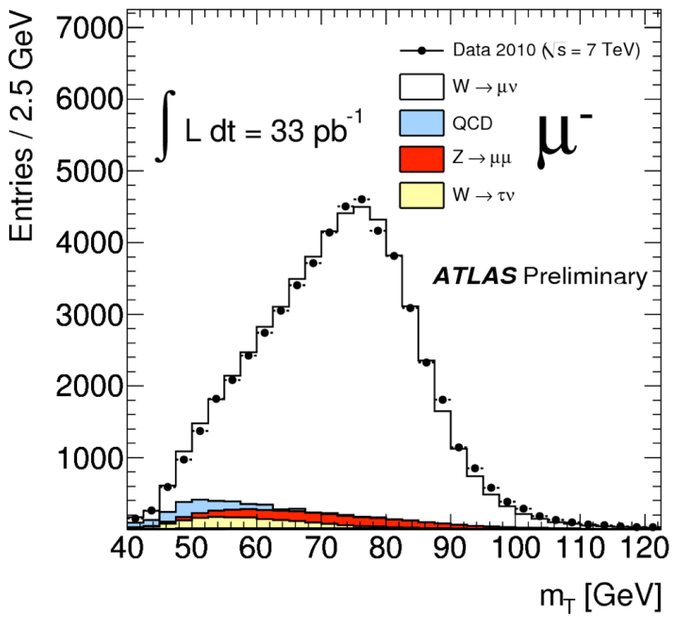
assume flat QCD in E_T^{miss} vs isolation space (uncorrelated)

obtain QCD in measurement region [orange]
extrapolating estimates in control regions [blue]

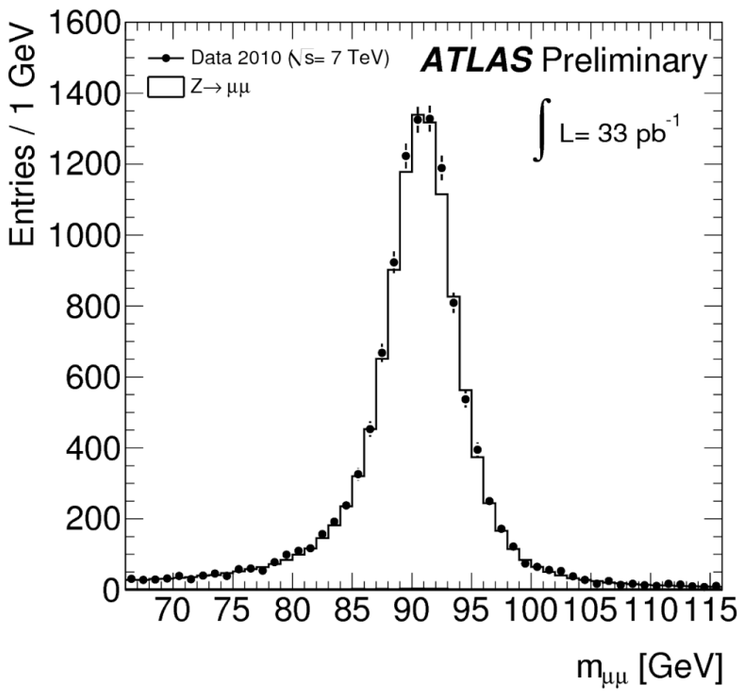
↪ similar method for $Z\to\mu\mu$ (using mass/isolation)

Results in the muon channels





	$\sigma^{\text{fid}}_{W^{(\pm)}} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$3.008 \pm 0.011(\text{sta}) \pm 0.080(\text{sys}) \pm 0.109(\text{lum})$
W^-	$1.950 \pm 0.009(\text{sta}) \pm 0.053(\text{sys}) \pm 0.072(\text{lum})$
W	$4.959 \pm 0.015(\text{sta}) \pm 0.120(\text{sys}) \pm 0.181(\text{lum})$
	$\sigma^{\text{tot}}_{W^{(\pm)}} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$6.215 \pm 0.023(\text{sta}) \pm 0.165(\text{sys}) \pm 0.225(\text{lum}) \pm 0.187(\text{acc})$
W^-	$4.107 \pm 0.020(\text{sta}) \pm 0.112(\text{sys}) \pm 0.152(\text{lum}) \pm 0.123(\text{acc})$
W	$10.322 \pm 0.030(\text{sta}) \pm 0.249(\text{sys}) \pm 0.377(\text{lum}) \pm 0.310(\text{acc})$
	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.456 \pm 0.004(\text{sta}) \pm 0.005(\text{sys}) \pm 0.015(\text{lum})$
	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.941 \pm 0.008(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.037(\text{acc})$



