First measurement of the W-boson mass with the ATLAS detector

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Motivation

- The electroweak sector of the SM is constrained by three parameters.
- The particularly useful set is:

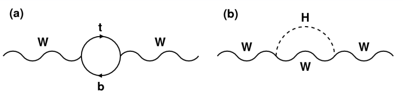
Fermi constant	$G_F = 1.16637(1) \times 10^{-5}$ GeV^{-2}
Fine structure constant	$\alpha = 1/137.03599911(46)$
Z-boson mass	$M_Z = 91.1876(21)$ GeV

- At tree-level, M_W is related as

$$M_W^2(1 - M_W^2/{M_Z}^2) = \frac{\pi\alpha}{\sqrt{2}G_F}$$

- However, there are higher order corrections (bosonic, fermionic loops). Examples of top-quark and Higgs boson contributions:

$\delta M_W \sim m_t^2$



$\delta M_W \sim \log M_H$

- Thus, M_W depends on other parameters in the SM

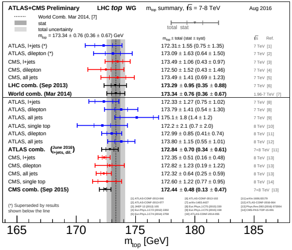
$$M_W^2(1 - M_W^2/{M_Z}^2) = \frac{\pi\alpha}{\sqrt{2}G_F(1-\Delta r)} \qquad \Delta r(m_t^2, \ln(M_H), M_W, M_Z, ...)$$

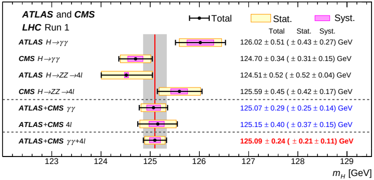
Motivation

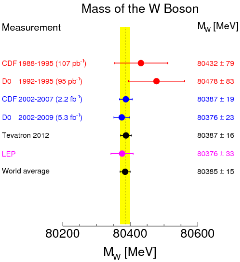
- Now the EW sector of SM is overconstrained → test the consistency via **global EW fit**
  → Measure SM observables
  → Fit SM relations to these measurements
- Many EW parameters are measured better than SM predictions

	measurement [GeV]	**prediction** [GeV]
M_H	125.09±0.24	102.8±26.3
m_t	172.84±0.70	176.6±2.5
M_W	80.385±0.015	80.360±0.008

- Huge activity and progress in measurements of m_t and M_H at LHC
- Last update of M_W by Tevatron in 2012

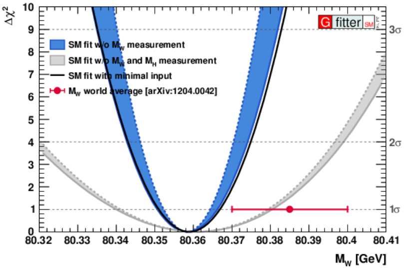






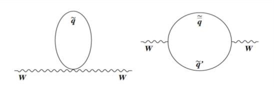
Motivation

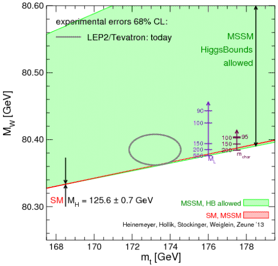
- Consistency test of the SM through M_W ($M_H = 125.09 \pm 0.24$, $m_t = 173.34 \pm 0.76$):
  SM prediction: 80.360±0.008
  World average exp.: 80.385±0.015
- Agreement within $\sim 1.6\sigma$
- **Objective:** experimental precision of about 8 MeV



Beyond-Standard-Model physics?

- New BSM particles could also be in these loops:



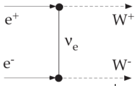


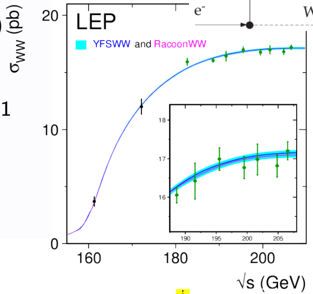
- 100-2000 GeV SUSY particles could contribute 100-200 MeV to M_W
- Precise M_W could place limits to such scenarios

Previous measurements

CERN

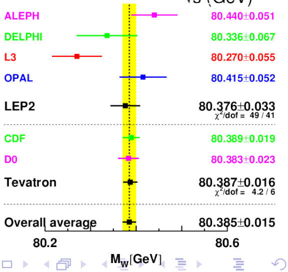
- 1981: W-boson **discovery** in UA1 and UA2 ($p\bar{p}-$collider) $\rightarrow$ few W events = few GeV accuracy in M_W
- 1995-2000: LEPII, two methods:
  - Scan of $\sigma(e^+e^- \rightarrow W^+W^-)$ at the treshold ($\sqrt{s} = 161$ GeV)
  - Reconstruct the invariant mass above treshold ($\sqrt{s} = 161 - 209$ GeV) using $WW \rightarrow q\bar{q}q\bar{q}$ and $q\bar{q}l\bar{\nu}_l$ channels





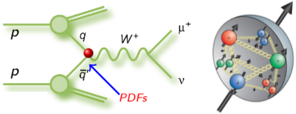
TeVatron from Run 2

- 2002-2011: $p\bar{p}-$collider $\sqrt{s} = 1.96$ TeV, two detectors
- $W \rightarrow l\nu$ decay channel, $l = e, \mu$
- Best M_W measurement from CDF: 80.387±0.019 GeV
- Combined TeVatron: 80.389±0.016 GeV

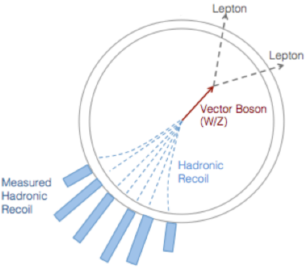


Difficulties in hadron colliders

- Dominant process is jet production → **background**
- W decays to quarks or leptons, but BKG is lower in lepton channel
- W production occurs via
  W^{+} from $u\bar{d} + u\bar{s} + u\bar{b} + \ldots$
  W^{-} from $d\bar{u} + d\bar{c} + s\bar{u} + \ldots$
- Precise knowledge of **PDFs** is required



