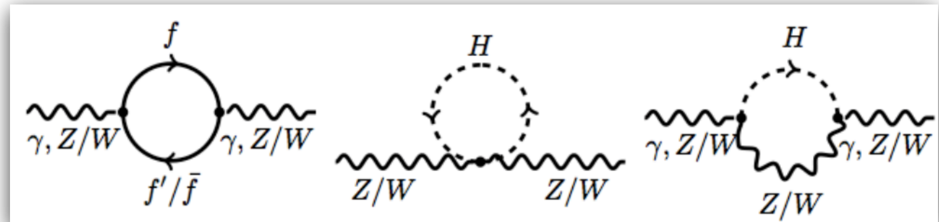
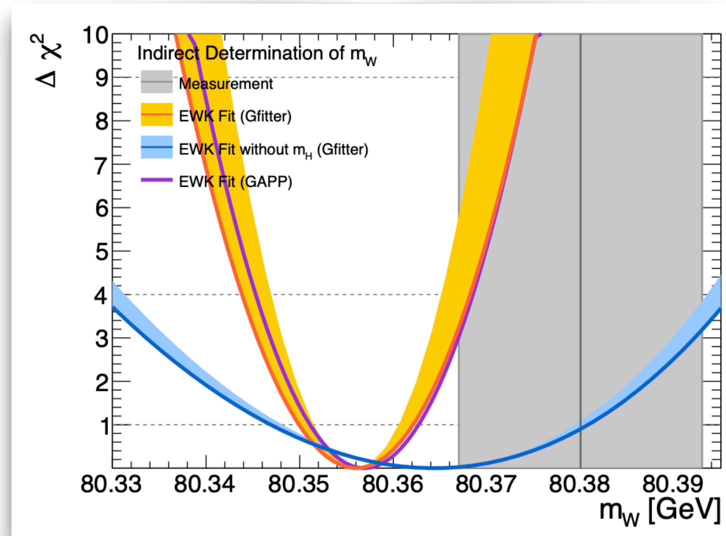
News on the W Boson Mass from the ATLAS Experiment

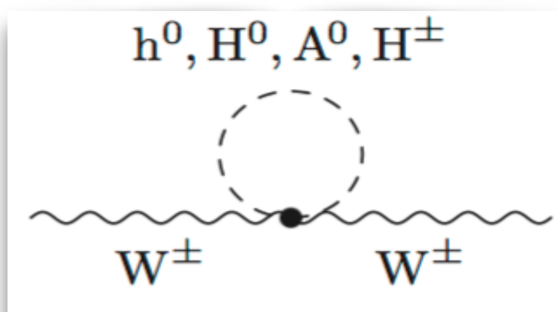
Matthias Schott
on behalf of the ATLAS Collaboration

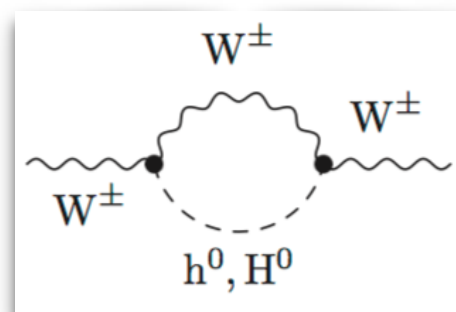
The Global Electroweak Fit



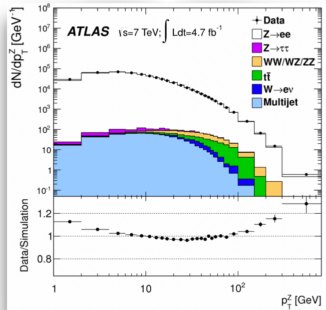


- Knowing four parameters of the electroweak sector (α_{em}, G_F, m_Z, $\sin^2\theta_W$) as well as m_H and m_{top}, allows to predict m_W within the SM
  - Δm_W=7 MeV
- Test prediction of m_W at the experiment
- New particles in the loops would change the SM prediction of m_W





The ATLAS History of the W Boson Mass



2008 Eur.Phys.J.C 57
ATLAS Potential on m_W

2012 Start of the m_W analysis Efforts

2014 JHEP 09 (2014) 145
Z Boson Transverse Momentum at 7 TeV

2016 Eur. Phys. J. C 77 (2017) 367
W and Z Boson Production at 7 TeV

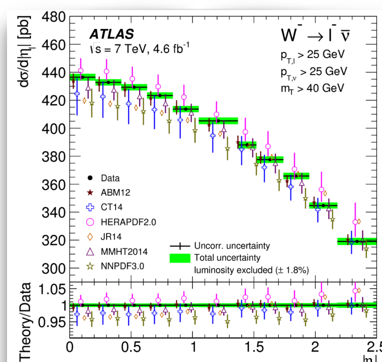
2016 JHEP 08 (2016) 159
Z Boson Angular Coefficients

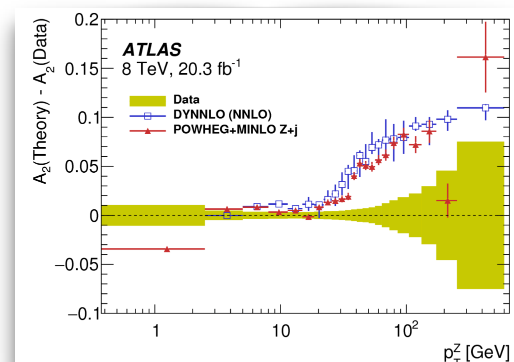
2017 Eur.Phys.J.C 78 (2018)
First Measurement of m_W

