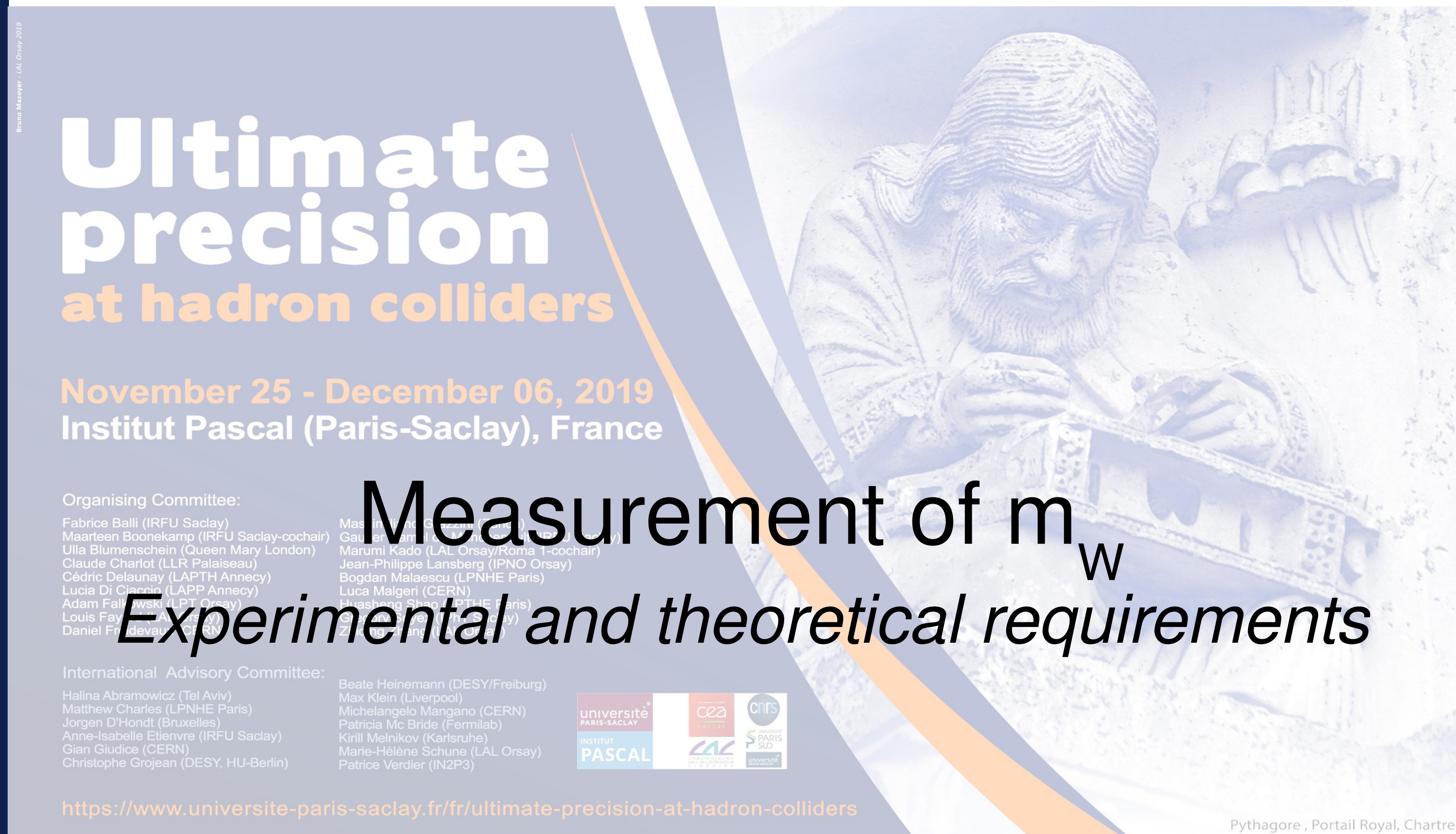
Measurement of m_W

Experimental and theoretical requirements



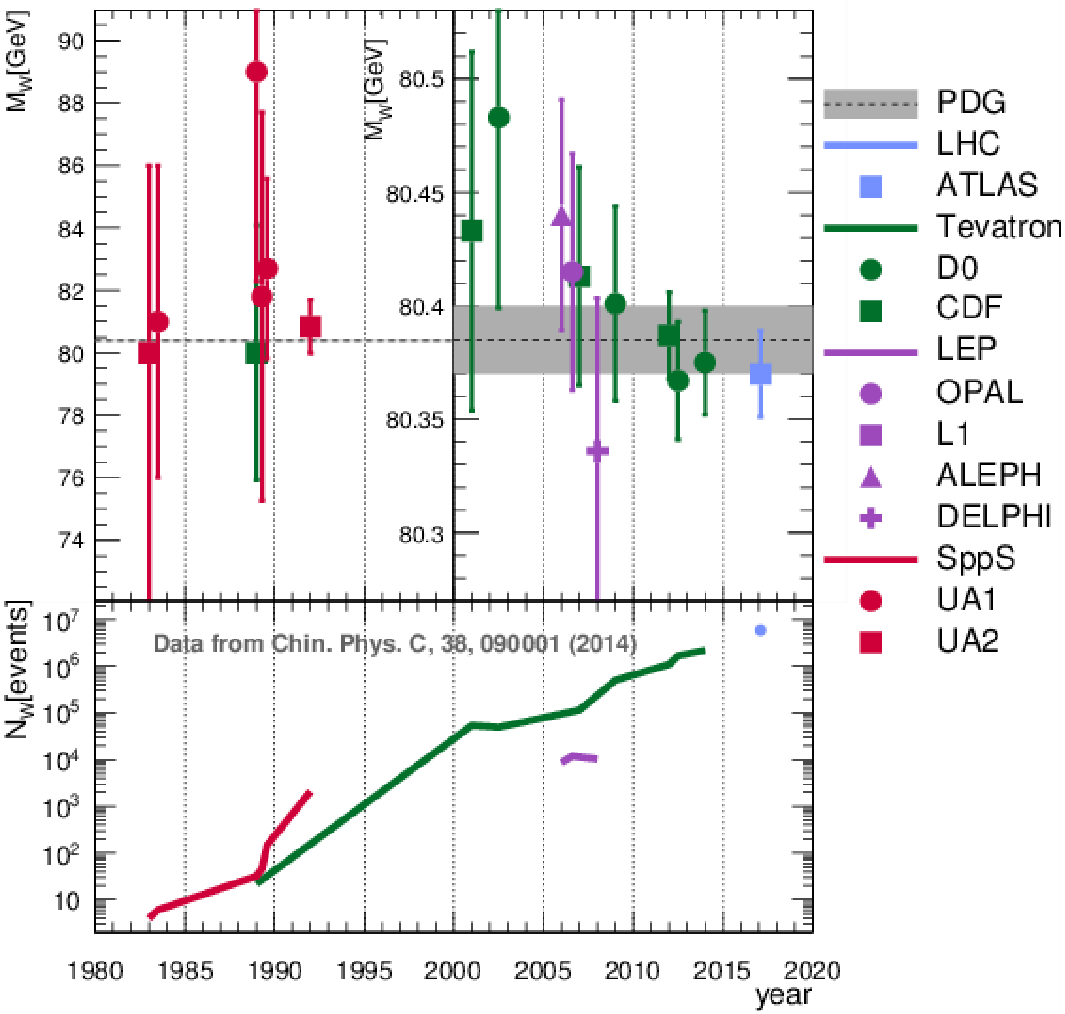
Stefano Camarda

Ultimate precision at hadron colliders
Paris-Saclay – 27 November 2019

Measurement of m_W

- Introduction
- Results and plans at ATLAS, CMS, LHCb
- Prospects and challenges
- Summary

W-boson mass history



- Only four W-boson mass measurements in the last 10 years

→ Complex measurements which require O(5-7) years

- 1983 CERN SPS – W discovery
- 1983 – UA1

  $m_W = 81 \pm 5$ GeV
- 1992 – UA2 (with m_Z from LEP)

  $m_W = 80.35 \pm 0.37$ GeV
- 2013 – LEP combined

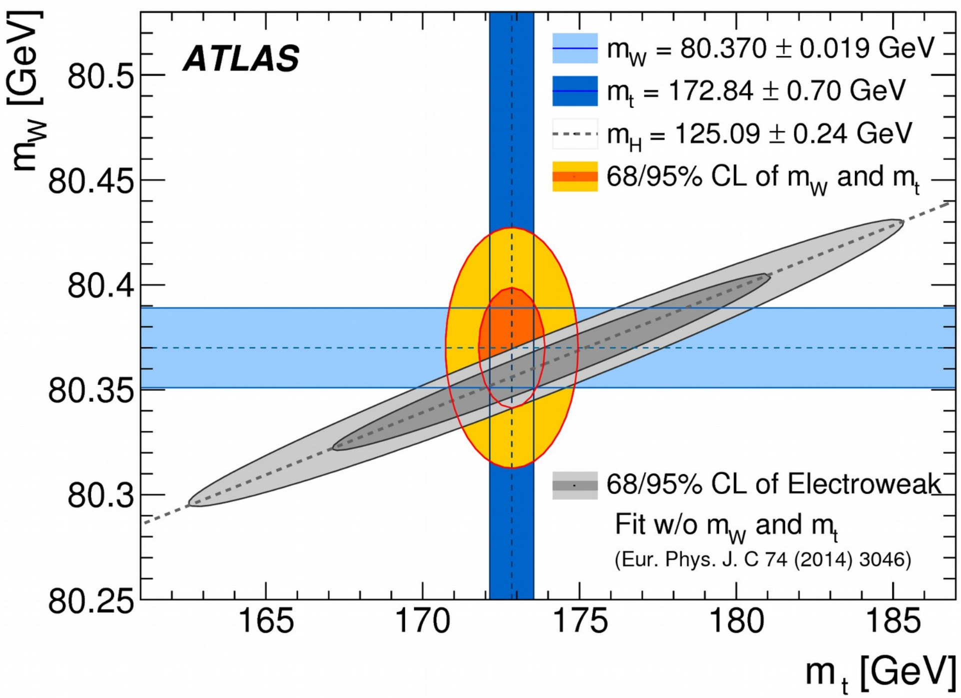
  $m_W = 80.376 \pm 0.033$ GeV
- 2013 – Tevatron combined

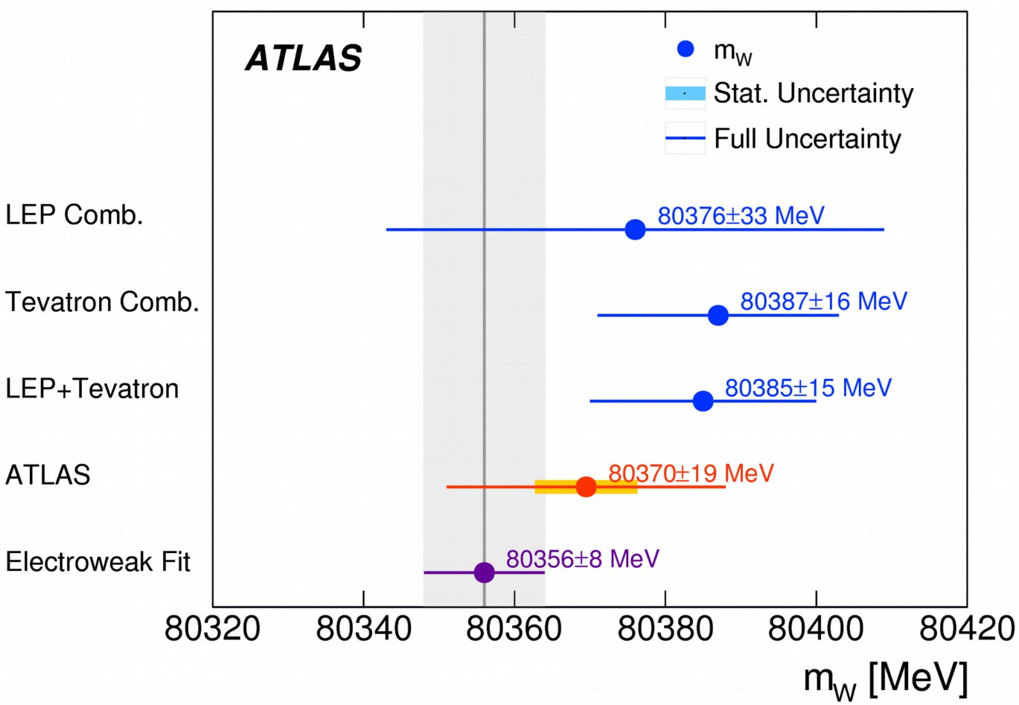
  $m_W = 80.387 \pm 0.016$ GeV
- 2017 – LHC (ATLAS)

  $m_W = 80.370 \pm 0.019$ GeV

W-boson mass today

arXiv:1701.07240

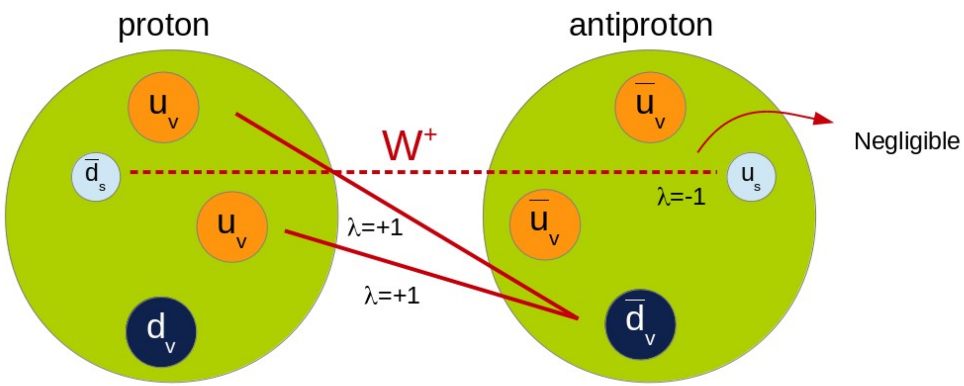




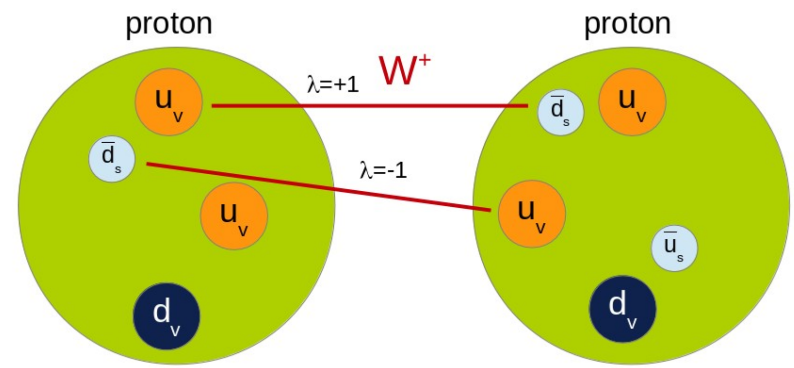
The standard model relations between electroweak parameters are confirmed by the data

W mass at the LHC

A proton-proton collider is the most challenging enviroment to measure m_W, worse compared to e+e- and proton-antiproton



In $p\bar{p}$ collisions W bosons are mostly produced in the same helicity state



In pp collisions they are equally distributed between positive and negative helicity states

Further QCD complications

- Heavy-flavour-initiated processes
- W+, W- and Z are produced by different light flavour fractions
- Larger gluon-induced W production

Large PDF-induced W-polarisation uncertainty affecting the p_T lepton distribution

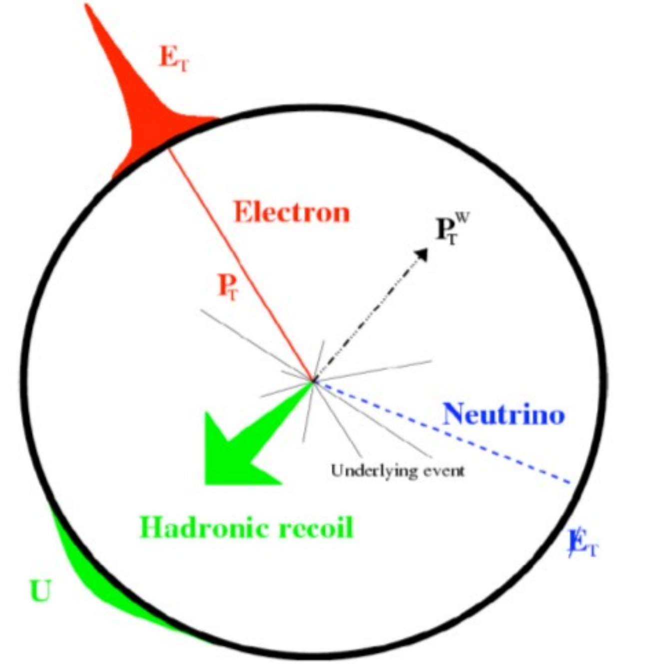
Larger Z samples, available for detector calibration given the precisely known Z mass → most of the measurement is then the transfer from Z to W