- W and Z bosons are produced with gluons (**hadronic recoil**)
- Recoil gives rise to $p_T^{W,Z}$ component (momenta balance)
- **QCD** at non-perturbative (low $p_T^{W,Z}$) and perturbative (high $p_T^{W,Z}$) regimes
- Need to be controled at sub-% level



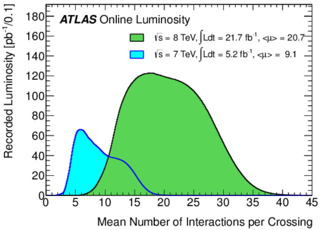
Tevatron results and LHC prospects

Source	CDF	D0
Lepton calibration	7	17
Recoil calibration	6	5
Backgrounds	3	2
PDFs	10	11
p_T^W modeling	5	2
QED radiation	4	7
Statistical	12	13
Total	**19**	**26**

- **D0:** 5.3 fb^{-1}, 1.7M events, $W \to e\nu$
- **CDF:** 2.2 fb^{-1}, 1.1M events, $W \to e\nu, \mu\nu$
- Dominant experimental: lepton+recoil
- Dominant physics modeling: PDFs

- LHC as W and Z factory: largest number of $W \to l\nu$ and $Z \to ll$ events
- W's in ATLAS:

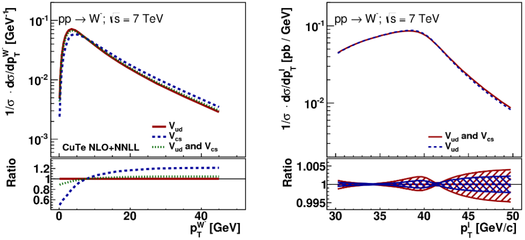
$\sqrt{s}$	7 TeV	8 TeV	13 TeV
Luminosity	4.6 fb^{-1}	20 fb^{-1}	30 fb^{-1}
W sample	15 M	80 M	190 M



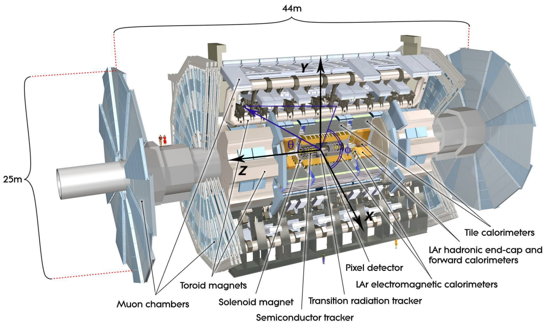
Challenges @LHC

Main differences between Tevatron and LHC

- Higher **pile-up** enviroment complicates the **hadronic recoil** calibration
- Larger role of sea-quarks in W-boson production
  W^+ from $u\bar{d} + u\bar{s} + u\bar{b} + ...$
  W^- from $d\bar{u} + d\bar{c} + s\bar{u} + ...$
  $\rightarrow$ Implies larger uncertainty on the lepton p_T distribution
- Assymetric production of W^+ and W^- $\rightarrow$ charge-dependent analysis
- Large role of heavy 2^{nd}−genereation quarks ($\sim$ 25% of W's produced from s or c)
  $\rightarrow$ implies larger uncertainty from modeling of p_T^W and W-polarisation
- Z-boson production still dominates by light quarks



The ATLAS detector

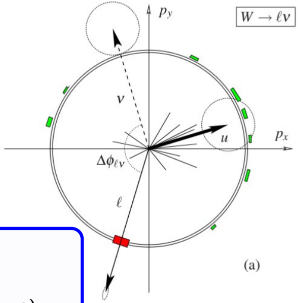


Pseudorapidity: $\eta = -\log[\tan(\theta/2)]$

	A Toroidal LHC ApparatuS
Magnets	Solendoid, three toroids
Inner Detector (ID)	Silicon (Pixel and SCT) + gaseous transition radiation tracker (TRT)
EM Calorimeter	Sampling LAr technology with accordion geometry, Pb absorbers
Hadronic Calorimeter	Plastic scintilator + LAr
Muon Spectrometer	Independent sub-detector designed to detect muons
Trigger	3 levels (1^{st} level is hardware)

Strategy of W-mass measurement

- Leptonic decays are used: $W \to l\nu$, $l = e, \mu$
- Basic objects: **lepton**(l) **and hadronic recoil**(u)



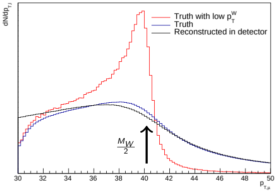
Object reconstruction

- **Muons**
  - Combined ID+MS
  - Muon p_{T} is measured from ID track (for this measurement)
- **Electrons**
  - Identification based on EM shower shapes and track/Calo matching
  - η and ϕ measured in ID
  - Transverse energy p_{T}^{e} obtained from cluster energy
- **Recoil** $\vec{u}$ = vector sum of all calorimeter clusters excluding cone around the signal lepton, and replaced by energy from another cone (same $|\eta|$, different ϕ)

Strategy of W-mass measurement

- Use observables sensitive to M_W:

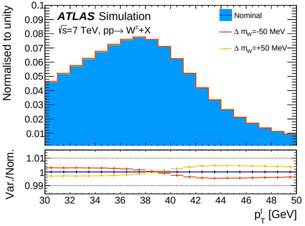
Lepton transverse momentum	p_T^l
Neutrino transverse energy	$E_T^\nu = \lvert \vec{p_T^\nu} \rvert, \vec{p_T^\nu} = -(\vec{p_T^l} + \vec{u})$
Transverse mass	$m_T^W = \sqrt{2 p_T^l p_T^\nu (1 - \cos \Delta\phi_{l\nu})}$

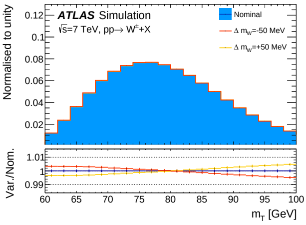


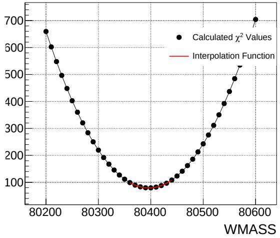
Note: p_T^l is smeared by non-vanishing p_T^W due to additional radiation

Template fit method:

- The p_T^l, m_T^W and E_T^{miss} distributions are computed with MC for different values of M_W
- Each template is compared to data
- The template which minimizes the χ^2 gives the preferred value of M_W







Measurement setup

- Lepton selections
  - **Muons:** $|\eta| < 2.4$; isolated (track-based)
  - **Electrons:** $|\eta| < 1.2$ or $1.8 < |\eta| < 2.4$; isolated (track+calorimeter-based)
- W kinematics
  - $p_T^l > 30$ GeV, $\not{E}_T > 30$ GeV
  - $u_T < 30$ GeV, $m_T^W > 60V$ GeV
- 7.8M $W \to \mu\nu$ and 5.9M $W \to e\nu$ events
- Background fraction: 5% in mu-channel; 6.5% in e-channel

- Simulation
  - W and Z productions: Powheg+Pythia (NLO QCD+PS); QED FSR using PHOTOS
  - Backgrounds: Herwig and MC@NLO
- Residual Data/MC discrepancies are corrected using known Z-resonance

Measurement categorization

Measurement methods and categories:

- Two observables: p_T^l and m_T^W for W mass extraction
- Perform measurement separately for $\mu-$ and $e-$channels, W^+ and W^-, and lepton η categories
  - $\rightarrow$ Results in $\mu-$ and $e-$channels provide a test of the experimental calibrations
  - $\rightarrow$ Results in W^+ and W^-, and lepton $|\eta|$ categories test the W production model

Channel	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$
Fitting observables	$p_T^e,\ m_T^W$	$p_T^\mu,\ m_T^W$
Charge-categories	+; -	+;-
$\lvert\eta\rvert$-categories	$[0, 0.6]$; $[0.6, 1.2]$; $[1.8, 2.4]$	$[0, 0.8]$; $[0.8, 1.4]$; $[1.4, 2.0]$; $[2.0, 2.4]$

- **In total:** 28 separate measurements

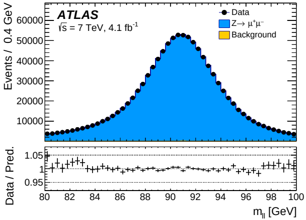
Calibration corrections

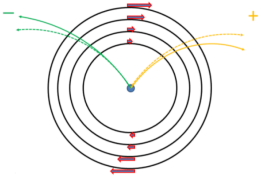
Muon calibration

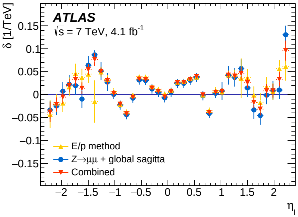
- Correct for imperfect knowledge of magnetic field, material, detector alignment
- Momentum scale and resolution corrected to match well-known M_Z and Γ_Z in $Z \to \mu\mu$ events
- Accuracy: $\delta\alpha \sim 0.5 \cdot 10^{-4}$
- Track sagitta bias δ correction (rotational detector deformation)

$$p_T^{\text{data,corr}} = \frac{p_T^{\text{data}}}{1+q\cdot\delta(\eta,\phi)\cdot p_T^{\text{data}}}$$

- Best controlled with E/p difference between e^+ and e^- fror $W \to e\nu$ events
- Sagitta effect important for M_{W^+}/M_{W^-} consistency

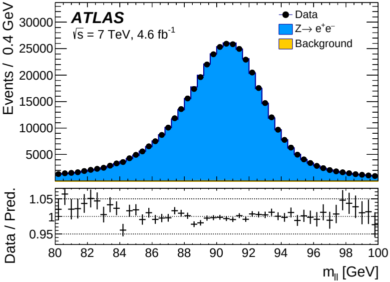


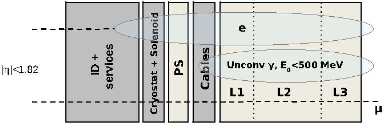




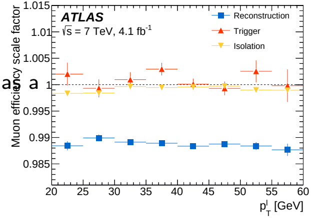
Electron calibration

- Difficult to predict the calorimeter response
- Main calibration steps:
  - Corrected response of different EM calorimeter layers to muons
  - Material effects corrected using longitudinal shower profiles of electrons (E_{PS} vs E_{L1}/E_{L2} correlation)
- Energy scale and resolution corrected to describe m_{ee} peak $Z \to ee$ events
- Excluded crack region $1.2 < |\eta| < 1.8$: large amount of passive material
- Accuracy: $\delta\alpha \sim 10^{-4}$



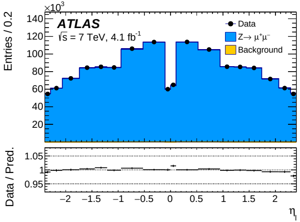


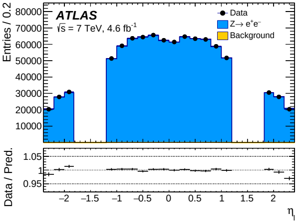
Efficiency corrections



- **Muons:** Reconstruction, isolation, trigger efficiency corrections
- Corrections based on $Z \to \mu\mu$ samples (relaxed one leg as a probe)
- Derived in bins of $\eta \times \phi$ and p_T^{μ})

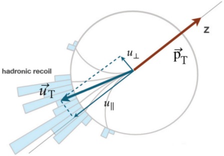
- **Electrons:** Reconstruction, identification, trigger and isolation efficiency corrections rely on arXiv:1404.2240.
- Corrections based on $Z \to ee$, $J/\psi \to ee$, $W \to e\nu$ samples
- Derived in bins of E_T and η
- Important for control of Jacobian peak in p_T^l