2018 Start of the m_W Re-analysis Efforts

2019 A. Düdder
PhD Theses
2020 L. Adam
PhD Thesis
2022: P. König
PhD Thesis

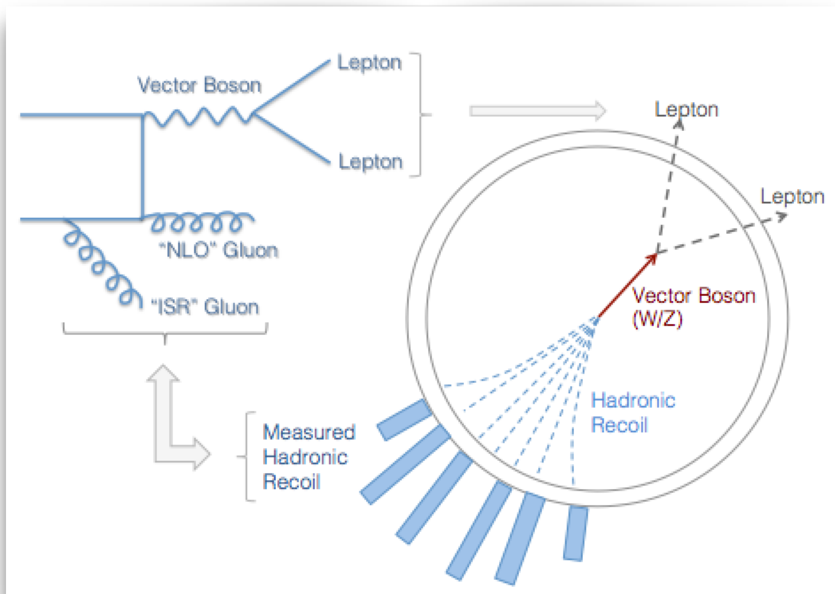
2023 This Work
Reanalysis of m_W

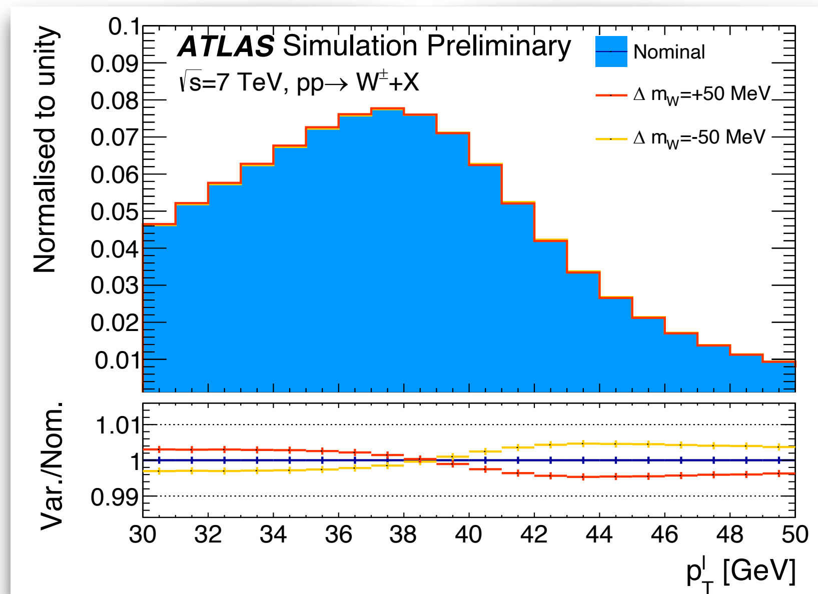




Analysis Strategy

- Study leptonic W Boson decays: use the dependence of the leptonic transverse momentum (p_T) and the transverse mass (m_T) to determine m_W