W mass at the LHC

- The measurement of m_W at the LHC is extremely challenging and prone to biases due to QCD effects
- They affect all aspects of the measurement: detector calibration, transfer from Z to W, PDF uncertainties, W polarisation, modelling of p_T W
- Need to design the measurement to be “waterproof” from the point of view of detector calibration and physics modelling
- At the same time, the challenge makes it very interesting, and provides a great occasion to understand QCD

W mass at the LHC

- Main signature: final state prompt and isolated lepton (electron or muon)
- The neutrino escapes detection, and its momentum can be reconstructed from momentum imbalance in the transverse plane: p_T^{miss}
- The transverse mass m_T is defined from variables measured in the transverse plane



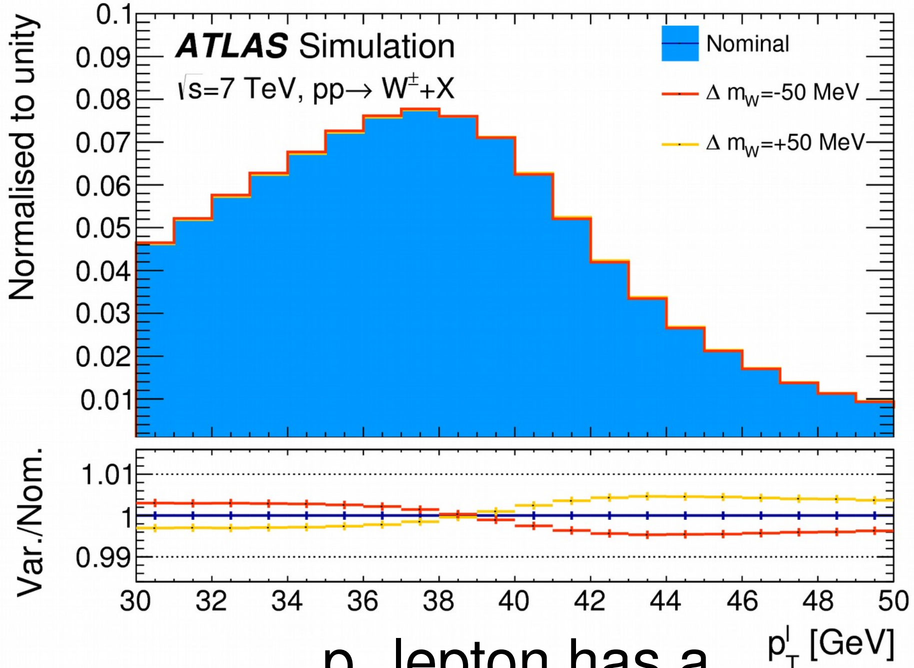
Observables sensitive to m_W are

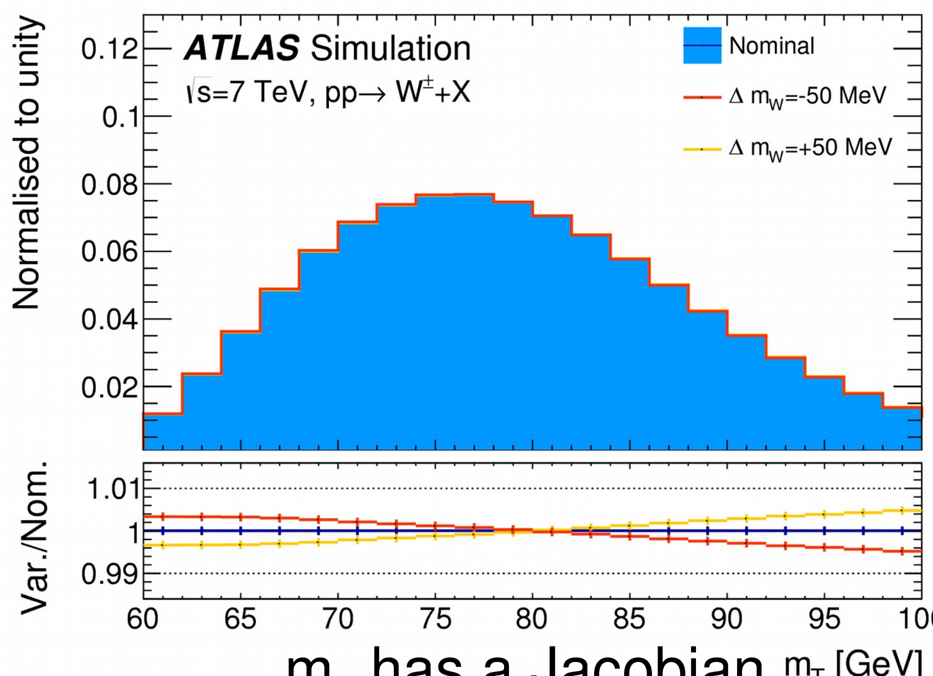
Lepton transverse momentum	p_T^ℓ
W transverse mass	$m_T = \sqrt{2p_T^\ell p_T^\nu(1-\cos\Delta\phi(\ell,\nu))}$
Neutrino transverse momentum (from hadronic recoil)	p_T^ν used only as cross-check

ATLAS W mass – Measurement strategy

m_W extracted from the p_T lepton and transverse mass (m_T) distributions

arXiv:1701.07240





p_T lepton has a Jacobian edge at $m_W/2$

m_T has a Jacobian edge at m_W

Template-fit approach:

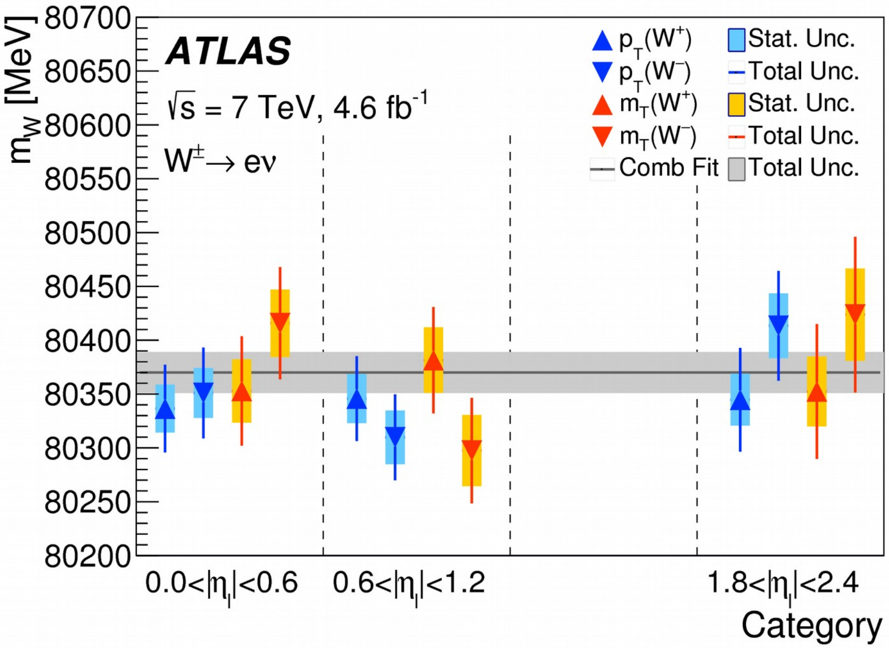
- Vary the W-boson mass values in the theory prediction, and predict the p_T lepton and m_T distributions
- Compare to data, and determine the W mass by χ^2 minimization

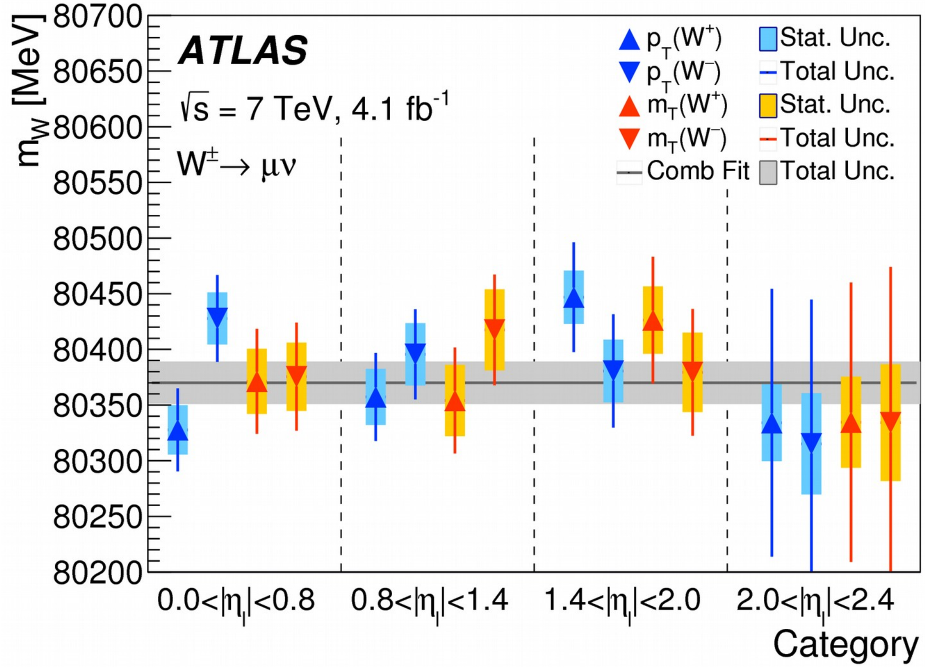
Measurement strategy – categories

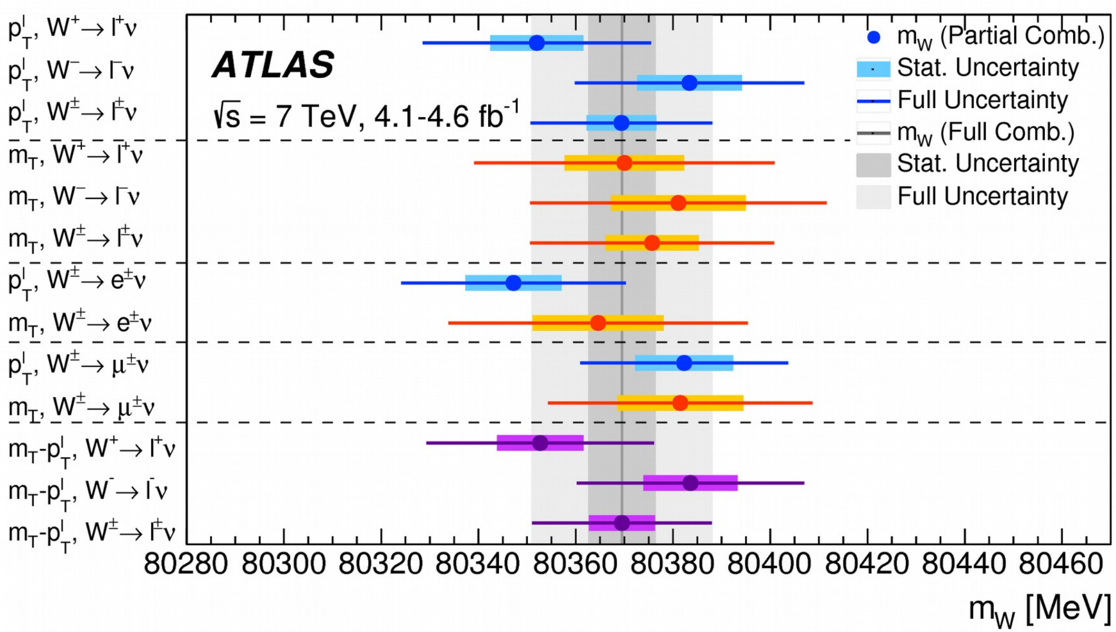
- A crucial aspect of the measurement design is the categorisation. Events are categorised according to their type and kinematic range. The importance of categories is twofold: validate detector calibration and physics modelling and improve accuracy
- The various set of categories are sensitive to different experimental and theoretical biases, the consistency of m_W across categories validates our knowledge of the detector and of QCD
- → The measurement was considered ready for unblinding only when all the categories yield consistent values of m_W
- The experimental and theoretical uncertainties have different correlation or anticorrelation patterns, the categorisation allows to constrain them, and increase the sensitivity to m_W
- Categories used for the combination (28 in total):

Decay channel	$W \to e\nu$	$W \to \mu\nu$
Kinematic distributions	p_T^ℓ, m_T	p_T^ℓ, m_T
Charge categories	W^+, W^-	W^+, W^-
$\|\eta_\ell\|$ categories	$[0, 0.6]$, $[0.6, 1.2]$, $[1.8, 2.4]$	$[0, 0.8]$, $[0.8, 1.4]$, $[1.4, 2.0]$, $[2.0, 2.4]$

Compatibility of categories







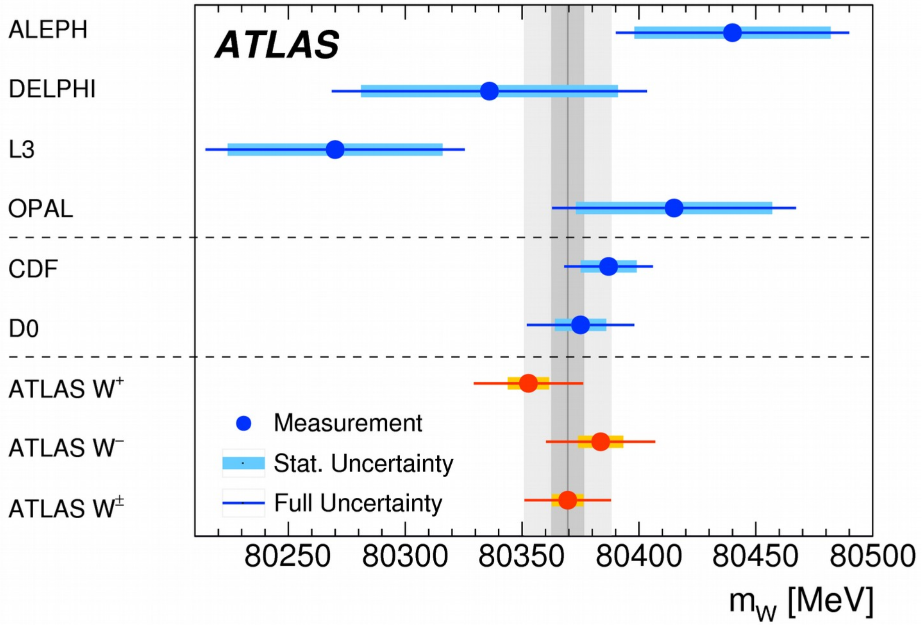
- All categories give consistent extractions of m_W

- Strong validation of physics modelling and detector calibration

ATLAS 7 TeV result for m_W

The ATLAS result equals in precision the previous single-experiment best measurement of CDF

$$M_W = 80369.5 \pm 18.5 \text{ MeV}$$



$M_W = 80369.5 \pm 6.8 \text{ (stat)} \pm 10.6 \text{ (exp.syst.)} \pm 13.6 \text{ (model.syst.)}$ MeV

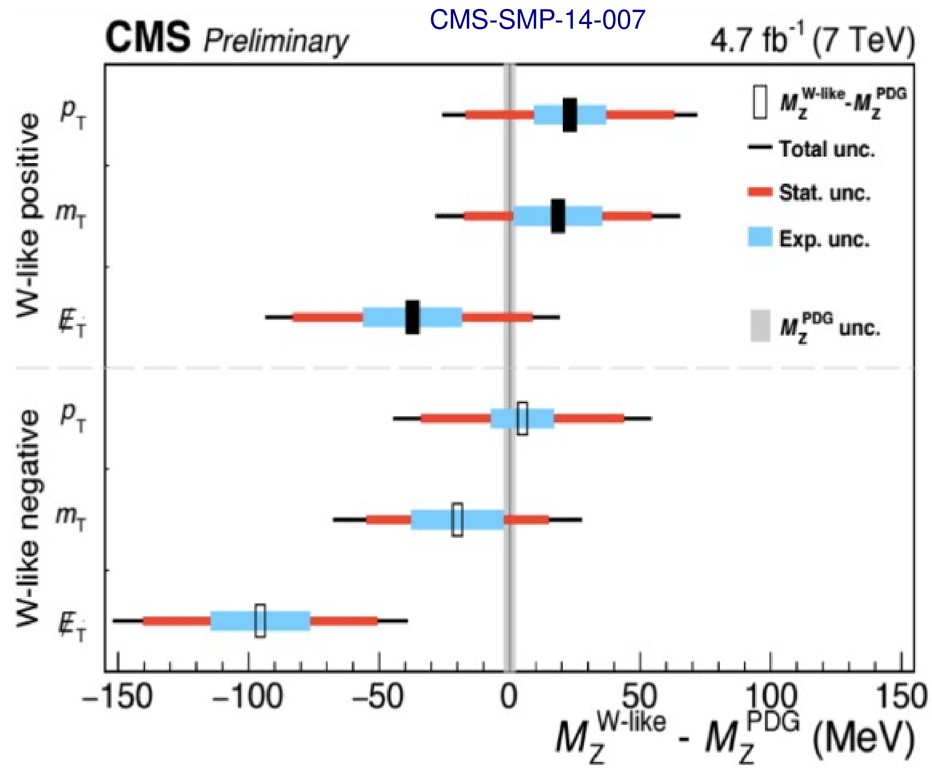
The dominant uncertainty is due to the physics modelling