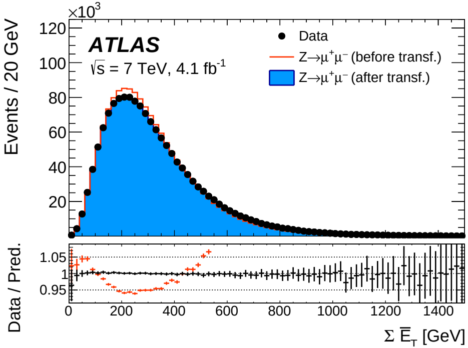


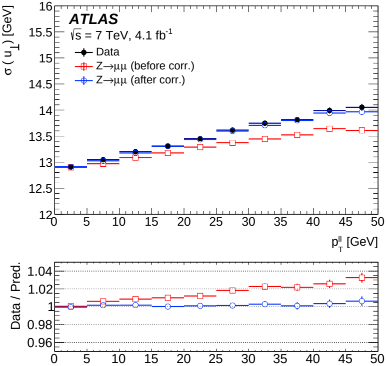


Hadronic recoil corrections

- Equalize event activity in data and MC (Number of pile-up interactions, ΣE_T)
- Residual recoil scale and resolution corrections based on parallel and perpendicular projections to Z direction
- Apply to W events (account for uncertainty in $Z \to W$ extrapolation)







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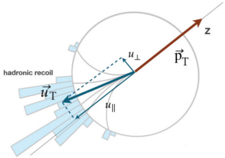
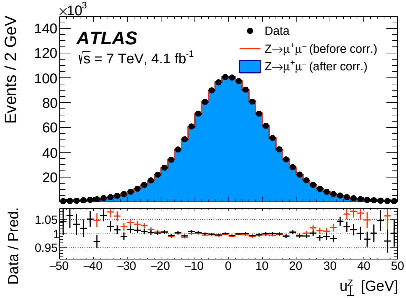
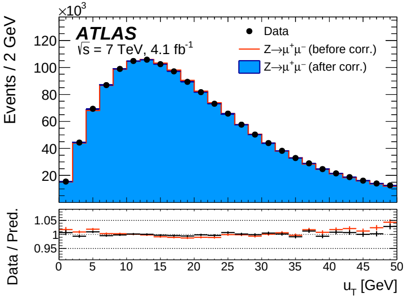






Impact on M_W measurement

Electrons

$\|\eta_\ell\|$ range Kinematic distribution	Combined p_T^ℓ	 m_T
δm_W [MeV]		
Energy scale	8.1	8.0
Energy resolution	3.5	5.5
Energy linearity	3.4	5.5
Energy tails	2.3	3.3
Reconstruction efficiency	7.2	6.0
Identification efficiency	7.3	5.6
Trigger and isolation efficiencies	0.8	0.9
Charge mismeasurement	0.1	0.1
Total	14.2	14.3

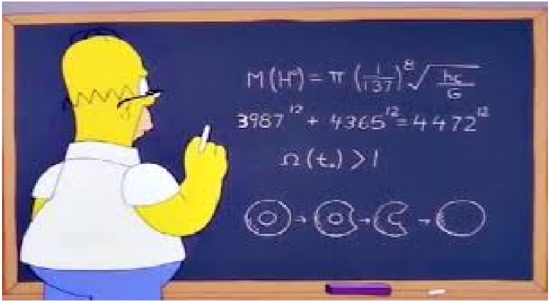
Muons

$\|\eta_\ell\|$ range Kinematic distribution	Combined p_T^ℓ	 m_T
δm_W [MeV]		
Momentum scale	8.4	8.8
Momentum resolution	1.0	1.2
Sagitta bias	0.6	0.6
Reconstruction and isolation efficiencies	2.7	2.2
Trigger efficiency	4.1	3.2
Total	9.8	9.7

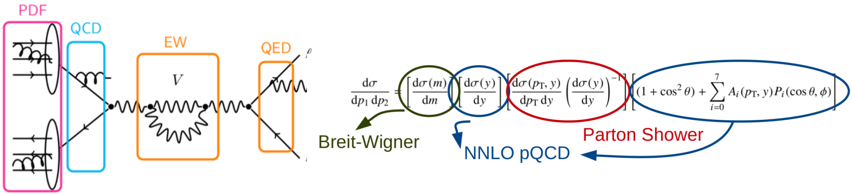
Recoil

W-boson charge Kinematic distribution	Combined p_T^ℓ	 m_T
δm_W [MeV]		
$\langle\mu\rangle$ scale factor	0.2	1.0
$\Sigma\bar{E}_T$ correction	1.0	11.2
Residual corrections (statistics)	2.0	2.7
Residual corrections (interpolation)	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.1
Total	2.6	13.0

Physics modeling



Physics modeling

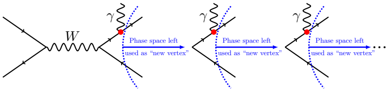


$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T,y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]\left[(1+\cos^2\theta)+\sum_{i=0}^{7}A_i(p_T,y)P_i(\cos\theta,\phi)\right]$$

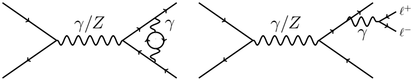
- No available generator can describe all these effects
- As starting point, we use **PowhegPythia** generator
- Corrections to **PowhegPythia** are based on factorization of fully differential leptonic DY cross section into 4 pieces:
  - Variation of $d\sigma/dm$ is modeled with Breit-Wigner+EW corrections
  - The $d\sigma/dp_T$ is modeled with parton shower MC
  - The $d\sigma/dy$ and A_i (describe spin correlations) are modeled with NNLO QCD predictions
- A model in each part is constrained using experimental measurements of Z and W production
- **Note:** the corrections are applied through (p_T, y, A_i) reweighting to insure a correct reweighting of p_T^l, m_T^W, η

Electroweak corrections

- Effects present in MC simulation:
  → FSR (dominant effect)



- Missing effects:
  → fermion pair emmision
  → NLO EW corrections

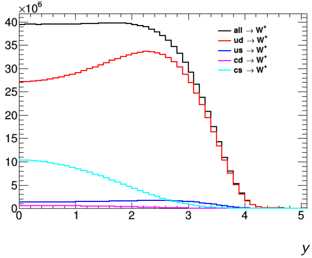


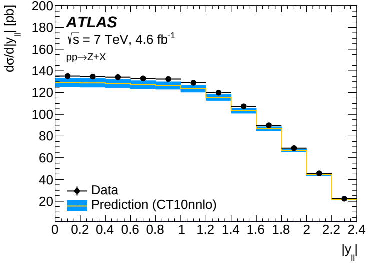
- Related uncertainties estimated using dedicated MC (Winhac)