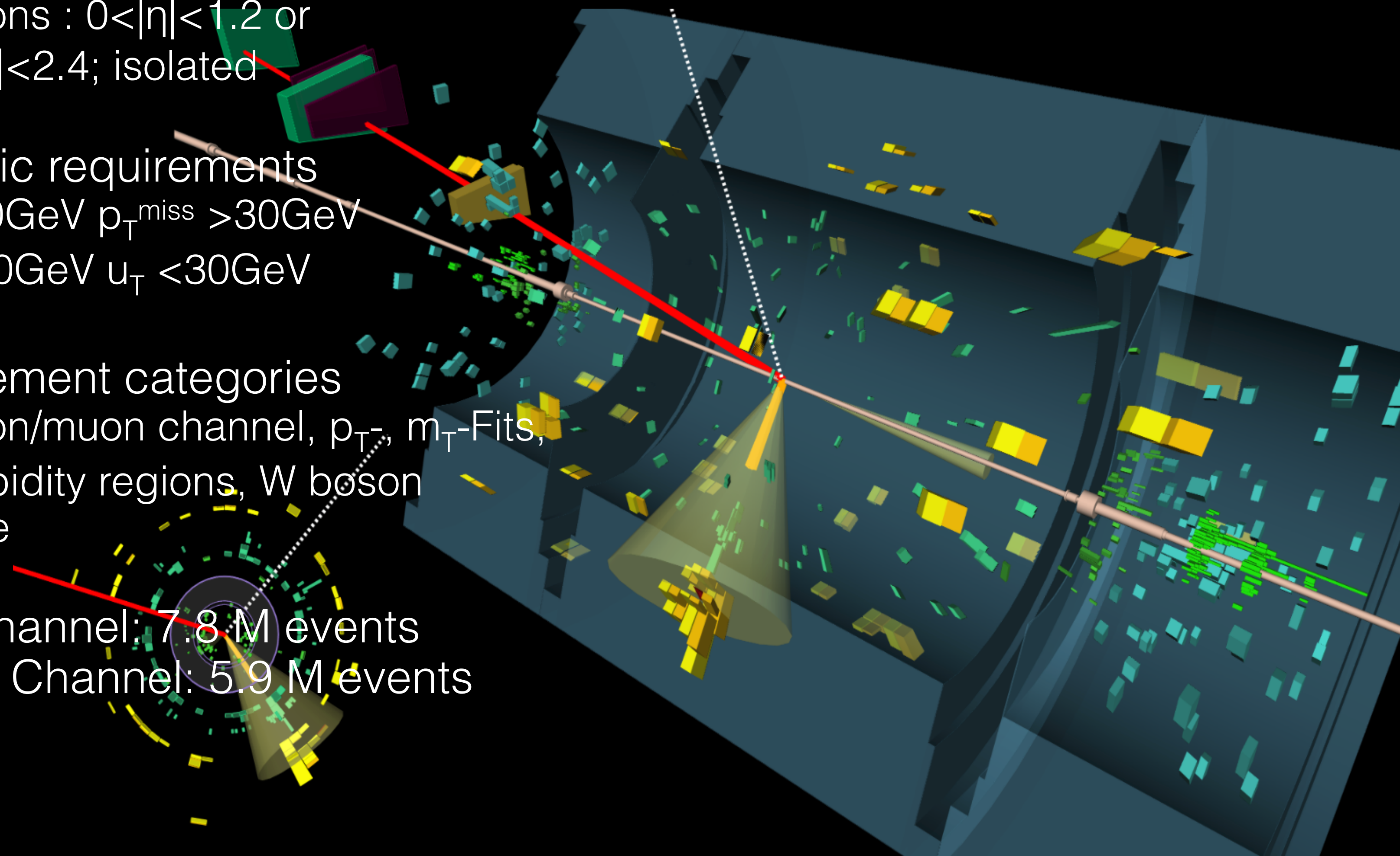


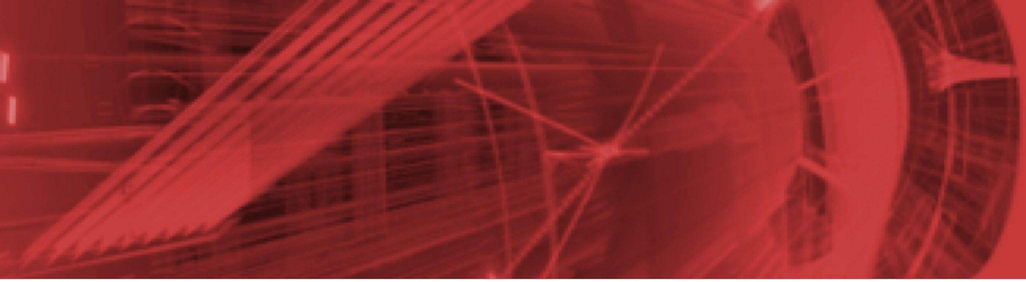


- Revisit 2016 measurement with advanced physics model and profile likelihood fitting
  - Advantage: Reduce systematic uncertainties during the fit
  - Disadvantage: Computational expensive, challenging to investigate systematics

Signal Selection and Measurement Regions

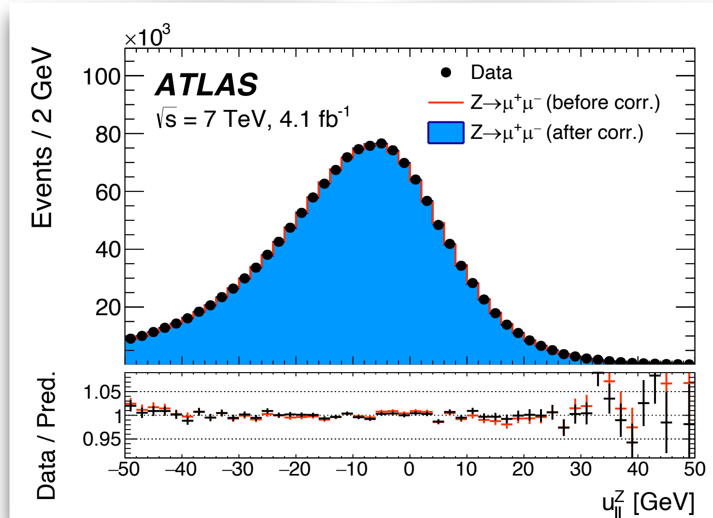
- Lepton selections
  - Muons : $|\eta| < 2.4$; isolated
  - Electrons : $0<|\eta|<1.2$ or $1.8<|\eta|<2.4$; isolated
- Kinematic requirements
  - p_T >30GeV p_T^{miss} >30GeV
  - m_T >60GeV u_T <30GeV
- Measurement categories
  - Electron/muon channel, p_T-, m_T-Fits, 3/4 rapidity regions, W boson charge
- Muon Channel: 7.8 M events
- Electron Channel: 5.9 M events

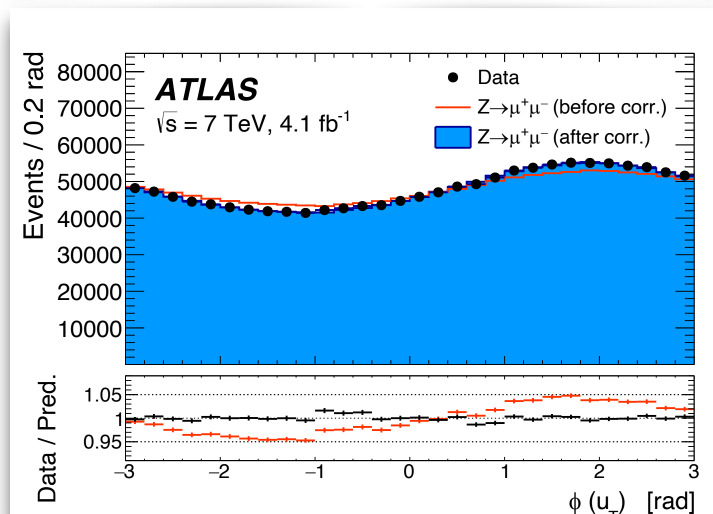




Calibration

- Detector calibration unchanged compared to legacy measurement
- Muon momentum and electron energy response calibrated using Z boson events
- Lepton efficiencies calibrated using Tag-and-Probe method
- Hadronic recoil response calibration based on the hadronic recoil in Z boson events





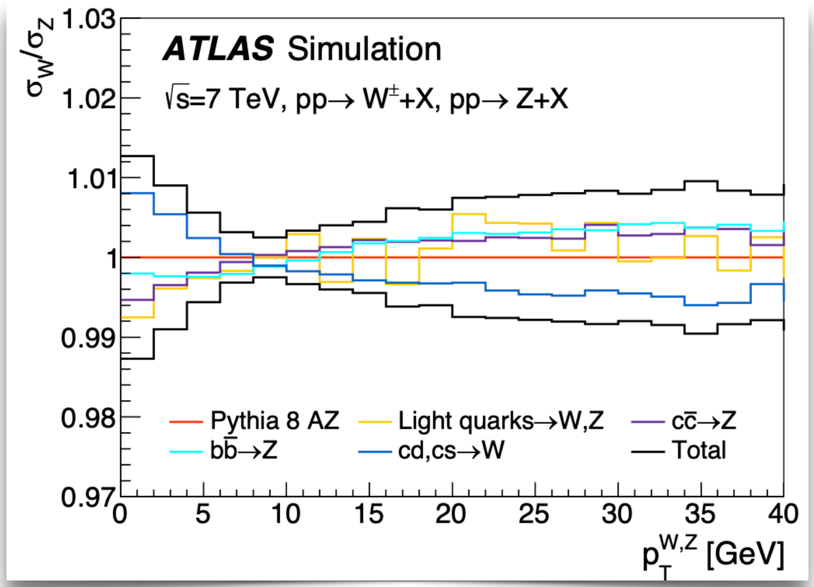
Physics Modeling

- Baseline: Pythia AZ tune (based on Z boson)
  - Z Boson Data, Parton Shower Variations
  - Z→W: factorization scale variations (light- and heavy-quarks), heavy quark masses

- New Verifications:
  - AZ tune describes hadronic recoil spectrum of W's in low-pileup data at 5 TeV within experimental uncertainties
  - DYTurbo (resumed calculation) also agrees with AZ Tune. See Talk of S. Camarda

- Treatment of angular coefficients unchanged
  - NNLO prediction + Uncertainties from Z boson measurements