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW 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

and the largest contributions are from QCD/PDF

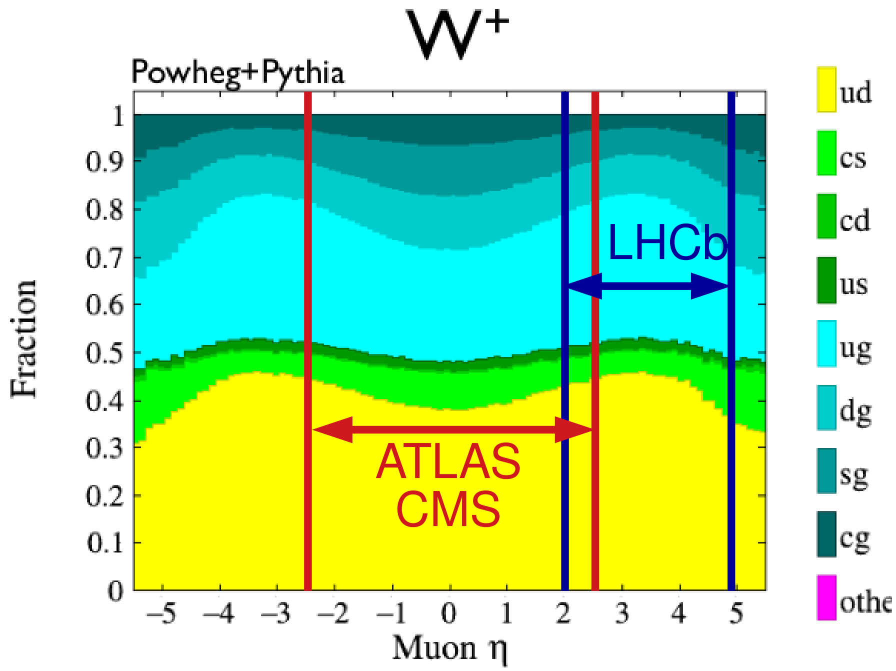
CMS W-like analysis

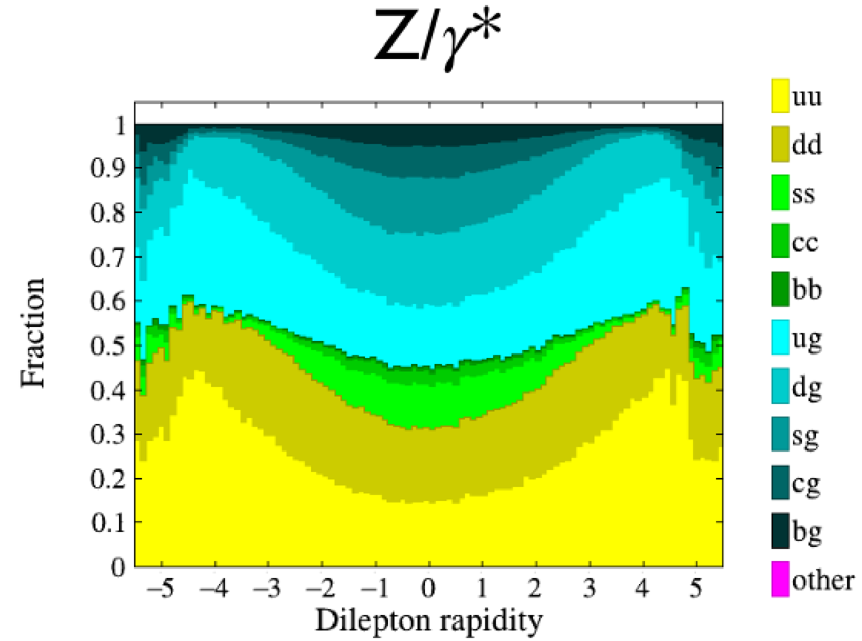
Sources of uncertainty	$M_Z^{W\text{like}+}$ p_T	$M_Z^{W\text{like}+}$ m_T	$M_Z^{W\text{like}+}$ $\not{E}_T$	$M_Z^{W\text{like}-}$ p_T	$M_Z^{W\text{like}-}$ m_T	$M_Z^{W\text{like}-}$ $\not{E}_T$
Lepton efficiencies	1	1	1	1	1	1
Lepton calibration	14	13	14	12	15	14
Recoil calibration	0	9	13	0	9	14
Alternative data reweightings	5	4	5	14	11	11
PDF uncertainties	6	5	5	6	5	5
QED radiation	22	23	24	23	23	24
Simulated sample size	7	6	8	7	6	8
Total systematic uncertainties	28	30	32	30	32	34
Statistics of the data sample	40	36	46	39	35	45
Total stat.+syst.	49	47	56	50	48	57



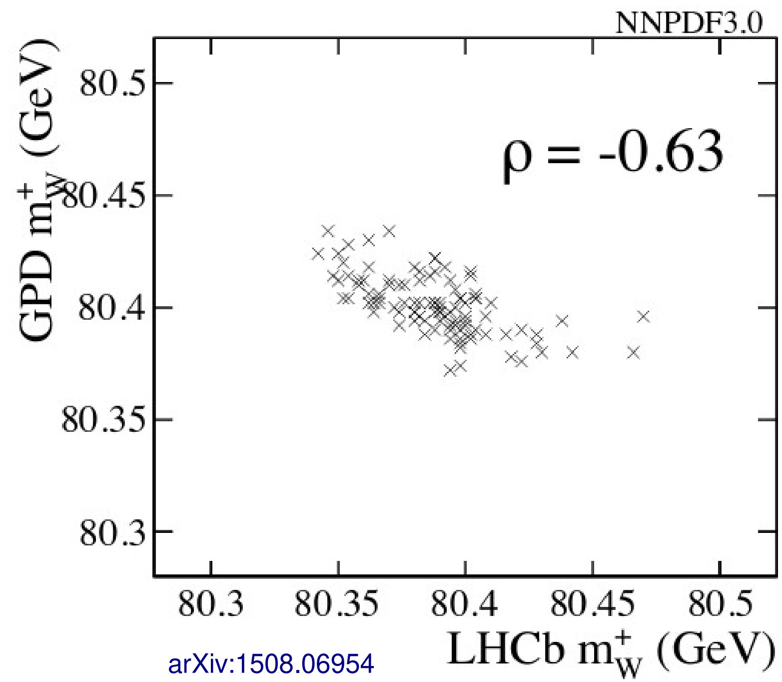
- CMS performed a W-like analysis: Z events are analyzed as W events, that is reconstructing one lepton from the missing p_T
- Demonstrates excellent control of detector calibration
- The big missing piece to convert this into a W-mass measurement is the physics modelling

W mass measurement with LHCb



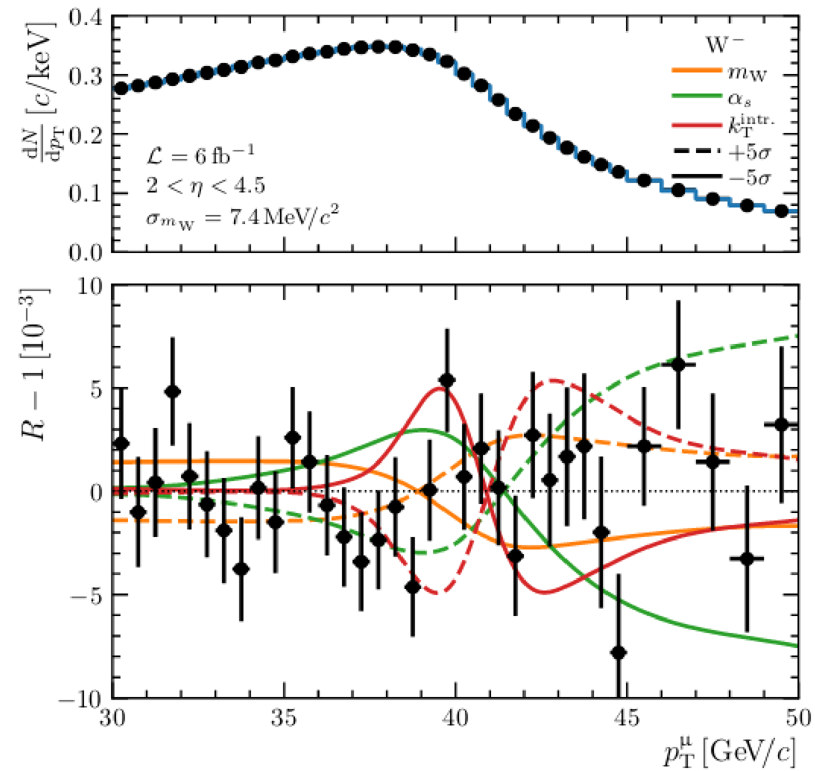


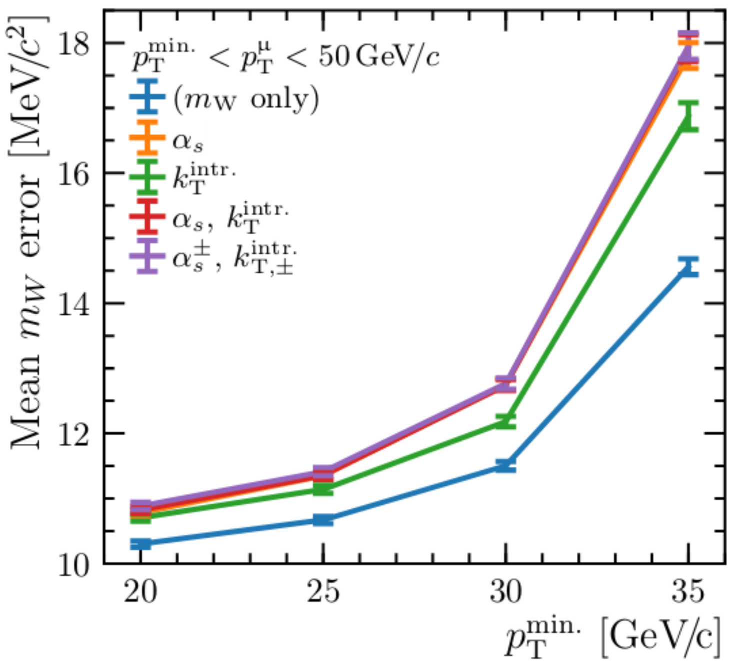
- LHCb acceptance is highly complementary to ATLAS and CMS
- W production at LHCb has a different flavour decomposition with respect to ATLAS and CMS
- PDF uncertainty are largely uncorrelated or anti-correlated between ATLAS-CMS and LHCb, and the corresponding uncertainty will be largely reduced in the combination



W mass measurement with LHCb

- Run 1 + 2 is enough to reach ~10 MeV statistical uncertainty
- LHCb analysis plans to exploit the sensitivity of the p_T lepton distribution to the W mass and to all components of the p_T W uncertainty
- → Simultaneous fit to W mass and p_T W nuisance parameters

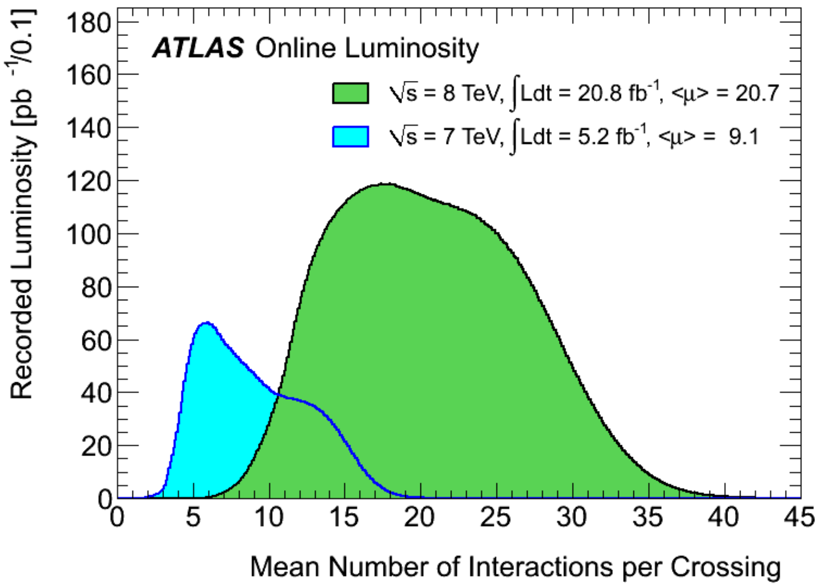


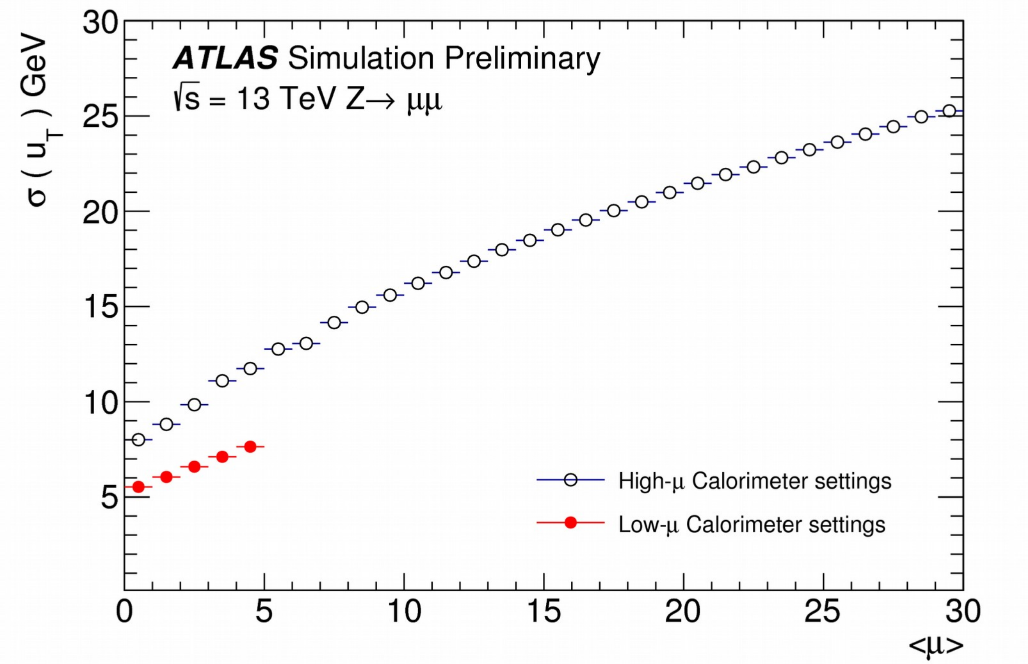


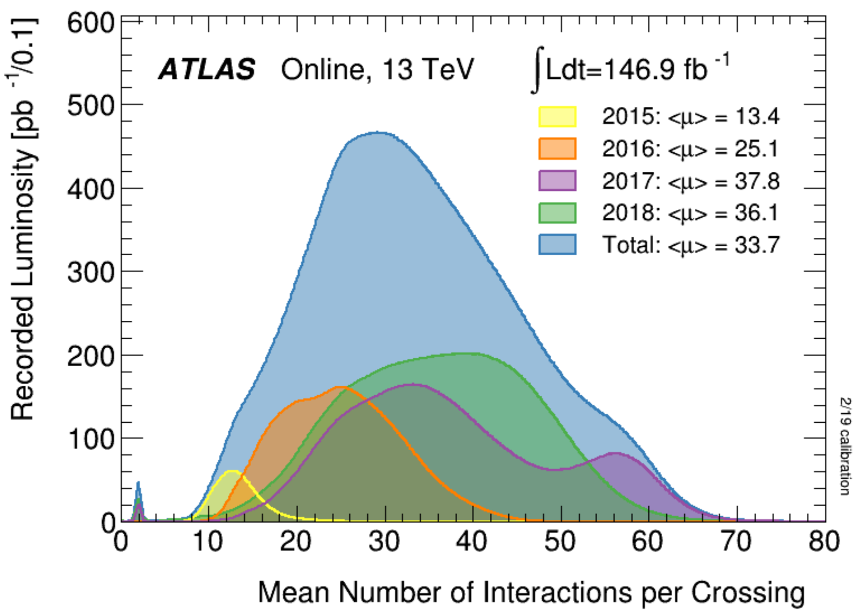
- When the fit range is large enough it is possible to determine all parameters with a relatively small loss in the precision of the W mass

Prospects and challenges

Recoil resolution degrades with pileup







- 7 TeV: <μ> ~ 9
- 8 and 13 TeV, <μ> ~ 20-30
- The recoil resolution degrades with higher pileup
- W mass measurements at high <μ> will be fully dominated by p_T lepton