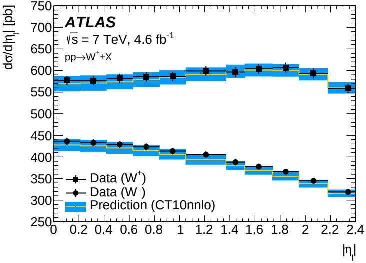
Kinematic distribution	p_T^e	$m_T^{e\nu}$	p_T^ν	p_T^μ	$m_T^{\mu\nu}$
δm_W [MeV]					
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
FSR (pair production)	3.6	0.8	< 0.1	4.4	0.8
Pure weak and IFI corrections	3.3	2.5	0.6	3.5	2.5
Total [MeV]	4.9	2.6	0.6	5.6	2.6

Rapidity distributions

- Modeled with NNLO QCD predictions using DYNNLO
- PDF set **CT10nnlo**: best agreement with 7 TeV data (sub-% precision measurement) that shows enhanced strage-density (arXiv:1612.03016)
- Envelope of CT14 and MMHT considered as uncertainty, other PDF sets are excluded by data
- Predictions validated with W^+, W^- and Z data: $\chi^2 = 45/34$ satisfactory





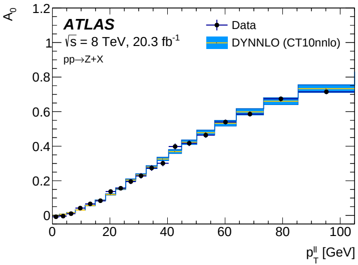


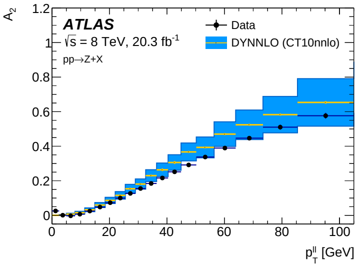
Angular coefficients A_i

- Fully differential cross section for spin-1 boson production, to all orders:

$$\frac{d\sigma}{dp_T^Z\, dy^Z\, dm^Z\, d\cos\theta\, d\phi} = \frac{3}{16\pi}\frac{d\sigma^{U+L}}{dp_T^Z\, dy^Z\, dm^Z} \Big\{(1+\cos^2\theta) + \frac{1}{2} A_0(1-3\cos^2\theta) + A_1 \sin 2\theta \cos\phi + \frac{1}{2} A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta + A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi\Big\}.$$

- A_i's are modeled with NNLO QCD predictions using DYNNLO
- Predictions are validated by comparisons to the Z measurement at 8 TeV (arXiv:1606.00689)
- Propagated from Z to W (differences are determined by well-known vector and axial couplings)
- Uncertainties: experimental uncertainty + observed discrepancy for A_2

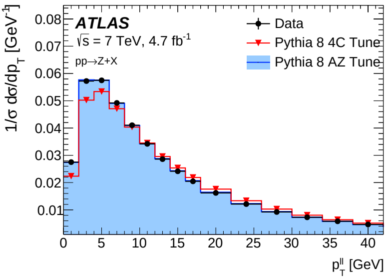


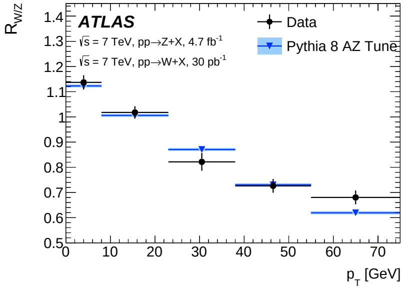


p_T^W modeling

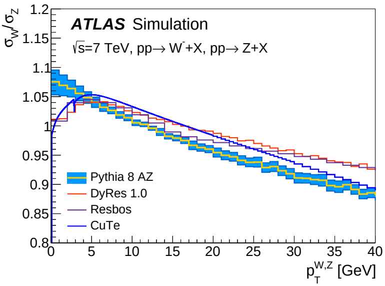
- Calibration W with Z: $\frac{d\sigma(W)}{dp_T} = \left[\frac{d\sigma(W)/dp_T}{d\sigma(Z)/dp_T}\right]_{pred} \times \left[\frac{d\sigma(Z)}{dp_T}\right]_{meas}$
- p_T^Z easy to measure in $Z \to ll$ events, but hard for $W \to l\nu$
- Use **Pythia8** parton shower, tuned to p_T^Z data at 7 TeV (AZ tune)
  $\to$ tuned parameters: α_s, intrinsic k_T, Q_0
- Pythia8 AZ tune describe the p_T^Z data within 2% inclusively and in rapidity bins
- $Z \to W$ extrapolation: PDF and heavy-quark effects
- Apply model to W relying on good prediction of W/Z ratio $\to$ validated on data

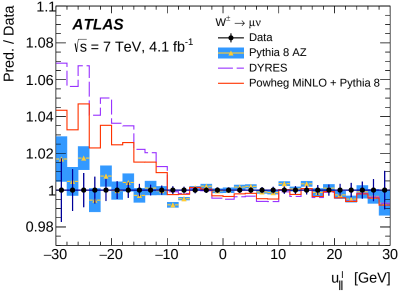
	Pythia8
Tune Name	AZ
Primordial k_T [GeV]	1.71 ± 0.03
ISR $\alpha_S^{ISR}(m_Z)$	0.1237 ± 0.0002
ISR cut-off [GeV]	0.59 ± 0.08
χ^2_{min}/dof	45.4/32





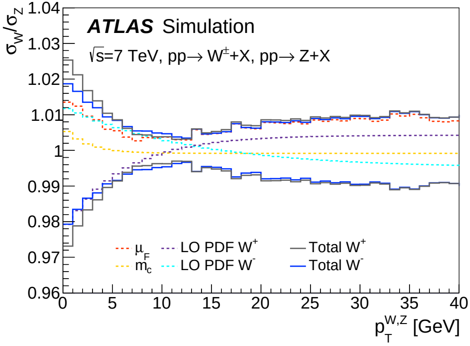
- Theoretically more advanced resummed predictions were also tried (DYRES, ResBos, Cute)
- They predict harder p_T spectrum wrt Pythia
- Such behaviour is strongly disfavoured by the $u_{||}(l)$ distribution in data $\rightarrow$ not used





p_T^W modeling uncertainty

- Difference between W and Z: PDF and heavy-quark effects
- $Z \rightarrow W$ extrapolation uncertainty: variation of remaining parton shower parameters
  - choice of LO parton shower PDF: CTEQ6L1, CT14, MMGT2014 and NNPDF2.3
  - factorization scale (separately for light and heavy quark induced production)
  - heavy quark masses ($\delta m_c = \pm 0.5$ GeV)