- Parton Distribution Functions
  - Study full set of available PDF Sets at NNLO: CT10, CT14, CT18, MMHT2014, MSHT20, NNPDF3.1, NNPDF4.0
  - New Baseline CT18



Analysis Improvements

- Multijet Background Estimation
  - Systematic shape variations using PCA
  - New transfer function from CR to SR
  - Reduction of 2 MeV uncertainty
- EW unc. are evaluated at detector level
  - increase of 1-2 MeV uncertainty
- Recovering data in the electron channel
  - Increase statistics by 1.5%
- Add Γ_W as NP parameter
- Improving random generator setup for the electron energy calibration
  - Minor effect on m_W
- Overall +2 MeV shift on m_W in p_T and +6 MeV shift in m_T channel
  - Driven by MJ background improvements

Details on the Fit-Setup

- Several 1000 NP need to be reduced

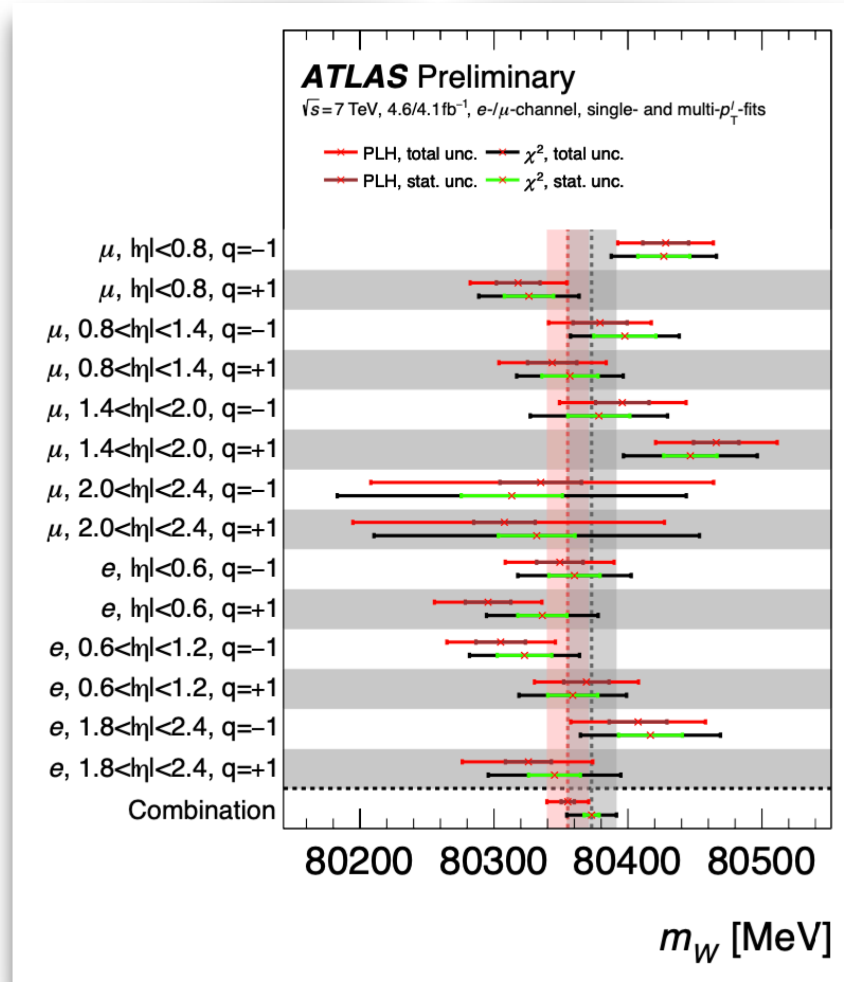
- Principle Component Analysis yields
  - 214 NP for p_T
  - 223 NP for m_T
  - Difference in final rel. unc. <0.1%

- Main Statistical Framework: TRExFitter
  - 12 Templates around m_W=80399 MeV
  - Morphing tested to 0.1 MeV precision

- Normalisation of the different templates is left free in the fit
  - A global normalisation factor is applied to all signal samples
  - Model independent approach (Cross-section depends on Γ_W)

Closure and Consistency Tests

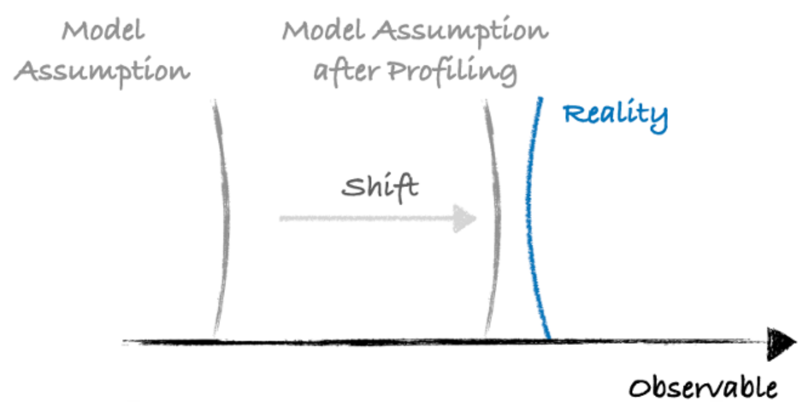
- Step 0: Reproduce the legacy results
  - Test PLH fit results with statistical uncertainties only
- Step 1-3: Test consistency of m_W for different setups
  - different fitting-ranges
  - positive and negative leptons
  - different regions of eta
- Step 4: Compare p_T and m_T based fits
  - correlation of p_T and m_T estimated using toy-variations of all systematics
  - Correlation: 0.6
- Good closure observed in all tests