Prospects and challenges

ATLAS W mass at 7 TeV

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

- The p_T lepton distribution dominates over m_T already with 7 TeV data (85/15)
- Muon channel more important than electron (60/40)

Prospects and challenges

Two paths for future measurements at ATLAS and CMS

	High pileup	Low pileup
Most sensitive observable	p_T lepton	m_T
Theory challenge	W/Z p_T ratio, PDFs	PDFs
Experimental challenge	p_T lepton calibration	Recoil calibration
Dominant uncertainties	Physics modelling, PDFs	Recoil, stat, PDFs

High pileup:

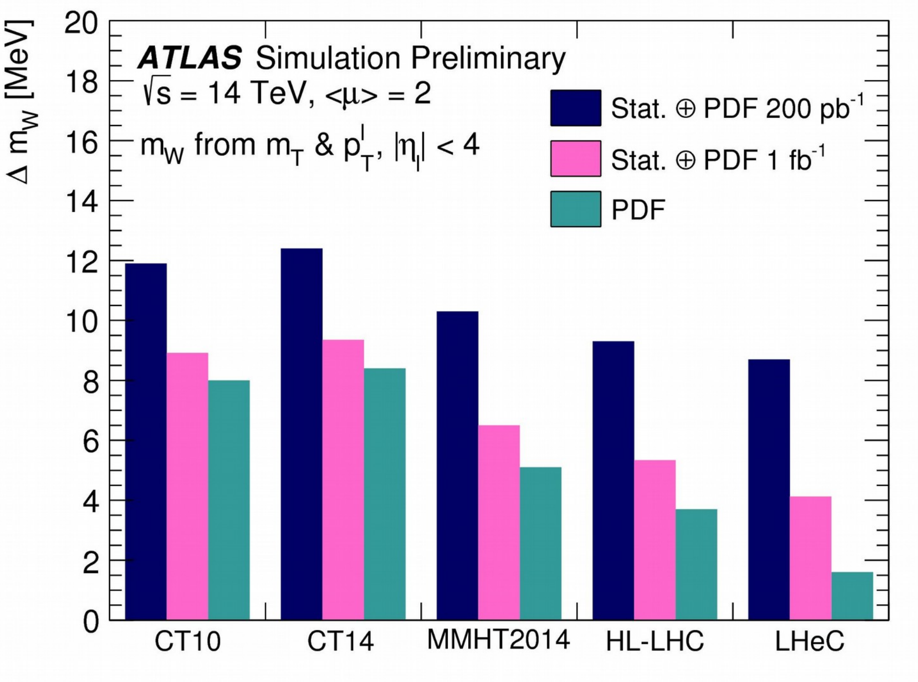
- Only option at LHCb
- Can benefit from very high stat of the HL-LHC program

Low pileup:

- Requires dedicated runs
- Provides measurement and data-driven modelling of p_T W

- Orthogonal approaches with different dominant uncertainties
- Should be both pursued, will benefit from the combination

Prospects for m_W at the HL-LHC with low pileup data



ATL-PHYS-PUB-2018-026

- Increased acceptance provided by the new inner detector in ATLAS, (ITk) extends the coverage up to $|\eta| < 4$
- Allows further in-situ constraints on PDFs from pseudorapidity bins
- With 1fb^{-1} of low pileup data ($<\mu>\sim 2$) likely to reach ~ 6 MeV of stat+PDF uncertainty
- LHeC ep collisions would largely reduce PDF uncertainties (< 2 MeV)

W mass at the LHC with high pileup data

- The statistical uncertainty is expected to be reduced by factors of 2 to 7 by analysing 8 and 13 TeV datasets

sqrt(s)	7 TeV	8 TeV	13 TeV
Lumi	~4.5 fb^{-1}	~20 fb^{-1}	~100 fb^{-1}
Events	15×10^{-6}	80×10^{-6}	600×10^{-6}
Stat Unc.[MeV]	7	3	1
	Measured	Expected	Expected

- The muon momentum calibration uncertainty in the ATLAS 7 TeV m_W result is ~9 MeV in the p_T lepton category and ~6 MeV in the combined result

$\lvert\eta_\ell\rvert$ range	[0.0, 0.8]		[0.8, 1.4]		[1.4, 2.0]		[2.0, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]										
Momentum scale	8.9	9.3	14.2	15.6	27.4	29.2	111.0	115.4	8.4	8.8

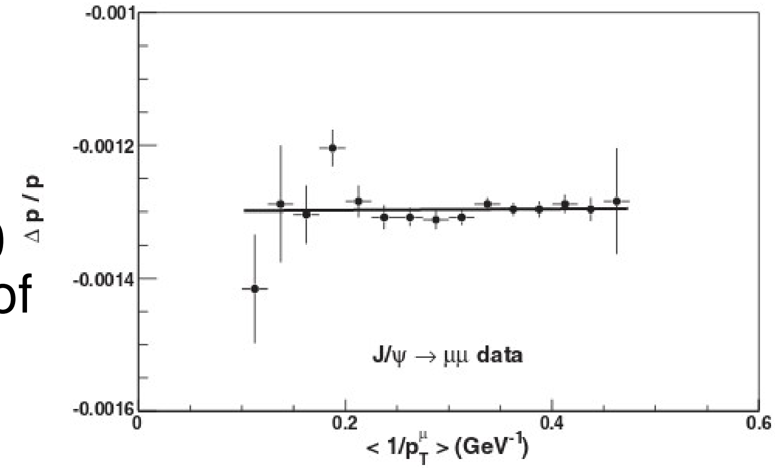
- This is likely to be the dominant experimental uncertainty in high pileup measurements

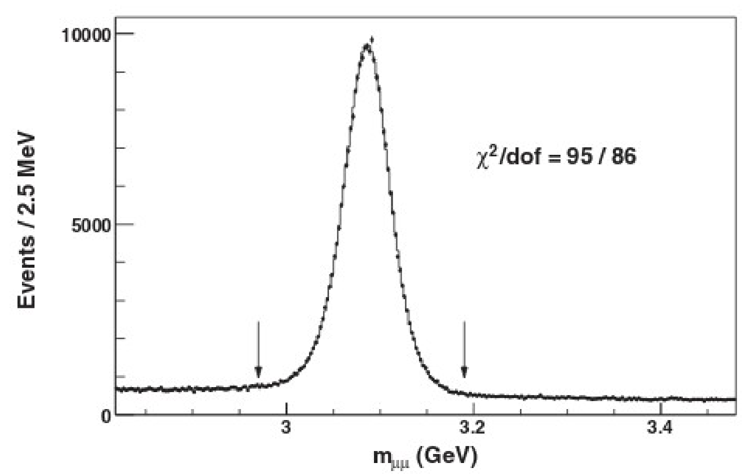
Momentum calibration

- Most measurements of m_W at hadron colliders (UA2, D0, ATLAS) lay the foundations of the energy and momentum calibration upon an external measurement of m_Z
- Drawbacks:
  - Effectively provide a measurement of m_W/m_Z, and suffer from an irreducible 2 MeV uncertainty from the LEP measurement of m_Z
  - Introduce correlation of momentum calibration uncertainites between different measurements

Muon momentum calibration with J/ψ

- One notable exception: CDF measurement of m_W based the muon momentum calibration on J/ψ (and Υ)
- Electron energy and recoil momentum are cross-calibrated to the muon-momentum scale
- Propagation of the momentum scale from ~5 to ~80 GeV is a great challenges, requires perfect control of
  - Misalignments
  - Magnetic field nonuniformities
  - Material and energy loss



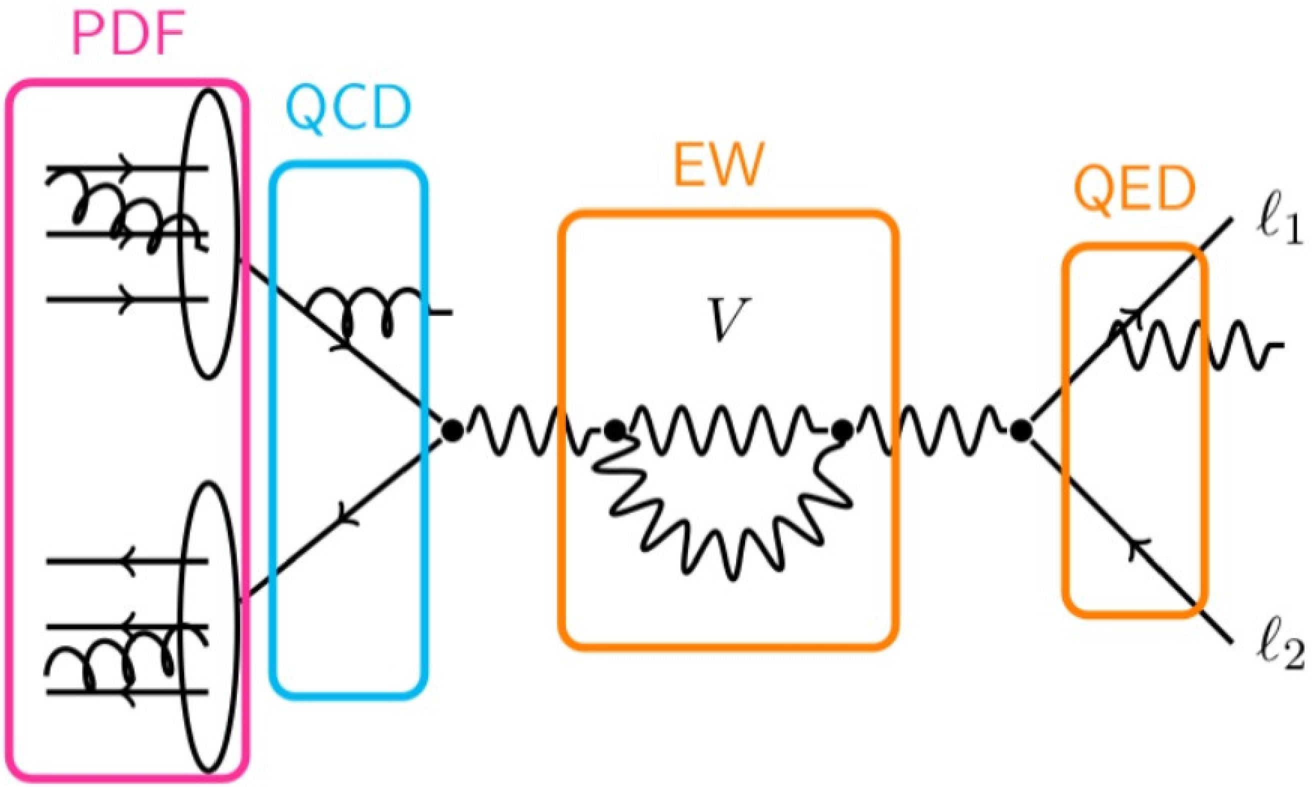


Source	J/ψ ($\times 10^{-3}$)	Υ ($\times 10^{-3}$)	Common ($\times 10^{-3}$)
QED and energy-loss model	0.080	0.045	0.045
Magnetic field nonuniformities	0.032	0.034	0.032
Ionizing material correction	0.022	0.014	0.014
Resolution model	0.020	0.005	0.005
Background model	0.011	0.005	0.005
COT alignment corrections	0.009	0.018	0.009
Trigger efficiency	0.004	0.005	0.004
Fit range	0.004	0.005	0.004
$\Delta p/p$ step size	0.002	0.003	0
World-average mass value	0.004	0.027	0
Total systematic	0.092	0.068	0.058
Statistical	0.004	0.025	0
Total	0.092	0.072	0.058

- Benefit from larger sample than Z, and more precise mass measurement (10^{-6})

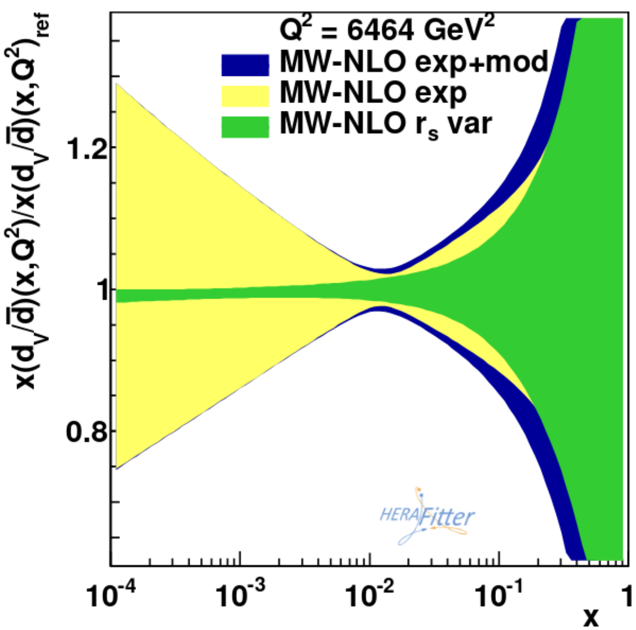
Physics modelling

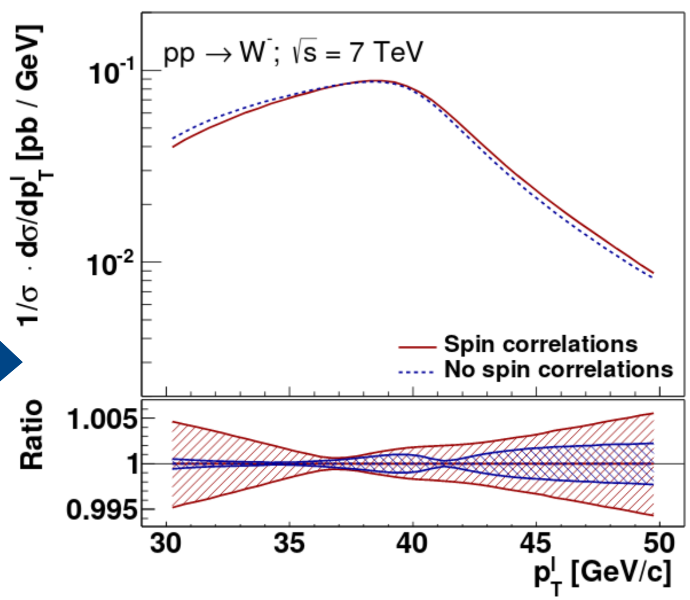
- Experimental and theoretical challenges:
  - Parton distribution functions
  - Measurements of p_T W, predictions of the W/Z p_T ratio
  - Electroweak corrections
  - Measurements and predictions of angular coefficients

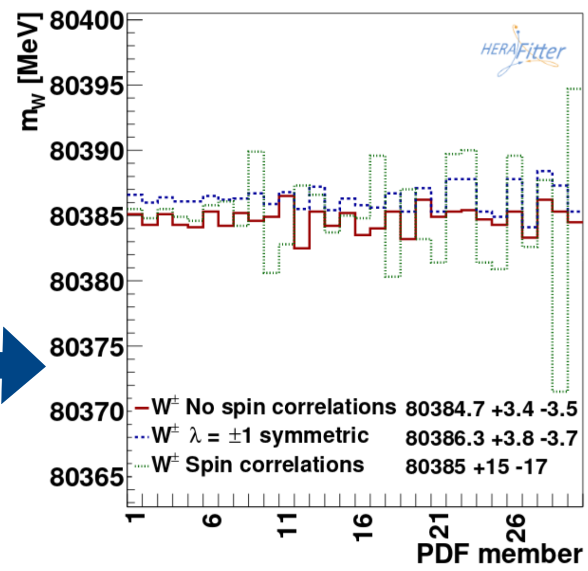


PDF uncertainties

- PDF uncertainties are currently the largest uncertainty at the LHC, and they are expected to remain dominant in future measurements
- The main mechanism which gives rise to large PDF uncertainties is: valence/sea → W helicity → p_T lepton → m_W