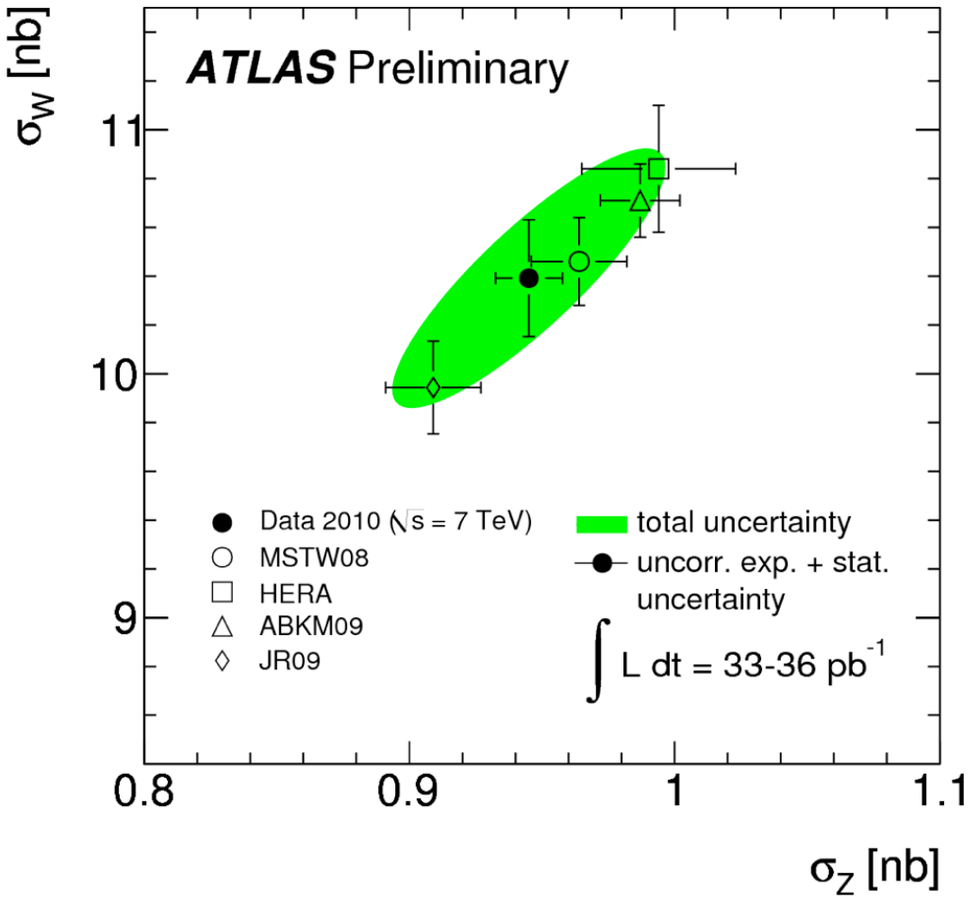
integrated measurement is dominated by systematics

good agreement with PYTHIA distributions

main systematics:

- W: E_T^{miss} resolution and scale (2%), QCD background (0.8%)
- Z/γ^*: muon reconstruction (0.8%) and isolation (0.6%)
- luminosity (3.4%)
- acceptance (theory) (~3/4%)

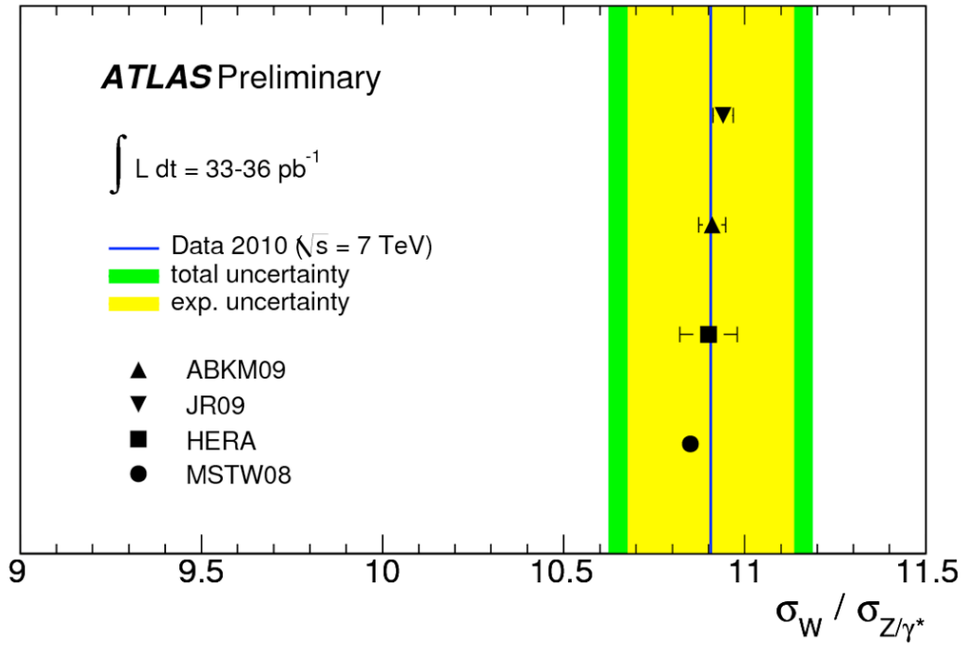
e/μ combined results



combining electron and muon channels

data consistent with NNLO predictions

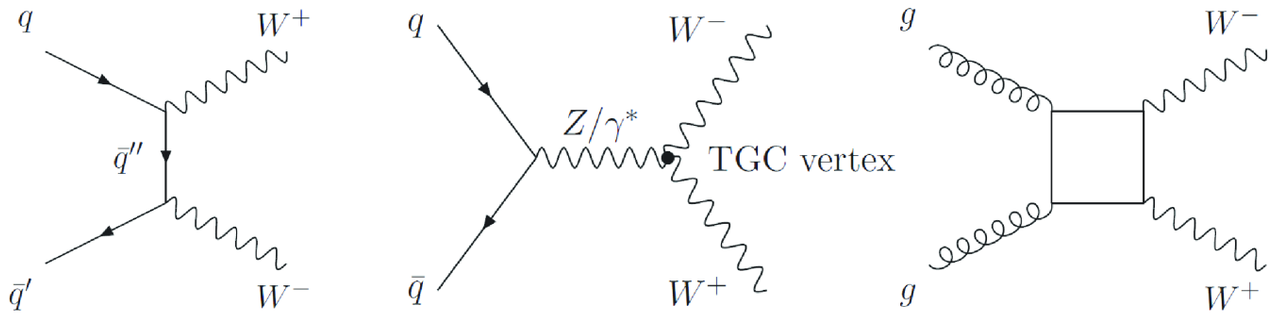
(http://arxiv.org/abs/1011.3540)