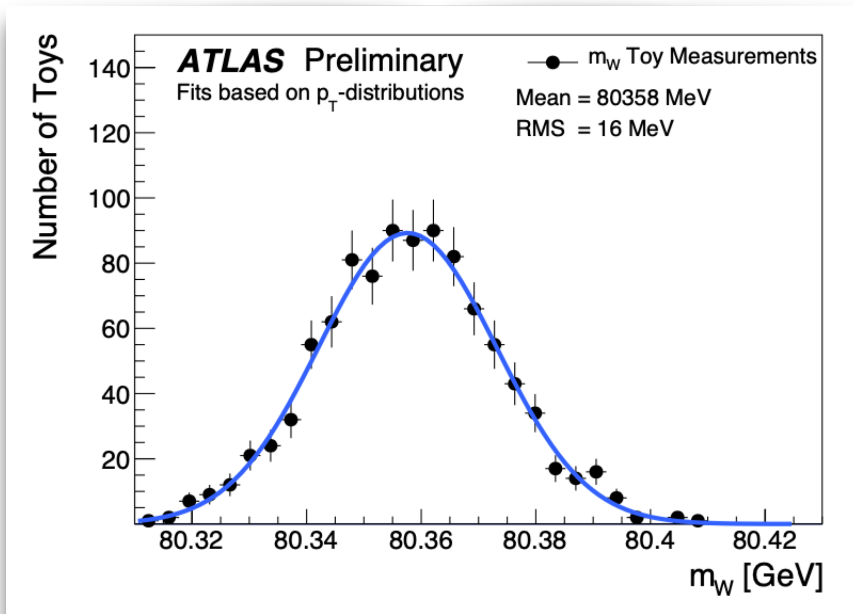


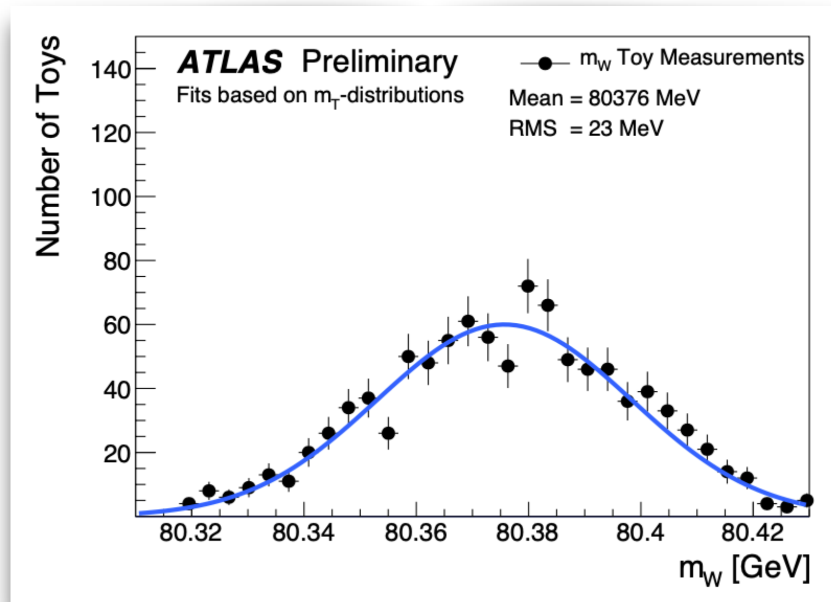
What do we expect?

- PLH fit will move the central value
  - How much?

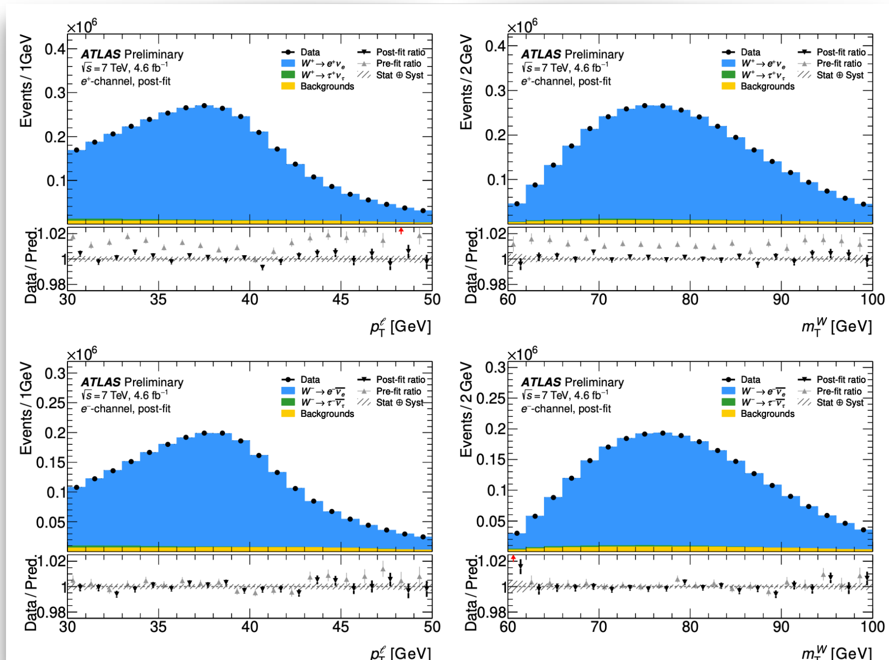
- MC Toy study of systematic variations
  - ±16 MeV (1σ) for p_T
  - ±23 MeV (1σ) for m_T