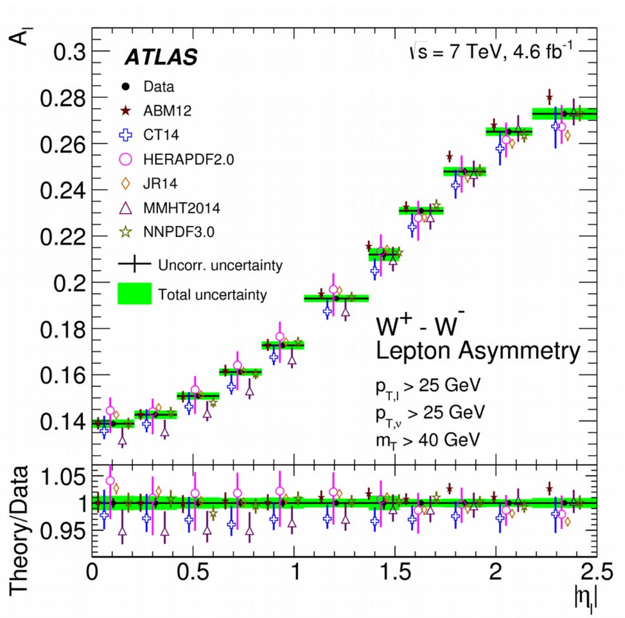


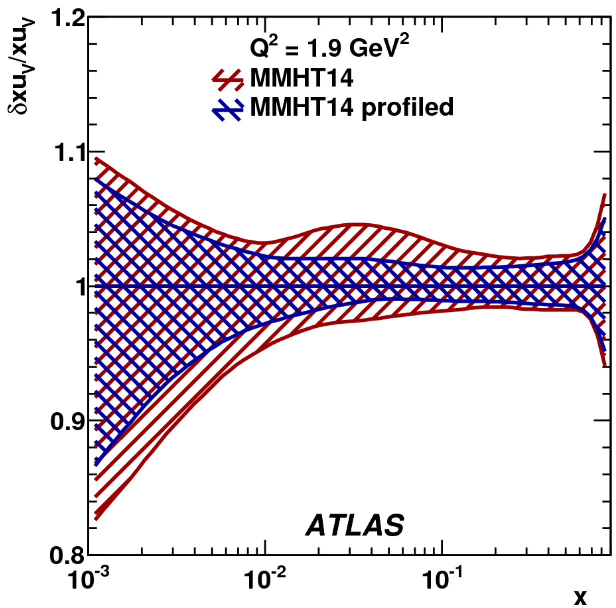


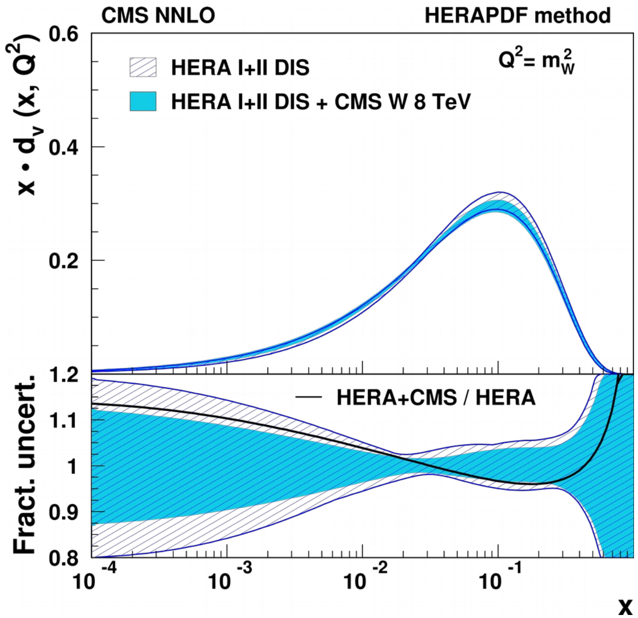


Measurements to constrain PDFs

- W asymmetry and Z rapidity measurements at the LHC directly constrain valence and sea PDFs in the x,Q region relevant for m_W



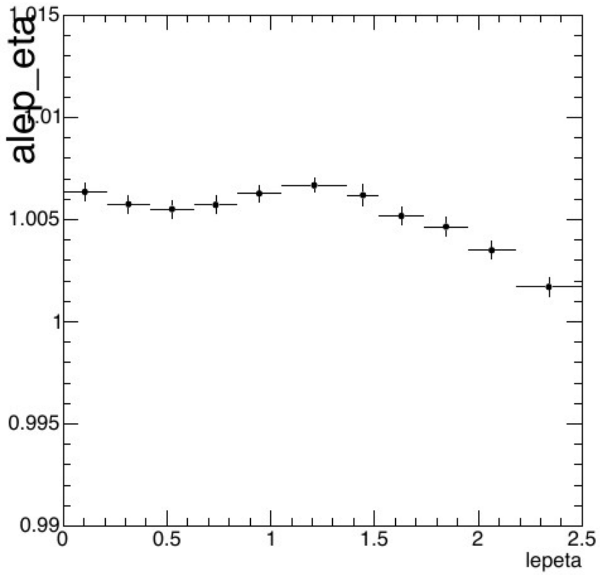




- These measurements are systematics limited already in Run 1
- New experimental methodology are needed to fully exploit the potential of the full LHC data sample
- With enough statistics, low pile up data can also be used to perform measurements with smaller systematic uncertainties

Measurements to constrain PDFs

- A major limitation in the usage of W asymmetry and Z rapidity measurements to reduce PDF uncertainties for m_W is the usage of inconsistent physics modelling for PDF fits (fixed order QCD) and the m_W measurements (including PS or resummation)



W+

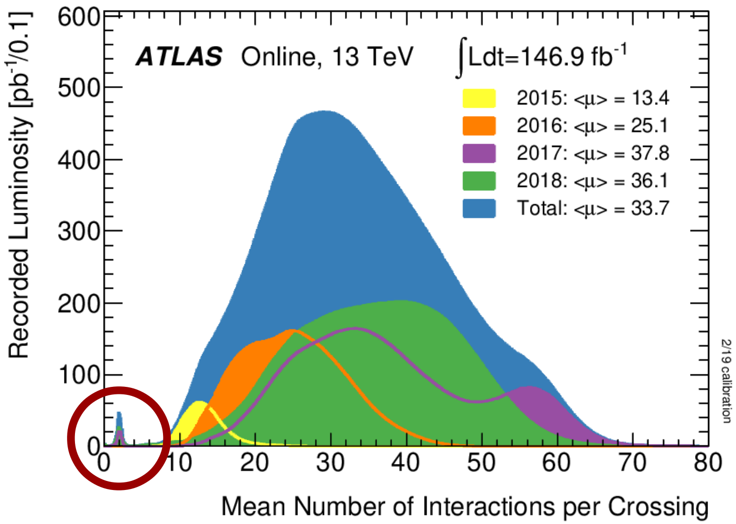
Dataset	CT14 published	CT14 NNLL
ATLAS low mass Z rapidity 2011	11 / 6 →	8.7 / 6
ATLAS peak CC Z rapidity 2011	16 / 12 →	10 / 12
ATLAS peak CF Z rapidity 2011	10 / 9 →	5.6 / 9
ATLAS high mass CC Z rapidity 2011	6.3 / 6	6.3 / 6
ATLAS high mass CF Z rapidity 2011	5.1 / 6	5.4 / 6
ATLAS W- lepton rapidity 2011	8.9 / 11	8.8 / 11
ATLAS W+ lepton rapidity 2011	10 / 11	10 / 11
Correlated χ^2	39 →	35
Log penalty χ^2	-4.11	-3.60
Total χ^2 / dof	103 / 61 →	86 / 61
χ^2 p-value	0.00	0.02

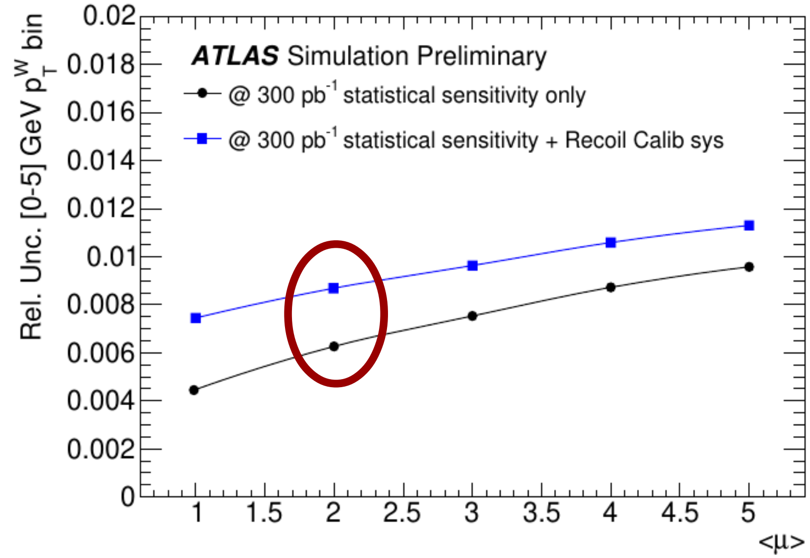
- Work in progress to overcome this limitation, by including log[q_T/m] corrections in PDF fits to Drell-Yan data
- Corrections are significant compared to the experimental accuracy, and gives large improvement in χ^2

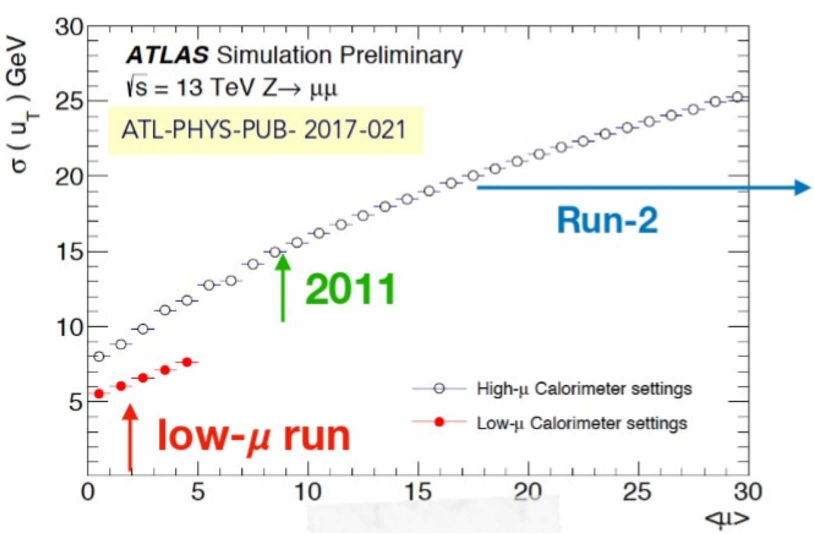
Modelling of p_T W

- The modelling of p_T W is crucial for the measurement of m_W, especially when using p_T lepton

- ~300 pb^{-1} already collected at <μ> = 2 by ATLAS and CMS can provide a new ~1% measurement of p_T W and significantly reduce the associated uncertainty



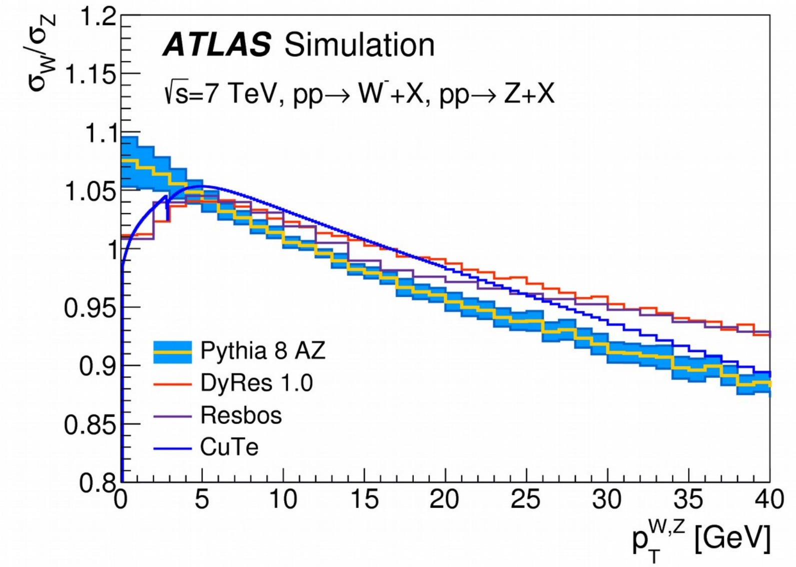




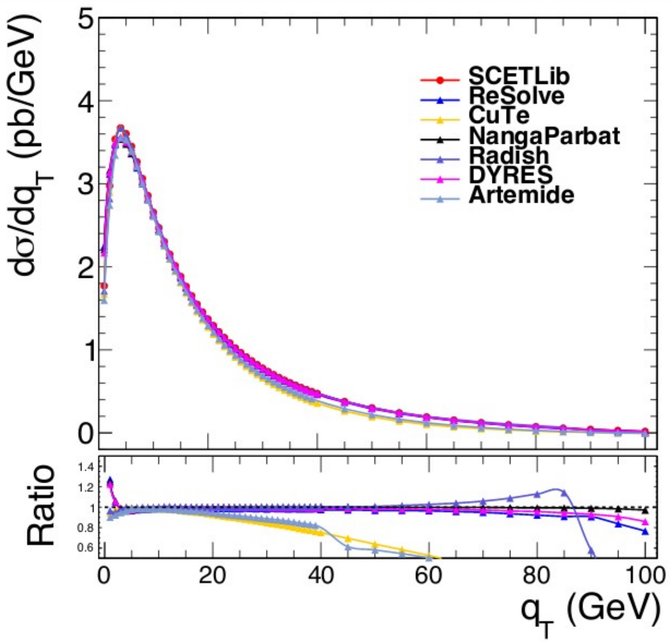
- The expected resolution at <μ> = 2 is ~5 GeV

Modelling of p_T W

- A complementary approach for the p_T W modelling is based on precise measurements of p_T Z and accurate predictions of the W/Z p_T ratio



- Require great control of:
  - non-perturbative QCD
  - q_T-resummation
  - heavy-flavour-initiated production



- Work in progress in the LPCC EW working group to benchmark various different predictions of the W/Z p_T ratio
- From the experimental perspective, aimed at
  - Define a common baseline where all predictions agree
  - Allow using the prediction which is best suited to derive each particular correction and/or uncertainty on top of the baseline
  - Avoid ill-defined two-points systematic uncertainties

Electroweak corrections

- QED FSR: dominant correction, included in the simulation with PHOTOS or others MC
- Other NLO electroweak corrections are usually estimated independently from QCD corrections, and applied as uncertainty

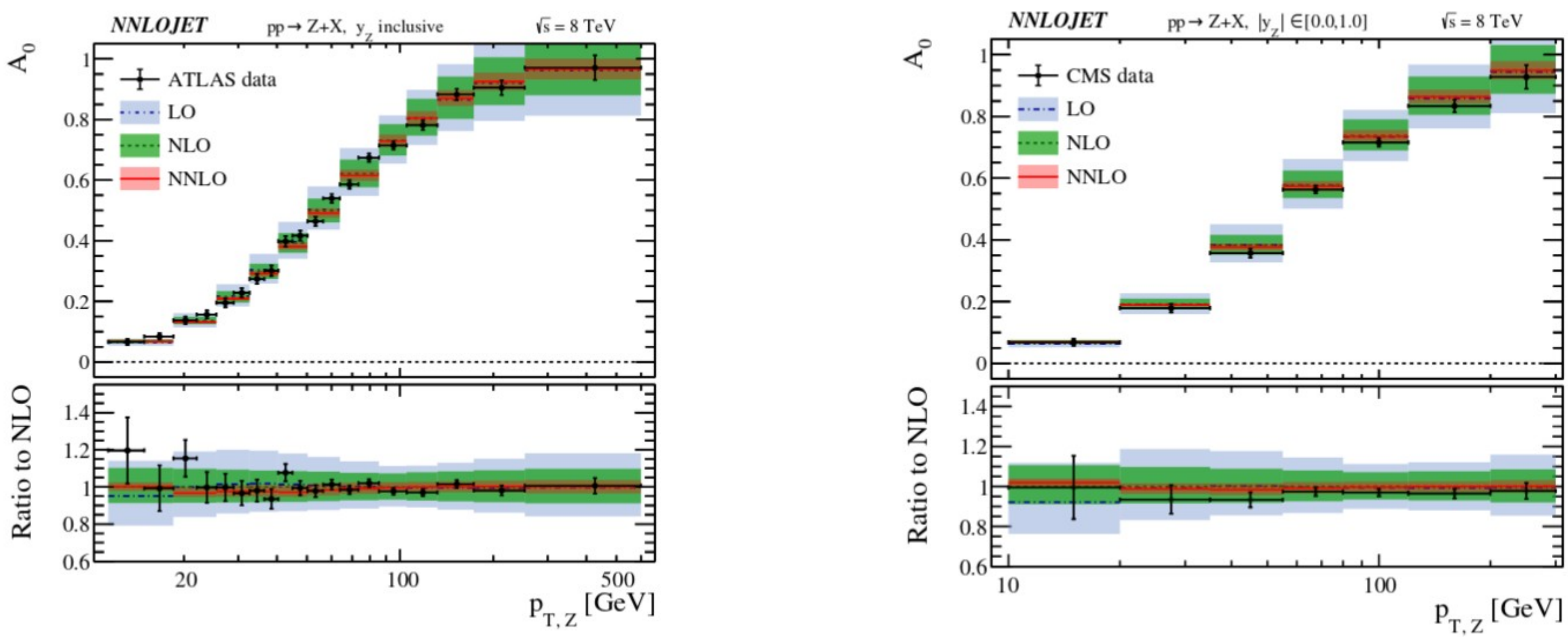
Decay channel	$W \to e\nu$		$W \to \mu\nu$	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

- Many recent developments in higher order corrections, and benchmarking between different codes presented in the LPCC EW working group
- Main challenge for the m_W analyses: include electroweak corrections in the analyses, coherently combined with QCD corrections. Available tools are Powheg-EW, DIZET form factors, WINHAC, KKMC
- Open point: is the running-width propagator still the best definition for m_W, in view of higher order EW corrections?