	$\sigma^{\text{tot}}_{W^{(\pm)}} \cdot \text{BR}(W \to \ell\nu)$ [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^*	$0.945 \pm 0.006(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.038(\text{acc})$

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	$10.906 \pm 0.079(\text{sta}) \pm 0.215(\text{sys}) \pm 0.164(\text{acc})$

Further steps: W^+W^-



↪ sensitive to TGC

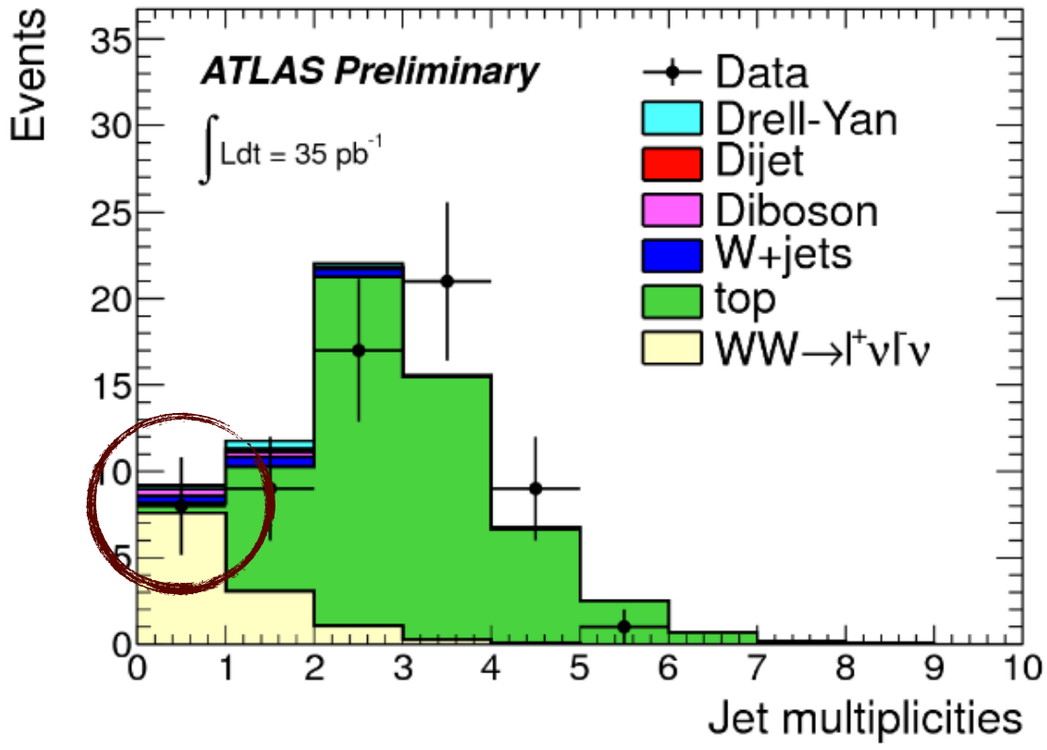
↪ dominant bkg to H→WW

(see http://cdsweb.cern.ch/record/1334877)

selection:

* opposite sign eμ/μμ/ee
* large E_T^{miss}
* Z mass veto
* jet veto (top bkg rejection)