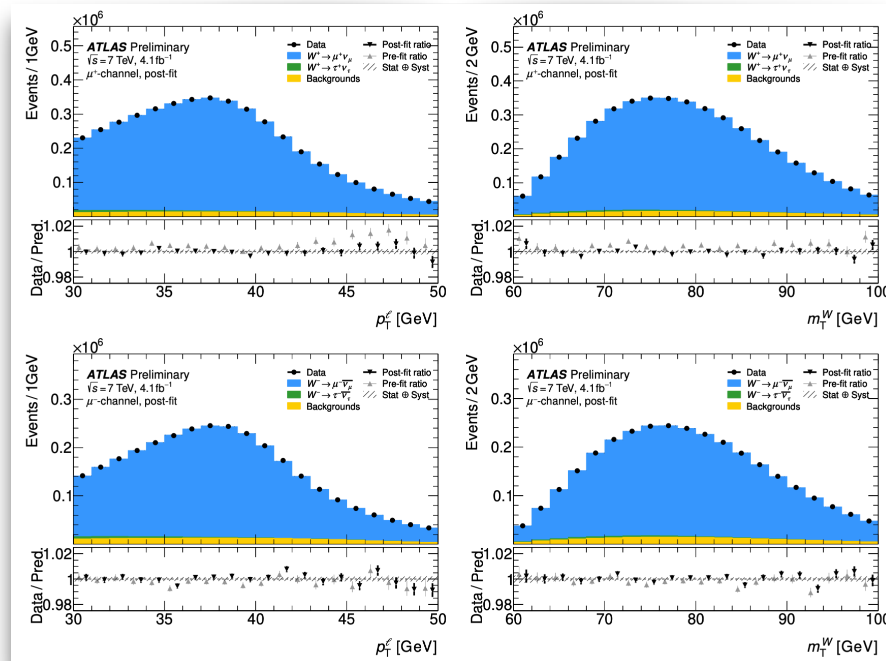






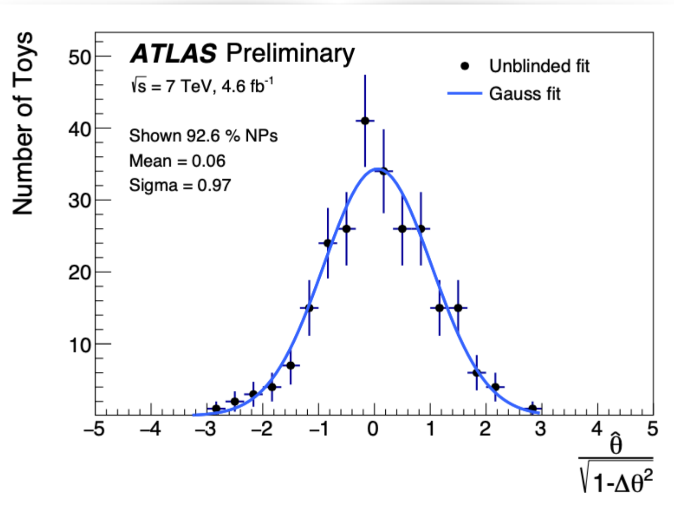
Post-Fit Distributions

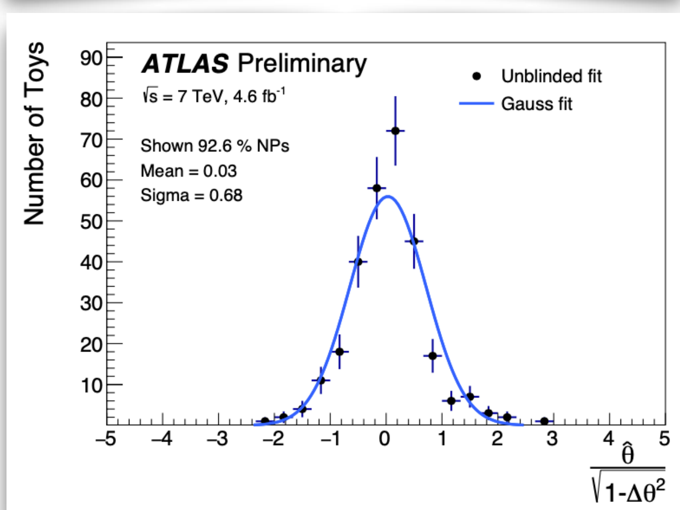




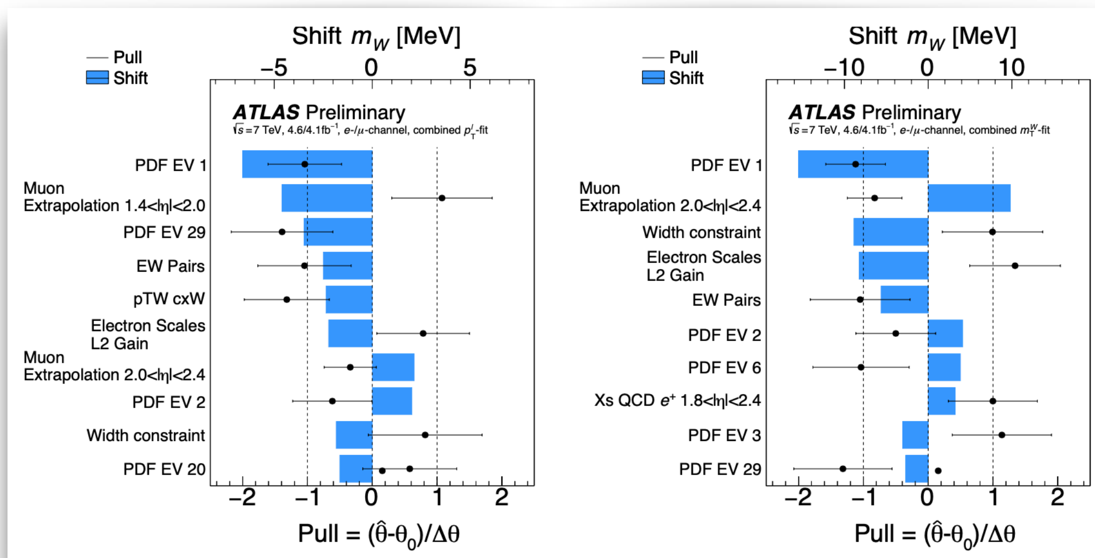
- Post-fit distributions show very good agreement with data
- Improvement compared to PLH fit when using statistical uncertainties only