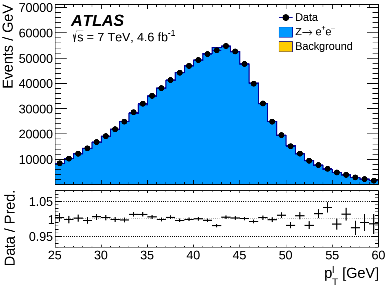


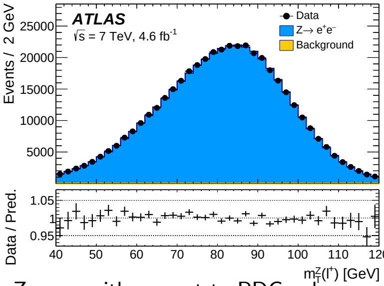
Summary of modeling uncertainties

- CT10nnlo PDFs (synchronized in DYNNLO and Pythia) + envelop CT10 to CT14 and MMHT: dominant uncertainty, followed by p_T^W uncertainty due to heavy-flavour-initiated production
- PDF uncertainty are **anti-correlated** between W^+ and W^- $\rightarrow$ significant reduction from the combination
- AZ tune uncertainty; parton shower PDF and factorization scale; heavy-quark mass effects
- A_i uncertainties from Z data + envelope for A_2 discrepancy

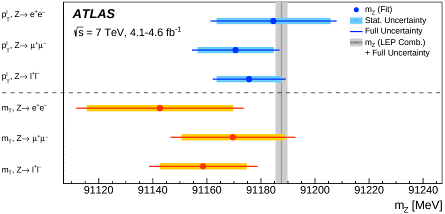
W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

Cross-check: Z-mass fits





Z mass with respect to PDG value

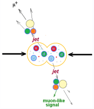


- W-like transverse mass $m_T(l)$:
  - Reconstructed from recoil and lepton
- Calibration is verified with M_Z
  $\rightarrow$ compatibility within $< 1\sigma$ (p_T^l)
  and 1.4σ (m_T^Z) with the PDG value

Backgrounds

- Backgrounds modeled in MC:
  - $Z \rightarrow ll$, $W \rightarrow \tau\nu$, top, $Z \rightarrow \tau\tau$
- Normalized using NNLO predictions or measurements
- Controlled at $\sim 5\%$ level

- Another important background comes from **jets**. Sources

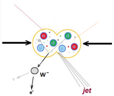


Muons	Electrons
$b\bar{b}/c\bar{c}$ quark decays to muons	$b\bar{b}/c\bar{c}$ quark decays to electrons
Punch-through hadrons	Jets misidentified as electrons
Pions and kaons decaying in ID	Converted photons

$\rightarrow$ Difficult to predict with MC (large cross-section, small efficiency)

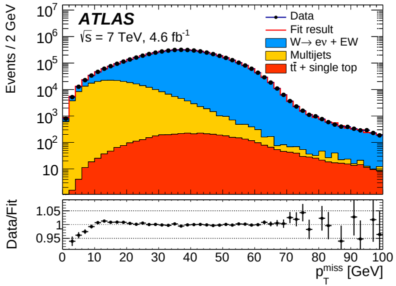
$\rightarrow$ Data-driven techniques are used

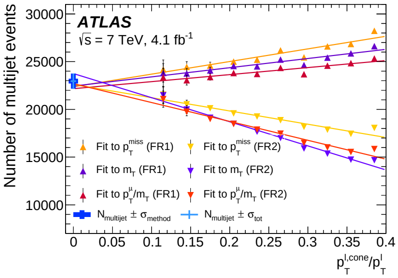
$\rightarrow$ **Goal:** estimate a fraction and shape for each distribution



Multijet background

- General method:
  - Define a background dominated fit region with relaxed kinematic cut(s)
  - Signal distribution from MC; background from control region with inverted lepton isolation cut (large activity around leptons)
  - The multijet background is normalized with fraction fit
- Variations:
  - 3 observables (p_T^{miss}, m_T^W, p_T^l/m_T^W); 2 fitting regions
  - Try different isolation criteria, extrapolate to the signal region
- Uncertainty: $\sim$ 4 MeV (mu); $\sim$ 8 MeV (e)

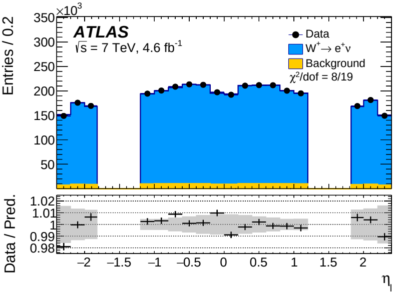




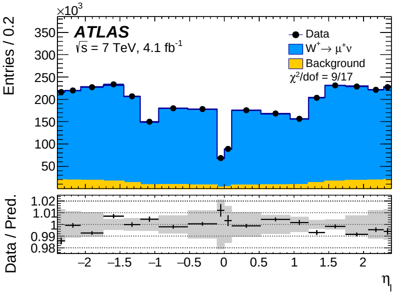
Control distributions

- Hundreds control plots were checked. Only most important are selected: $\eta, p_T^W, u_{||}$ for W^+
- All predictions are normalized to the data
- Total uncertainty bands are shown
- χ^2 is statistical+systematics

$W^+ \to e\nu$



$W^+ \to \mu\nu$



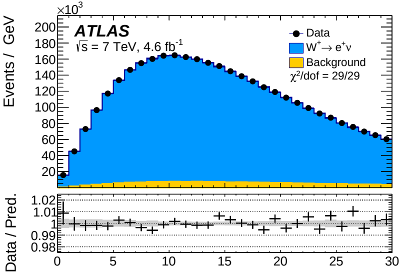
Control distributions

- Hundreds control plots were checked. Only most important are selected: $\eta, p_T^W, u_{||}$ for W^+
- All predictions are normalized to the data
- Total uncertainty bands are shown
- χ^2 is statistical+systematics