	eμ	μμ	ee
events	5	2	1
s/b ratio	3.7	6.7	5.0



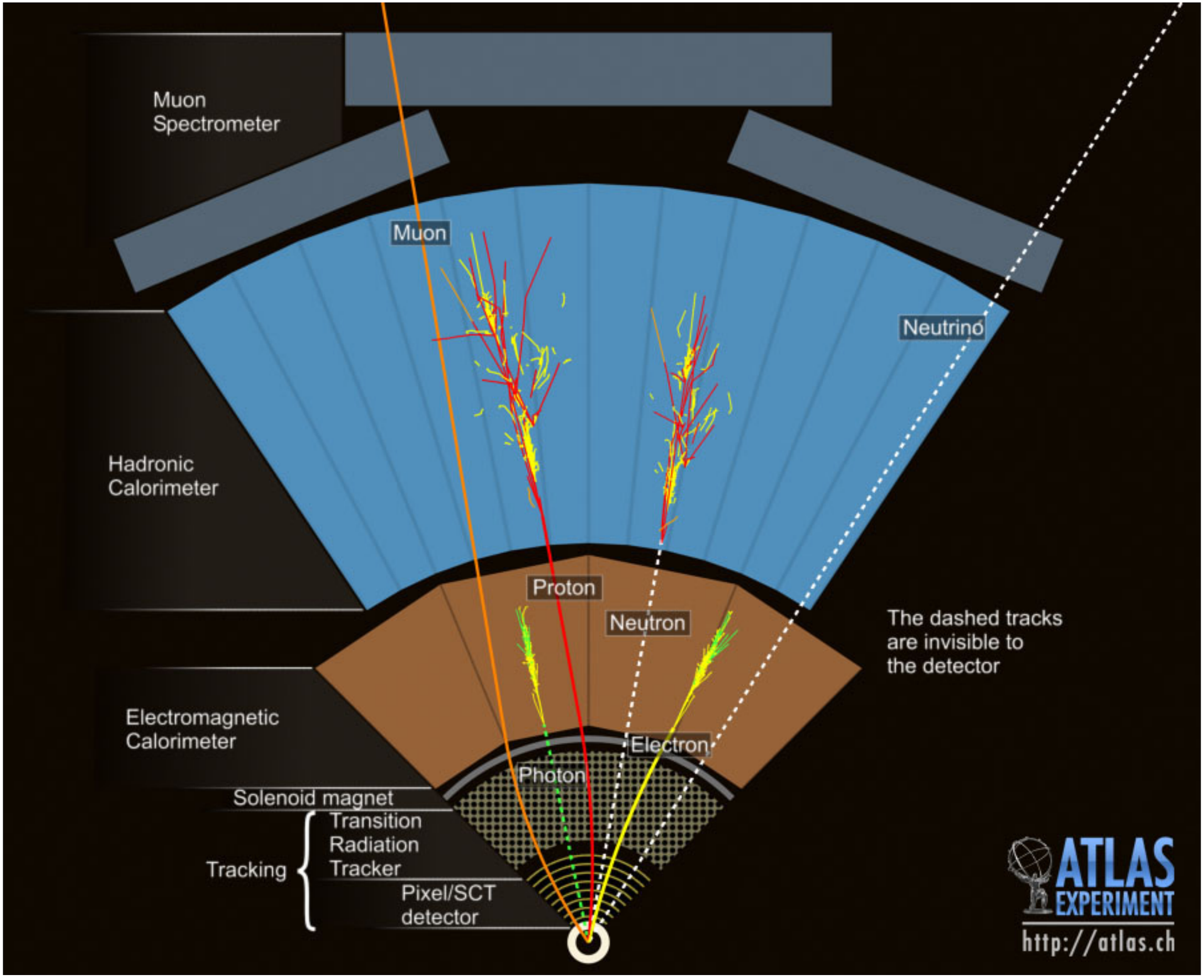
$\sigma_{WW} = 40^{+20}_{-16}(stat)\pm7(syst)$ pb

$[\sigma_{WW(NLO)} = 46\pm3$ pb$]$

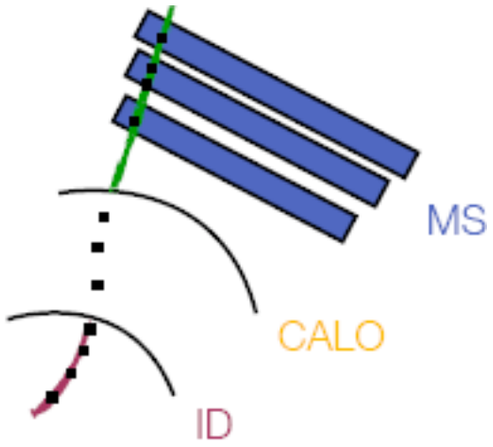
Conclusions and future steps

- W/Z cross section in muon channels
  - good agreement with simulation
- combination with electron channels
  - data consistent with NNLO predictions (different PDFs choice)
  - total experimental uncertainty at percent level (2.4% for $W^{\pm}$, 1.1% for Z)
  - theory (3-4%) and luminosity uncertainties (4%) already dominant
- differential measurements forthcoming
  - stronger constraints on proton PDFs
- next step: diboson
  - WW cross section measurement with 2010 data
  - more to come with 2011 improved statistics

Backup slides


Muon
Spectrometer
Muon
Neutrino
Hadronic
Calorimeter
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch

Detailed event selection



	$W^{\pm} \rightarrow \mu^{\pm}\nu$	$Z \rightarrow \mu^{+}\mu^{-}$
event selection	• ≥ 1 vertex (with ≥ 3 tracks) within 20 cm of the nominal position • p_T > 13 GeV muon trigger	
muons	• combined ID and MS reconstruction • p_T > 20 GeV, ID quality cuts, $\lvert z_0 \rvert$ < 10 mm • track based isolation (Σ_{ID} p_T (ΔR < 0.4) / $p_T(\mu)$ < 0.2)	
candidates	• MET > 25 GeV • m_T > 40 GeV	• muons of opposite charge • 66 < $m_{\mu\mu}$ < 116 GeV

Backgrounds to W/Z analyses

$W^{\pm} \rightarrow \mu^{\pm}\nu$		$Z \rightarrow \mu^{+}\mu^{-}$	
$Z \rightarrow \mu^{+}\mu^{-}$	[3.5%]	$t\bar{t}$	[0.1%]
$W^{\pm} \rightarrow \tau^{\pm}\nu$	[2.8%]	$Z \rightarrow \tau^{+}\tau^{-}$	[0.07%]
$Z \rightarrow \tau^{+}\tau^{-}$	[0.1%]	$W^{\pm} \rightarrow \mu^{\pm}\nu$	[0.006%]
$t\bar{t}$	[0.4%]	WW/WZ/ZZ	[0.2%]
WW/WZ/ZZ	[0.1%]		
QCD (heavy quarks, π/K, fakes)	[1.7±0.2±0.7%]	QCD (heavy quarks, π/K, fakes)	[0.22±0.16±0.09%]