Discussion of Pulls

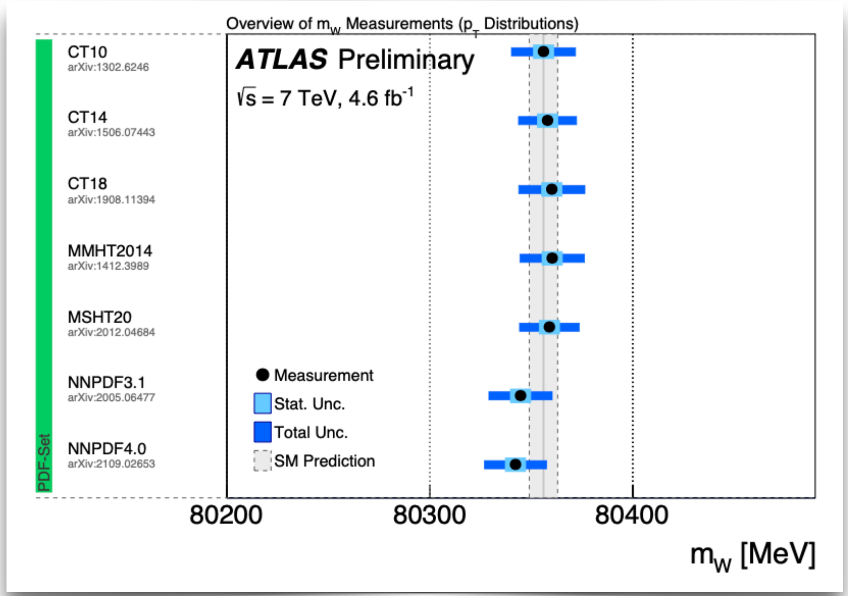


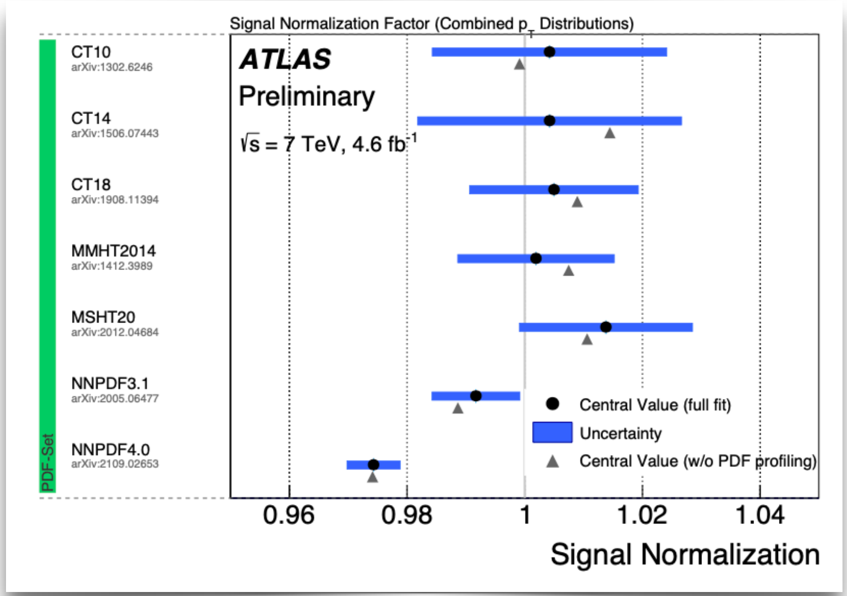


- The pulls of NP behave as expected
- NP with largest impact on m_W:
  - PDF Eigenvector 1 of CT18
  - Extrapolation of muon momentum scale in the forward region



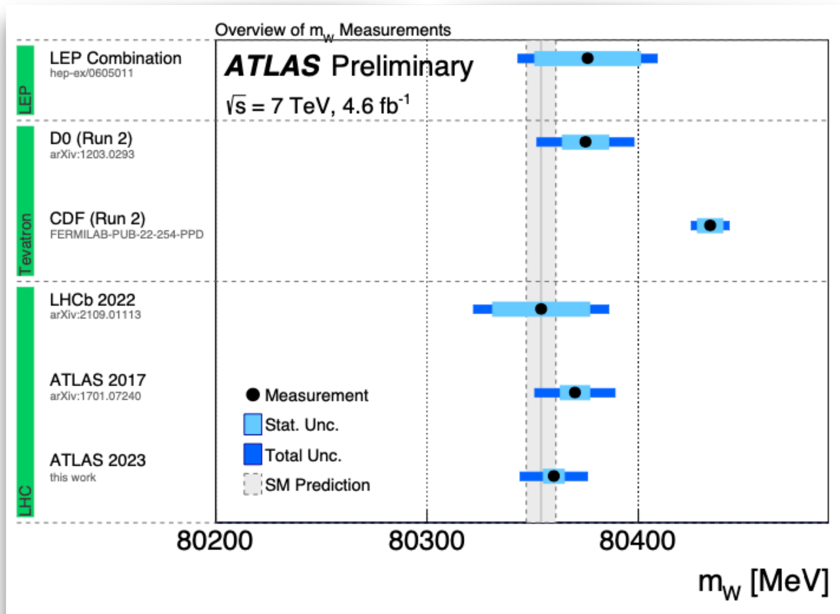
Study of Parton Distribution Functions

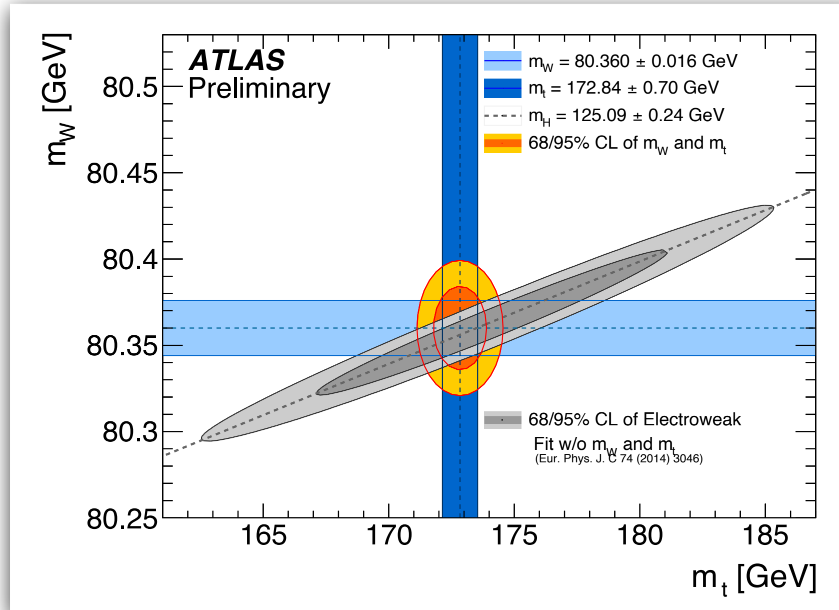




- Profiling moves central values of all PDF sets closer together
- Normalization of NNPDF4.0 not consistent with 1
- CT18 PDF Set as new baseline
  - yields most conservative uncertainties
  - CT18 PDF uncertainties cover the central values of CT10, CT14, MMHT2014 and MSHT20

Final Results and its Interpretation





- New ATLAS W mass measurements yields a value of

  $m_W = 80360 \pm 5_{(stat.)} \pm 15_{(syst.)} = 80360 \pm 16$ MeV

- We are even more Standard Model like as we have been previously
  - Reminder: Legacy Measurement of 2017 m_W = 80370 ±19 MeV