Angular coefficients A_i

- The angular coefficients provide a powerful framework to describe asymmetries of the DY cross section as the azimuthal (A2) and the forward-backward (A4). The decomposition holds at all order in QCD

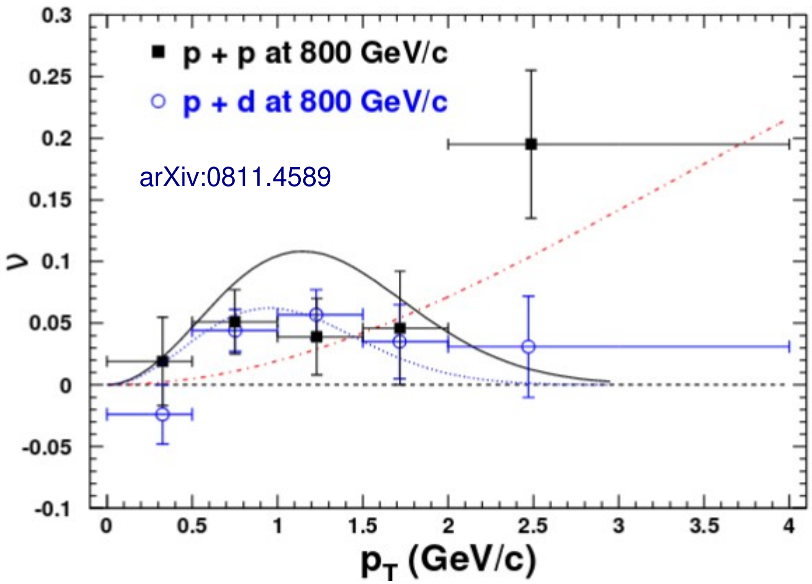
$$\frac{d\sigma}{dpdq} = \frac{d^3\sigma}{dp_T\,dy\,dm} \sum_i A_i(y, p_T, m) P_i(\cos\theta, \phi)$$



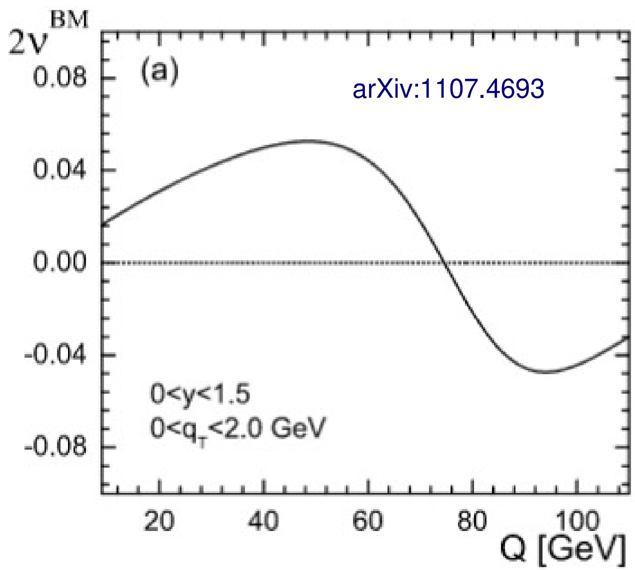
- Precise measurements from ATLAS and CMS as well as accurate perturbative QCD predictions at $O(\alpha_s^3)$ are available

Angular coefficients A_i

- Beyond the current precision, the measurement of m_W could be sensitive also to asymmetries from non-perturbative QCD effects



- cos(2ϕ) (A2) asymmetries in the non perturbative regime were observed in fixed target Drell-Yan experiments (NA10, E866)
- They are well described by Boer-Mulder TMD functions



- The non-perturbative conribution to A2 at small q_T is expected to change sign between γ^* and Z exchange
- Is such an asymmetry expected also in W?
- The effect on m_W is expected to be small, but it may be necessary to quantify it precisely for future measurements

- The ultimate precision on m_W can be achieved at e^+e^- colliders through an energy scan of the WW production threshold

- Near threshold, the WW cross section is proportional to the non-relativistic W velocity

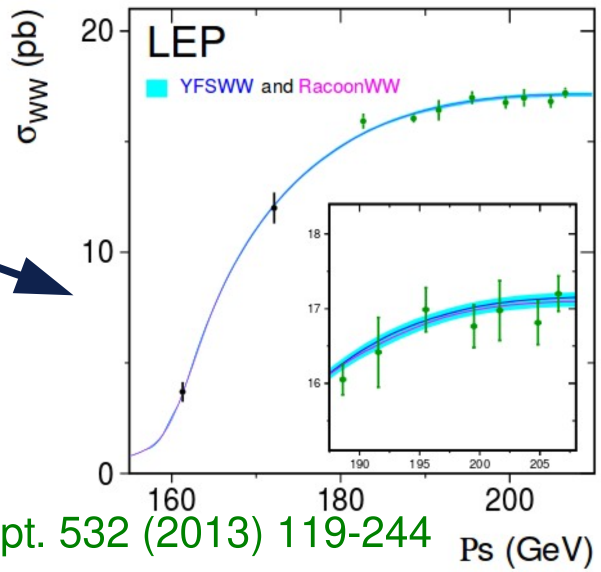
$$\sigma(WW) \propto \beta_W$$

arXiv:1306.6352

ILC Giga-Z program
- Energy scan 160 to 170 GeV
- δM_W = 6-7 MeV

FCCee WW program
- δM_W = 0.5 MeV
  → dominated by statistical uncertainty

Dominant theory uncertainties
- Initial state QED corrections
- Parametrization of cross section near threshold



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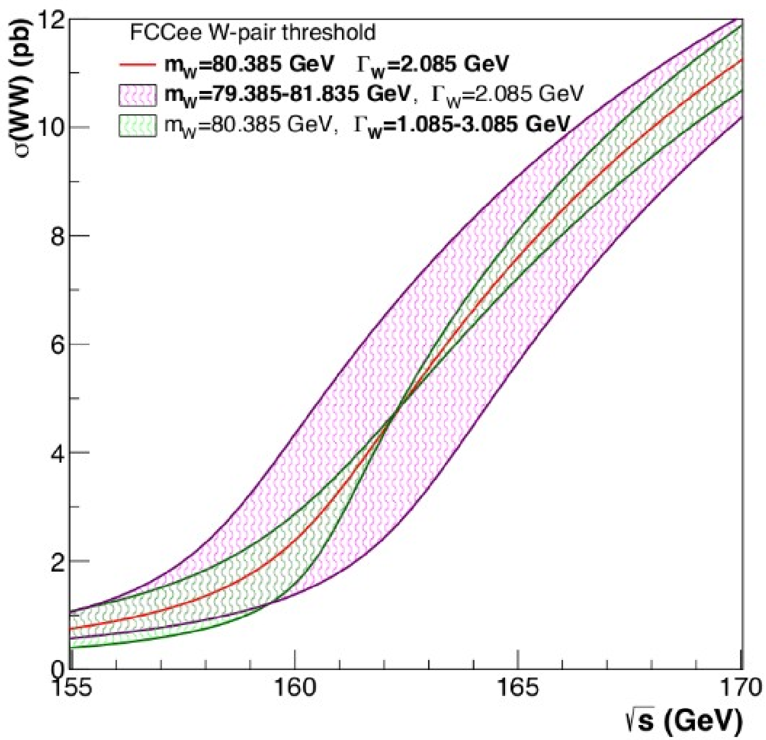


Summary

- The W-boson mass measurement is dominating the global fit of the electroweak observables
- The ATLAS measurement demonstrated that it is possible to perform a measurement of the W-boson mass with ~20 MeV uncertainty competitive with current best measurements. m_W measurements at CMS and LHCb are expected soon.
- Future measurements of the W-boson mass will likely follow two orthogonal paths: low pileup measurements dominated by m_T, and high pileup measurements dominated by p_T lepton.

What is needed?

- Muon momentum scale calibration preferably be based on J/ψ → more statistics, reduced correlation between experiments, but also more challenging
- Further constraints on PDFs from W charge asymmetry measurements and PDF fits to Drell-Yan including q_T-resummation
- Low pileup measurements of p_T W, and more precise modelling of the W/Z p_T ratio.
- Measurements and predictions of angular coefficients at high and low p_T

Additional topics

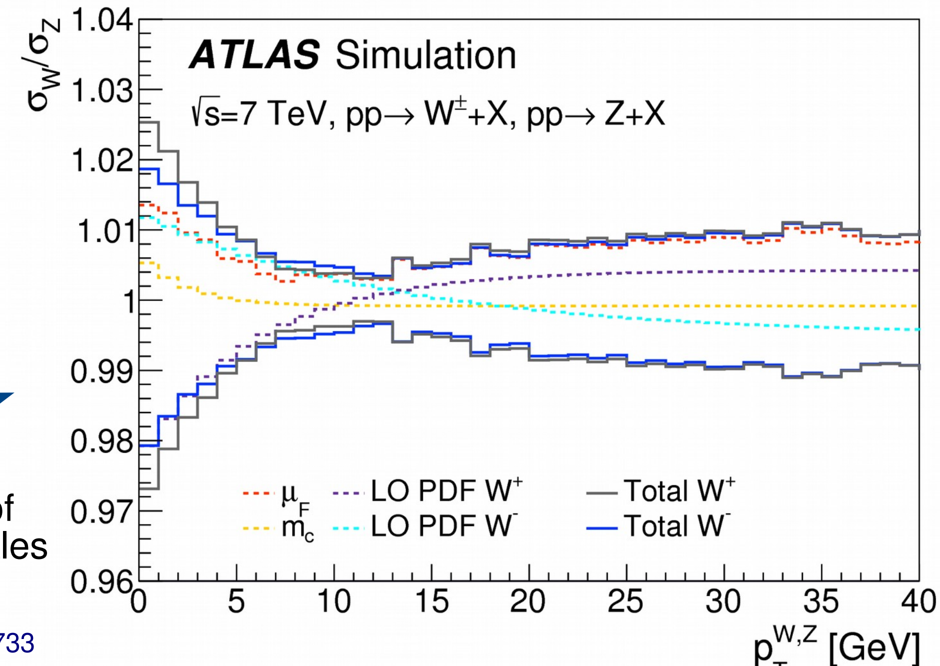
- Tevatron-LHC combination → Nansi's talk
- PDF in-situ constraints → Emanuele's talk

BACKUP

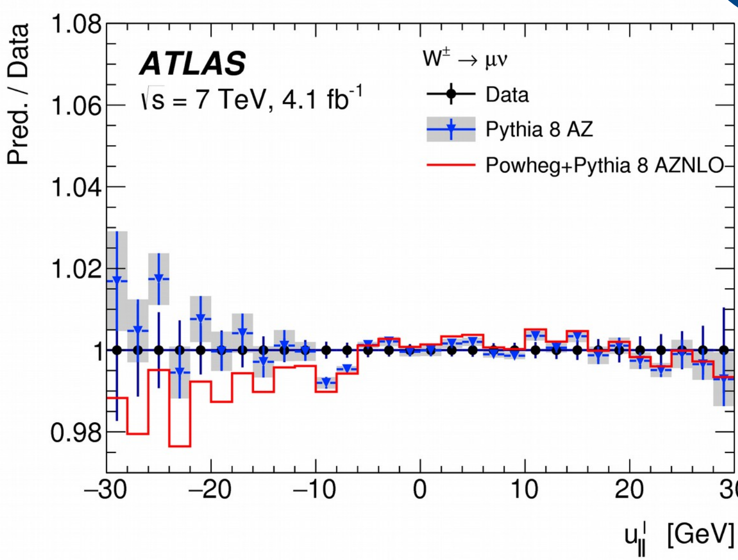
Uncertainties in the p_T W modelling

- Heavy-flavour-initiated (HFI) production introduce differences between Z and W production
- HFI production determines a harder boson p_T spectrum, $cc \to Z$ and $bb \to Z$ are 6% and 3% of Z production, $cs \to W$ is ~20% of W production
- HFI addressed with charm-quark mass variations, and by decorrelating the PS μ_F between light and HFI processes

p_T W theory uncertainties are evaluated as the sum of experimental Z p_T unc. and theory unc. on the W/Z p_T ratio



This procedure is a proxy for variations of the HF matching scales in the PDFs, see arXiv:1605.01733



Central prediction and uncertainty validated with the recoil distribution → when using the data to constrain the model we end up with compatible central value and similar uncertainties

Physics modelling – Summary of QCD uncertainties

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

- PDFs are the dominant uncertainty, followed by p_T W uncertainty due to heavy-flavour-initiated production
- PDF uncertainties are partially anti-correlated between W+ and W-, and significantly reduced by the combination of these two categories.
- p_T W uncertainties are similar for m_W extracted from p_T lepton and from m_T

Muon calibration

Muon identification using combined ID+MS tracks

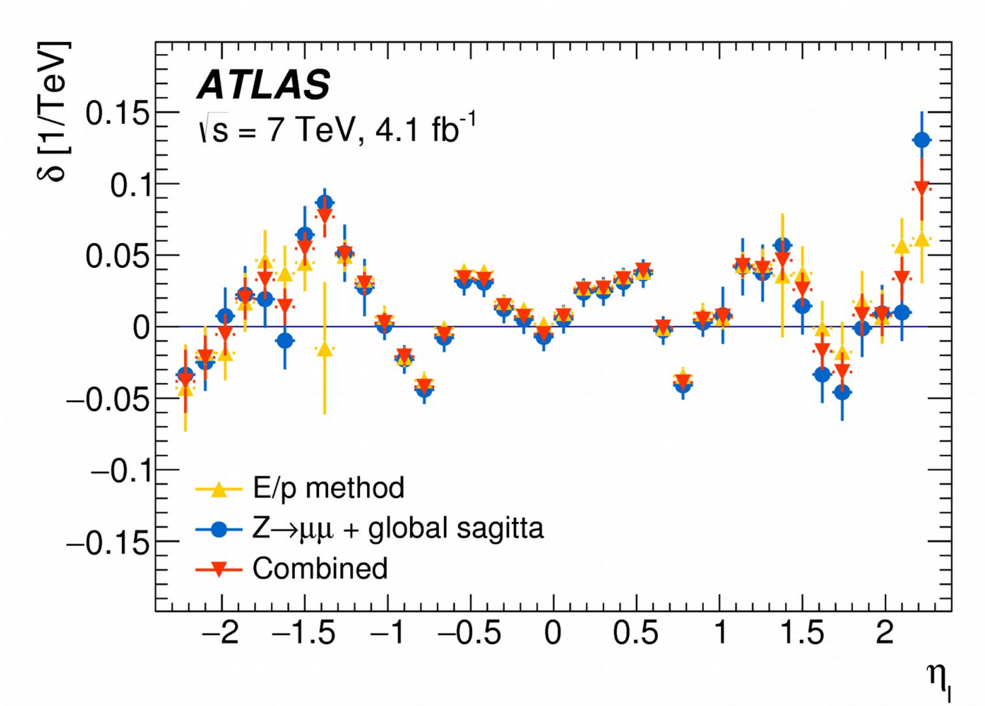
Momentum measurement from ID only

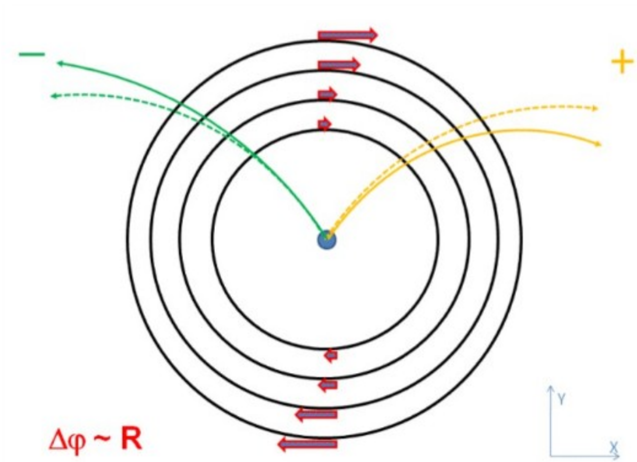
→ simplifies calibration, some loss in resolution

Parameterisation of momentum corrections:

- α: radial bias (scale)
- δ: sagitta bias
- β: resolution correction

$$p_{\mathrm{T}}^{\mathrm{corr}} = p_{\mathrm{T}}^{\mathrm{MC}} \times \frac{1+\alpha(\eta,\phi)}{1+q\cdot\delta(\eta,\phi)\cdot p_{\mathrm{T}}^{\mathrm{MC}}}\left[1+\beta_{\mathrm{curv}}(\eta)\cdot G(0,1)\cdot p_{\mathrm{T}}^{\mathrm{MC}}\right]$$