QCD backgrounds are extracted from data control regions

Detailed systematics [%]

	$\delta\sigma_W/\sigma_W$	$\delta\sigma_{W+}/\sigma_{W+}$	$\delta\sigma_{W-}/\sigma_{W-}$	$\delta\sigma_Z/\sigma_Z$
Trigger	0.7	0.8	0.9	0.1
Muon Reconstruction	0.5	0.6	0.6	0.8
Muon Isolation	0.3	0.3	0.3	0.6
Muon p_{T} Resolution	0.02	0.03	0.02	0.01
Muon p_{T} Scale	0.4	1.1	0.8	0.2
QCD Background	0.8	0.7	1.1	0.1
Electroweak Background	0.4	0.4	0.5	0.02
$E_{\mathrm{T}}^{\mathrm{miss}}$ Cleaning	0.07	0.07	0.07	-
$E_{\mathrm{T}}^{\mathrm{miss}}$ Resolution and Scale	2.0	2.0	2.0	-
$C_{W/Z}$ Theoretical uncertainty	0.3	0.3	0.3	0.3
Total experimental uncertainty	2.4	2.7	2.7	1.1
$A_{W/Z}$ Theoretical uncertainty	3.0	3.0	3.0	4.0
Total excluding Luminosity	3.9	4.0	4.0	4.1
Luminosity	3.4			

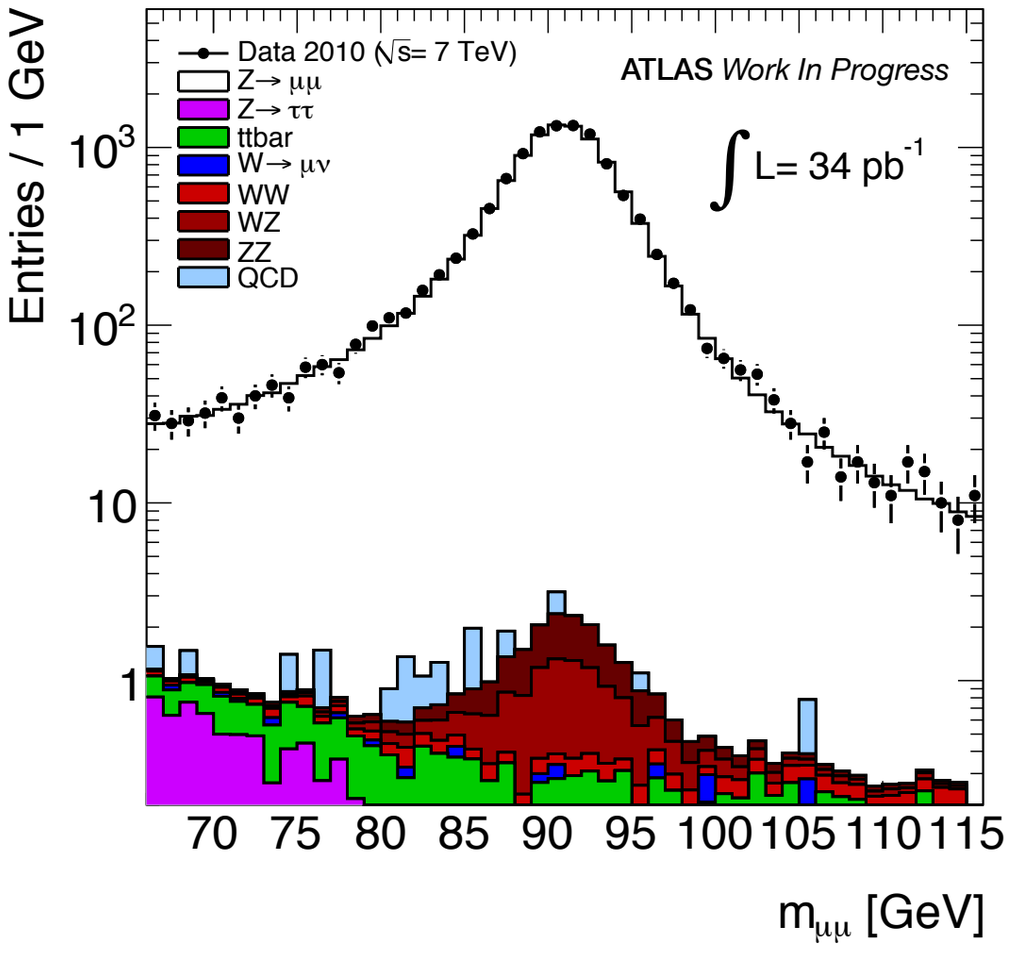
[systematics on acceptances and luminosity are treated as correlated in W/Z comparison]