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Summary

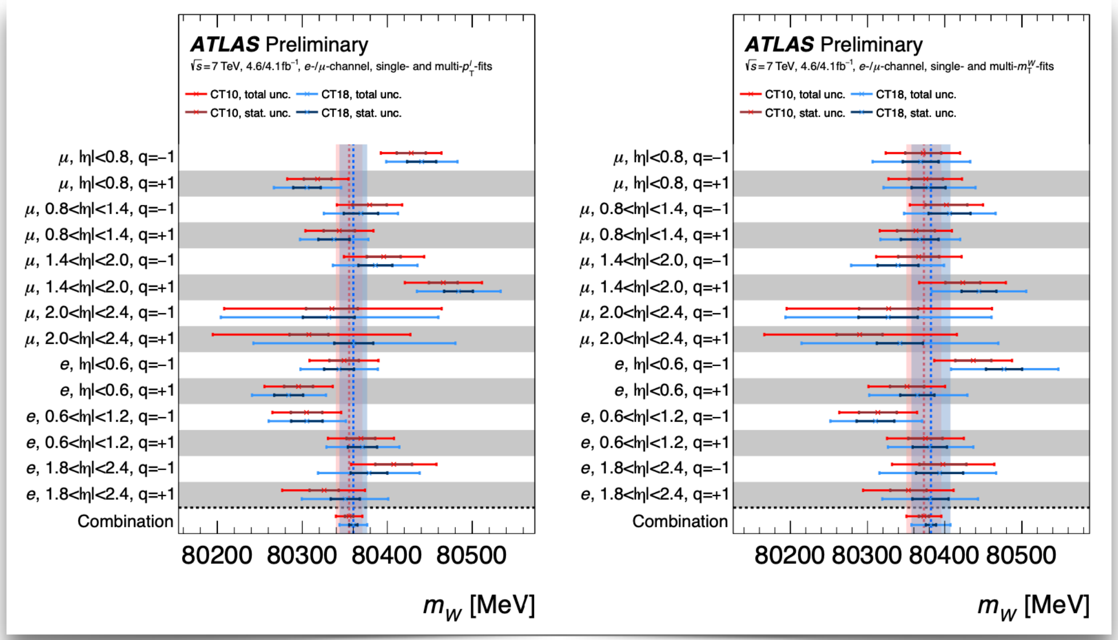
- First W boson mass measurement using a PLH approach yields a value of
  - m_W = 80360±16 MeV
- Improvement by 15% in precision
  - Shift by -10 MeV to previous result
- More preliminary information under
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults

Where do we gain? Comparison of CT10 and CT18

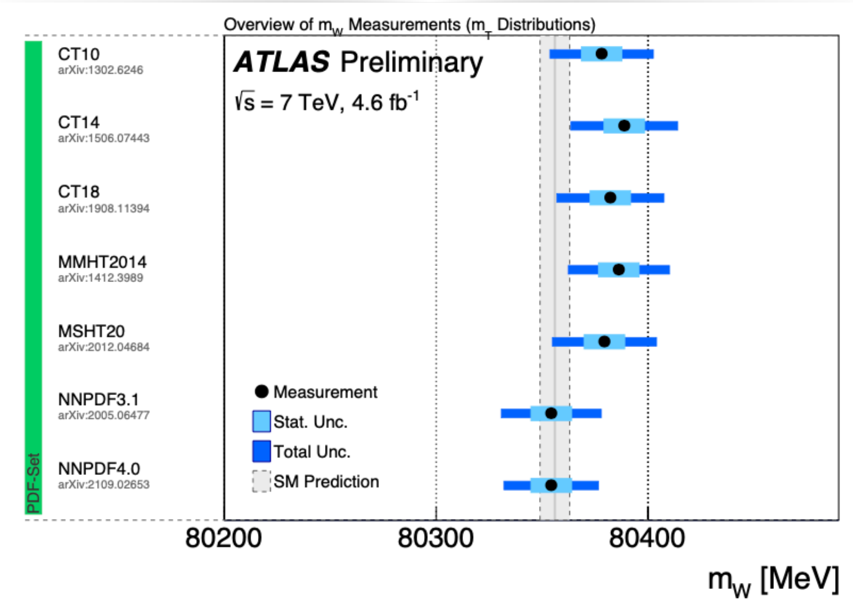
- Profiling helps to reduce essentially all systematics

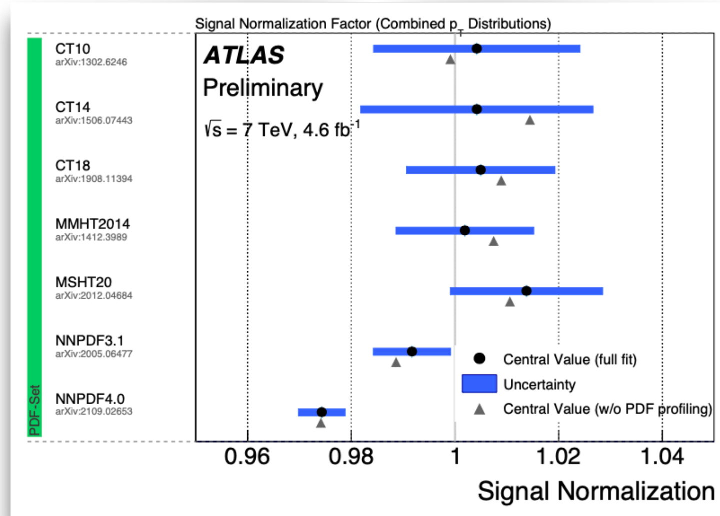
Obs.	Mean [MeV]	Elec. Unc.	PDF Unc.	Muon Unc.	EW Unc.	PS & A_i Unc.	Bkg. Unc.	Γ_W Unc.	MC stat. Unc.	Lumi Unc.	Recoil Unc.	Total sys.	Data stat.	Total Unc.
p_T^ℓ	80360.1	8.0	7.7	7.0	6.0	4.7	2.4	2.0	1.9	1.2	0.6	15.5	4.9	16.3
m_T	80382.2	9.2	14.6	9.8	5.9	10.3	6.0	7.0	2.4	1.8	11.7	24.4	6.7	25.3
Improvements			≅15% ≅30%			≅40% ≅10%								≅15%

- Overview of the fit results in all categories CT18 PDF set shows good agreement.
  - Also shown is the result when using all categories simultaneously.



Impact of Parton Distribution Functions





PDF-Set	p_T^ℓ [MeV]	m_T [MeV]	combined [MeV]
CT10	$80355.6^{+15.8}_{-15.7}$	$80378.1^{+24.4}_{-24.8}$	$80355.8^{+15.7}_{-15.7}$
CT14	$80358.0^{+16.3}_{-16.3}$	$80388.8^{+25.2}_{-25.5}$	$80358.4^{+16.3}_{-16.3}$
CT18	$80360.1^{+16.3}_{-16.3}$	$80382.2^{+25.3}_{-25.3}$	$80360.4^{+16.3}_{-16.3}$
MMHT2014	$80360.3^{+15.9}_{-15.9}$	$80386.2^{+23.9}_{-24.4}$	$80361.0^{+15.9}_{-15.9}$
MSHT20	$80358.9^{+13.0}_{-16.3}$	$80379.4^{+24.6}_{-25.1}$	$80356.3^{+14.6}_{-14.6}$
NNPDF3.1	$80344.7^{+15.6}_{-15.5}$	$80354.3^{+23.6}_{-23.7}$	$80345.0^{+15.5}_{-15.5}$
NNPDF4.0	$80342.2^{+15.3}_{-15.3}$	$80354.3^{+22.3}_{-22.4}$	$80342.9^{+15.3}_{-15.3}$