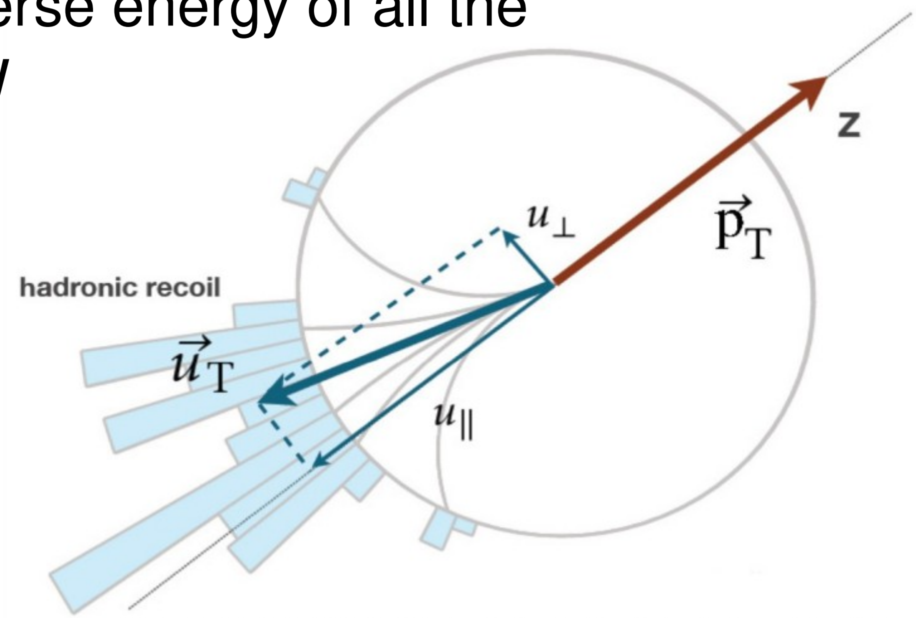




- Charge dependent corrections
- Scale and resolution corrections derived form Z → μμ line shape, sagitta bias also from E/p in W → eν

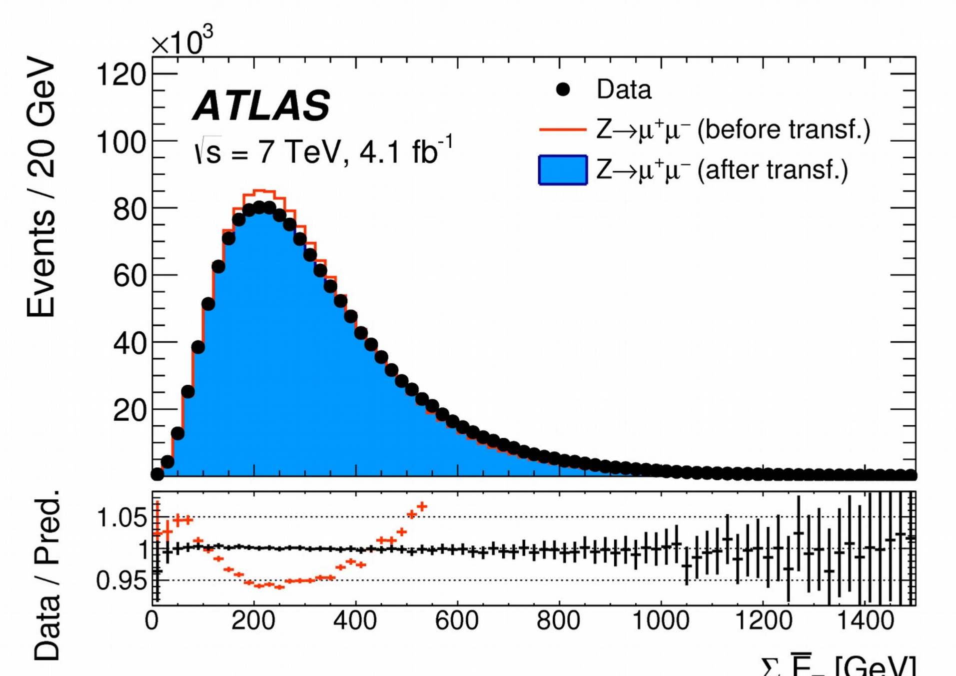
Recoil calibration

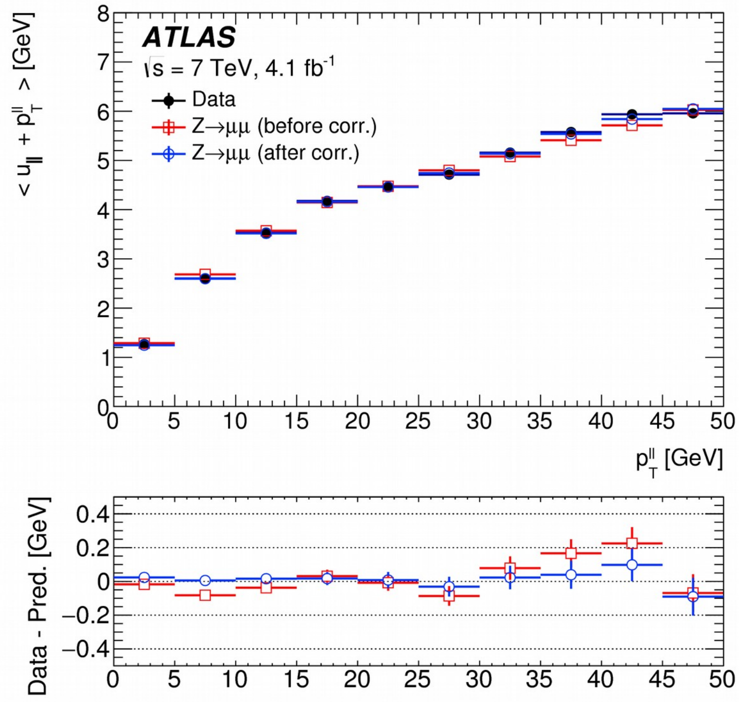
The recoil u_T is the vector sum of the transverse energy of all the calorimeter clusters: u_T is a measure of p_T W



Calibration steps:

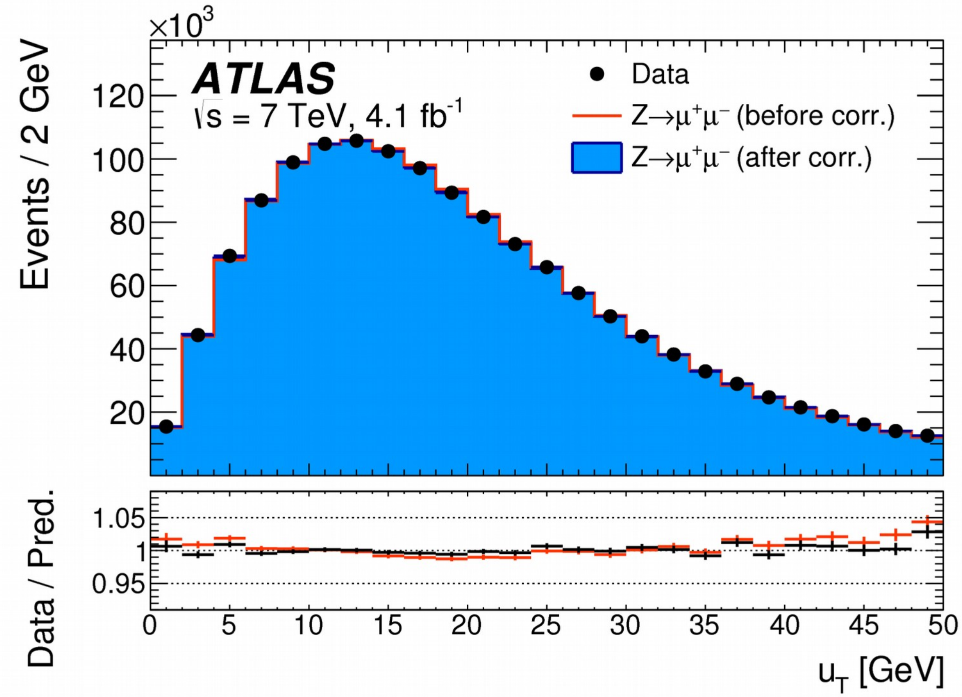
- Correct pile-up multiplicity in MC to match the data
- Correct for residual differences in the ΣE_T distribution
- Derive scale and resolution corrections from the p_T balance in Z events





Recoil calibration

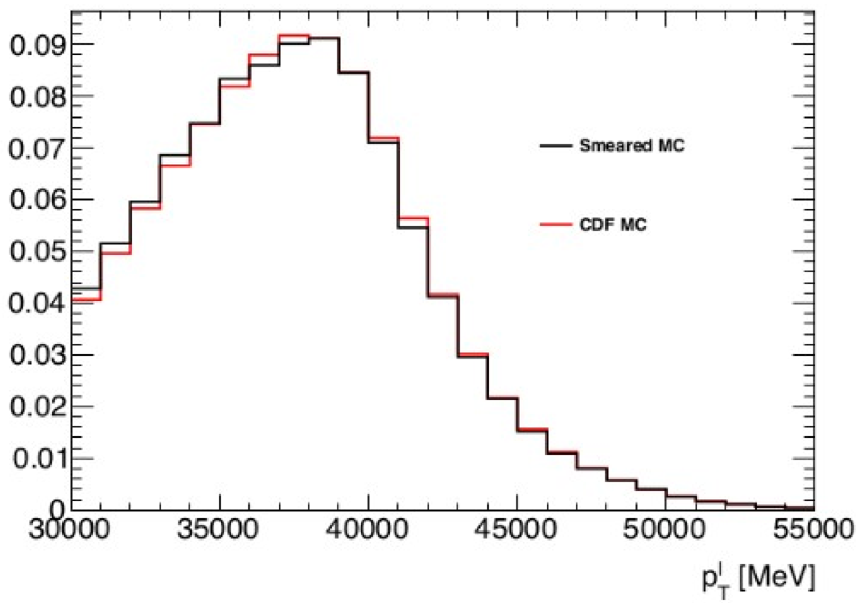
- u_T distribution well modelled after corrections
- ΣE_T correction is the dominant uncertainty



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]						
$\langle\mu\rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma\bar{E}_T$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

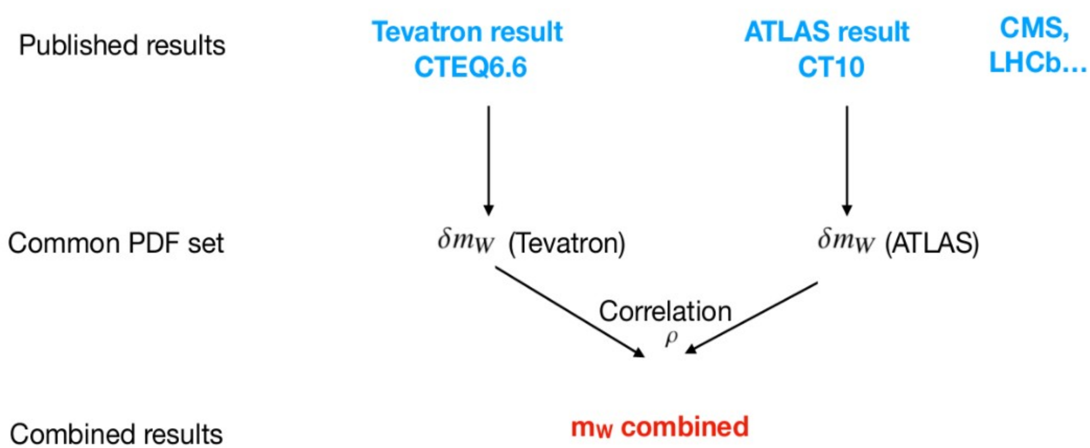
W mass combination

- Aim to provide an official ATLAS-Tevatron combination
- Set the stage for combining ATLAS, CMS and LHCb results
- Consider all experimental uncertainties as uncorrelated
- Evaluate physics modelling correlation with a simplified model
  → PDFs are the main source of correlation



- Methodology: mock up the measurements using generator-level predictions plus smearing based on simple parametrization for the lepton and recoil resolutions
- Does not allow a proper reproduction of central values of course, but sufficient for an accurate estimate of PDF uncertainties

W mass combination



pTl observable

Correlations
Preliminary

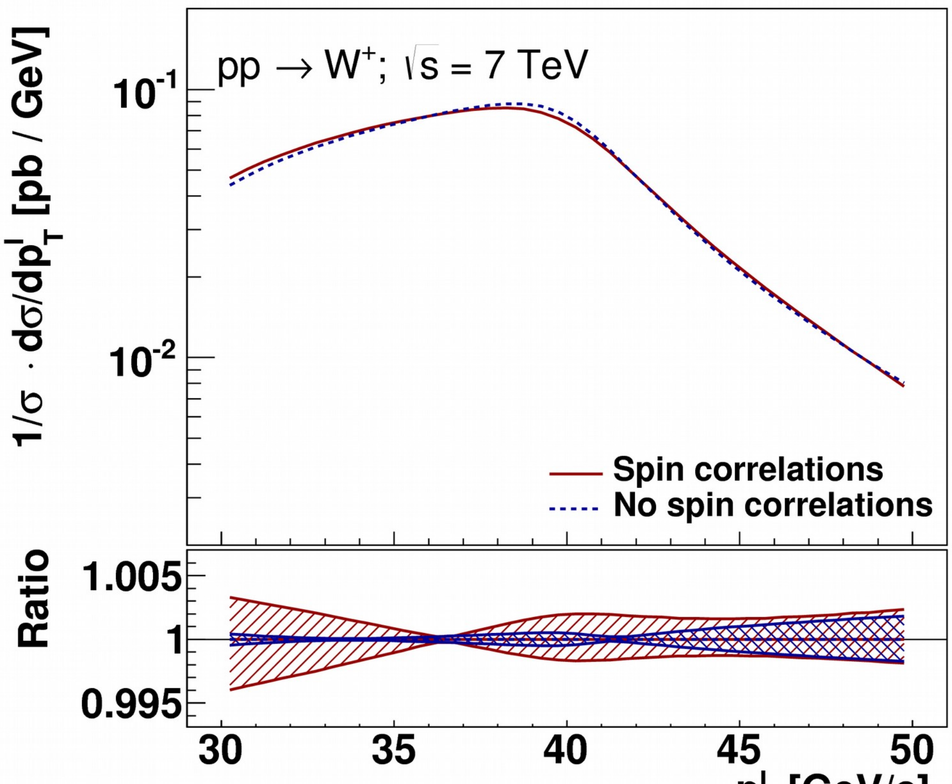
CT10	1.	2.	3.	4.
1. W^+ 2 TeV	1	0.99	0.26	0.51
2. W^- 2 TeV	0.99	1	0.31	0.52
3. W^+ 7 TeV	0.26	0.31	1	-0.23
4. W^- 7 TeV	0.51	0.52	-0.23	1

CTEQ6.6	1.	2.	3.	4.
1. W^+ 2 TeV	1	1	0.37	0.45
2. W^- 2 TeV	1	1	0.36	0.46
3. W^+ 7 TeV	0.37	0.36	1	-0.42
4. W^- 7 TeV	0.45	0.46	-0.42	1

- Need to translate m_W measurements to a common PDF set
- ATLAS-Tevatron PDF correlation estimated at the level of 30% (50%) for W+ (W-)

W mass at the LHC

- A large fraction of W production at the LHC is inititiated by sea quarks
- The W polarisation at the LHC is more influenced by PDF uncertainties, implying larger uncertainties on the lepton p_T distribution
- The valence-sea difference, as well as the amount of sea quarks with u and d flavour, must be known with better precision than needed at the Tevatron

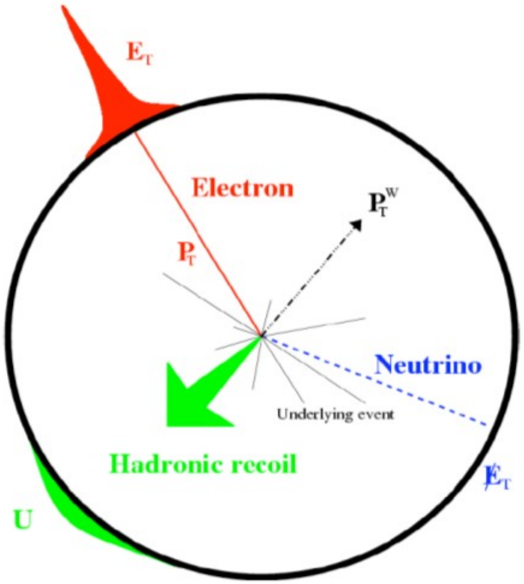


ATL-PHYS-PUB-2014-015

- The effect can be isolated by switching off spin correlations
- O(10-20) MeV effect for m_W extracted from the p_T lepton distribution