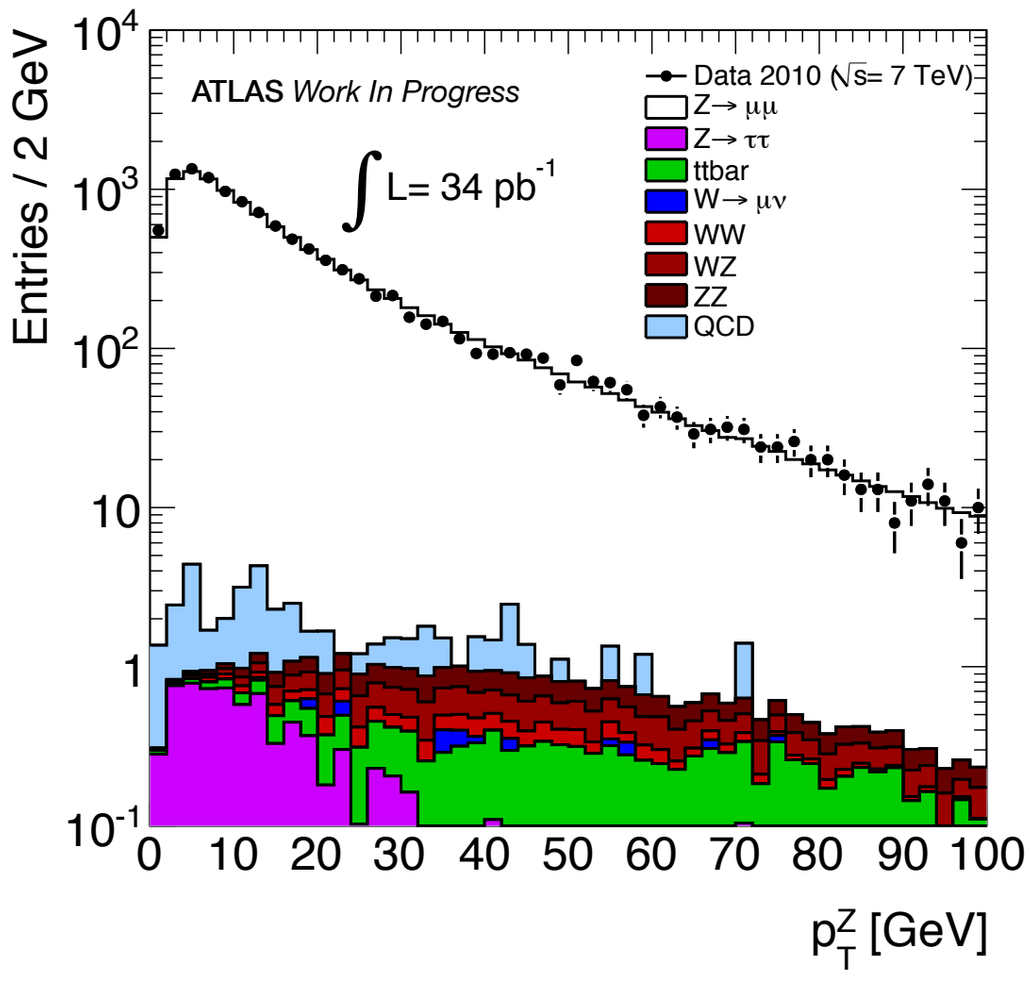
Acceptance systematics

method	$A_{W/Z}$ systematics [%]		
	W^+	W^-	Z/γ^*
CTEQ6.6 set @ 90% C.L, MC@NLO	1	1.8	1.6
MRST LO* / CTEQ6.6 / HERAPDF 1.0 sets, PYTHIA	2.7	0.9	2.0
CTEQ6.6 set, PYTHIA / MC@NLO	0.4	1.4	2.3
overall	3		4

(see http://arxiv.org/abs/1010.2130v1)