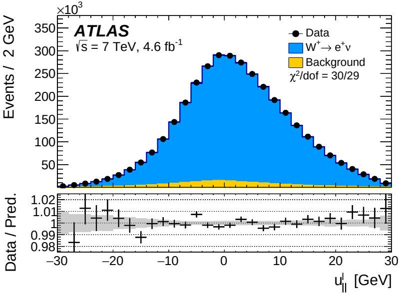
$u_T \sim p_T^W \rightarrow$ tests recoil resolution; p_T^W modeling

$u_{||} = \vec{u_T}\frac{\vec{p_T^l}}{p_T^l} \rightarrow$ also tests spin correlations

$W^+ \rightarrow e\nu$



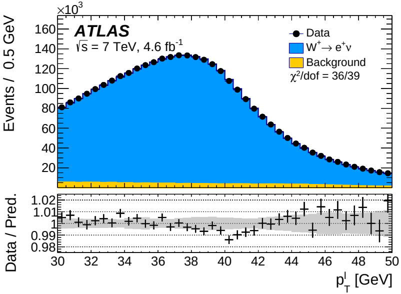
$W^+ \rightarrow e\nu$



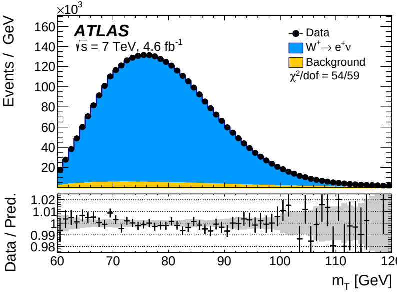
Mass sensitive distributions

- M_W sensitive distributions. Shown plots for W^+: p_T^l, m_T^W
- All predictions are normalized to the data
- Total uncertainty bands are shown
- χ^2 is statistical+systematics

$W^+ \to e\nu$



$W^+ \to e\nu$



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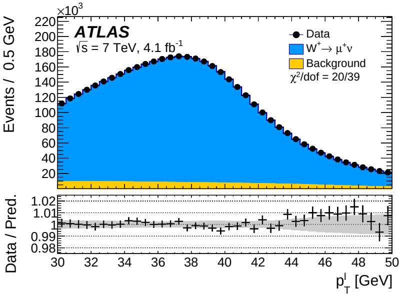
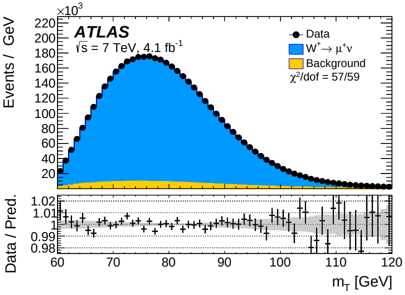


$W^+ \to \mu\nu$



Summary of uncertainties

Channel	m_W [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.
m_T-Fit										
$W^+ \to \mu\nu, \|\eta\| < 0.8$	80371.3	29.2	12.4	0.0	15.2	8.1	9.9	3.4	28.4	47.1
$W^+ \to \mu\nu, 0.8 < \|\eta\| < 1.4$	80354.1	32.1	19.3	0.0	13.0	6.8	9.6	3.4	23.3	47.6
$W^+ \to \mu\nu, 1.4 < \|\eta\| < 2.0$	80426.3	30.2	35.1	0.0	14.3	7.2	9.3	3.4	27.2	56.9
$W^+ \to \mu\nu, 2.0 < \|\eta\| < 2.4$	80334.6	40.9	112.4	0.0	14.4	9.0	8.4	3.4	32.8	125.5
$W^- \to \mu\nu, \|\eta\| < 0.8$	80375.5	30.6	11.6	0.0	13.1	8.5	9.5	3.4	30.6	48.5
$W^- \to \mu\nu, 0.8 < \|\eta\| < 1.4$	80417.5	36.4	18.5	0.0	12.2	7.7	9.7	3.4	22.2	49.7
$W^- \to \mu\nu, 1.4 < \|\eta\| < 2.0$	80379.4	35.6	33.9	0.0	10.5	8.1	9.7	3.4	23.1	56.9
$W^- \to \mu\nu, 2.0 < \|\eta\| < 2.4$	80334.2	52.4	123.7	0.0	11.6	10.2	9.9	3.4	34.1	139.9
$W^+ \to e\nu, \|\eta\| < 0.6$	80352.9	29.4	0.0	19.5	13.1	15.3	9.9	3.4	28.5	50.8
$W^+ \to e\nu, 0.6 < \|\eta\| < 1.2$	80381.5	30.4	0.0	21.4	15.1	13.2	9.6	3.4	23.5	49.4
$W^+ \to e\nu, 1,8 < \|\eta\| < 2.4$	80352.4	32.4	0.0	26.6	16.4	32.8	8.4	3.4	27.3	62.6
$W^- \to e\nu, \|\eta\| < 0.6$	80415.8	31.3	0.0	16.4	11.8	15.5	9.5	3.4	31.3	52.1
$W^- \to e\nu, 0.6 < \|\eta\| < 1.2$	80297.5	33.0	0.0	18.7	11.2	12.8	9.7	3.4	23.9	49.0
$W^- \to e\nu, 1.8 < \|\eta\| < 2.4$	80423.8	42.8	0.0	33.2	12.8	35.1	9.9	3.4	28.1	72.3
p_T-Fit										
$W^+ \to \mu\nu, \|\eta\| < 0.8$	80327.7	22.1	12.2	0.0	2.6	5.1	9.0	6.0	24.7	37.3
$W^+ \to \mu\nu, 0.8 < \|\eta\| < 1.4$	80357.3	25.1	19.1	0.0	2.5	4.7	8.9	6.0	20.6	39.5
$W^+ \to \mu\nu, 1.4 < \|\eta\| < 2.0$	80446.9	23.9	33.1	0.0	2.5	4.9	8.2	6.0	25.2	49.3
$W^+ \to \mu\nu, 2.0 < \|\eta\| < 2.4$	80334.1	34.5	110.1	0.0	2.5	6.4	6.7	6.0	31.8	120.2
$W^- \to \mu\nu, \|\eta\| < 0.8$	80427.8	23.3	11.6	0.0	2.6	5.8	8.1	6.0	26.4	39.0
$W^- \to \mu\nu, 0.8 < \|\eta\| < 1.4$	80395.6	27.9	18.3	0.0	2.5	5.6	8.0	6.0	19.8	40.5
$W^- \to \mu\nu, 1.4 < \|\eta\| < 2.0$	80380.6	28.1	35.2	0.0	2.6	5.6	8.0	6.0	20.6	50.9
$W^- \to \mu\nu, 2.0 < \|\eta\| < 2.4$	80315.2	45.5	116.1	0.0	2.6	7.6	8.3	6.0	32.7	129.6
$W^+ \to e\nu, \|\eta\| < 0.6$	80336.5	22.2	0.0	20.1	2.5	6.4	9.0	5.3	24.5	40.7
$W^+ \to e\nu, 0.6 < \|\eta\| < 1.2$	80345.8	22.8	0.0	21.4	2.6	6.7	8.9	5.3	20.5	39.4
$W^+ \to e\nu, 1,8 < \|\eta\| < 2.4$	80344.7	24.0	0.0	30.8	2.6	11.9	6.7	5.3	24.1	48.2
$W^- \to e\nu, \|\eta\| < 0.6$	80351.0	23.1	0.0	19.8	2.6	7.2	8.1	5.3	26.6	42.2
$W^- \to e\nu, 0.6 < \|\eta\| < 1.2$	80309.8	24.9	0.0	19.7	2.7	7.3	8.0	5.3	20.9	39.9
$W^- \to e\nu, 1.8 < \|\eta\| < 2.4$	80413.4	30.1	0.0	30.7	2.7	11.5	8.3	5.3	22.7	51.0