Large reduction of PDF uncertainties near the Jacobian peak

W mass measurement definitions



$$\vec{u}_{\mathrm{T}} = \sum_i \vec{E}_{\mathrm{T},i}$$

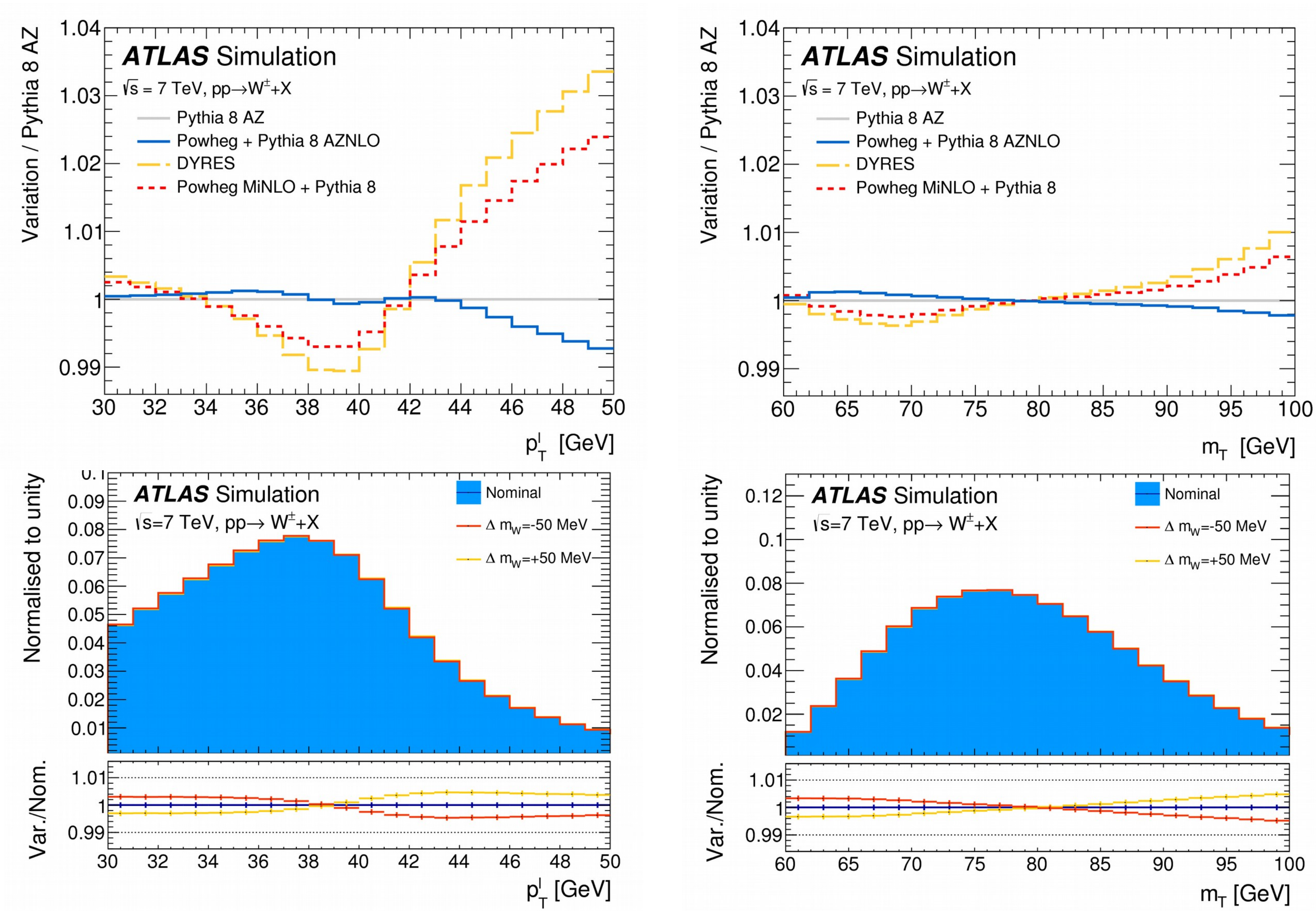
$$\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} = -\left(\vec{p}_{\mathrm{T}}^{\,\ell} + \vec{u}_{\mathrm{T}}\right)$$

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos\Delta\phi)}.$$

- The recoil is the vector sum of the transverse energy of all the calorimeter clusters: u_T is a measure of p_T W
- $u_{||}$ and uperp are the parallel and perpendicular projections of the recoil on the charged lepton (W events) or on the dilepton p_T (Z events)
- p_T nu is inferred from the momentum imbalance in the transverse plane
- The transverse m_T is defined from variables measured in the transverse plane

p_T W uncertainties on p_T lepton and m_T

p_T W uncertainties are similar for m_W extracted from p_T lepton and from m_T

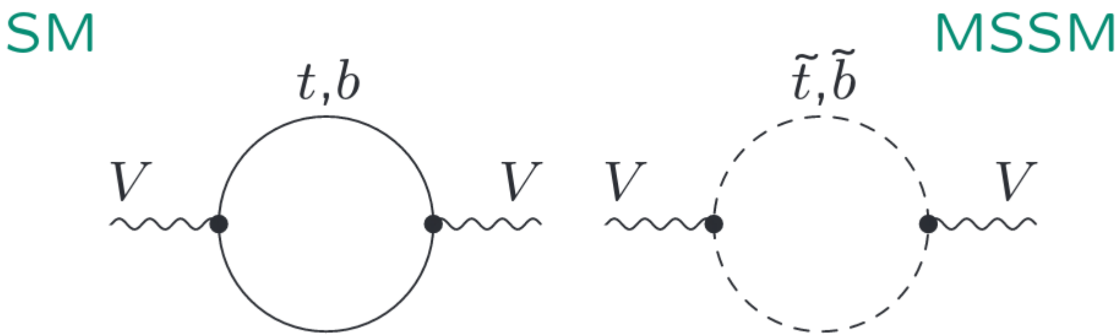


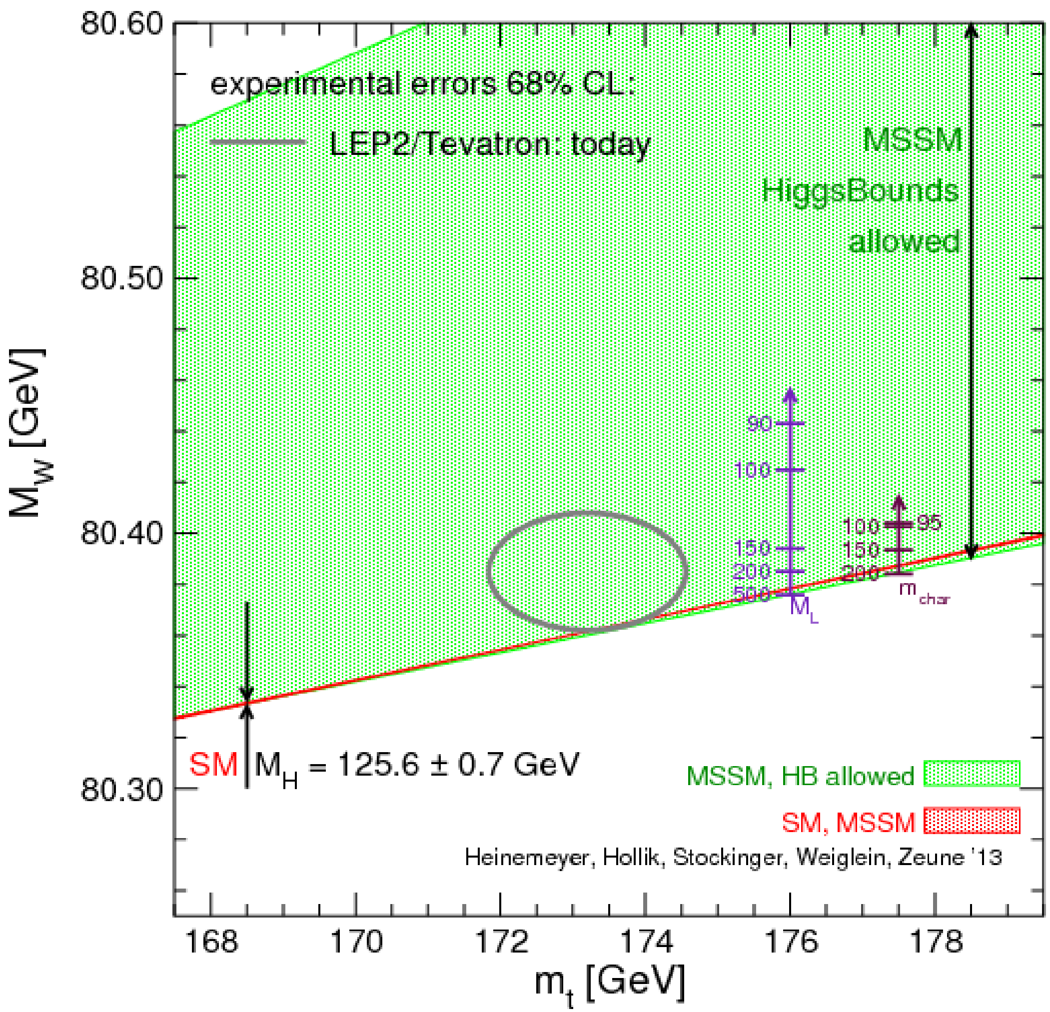
→ m_T is less sensitive to p_T W, but p_T W variations on m_T are less distinguishable from m_W variations

Measurement categories

Channel m_{T}-Fit	m_W [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.
$W^+ \to \mu\nu, \|\eta\| < 0.8$	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

MSSM constraints from the W mass measurement

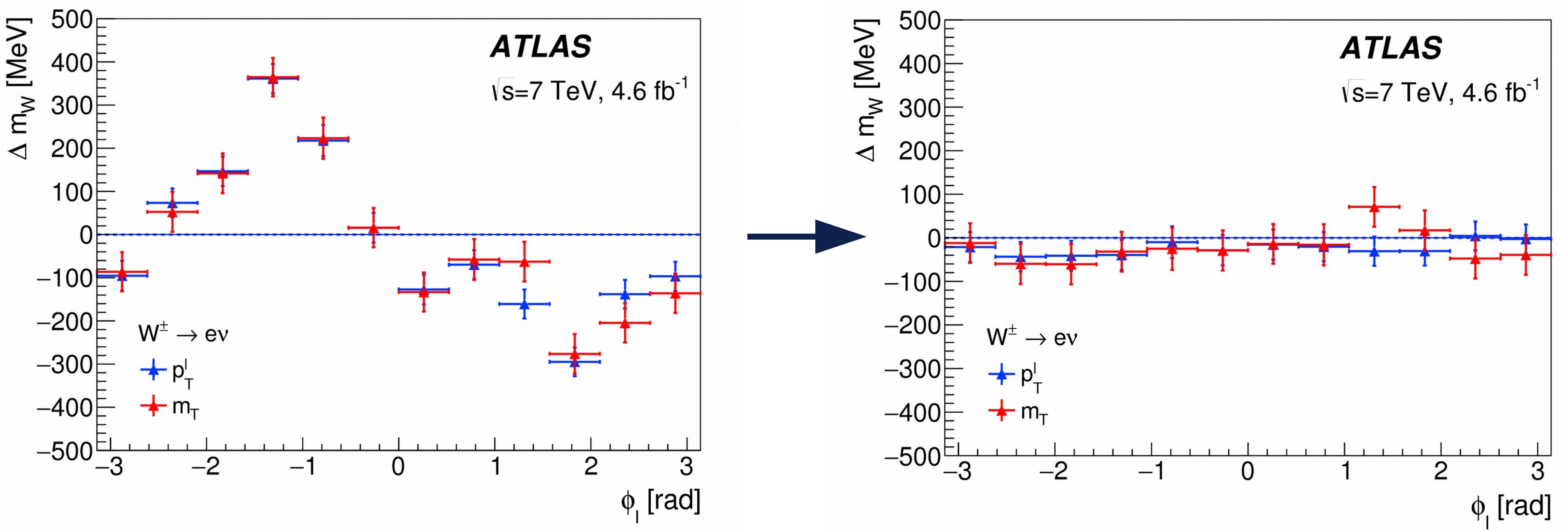




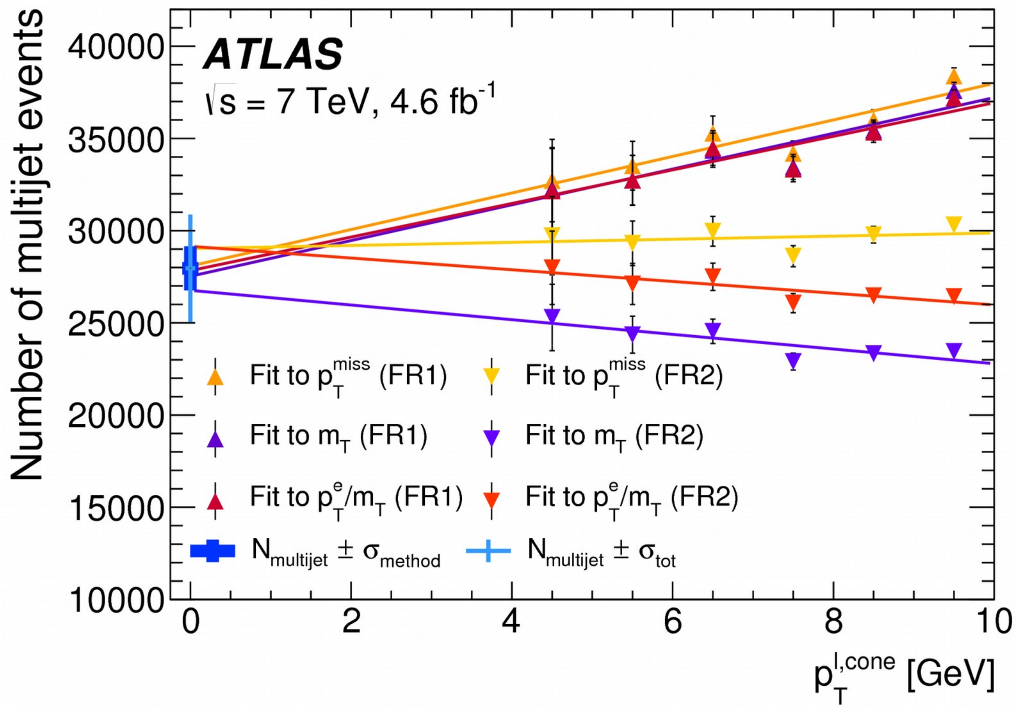
Electron calibration

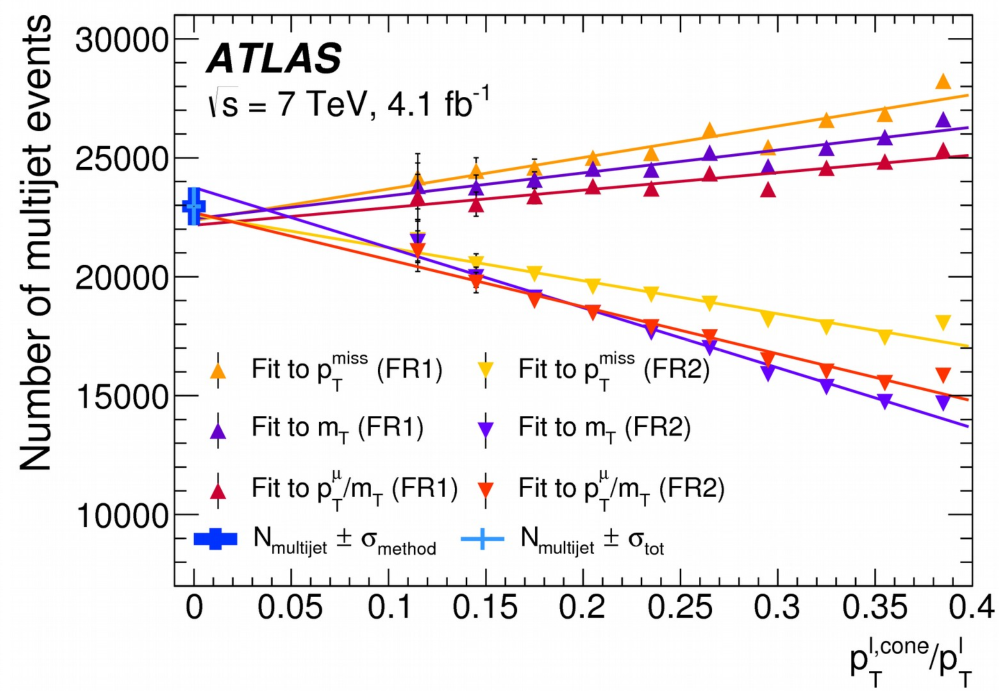
- Electron measurement: energy from the EM calorimeter, η, ϕ from the ID
- Scale and resolution corrections derived from the Z → ee line shape
- ϕ-dependent corrections are important for the Z to W extrapolation

The p_T^{miss} requirement, which is only used for W events, induces a ϕ asymmetry in the selected W events distribution



W mass multijet background





- Novel technique for the multijet background estimation
- The multijet background is determined with template fits, and by extrapolation of the lepton isolation to the signal region
- Both normalisation and shape are extrapolated