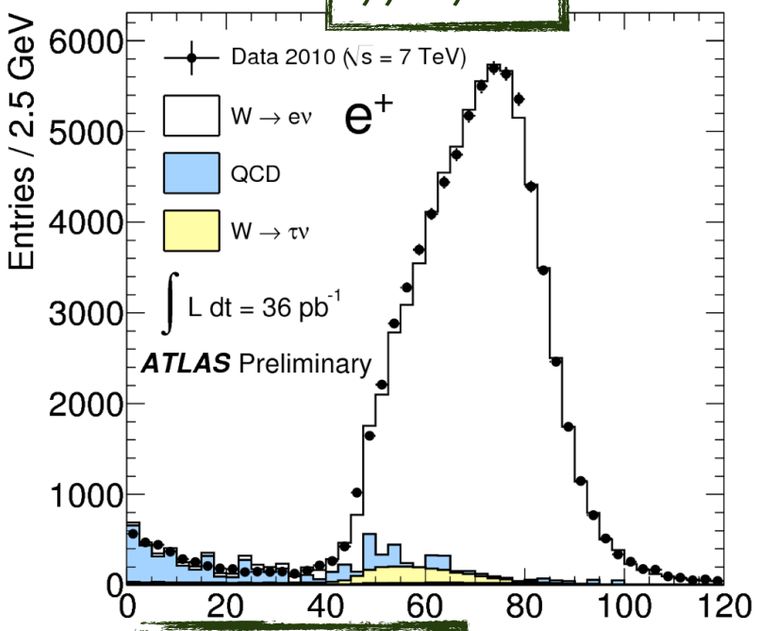
$Z \rightarrow \mu^+\mu^-$ kinematics



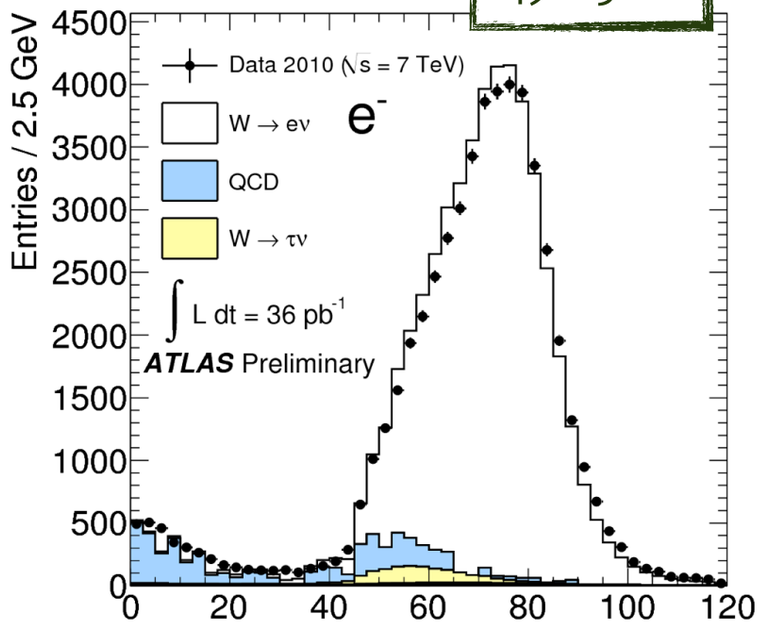


Electron channels [E_T > 15 GeV electron trigger]

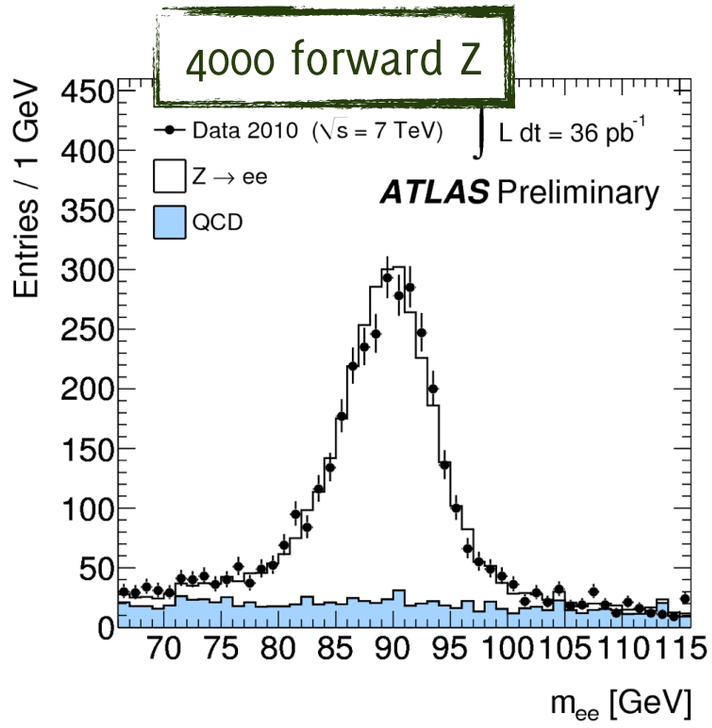
77207 W^+



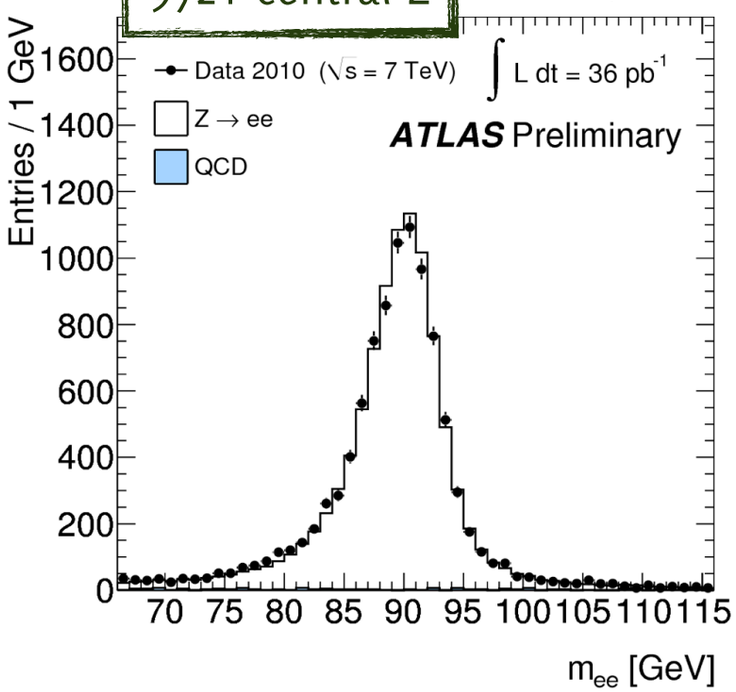
49103 W^-



4000 forward Z



9721 central Z



$e^{\pm}$: p_T > 20 GeV, $|\eta|$ < 2.47
excluding crack [1.37, 1.52]