|η| comb e → ~15 MeV
μ → ~11 MeV

Strongly correlated (Recoil)

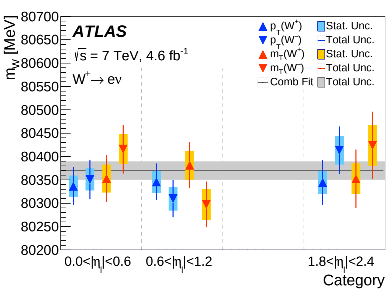
Strongly correlated (QCD)

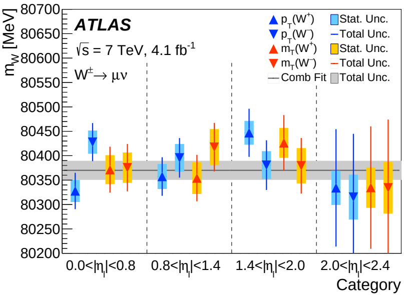
|η| comb. → ~14 MeV
W+/W- comb → ~8 MeV

Fit ranges : $32<p_T^l<45$ GeV; $66<m_T<99$ GeV, minimizing total expected measurement uncertainty

Mass measurements in different categories

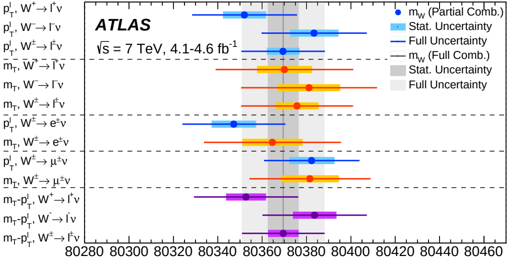
- Results in all measurement categories (p_T^l, m_T^W; electrons, muons; $|\eta|$−bins)
- Compatibility tests performed before **unblinding**: $\chi^2/n_{dof} = 29/27$





Results

- Good compatibility between partial combinations
- Dominant contribution from p_T^l
- Significant impact from electron channel



Combination	Weight
Electrons	0.427
Muons	0.573
m_{T}	0.144
p_{T}^{ℓ}	0.856
W^+	0.519
W^-	0.481

Results

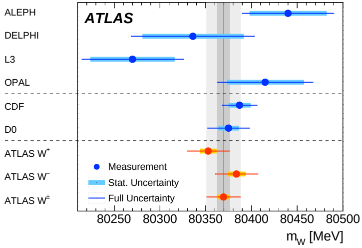
$$m_W = 80369.5 \pm 6.8\,\text{MeV(stat.)} \pm 10.6\,\text{MeV(exp. syst.)} \pm 13.6\,\text{MeV(mod. syst.)}$$
$$= 80369.5 \pm 18.5\,\text{MeV},$$

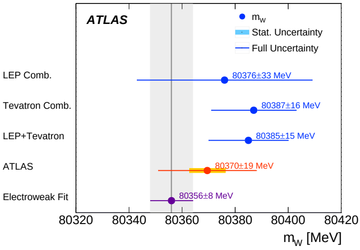
Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_{T}-p_{T}^{ℓ}, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

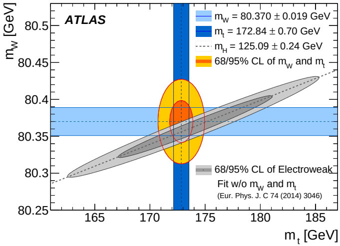
$$m_{W^+} - m_{W^-} = -29 \pm 28\ \text{MeV}$$

Results

- Consistent with the SM prediction and with the current world average value
- Reached precision of CDF and is now the world leading measurement
- Closer to the Standard Model prediction







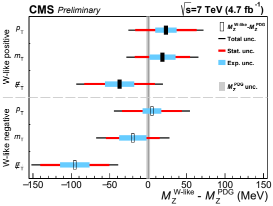
Summary and perspectives

Summary

- Presented ATLAS measurement of M_W: 80.370±0.019 GeV
- Competitive precision but no sign for new physics
- Uncertainty is dominated by theory → Help from the theorists is needed!

Perspectives

- **Update** of the presented result is foreseen:
  - PDF uncertainties can be reduced by inclusion of ATLAS W, Z measurements currently used only for validation
  - p_T^W uncertainties can be reduced by using predictions of analytical ressumation
- ATLAS still has data-sets of **8 and 13 TeV**!
- M_W results from **CMS** is expected soon
- **TeVatron** still has x2-5 of available data + PDFs improved by LHC measurements



Thank you!

BACKUP