W: E_T^{miss} > 25 GeV,
m_T > 40 GeV, tight $e^{\pm}$

Z: two medium $e^{\pm}$,
66 < m_{ee} < 116 GeV

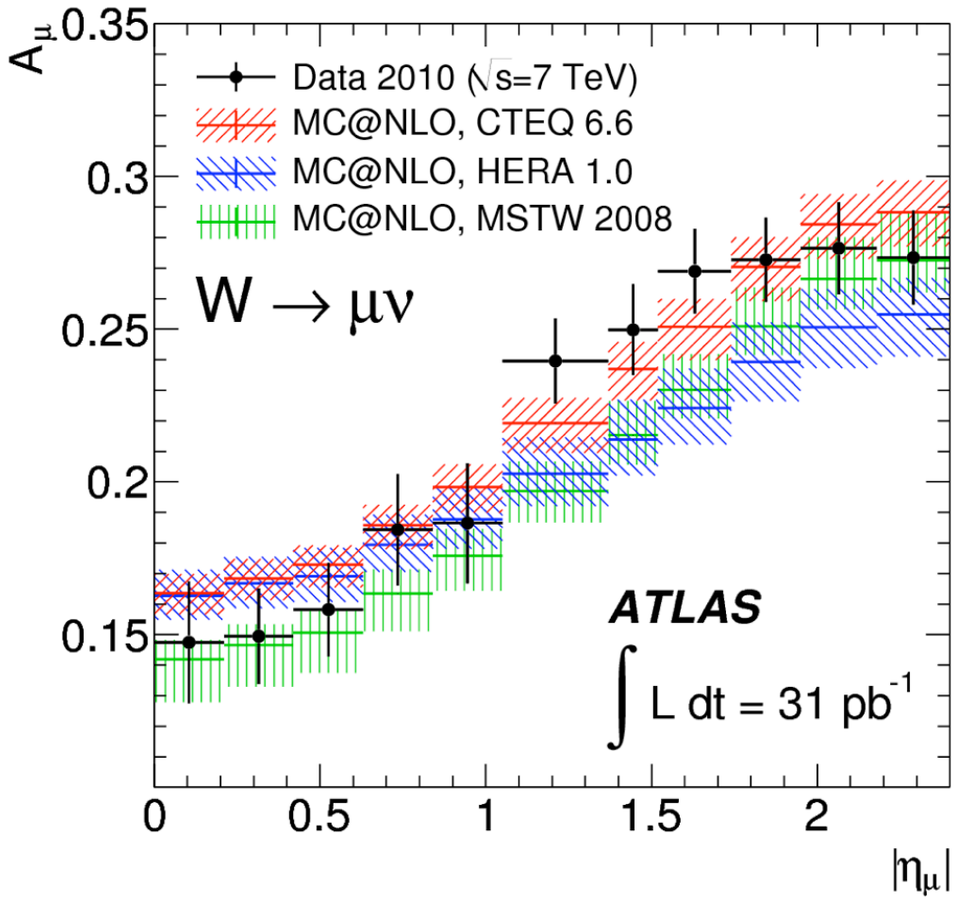
forward Z: tight electron,
second in 2.5 < $|\eta|$ < 4.9

~10% uncertainty,
not used in combination

	$\sigma^{fid}_{W^{(\pm)}} \cdot BR(W \to e\nu)$ [nb]
W^+	$2.950 \pm 0.011(sta) \pm 0.090(sys) \pm 0.100(lum)$
W^-	$1.927 \pm 0.009(sta) \pm 0.059(sys) \pm 0.063(lum)$
W	$4.877 \pm 0.015(sta) \pm 0.138(sys) \pm 0.166(lum)$
	$\sigma^{tot}_{W^{(\pm)}} \cdot BR(W \to e\nu)$ [nb]
W^+	$6.333 \pm 0.025(sta) \pm 0.193(sys) \pm 0.215(lum) \pm 0.190(acc)$
W^-	$4.217 \pm 0.021(sta) \pm 0.129(sys) \pm 0.138(lum) \pm 0.127(acc)$
W	$10.551 \pm 0.032(sta) \pm 0.300(sys) \pm 0.359(lum) \pm 0.316(acc)$
	$\sigma^{fid}_{Z/\gamma^*} \cdot BR(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^* Central	$0.433 \pm 0.004(sta) \pm 0.016(sys) \pm 0.015(lum)$
Z/γ^* Forward	$0.179 \pm 0.004(sta) \pm 0.017(sys) \pm 0.006(lum)$
	$\sigma^{tot}_{Z/\gamma^*} \cdot BR(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV
Z/γ^* Central	$0.972 \pm 0.010(sta) \pm 0.034(sys) \pm 0.033(lum) \pm 0.038(acc)$
Z/γ^* Forward	$0.903 \pm 0.022(sta) \pm 0.087(sys) \pm 0.031(lum) \pm 0.035(acc)$

$W^{\pm}$ charge asymmetry

- sensitive to valence quark distributions
  - access u/d below x ~ 0.05
- same selection criteria as in W integrated cross-section measurement
  - efficiency charge dependence has been checked
  - MC muon p_T scale and resolution corrected for each charge
- data compatible with all PDF sets so far
  - expect to contribute in PDF uncertainty reduction, particularly for valence quarks at low x



$$A_\mu = \frac{d\sigma_{W\mu^+}/d\eta_\mu - d\sigma_{W\mu^-}/d\eta_\mu}{d\sigma_{W\mu^+}/d\eta_\mu + d\sigma_{W\mu^-}/d\eta_\mu}$$

(see http://arxiv.org/abs/1103.2929)